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ERGONOMICS IN LAPAROSCOPIC SURGERY: A WORK SYSTEM ANALYSIS TO REDUCE WORK-RELATED MUSCULOSKELETAL DISORDERS ACROSS SURGEONS IN PERUVIAN HOSPITALS

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Abstract

Laparoscopic surgery, also called minimally invasive surgery, is a type of surgery in which the surgeon operates by viewing the surgery on a screen that projects images from a camera inserted into the patient's abdomen. Laparoscopic tools are long (usually up to 35 cm) and require fine motor skills and visual perception for manipulation, restricting the degrees of freedom to move within the patient. This restriction causes surgeons to operate with limited vision and restricted movement and force them to work with assistants who assist in conducting the cameras, acting as "the surgeons' eyes".

Because of its minimally invasive nature, laparoscopic surgery is well accepted by patients but is challenging and complex for the surgeon. This is due to the restriction of movement and perception that forces surgeons to adopt awkward postures with high exposition, which increases the likelihood of work-related musculoskeletal disorders (WRMSD). WRMSDs are detrimental to surgeons' health and potentially may impact patient safety. Studies often highlight the problems of surgeons in high-income countries, whose solutions and clinical guides often cannot be applied to countries like Peru, which have severe deficiencies in its healthcare system.

For this reason, the thesis proposes a contextualised investigation of the Peruvian surgical work system to investigate the main factors contributing to the development of WRMSD in laparoscopic surgeons, which may affect patient safety. The analysis aimed to propose possible recommendations to support redesigning the laparoscopic surgery work system in Peruvian hospitals. Five studies were developed to achieve the aims based on the Systems Engineering Initiative for patient safety model, an ergonomics model for healthcare systems analysis. The first three studies were developed parallel with a mixed convergent design approach concluding in an integrating study. The last two studies (study four and five) had a quantitative approach.

The first study used a qualitative approach by collecting information through interviews with laparoscopic surgeons and observing their work in real surgeries. The second study adopted a quantitative approach through a questionnaire-based survey applied to 140 surgeons in Peru. The third study analysed the extent to which the postures adopted by surgeons in real surgeries increase the risk of WRMSD and their association with factors in the work system using the RULA method.

The results of the three studies were integrated into an integrative study, concluding that the raised height of the operating table and other system factors related to tasks, person and technology raises the risk of WRMSD. Based on these results, the fourth study analysed the relationship between surgeons and operating tables to understand how many surgeons could reach suitable working heights. The study concluded that no operating table available in Peruvian hospitals nor in the market would be suitable for 90% of Peruvian surgeons. The tables were too high to accommodate surgeons with optimal working surface height to perform laparoscopic surgery. Then, a fifth study was conducted to determine an acceptable working height based on surgeon preferences and system factors and concluded that surgeons would accept a working height between 49 cm to 70 cm in height, which is lower than current operating tables. The lowest height was reached when surgeons had to operate on obese patients and perform intracorporeal suturing tasks.

Finally, the thesis concludes with recommendations for redesigning working heights for 90% of the Peruvian medical population, considering work system elements of the Peruvian context.

Publications and Awards

Conferences and publications

- ✓ Aceves-González, C., Rodríguez, Y., Escobar-Galindo, C. M., Pérez, E., Gutiérrez-Moreno, B., Hignett, S., & Lang, A. R. (2021). Frontiers in human factors: Integrating human factors and ergonomics to improve safety and quality in Latin American healthcare systems. International Journal for Quality in Health Care, 33(Supplement_1), 45-50. https://doi.org/10.1093/intqhc/mzaa135

- ✓ Escobar Galindo, C. M. (2020). Perfil antropométrico de trabajadores del Perú utilizando el método de escala proporcional. Ergonomía, Investigación y Desarrollo, 2(2), 96-111.

- ✓ Escobar-Galindo, C. M. (2019,). Ergonomics in laparoscopic surgery: A work system analysis in Peruvian Hospitals. Latin American Congress of Ergonomics and Human Factors, Buenos Aires , Argentina.

- ✓ Escobar-Galindo, C. M. (2020). Síntomas Musculoesqueléticos y factores asociados en cirugía laparoscópica en Hospitales Peruanos. Oral presentation. Peruvian Congress of Ergonomics and Human Factors, Lima , Perú

- ✓ Escobar-Galindo, C. M. , Lang, A., Ryan, B., & Cobb, S. (2021). Work-Related Musculoskeletal Symptoms and Associated Factors in Laparoscopic Surgeons of Peruvian Hospitals. (oral presentation). *21st Congress of the International Ergonomics Association*, 728-737.

Awards

- ✓ Anibal Hermoza" Award Mention "Outstanding Ergonomist of 2021" in recognition of outstanding work favouring Ergonomics in Peru. Recognition by the Peruvian Society of Ergonomics in Lima, Peru. Federated Member of the International Ergonomics Association (IEA)
- ✓ Recognition in the category "Researcher in Ergonomics". It is awarded by the Latin American Union of Ergonomics. Buenos Aires , Argentina 2020
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Acronyms and abbreviations

WRMSD	Work Related Musculoskeletal disorders
LAPS	Laparoscopic surgery
LMIC	Lower Middle Income Country
HIC	High Income Country
WHO	World Health Organization
SEIPS	System Engineering Initiative for Patient Safety
MSD	Musculoskeletal disorders
QUAL1	Qualitative study one
QUAN2	Quantitative study two
QUAN3	Quantitative study three
RULA	Rapid Upper Limbs Assessment
WSH	Working surface height
TSH	Table surface height
EH	Elbow height
SRH	Suitable regulation height

Chapter 1: Introduction

1.1. Background

One of the main challenges of ergonomics in healthcare systems is surgical safety issues since they directly impact patient safety (Hignett et al., 2013). These challenges become even more relevant when applied to healthcare systems in Low-middle income countries (LMICs), such as Latin American countries with more significant healthcare limitations (Aceves-González et al., 2021).
Recent studies conducted by Jop Hopkins University estimated that the average number of deaths annually from medical errors in the USA reached 251,454 from 1999 to 2013 (Makary & Daniel, 2016). Comparing the data with cases reported by the Center for Disease Control and Prevention (CDC), it is estimated that medical errors would be the third most common cause of death in the USA after heart disease and cancer (Heron, 2021).

Medical errors usually occur in fast-paced environments such as emergency rooms, intensive care and operating rooms. When multiple people are involved in the process (e.g. nurses, students, residents, assistants), or the medical manoeuvre requires complex skills such as surgery, the likelihood of medical errors increases (Rodziewicz et al., 2021). An error may or may not cause an adverse event. Adverse events are harms to the patient that result from medical practice. Adverse events can be quite frequent in the operating room, accounting for 47.7% to 50.3% (Brennan et al., 1991). In a study carried out by the Harvard Medical Practice study,13.6% died in the United States due to adverse events, and at least half of these errors could have been prevented by identifying the main factors (Kohn et al., 2000). Most of these events are catalogued as a consequence of poor surgical skills or lack of training of healthcare staff. However, recent studies in the United Kingdom (UK) have shown that there is an undeniable mismatch between the healthcare work system and the human capabilities of medical staff, raising the likelihood of medical error (D'Addessi et al., 2009).

In Latin America, studies are scarce, but it is estimated that adverse events and medical errors are higher than in high-income countries (HICs) (Johnston et al., 2019). The World Health Organization (WHO) led The Latin American Study of Adverse Events (IBEAS) project that aimed to assess the patient safety situation in several Latin American Hospitals in 2011. The study estimated that 10% of the patients admitted to hospitals in Latin America had experienced some harm due to healthcare, and 20% of inpatients experienced at least one harmful incident during their hospital stay. The surgical units were one of the main critical services most frequently causing patients harm (World Health Organization[WHO], 2011).

Compared to the early nineties, surgeries do not necessarily involve large incisions or the development of invasive procedures. Currently, the surgery methods in operating rooms have evolved to be mainly open surgery and minimally invasive surgery. Open surgery consists of cutting skin and tissues to give surgeons a full view of the patient's organs and structures. While in minimally invasive surgery, also known as laparoscopic surgery, surgeons operate indirectly through the patient's abdomen using long instruments and view the surgery on a screen (Supe et al., 2010).Unlike open surgery, laparoscopic surgery demands work with monocular vision, limited depth perception and movement and long instruments (approximately 35 cm long) (Fried, 2008; Zachariou, 2019), as shown in Figure 1.1.

Laparoscopic surgery in operating rooms demands a more ample space to include several types of equipment and a larger number of surgical team members than open surgery (Albayrak et al., 2007; Supe et al., 2010). The surgeon's work is accompanied by the camera assistant, who acts as the surgeon's eyes since he must conduct the endoscope into the patient and hold static positions for long periods according to the surgeon's instructions (Zihni et al., 2016). Usually, the camera assistant is a student or resident, requiring significant coordination and teamwork with the surgeon. Also within the surgical team are scrub nurses and the anaesthetist, who play an active role in the surgical process, assisting surgeons and controlling patients' vital signs.

Compared with traditional open surgery, the high level of technological integration and socio-technical skills required to perform laparoscopic surgery and the variety of human interfaces between surgeons and technology raises the probabilities of medical errors (Parker, 2010; Satava , 1999).

Open Surgery

Laparoscopic surgery

Note. Open surgery image was extracted from Bowen Hefley orthopaedics (https://www.drbillhefley.com/minimally-invasive-surgery-vs-open-surgery/); Laparoscopic surgery image extracted from National Institute of Neoplastic Diseases of perú (INEN) (https://portal.inen.sld.pe/la-cirugia-radical-eleva-las-posibilidades-de-curacion-en-el-tratamiento-del-cancer-de-prostata/

Figure 1.1 Open and laparoscopic surgery

Laparoscopic surgery has been implemented widely in operating rooms worldwide and is currently the most common technical procedure for treating different conditions (Eurostat information, 2017; Kohn et al., 2018). This is partly due to patients prefer laparoscopic surgery to open surgery because; it is minimally invasive, reduces the risk of bleeding, has better cosmetic results, and necessitates a shorter post-surgery hospital stay (Santos-Carreras et al., 2012). However, open surgery is still necessary for more complex and precise procedures such as; tissue repairs, complete tissue removal, accurate diagnoses, and implanting stents and other materials (Standford Healthcare, 2021). Despite patients´ preferences, laparoscopic surgery is more challenging for surgeons because it raises their physical and mental demands to face surgeries and ensure patient safety (Zachariou, 2019).

High financial investment, an increase in the number of professionals required, and training demands of technology transfer make the implementation of laparoscopic surgery complex, especially in countries with low investment in healthcare, such as Peru (Alfa-Wali & Osaghae, 2017). Of Latin American countries, Peru has one of the lowest investments in healthcare, spending 5.5% of GDP, twelve percent lower than HICs, being one of the lowest health expenditures (WHO, 2020). Also, the number of physicians per 10,000 inhabitants is much lower (13) than HICs such as in the USA or the UK (26, 28), even compared to Latin American countries (WHO, 2020). Even though health insurance is a central politic, only 72 % of the population have access to a hospital. Moreover, the healthcare system is fragmented and managed by different institutions, increasing patient care inequality, which manifests in poor patient safety culture (Aceves-González et al., 2021; Arrieta et al., 2017).

Regards medical technology, Peru imports around 98% of its medical devices; however, it is estimated that 60% of medical equipment may be obsolete, with only 1% of the healthcare budget allocated for maintenance (Camara de Comercio de Lima[CCL], 2019). Furthermore, the Peruvian government reported that 44.6% of medical centres do not have medical equipment, and 33% are in deplorable conditions (La Contraloria General de la Republica, 2016). Thus, Peru will take 20 years to catch up with HICs to acquire medical technology (Cornejo et al., 2019).

The high predisposition of laparoscopic surgeons to adopt awkward postures and repetitive motions for extended periods raises the risk of work-related musculoskeletal disorders (WRMSD) (Zachariou, 2019). WRMSD are associated with; high costs to employers, high rates of absenteeism worldwide, lost productivity and increased health care, disability, and compensation costs (EU-OSHA, 2019). WRMSD may affect muscles, joints and tendons in all body parts, being episodic or chronic in duration, but their main characteristic is work-related. In 2001, the median number of work days lost due to WRMSD was eight days compared to six days for non-fatal injuries and illnesses (Sestito et al., 2004). In 2013 the UK statistical office reported that the leading sickness absence was 30.6 million days due to WRMSD (Jenkins, 2014). The US Institute of Medicine estimated that the costs for compensation, lost productivity, and lost wages due to WRMSD were between 45 and 54 billion dollars annually (Calnan, 2002).

HICs, and Latin American countries, have experienced a substantial increase in WRMSD rates since the 1990s, possibly due to industrial development and globalisation, which increased their productivity to meet the global competitive demand. However, monitoring and surveillance of WRMSDs are very limited in Latin American countries being classified as occupational accidents or common diseases. This scenario is not unusual in Peru, where there is an underestimation of the actual data on WRMSD (Jhonston et al., 2018).

According to the most recent UK statistics report, the highest prevalence of WRMSD was in human health and social work activities (including healthcare workers), with skilled trade occupations (Health and Safety Executive, 2021). Despite no precise numbers in the Peruvian context, it is clear that a high rate of healthcare workers exposed to ergonomics risk factors in healthcare systems raises the risk of WRMSD (Instituto de Salud y Trabajo (ISAT), 2011; Jhonston et al., 2018)). Among the main groups studied in the literature are nurses and technicians due to the high exposure to manual handling of patients (Bureau of Labor Statistics, 2015).

However, other groups are exposed to repetitive movements, awkward postures, and physical and mental fatigue, which also have an apparent relationship with the development of WRMSD, such as laparoscopic surgeons and assistants in operating rooms.

Although literature from HICs evinces high rates of WRMSD resulting from hostile surgical environments (Armijo et al., 2018; Park et al., 2010), there are no official statistics related to the surgical field in Peru nor a description of current surgical environments, which may differ tremendously from other HICs (Matern, 2009).

WRMSD can be caused by combining several factors that, include physical, organizational and psychosocial factors. Many of the risk factors affecting the physical health of workers are related to several external factors, such as the social, political and economic environment, the organization of the workplace and individual factors (EU-OSHA, 2019). Hence, the analysis of the work system and their interaction is vital to understand the real impact on the surgeon and take measures to correct or anticipate.

Although multifactorial WRMSD models have been applied in the healthcare sector, the main focus of these models has been the industrial sector without specific insights into the healthcare sector (Kumar, 2007). For this reason, analysis from a systems approach emphasising patient safety based on an Ergonomics framework is imperative to understand the global problem, especially in the healthcare sector (WHO, 2008). In this way, different approaches in ergonomics propose different alternatives to analyse work systems, one of the main ones being the System Engineering Initiative for Patient Safety (SEIPS) model. The SEIPS model analyses healthcare systems to find solutions that restore the balance of the system by optimising the well-being of workers and patients, making SEIPS a fundamental tool for system improvement. Despite its wide use in HICs (Holden et al., 2013), there is no history of its application in LMICs, especially in the Latin American region.

Laparoscopic surgery demands high technological support and specific surgical expertise, so an appropriate technology transfer process, which includes stage-by-stage ergonomics analysis in the receiving country, is necessary for successful implementation in LMICs (Shahnavaz, 2009). However, ergonomics studies in laparoscopic surgery are focused mainly on operating rooms in HICs, establishing recommendations for the design of equipment, tools and clinical guidelines, which are used as a global standard to be applied in any context (Clift et al., 2011; Matern, 2009; Muratore et al., 2007; Smith-Jackson et al., 2013; Supe et al., 2010; Wauben et al., 2006; Zachariou, 2019).

Many of these recommendations may be inapplicable in LMICs such as Peru due to different contextual factors, such as educational, legal, political and economic factors, and related to the anthropometry of the population, which differs entirely from those in HICs (Budnick et al., 2012; Chinelli & Rodríguez, et.al, 2018; Escobar-Galindo, 2020; NCD Risk Factor Collaboration, 2016; Pheasant and Haslegrave, 2006a; Rodríguez-Sanjuán et al., 2010; Shahnavaz, 2009; Smith-Jackson et al., 2013).

By determining the real contextual needs and identifying the relevant ergonomic issues that may affect system performance, receiving countries and suppliers of technology can achieve a safer and more responsible technology transfer. Besides, by understanding how the system functions, more realistic and efficient solutions can be implemented to improve clinicians' well-being by reducing WRMSD risk, system performance and patient safety (Scott, 2009; Shahnavaz, 2009).

For these reasons, using a mixed research approach, the thesis investigated the work systems in laparoscopic surgery in Peruvian hospitals to identify the main factors contributing to surgeons' WRMSD. This analysis prioritised identifying factors based on the work system analysis to achieve a redesign of the work system in laparoscopic surgery operating rooms of Peruvian hospitals.

1.2. Research aims and objectives

The thesis proposed the following aims and objectives based on the two stages of the work system analysis: work system analysis and work system redesign

AIM 1: Work system analysis

This thesis aimed to investigate the main factors contributing to the development of work-related musculoskeletal disorders across surgeons that perform laparoscopic surgery and may affect patient safety in Peruvian operating rooms.

To achieve this aim, the following questions were formulated:

RQ1: *What factors in laparoscopic surgery contribute to developing work-related musculoskeletal disorders and affect patient safety, and how do they interact in the work system of Peruvian operating rooms?*

RQ2: *What is the prevalence of WRMSD in laparoscopic surgeons?, What factors in laparoscopic surgery systems are associated with work-related musculoskeletal disorders, and what is the impact on the surgeon's performance and patient safety?*

RQ3 : *To what extent do surgeons' posture during laparoscopic tasks raise the risk of developing work-related musculoskeletal disorders?*

RQ4: *What main factors associated with work-related musculoskeletal disorders of surgeons emerged from studies one, two and three? To what extent do the quantitative and qualitative results converge or diverge?*

The following objectives were proposed to achieve the first aim and respond to questions

Objectives

1.1 To undertake a literature review to understand the context of risk factors for WRMSD in laparoscopic surgeons, in Perú, under a working system and patient safety perspective.

1.2 To conduct qualitative research to investigate the laparoscopic surgery system in Peruvian hospitals following the SEIPS model framework (qualitative study)

1.3 To carry out a questionnaire-based survey to determine the prevalence of WRMSD in Peruvian surgeons, assess risk factor associations and quantify the impact on the performance of laparoscopic surgeries (quantitative study)

1.4 To investigate the extreme postures adopted by surgeons in laparoscopic surgery and how they contribute to the risk of WRMSD in Peruvian hospitals (quantitative study)

1.5 To integrate the results from quantitative and qualitative studies to determine the main risk factors in the work system that contribute to the development of WRMSD in laparoscopic surgery and to confirm results (Quantitative and qualitative integration)

The second research aim was based on the results of the first one. Therefore, two research questions and two objectives were proposed based on these results.

AIM 2: Work system redesign

To propose recommendations for work system redesign suitable for laparoscopic surgeons' characteristics that reduce WRMSD risk and improve patient safety in Peruvian hospitals.

To achieve this aim, the following questions were formulated

RQ5: *Are the height regulation levels of operating tables in Peruvian hospitals sufficient for the majority of surgeons when operating with laparoscopy?*

RQ6: *What would be acceptable operating height levels for laparoscopic surgery considering work system elements, and to what extent is this height affected by laparoscopic tasks?*

The following objectives were proposed to achieve the second aim and respond to questions

2.1 To investigate the percentage of surgeons that match with current operating table heights in Peruvian hospitals based on anthropometrical analysis (quantitative study)

2.2 To investigate the acceptable working surface heights limits to perform laparoscopic surgery tasks deeming surgeons' preferences to accommodate 90% of the surgeon population (quantitative study)

1.3. Thesis overview

The following sections present a summary of the thesis chapters

1.3.1. Chapter 1: Introduction

This chapter describes the background, research aims and objectives, research questions and structure of the thesis.

1.3.2. Chapter 2: Literature review

Chapter 2 introduces the research background of the thesis. This chapter sets out a review of literature in several areas to understand the scope of laparoscopic surgery and ergonomics in the current literature and identify the main issues that have been reported as related to musculoskeletal disorders. Also, this chapter presents a literature review of the Peruvian healthcare system, drawbacks and strengths in terms of ergonomics and patient safety with an emphasis on surgical units. Furthermore, this chapter explains the framework and theoretical model used in this study to explain the reasoning in the process of identifying factors and the system redesign of operating rooms in Peruvian hospitals

1.3.3. Chapter 3: Methodology

Chapter three presents the research methodology of the thesis, the framework and philosophy of the research design and the research methods applied in the studies conducted.

1.3.4. Chapter 4: Study 1 – Ergonomics in laparoscopic surgery: A work system analysis in Peruvian hospitals

Chapter four presents the results of an exploratory qualitative study that aimed to identify factors that contribute to the development of work-related musculoskeletal disorders and affect patient safety in operating rooms of Peruvian hospitals. This study is part of the qualitative strand of the mixed convergent method design and analyses the "Work system" component in the SEIPS framework.

1.3.5. Chapter 5: Study 2- Work-related musculoskeletal symptoms and associated factors in laparoscopic surgeons of Peruvian hospitals

Chapter five presents the results of a questionnaire-based survey applied to 140 surgeons that aimed to determine the prevalence of WRMS in Peruvian surgeons, set up associations with risk factors in the laparoscopic surgery system, and measure the impact on surgeons. This study is part of the quantitative strand of the mixed convergent method design and analyses the "Outcome" and Work system components in the SEIPS framework.

1.3.6. Chapter 6: Study 3 – Ergonomics risk of surgeons and camera assistants during real laparoscopic surgeries in Peruvian hospitals

Chapter six presents the results of the postural analysis of surgeons and assistants and how they contribute to musculoskeletal disorder risk. This study is part of the quantitative strand of the mixed convergent method design and analyses the "Work Process" component in the SEIPS framework. The RULA method was applied in laparoscopic surgeries of different levels of complexity.

1.3.7. Chapter 7: Studies integration

This chapter presents the integration process results of the qualitative study in chapter four and the quantitative studies carried out in chapters five and six. It also shows the convergence , expansion and divergence process results that confirm the results found in the different studies.

1.3.8. Chapter 8: Study 4 – Match analysis between operating table height and surgeons' anthropometrical characteristics in Peruvian hospitals

Based on the results of previous studies, chapter eight examined the anthropometry match level of surgeons with operating tables available in Peruvian operating rooms. This analysis was carried out using a modification of the method of limits and following the anthropometrical design process described by Helander (2005) and Pheasant and Haslegrave (2006c). The study provided an anthropometric chart of the physician population detailing working height and reach measures.

1.3.9. Chapter 9: Study 5 - Remote fitting trial to determine recommendations for designing operating table heights in laparoscopic surgery

This chapter presents the results of a fitting trial study (psychophysical study) to determine the recommended working height and operating table heights necessary to operate with the laparoscopic technique, taking into account the factors identified in previous studies: elevated height of the operating table, the complexity of the surgery, patient's size, surgeon's anthropometry and level of training in laparoscopy.

1.3.10. Chapter 10: Discussion

This chapter summarises the thesis results and discusses the key findings. It also includes the thesis's limitations, sets up recommendations, describes future research opportunities, and ends with the conclusion statement.

1.4. Summary

This chapter presented an introduction to the thesis, a brief description of the research background, and the structure of the thesis, including the research questions, aims and objectives.

Chapter 2: Literature Review

2.1. Introduction

This chapter presents a review of literature on ergonomics, work-related musculoskeletal disorders and laparoscopic surgery in LMICs, especially in Peru, to establish a background to expose the gaps in knowledge necessary to formulate the research questions. The review is divided into four sections:

2.1.1 What is laparoscopic surgery?:

This section contains a description of laparoscopic surgery, definitions, surgical instruments and equipment used, surgical procedures, complications and challenges for ergonomics.

2.1.2 Ergonomics and cultural context: A review of the Peruvian healthcare system

This section reviewed the importance of ergonomics and cultural context in healthcare, emphasising Peru. It also reviews the Peruvian healthcare system, its strengths and weaknesses, and the reality of laparoscopic surgery.

2.1.3 Work-related musculoskeletal disorders in laparoscopic surgery:

This section reviewed the concepts of Work-related musculoskeletal disorders (WRMSD), aetiology of injury, causation theories, associations and impact on patient safety.

2.1.4 A systemic approach based on Ergonomics to redesign surgical systems:

This section reviewed the SEIPS model as a framework used in the thesis. In addition, a review of the main ergonomic interventions in laparoscopic surgery with a system approach.

2.2. Methods

The literature review was carried out by identifying and analysing documents containing relevant information on the research problem (Gay & Airasian, 2007). The following electronic databases were mainly used for the literature search: Scopus, Web of Science, Google scholar and Scielo, Pubmed. In addition, the review included press articles, journalistic reports, theses published in university repositories, statistical compendiums and books related to the search topic. As an additional search strategy, the reference lists of the relevant articles identified were used to identify other potential references following a pearl-growing approach (McColl et al., 2001).

2.3. What is Laparoscopic surgery?

Laparoscopy surgery is a surgical technique performed by trained surgeons that consist of operating through the patient's abdominal cavity without making large incisions in the skin and viewing the surgery through a monitor display. The laparoscope makes this technique revolutionary for developing surgery with minimal injury. For this reason, it is also known as minimally invasive surgery. The surgery usually demands working with several assistants: a surgeon, student or resident to hold the laparoscope; a surgeon to assist the surgery; scrub nurses and an anesthesiologist (see Figure 2.1). The main benefits for patients are a lower risk of bleeding, better cosmetic results, shorter hospital stays, and a lower risk of infections (Powell & Khaund, 2016; Zachariou, 2019). Although laparoscopy has excellent patient benefits, it is not indicated in all cases (Winslow et al., 2004).

Figure 2.1 Laparoscopic surgery team

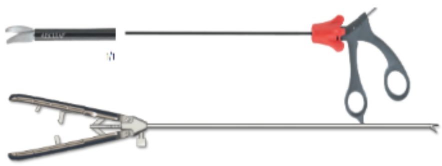
2.3.1. Surgery equipment

The equipment and instrumentation used in laparoscopic surgery are more complex than in open surgery, requiring more space in the operating rooms. The following is a brief review of the essential equipment that will serve as a basis for understanding the following chapters (see Figure 2.2).

a)

b)

c)



d)

e)

Note. (a)laparoscopic tower with imaging system ; (b) foot pedals ; (c) trocar ; (d) laparoscopic instruments (top : dissector ; bottom: needle driver)(e) operating table. Figures extracted from :Foot pedal : https://www.indiamart.com/proddetail/high-frequency-surgery-electrosurgical-double-pedal-switch-22301690555.html; Laparoscopic tower : https://m.made-in-china.com/product/1080P-HD-Endoscopy-Camera-Laparoscopic-Surgery-Equipment-878104225.html;Trocar: https://www.medicalexpo.es/prod/genicon/product-68575-481764.html

Figure 2.2 Laparoscopic equipment

2.3.1.1. Surgical insufflator

The insufflation system allows surgeons to create a working space inside the abdomen called the pneumoperitoneum. The system's main elements are the insufflator (to transport the gas), the insufflant (gas), and the insufflator needle (Verres syringe or trocar). The insufflant is usually a gas, mainly carbon dioxide, because it is not flammable and quickly absorbed by the body. Usually, in laparoscopy, the pressure should be between 10 to 15 mmHg to reduce the risk of embolism (Wu, 2004).

2.3.1.2. Imaging system

The imaging system is essential in laparoscopic surgery as it functions as the eyes of the surgical team. The system's main components are the laparoscope, the camera, the monitor, and the light source (Arregui et al., 2012; Jones, 2004). The laparoscope, also known as an endoscope, consists of a rigid rod imaging system with an eyepiece at the tip, through which a flexible fibre-optic light-conducting cable runs. The camera is attached to the eyepiece of the laparoscope and transmits the digitised optical information from the endoscope via cable to the video box (the digital image displayed on the screen).

The camera must be in focus, and the camera/video system must be white-balanced to optimise the image's colour representation. There are different presentations, the most common being 5 to 10 mm with angled or straight lenses (0° to 50°) (Jones, 2004). Light sources comprise focused energy bulbs loaded with mercury, fume xenon or halogen to give brilliant enlightenment. The output intensity is adjustable and can be controlled at the source. The video monitor provides the internal image of the patient and the laparoscopic procedure, which should be of high quality. Currently, digital design panels mounted on an overhead boom or placed on the laparoscopic tower are used.

2.3.1.3. Positioning system for patients (operating table)

Operating tables are designed to provide a surface that supports the patient's body during surgical procedures. The operating table used in laparoscopy is usually the same as open surgery, with certain modifications (National Health Service[NHS], 2009; Wauben et al., 2006).

Operating tables are rectangular tabletops supported on a properly fixed platform base or a portable base (versatile surgical table). The accessories can be adjusted or removed to accurately situate the patient facilitating the use of electric pedals, hand switches, or operating systems. These adjustment systems facilitate the adoption of different patient positions required for different surgeries. The main positions are Trendelenburg (head lowered, feet elevated); reverse Trendelenburg (head elevated, feet lowered); lateral tilt, flexion, extension, chair, and lithotomy (split legs) (NHS, 2009). However, these positions may be limited depending on the models and the condition of the operating table.

2.3.2. Instruments

a) ***Trocars:*** Trocars are surgical instruments used in laparoscopy to establish an access port to internal organs. The trocar works as an access point for introducing laparoscopic forceps, scissors and needle drivers. The trocar consists of an awl or diaphragm (which can be metallic or plastic or with a non-cutting end), a cannula (hollow tube) and a seal (Gourash et al., 2015). Trocar sizes can vary in diameter depending on the instruments used; for example, laparoscopic staplers require 10 to 14 mm diameter trocars, while traditional instruments require 5.5 mm ports on average (Arregui et al., 2012). Trocars with 100 mm shafts are sufficient to work, but exceptionally trocars up to 150 mm can be used for obese patients (Gourash et al., 2015).

b) ***Laparoscopic surgical instruments:*** The hand instruments allow various surgical actions such as dissecting, clamping, suturing, and cutting, among others. The handle can be of different shapes and sizes, with the most common being pistol, ring and axial handles (Arregui et al., 2012). Generally, instruments for adults have a length of 32 to 33 cm; however, they can have shorter presentations of 25 cm (in the case of children) or 45 cm (in the case of obese patients). Laparoscopic instruments can be disposable (single-use) or reusable (can be used more than once but require regular maintenance). Among the main instruments are:

- ✓ Graspers: They allow to grasp of organs or tissues and can be traumatic (the tips have jaws that allow removing residual tissue) or atraumatic (allow to mobilise tissues without risk of cutting).

- ✓ Staplers: used for staple structure for large-vessel hemostasis. There are varieties of clips depending on the need for the surgery.

- ✓ Scissors: allow to make controlled cuts. Scissors are the best instrument for cutting avascular or congenital adhesions and the peritoneum.

- ✓ Electrosurgery: allows cauterising of blood vessels in different procedures and cutting structures in a precise way. There are different applications, but monopolar and bipolar (diathermic) cauterisations are the most common.

- ✓ Needle driver (holders): Hold the needle and perform suturing tasks on the tissues involved. They usually have axial (straight) handles and exist in several presentations.

2.3.3. Foot pedals

The diathermic energy and ultrasonic equipment are operated by foot pedals positioned on the floor in front of the surgeon. According to the surgeon's request, the pedals usually consist of two switches activated by stepping on them. In the case of diathermic cuts, the left pedal acts as a cutter and the right for coagulation (sealing). The left pedal is for the low potential for ultra-scission equipment, and the right is for the maximum (Van Veelen et al., 2003).

2.3.4. Main Tasks of developing a laparoscopic surgery

a) ***Make pneumoperitoneum*.** This task consists of insufflating an inert gas into the peritoneal cavity through a Verres needle (needle with protection to avoid damaging the viscera). Without the pneumoperitoneum, it is impossible to operate because there would be no space for the displacement of the instruments and manipulation of the organs.

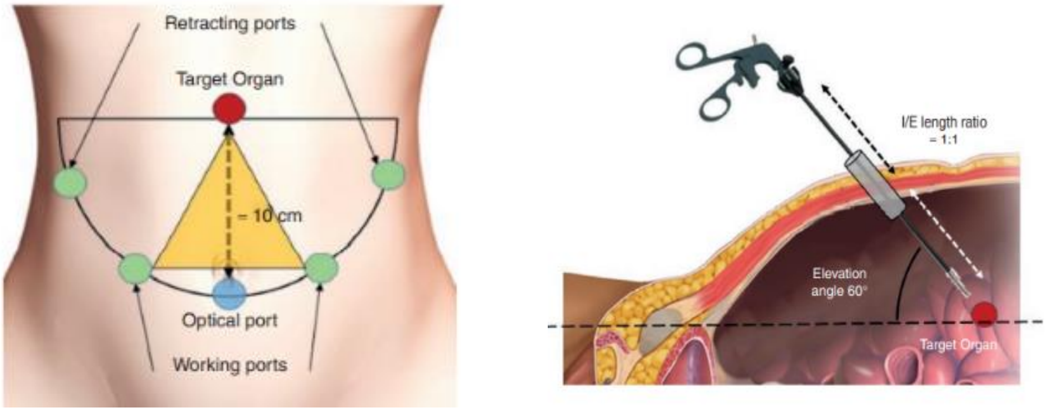
b) **Trocar insertion.** The first trocar must be placed through the umbilicus, then the trocar is removed, and the valve is opened to check the free exit of the gas, thus confirming its correct position. Then the trocars are placed in the abdomen according to the type of operation programmed. Generally, the best arrangement to operate is to triangulate trocars in the patient's abdomen by placing the camera in the posterior vertex to the trocars to have space for visualisation (see Figure 2.3).

c) **Laparoscopic surgery procedure**. Instruments manipulation should be between 45-75°. The intra/extracorporeal radius of the instruments should be a 1:1 ratio**.**

d) **Exuflation and removal of instruments.** Once the operation is finished, the cavity should be washed if necessary, and all the remaining liquid and gas should be aspirated. Subsequently, the trocars are removed, and the aponeurosis is sutured in all the spaces to avoid eventrations.

2.3.5. Laparoscopic surgery skills and constraints

Despite the advantages that laparoscopic surgery offers to patients, for surgeons, it proves to be physically and mentally demanding because it reduces the freedom of manoeuvre within the patient, increasing the risk of static postures and adopting and maintaining forced postures for long periods (Avci & Schiappa, 2019; Supe et al., 2010).



Note. (a)Triangulation of the trocars; (b) Elevation angle, intra/extracorporeal length radio. Figures extracted from Zachariou (2019)

Figure 2.3 Triangulation and length radio of instruments in laparoscopic surgery

The implementation of laparoscopic surgery requires more space in operating rooms, as it must include several types of equipment and a larger number of surgical team members than open surgery (Albayrak et al., 2007; Zachariou, 2019). Laparoscopic surgery requires working in two dimensions with limited angles of movement (only four degrees, whilst open surgery allows six) (Buchel et al., 2010; Lucas-Hernández et al., 2014; Zachariou, 2019).

Laparoscopic surgery demands new psychomotor skills with an evident reduction of tactile feedback, limiting the ability to obtain kinetic force and manual dexterity to handle surgery (Puangmali et al., 2008). In addition, the activity must be performed through a monitor screen, limiting the visual field and spatial perception and creating a new human-machine interface that requires high hand-eye coordination (Supe et al., 2010).

The limited spatial perception requires working with the "fulcrum effect", which shows the surgeons' movement on the screen but on the opposite side to the one being performed (Choi, 2012). For these reasons, operating rooms must be prepared to perform laparoscopic surgery to avoid errors and adverse events (Avci & Schiappa, 2019).

2.4. Ergonomics and cultural context: A review of the Peruvian healthcare system

According to the IEA (2001): *"Ergonomics (or human factors) is the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system, and the profession that applies theoretical principles, data and methods to design in order to optimise well-being and overall performance."* This definition frames the importance of ergonomics as studying the interaction between people, technology and the factors that affect this interaction within a system.

The system defined from ergonomics is a set of related elements whose central point is the human being who receives information from the environment (Input), interacts with the elements through the activity (Process), and generates outcomes (Output).

The environment is where the system's dynamics are developed and comprises some artefact, workplace, tool, product, and service tasks that include other humans and the culture itself (Wilson, 2000). All these elements make up the work system whose dynamic structure allows to achieve a result, people's welfare, and the improvement of systems. From this perspective, the application of ergonomics must follow three fundamental principles: (a) it must take a systems approach; (b) it must be design-driven; and (c) it must pursue two fundamental outcomes: performance and well-being (Dul et al., 2012). These principles differ from other disciplines, such as biomechanics, sociology, kinesiology and anthropology. On the contrary, an unbalanced system can cause adverse outcomes such as inefficiency, fatigue, accidents, injuries, errors and user difficulties.

External environmental factors, such as the culture, politics, and economy in which the system is developed, can directly impact the people and the system itself (Holden et al., 2013; Santos et al., 2016; Smith-Jackson et al., 2013). This somewhat limits the application of principles and concepts from other realities to specific systems, making it necessary to analyse the environment and external factors specific to the system as part of the ergonomic assessment.

The ergonomics concept begins to spread, taking culture to encompass science and engineering in a broader concept. Hence, cultural ergonomics becomes essential to investigate, design, and evaluate inclusive systems and cross-national, global technology in multiple contexts considering the population's culture (Smith-Jackson et al., 2013).

2.4.1. Importance of setting up a cultural ergonomics framework in Latin America operating rooms

The classic concepts of "normal workers" working under "normal" conditions continue to be applied when these concepts often represent an erroneous generalisation of normality. Studies present results as "normal or standard workers" to people between 20 and 50 years living in countries with a "developed economy", such as the United States, United Kingdom, New Zealand and Australia (Kroemer, 2005). However, these concepts of normality represent a continuing bias among workers. Even within these same HICs, there are individuals of indigenous or aboriginal ancestry, restricting their participation by classifying them as a group with extraordinary characteristics and ignoring the ethnic and social variability of the populations (Pheasant & Haslegrave, 2006a). This narrow view of human factors and ergonomics threatens the development of science and technology by reducing the capacity for effective, valuable and safe translational research and technology transfer (Smith-Jackson et al., 2013).

Many of the products designed under the unique concept of normality will be used in multicultural contexts where the standards of a cultural group do not necessarily fit with groups of other cultures could lead to risky results in performing tasks for the worker. Many possible solutions could not be helpful in terms of the economy and would be challenging to implement because many other priorities must be covered first (Scott, 2009; Soares, 2006). The lack of a comprehensive concept in studies would be ignoring the cultural component of different experiences, reducing the external validity since the little understanding of their real needs. Therefore, understanding these differences in the population will allow them to be translated and lead to an inclusive product, service, interaction and design (Matsumoto, 2017).

Shahnavaz (2009) pointed out that first-world ergonomics cannot be applied to third-world problems without making essential and necessary modifications to accommodate the indigenous labour force within local industries. From this perspective, the development of ergonomics of LMICs ' cultures and natural context is necessary, where the variability and emerging needs of the different realities can be considered. Therefore, the challenge is to recognise the specific needs of different cultures and stimulate the local cultural development of ergonomics (Scott, 2009).

More and more countries are beginning to develop ergonomics by studying their populations and generating necessary standards to fit systems to people considering their diversity. For example, in Latin America, significant efforts have been made to characterise the populations of different countries, which have given significant inputs to product development (Aceves-González et al., 2021; Apud, 1995; Apud & Meyer, 2010; Avila et al., 2007; Castellucci et al., 2020).

Healthcare systems, mainly operating rooms in LMICs, have many deficiencies that may affect healthcare workers' and patients' quality of care. The informality of work is the most common mode of work where lack of organisation, training and systems support makes it challenging to apply ergonomic principles (Smith-Jackson et al., 2013). Even though informal work is a usual practice in LMICs, these practices are also observable in HICs where the lack of an ergonomic culture makes its implementation difficult (Scott, 2009). Therefore, healthcare systems are not oblivious to this and can also be affected by cultural diversity.

The situation of laparoscopic surgery is quite worrisome in Low-income countries. The high costs of laparoscopic surgery have led many to wait for donations from abroad to have sufficient stocks of equipment to operate (Chao et al., 2016). In countries with health insurance for the population, the insurance covered open surgeries but partially (in some cases none) laparoscopic surgeries, making them expensive for patients without money to pay for them. On the other hand, there was a lack of laparoscopic clinical guides and adequate equipment to perform surgeries, replacing them with unsafe equipment. For instance, replacement of mechanical insufflation by room air or suction syringe with homemade endoloops , hand-assisted techniques, and reuse of disposable trocars) (Alfa-Wali & Osaghae, 2017; Bal et al., 2003; Brekalo et al., 2007; Gnanaraj, 2010; Nande et al., 2002; Udwadia, 2007). Furthermore, there were limitations of laparoscopic surgery in complex techniques due to a lack of training and lack of training opportunities for practitioners (Bekele & Biluts, 2012; Brekalo et al., 2007; Khan et al., 2020; Raiga et al., 1999; Teerawattananon & Mugford, 2005).

Although many countries in Latin America are middle-income countries (MIC), it does not mean that they have serious weaknesses in their healthcare systems. Aceves-González et al. (2021) stated that ergonomics in Latin American healthcare systems have become more critical due to the high rates of mortality, errors, and adverse events in hospitals, which require professionals to help find solutions from a systems perspective. However, although there are minimal published studies on ergonomics in healthcare systems in Latin America, what is certain is abundant experience and situations that have not been reported.

2.4.2. Peruvian Healthcare system and laparoscopic surgery: A review

2.4.2.1. Peruvian healthcare situation

Peru is a pluricultural and multi-ethnical Latin American country located in South America with a population of 31,151,643 inhabitants distributed in three central regions: coast, highland and jungle. Lima, the capital, is the most inhabited city reaching 9,985,664 inhabitants, of which 50.1% are men and 49.9% are women (Instituto Nacional de Estadística e Informática [INEI], 2015).

Peruvians have an average height of 1.65 m for men and 1.53 m for women, with a genetic load of 80% Native American that characterises the Peruvians' short stature compared to other populations (Asgari et al., 2019; Escobar- Galindo, 2020; NCD-RisC, 2016). At least two out of every three adults are overweight or obese, mainly in urban areas and with less poverty. The total prevalence of overweight in the population of 30-59 years was 46.1%, with obesity level I at 18.6% and level II at 4.2%, with overweight being more prevalent in men and obesity in women (Centro Nacional de Alimentación y Nutrición [CENAN], 2014).

According to the United Nations, Peru is a developing and emerging industrial economy (E&IE) due to economic growth with limitations in the diversification of productivity, connectivity, inequality and institutional capacities (United Nations, 2014). The World Bank classified Peru as a developing economy, precisely as a middle-income country in the category of Upper middle-income country, similar to most Latin American countries, being positioned below other countries in the region, such as Chile and Uruguay, classified as HICs (OECD, 2016). Among the significant difficulties Peru is experiencing in achieving a higher status are the quality of education, lack of management and governance, and limitations to having an efficient and equitable healthcare system.

Peru's health expenditure is 5.5 % of GDP, being below that of Chile (7.8%) and Colombia (7.2%), whilst compared with HICs such as the UK (9.1%) or the USA (17.1%), the gap is greater (WHO, 2020). The level of health insurance is another situational problem, about 82% of Peruvians are affiliated with at least one healthcare insurance, whereas 18% are without any insurance to cover their health needs (OECD, 2017). The Peruvian current health expenditure (CHE) per capita measured in dollars ($) was about $656 in 2015, as long as Colombia and Chile spent more than Peru (about 40% and 70% more, respectively). In contrast, compared with HICs, the difference is overwhelming. The CHE per capita in the UK is $4125, and in the USA, $9507, evidencing a completely different reality in terms of budget direct to contribute to patient benefit (WHO, 2015). Hence, Peru is one of the countries with low expenditure in the healthcare systems of Latin America.

Peru has a deficit of physicians; the average number is 13.1 physicians per 10,000 inhabitants, while other LMICs in Latin America, such as Colombia and Mexico, have more than 20 physicians per 10,000 inhabitants. Other HICs exceed this number, surpassing the average of 40 physicians per 10,000 inhabitants (Germany, Italy) (WHO, 2020). This deficit creates a gap that accentuates inequities in the country and hinders quality care. Thirty-two per cent of the total medical specialities are concentrated in surgeons, with general surgery being the third most common medical speciality. In addition, there are very few beds for hospitalisation: 16 per 10,000 inhabitants, while in Chile, there are 21 beds; in Brazil, 22 and in

Spain, 30 (WHO, 2020). To this must be added the poor organisation of logistics that forces patients to wait two weeks for an appointment and up to 2 hours and 15 minutes to receive care; in the best of cases, only 11 minutes (Aceves-González et al., 2021; Asociacion de Contribuyentes, 2018).

The Head of the Healthcare Sector is led by the Ministry of Health (MINSA), which addresses healthcare politics to regulate the different levels of care to populations, including hospitals and medical centres in Peru. Nevertheless, the healthcare system is fragmented into five institutions: The Social Security of Health (ESSALUD), attached to the Ministry of Labor; the healthcare services of the Armed Forces (Navy, Aviation and Army), attached to the Ministry of Defence; the healthcare of the National Police of Peru, attached to the Ministry of the Interior; and Private sector institutions healthcare providers, private insurers, clinics and civil society organisations. This distribution makes it difficult to establish healthcare politics (Cevallos, 2017).

Latin American countries, including Perú, had the lowest availability and use of equipment and technology in hospitals and healthcare centres (WHO, 2015). The General Office of Control (Contraloria) reported that 79% of the healthcare centres in Peru did not have the minimum equipment required to work correctly. The report indicated that 36% of the equipment was not operative, 33% were stored in poor conditions, increasing the probability of damage, and 28% were not used (La Contraloria General de la Republica, 2016). Even though there are no precise numbers about the real state of the operating room in Peru, it is presumed there exists a gap in access to technology and equipment to improve patient safety.

2.4.2.2. Surgery in Peru

The WHO states that approximately 234 million surgical operations are performed worldwide, of which 7 million are complicated and 1 million die. Complications can lead to situations of disability that prolong hospitalisation in 25% of patients (WHO, 2008). More than 125,000 surgical interventions are currently performed annually in Peru, of which 50% are elective surgeries (Ministerio de Salud [MINSA], 2014).

During the literature review, no studies on the prevalence or frequency of laparoscopic surgery in Peruvian hospitals were evidenced. Nevertheless, there are statistical compendiums with general information on the different surgical procedures and the reality of operating rooms.

The report of the hospitals of the social security “ESSALUD” is one of the most representative and could give greater scope on the reality of surgeries in Peru. The total number of surgeries performed in Hospitals during 2018 and 2019 was 381 083, higher than the 2019/2020 period as a possible effect of the Covid-19 pandemic, so it is not regular. During the last two years, the number of operating rooms was reduced by 20% compared to 2018 and 2020. Likewise, the percentage of suspended hospital surgeries increased by 0.6% from 2005 to 2019, reaching 5884 (ESSALUD, 2020). The average number of surgeries per operating room is 1.4, maintaining the same level since 2015 but lower than in 2010 (1.6) and 2011 (1.6). The total number of minor surgeries of low requirement decreased by 11.3% since 2005, but complexity surgeries doubled, reaching 12.4%. Complex cases are attended to by a larger population with fewer operating rooms available, a more significant number of suspended surgeries, and fewer scheduled surgeries.

Concerning laparoscopic surgery indicators, no official published data summarises this reality, so the statistical compendiums of the hospitals were analysed, choosing one of the most representative to provide further scope. For the analysis, data was taken from one of the most emblematic and representative hospitals in southern Lima, the Maria Auxiliadora hospital, which has 470 beds and attends more than 2,000 consultations per day and 300 emergency consultations. The referential population it serves represents 25.5% of Lima; however, it has serious infrastructure deficiencies and a lack of medical technology (Plataforma del Estado Peruano, 2017).

According to reports, between 2016 to 2020, in the hospital's general surgery department, laparoscopic surgery ranked among the 30 most frequent surgical procedures increasing from 38% to 56.2% from 2018 to 2019.

The most frequent surgical procedure in the hospital's surgery department was cholecystectomy with laparoscopic technique, reaching 1593 cases (87%), while surgery with open technique reached 201 cases (13%).

On the other hand, appendectomy was one of the most prevalent surgeries in emergencies, being more frequent in open surgery (76.3%) than laparoscopic (23.7%). Other procedures that ranked in the top 30 were: laparoscopic inguinal hernia, appendectomy and laparotomy (Oficina de Estadística e Informática, 2016, 2017, 2018, 2019, 2020). Therefore, the implementation of laparoscopic surgery in Peruvian hospitals is increasing and demands many emergency and elective surgeries, being the most common laparoscopic cholecystectomy.

2.4.2.3. Patient safety in Peruvian operating rooms

Mortality in the medical services of Peruvian hospitals is relatively high in contrast to other countries in Latin America and globally (Sanclemente et al., 2004). Peru is one of the countries with the lowest patient safety culture globally.

According to the IBEAS project (project led by WHO), in which 58 Latin American countries (including Peru) were evaluated, 10% of patients admitted to hospitals had experienced some harm, and 20% had had at least one incident during their stay in the hospital. In Peru, adverse events in hospitals were 11.6%, with women being the most affected (WHO, 2011). More harmful incidents occurred in surgical units and intensive care units. Among the main medical procedures that had more adverse errors were surgical wound infection, lesion of an organ due to medical intervention or procedure, and haemorrhage or haematoma due to medical intervention or procedure (WHO, 2011).

The safety culture in Peruvian hospitals is very restricted by the lack of specific measures to help preserve patient safety. During the review of the available literature, technical documents formulated by various hospitals were identified to establish a management system for patient safety improvement, aligned with the directives of the Peruvian Ministry of Health (ESSALUD, 2016; MINSA, 2006; MINSA, 2009). However, implementing these policies in operating rooms has limitations due to a lack of awareness and commitment, high workload, poor infrastructure and lack of equipment and trained personnel (Mira et al., 2020; Palomino Sahuiña et al., 2020).

On the other hand, many of the clinical guidelines recommended in Peruvian hospitals are inapplicable due to a lack of material and human resources, especially when guidelines come from outside Peru and there is poor quality in their implementation (Canelo-Aybar et al., 2016; Soto, 2019).

2.4.2.4. Deficiencies of Peruvian operating rooms

Various reports in recent years have pointed out severe deficiencies in the surgical systems of hospitals in Peru. These include inoperative operating rooms, inoperative operating tables with failures in the regulation systems, deteriorated and rusted surgical equipment, monitors with failures in electrical connections, burned surgical lamps, and cars for the displacement of surgical material with deteriorated wheels (Condori, 2018; Defensoría del Pueblo, 2019).

Biosafety conditions are also not guaranteed. In the semi-rigid zone of hospitals in southern Peru, the post-anaesthesia recovery area does not have a septic room, bedpan washer, dirty linen and solid waste storage area, or a changing and cleaning area (Defensoría del Pueblo, 2019). In addition, reports indicate that hospitals had a high patient waiting list for surgery, reaching up to 3896 patients in 2018 as a product of deficiencies.

Legal demands in Peru of presumed medical responsibility were high in surgical specialities, with the highest being gynaecology and obstetrics speciality (50%) and followed by general surgery with 20.6% (70 cases) (Navarro-Sandoval et al., 2013). Nogoy et al. (2021) stated that performing laparoscopy in countries like Peru is challenging due to poor infrastructure, especially in decentralised regions, which can jeopardise patient safety.

2.5. Work-related musculoskeletal disorders in laparoscopic surgery: A review

2.5.1. Definitions, aetiology and theories

Work-related musculoskeletal disorders (WRMSD) is the term used to refer to injuries or painful disorders of muscles, tendons, nerves, cartilage and vertebral discs associated with the work environment and work demands (EU-OSHA, 2019). When disorders are not work-related and may be due to multiple causes that do not necessarily involve work, they are commonly referred to as musculoskeletal disorders (MSD). WRMSDs involve certain specific conditions and are clinically described by naming them according to the region of the body involved and the type of condition. Common WRMSD comprises mainly soft connective tissue injuries, including ligaments, tendons, and muscles and less frequent nerve, bone, and cartilage injuries (Freivalds, 2011; Kumar, 2007).

WRMSDs are usually described according to the clinical condition of the body segments and the type of condition. Among those described are muscle strain, tendonitis, tenosynovitis, bursitis and related conditions, ligament sprain, osteoarthritis, nerve compression syndromes and regional pain syndromes (Bridger, 2018c; Punnett & Wegman, 2004). However, WRMSDs do not only contemplate clinical medical conditions or specific diagnoses but also refer to multiple or localised pain syndromes (non-specific MSDs) that are commonly characterised by the appearance of musculoskeletal symptomatology that limits occupational performance.

Work-related musculoskeletal symptoms (WRMS) are painful disorders that affect mechanical body structures and have a possible cause at work (EU-OSHA, 2019; Sokas et al., 2011). However, WRMS have less clinical characterisation and involve localised pain in specific anatomical areas. According to Roquelaure (2018), the following syndromes are non-specific: upper extremity pain, neck muscle tension, cervical pain, dorsal pain (mid-spine pain), low back pain and lumbago, and lower limb pain.

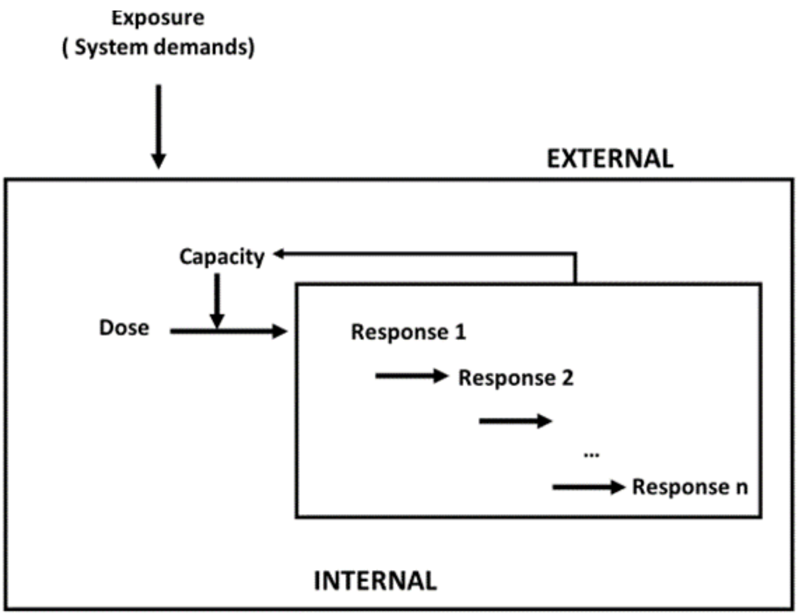
On the other hand, some non-specific pain considered systemic is not possible to classify or label acceptably because they are process descriptions that produce problems and confusion in attributing the cause. These are generally referred to as Repetitive Strain Injury (RSI) or cumulative trauma disorder (CTD). They are considered to be upper limb musculoskeletal disorders, but there is also a wide variety of locations and history of this type of injury (Bridger, 2018c). Therefore, contributory factors in this group can include static workload in the same person, repetitive /dynamic workloads, tendons inflammation (epicondylitis, carpal tunnel syndrome) and cold environments. However, there is a consensus that if several of these symptoms coincide during work activities and the possible cause of these symptoms is known, it is referred to as RSI (Bridger, 2018c; EU-OSHA, 2019; Hagberg, 1995).

Another term used synonymously with WRMS is physical discomfort or musculoskeletal discomfort, commonly used in the literature as a descriptor for fatigue, tiredness, pain/biomechanical strain and circulation (Helander, 2005b; Zhang et al., 1996), or simply the state of non-comfort (De Looze et al., 2003). Thus, identifying WRMSD and risk factors in the work system is crucial for better management to improve work efficiency, promote job satisfaction and prevent disability (Hosseini et al., 2021; Putz-Anderson et al., 1997). This thesis will use the term WRMSD to identify clinically specific and non-specific work-related disorders, including WRMS and discomfort, to distinguish them from musculoskeletal injuries not related to work.

Musculoskeletal injuries are defined as mechanical disruption of tissues resulting in pain and a series of symptomatologies. When an external traumatic event has affected the integrity of the tissue and its mechanical properties are disturbed, the tissue is injured. Injuries are generally traumatic and do not necessarily involve a prepathogenic factor or prepathogenic progression (Kumar, 2007). For example, sudden imbalance, rolling apart, crushing, slipping and falls. However, injuries can also involve mechanical degradation of tissues due to repeated use or overuse of a muscle group, leading to tissue inflammation.

WRMSD involves overexposure of tissues to work system factors that produce mechanical stress and affect the tissue. Therefore, the continuous repetition of movements without rest and prolonged effort could constitute risk factors for WRMSD establishing a causal or exposure-dose-response relationship (Armstrong et al., 1993; Bridger, 2018c; Kumar, 2007).

The concepts of exposure, dose, response and effect are used in epidemiology to describe the stages in the development chain of occupational diseases. The model described by Armstrong et al. (1993) is relevant to establishing the dose-response-effect relationship taking into account a systemic model of risk factors (see Figure 2.4). Therefore, it is one of the best ways to analyse the risk factors of WRMSD and their effect on individuals.



Note. Figure extracted from Armstrong et al.(1993)

Figure 2.4 Exposure- Doses -Response model

This model identifies four components: "exposure", "doses", "responses" and capacity. "Exposure" refers to the work demands that affect the internal body, e.g. workplace layout, tool design, cycle time, job dissatisfaction, cold, and heat. These factors demand workers to work with exposure to awkward postures, repetition, and strain, which affects the body's internal parts (doses). This effect can produce a metabolic response on muscles and tendons, leading to stretching or deformation and compression of the articular surfaces. Some dose effects are mechanical, physiological or psychological. As a result of the dose, a first internal response can lead to changes in the shape and metabolism of tissues.

This first effect is called the "primary response". Examples of primary responses include changes in substrate levels and changes in muscle, among others. These primary responses can then act as a dose to generate a secondary and tertiary response, behaving as a chain reaction. Examples of secondary responses include physical responses (e.g. change in strength and mobility) and physiological responses (discomfort, pain). Capacity refers to the ability of an individual to cope with multiple doses that their musculoskeletal system is exposed. Individuals are not born with a fixed capacity but develop with experience, age and training. Examples of capacity are soft tissue strength, bone density/strength, aerobic capacity, self-esteem, and discomfort tolerance.

Training can increase an individual's muscular strength and aerobic capacity to resist and cope with the doses resulting from exposure to the work system. Hence, the imbalance in the system occurs when the working conditions and work demands (exposure - doses) do not fit with the capabilities of people resulting in an injury that could affect the development of the work activity (Delleman et al., 2004; Grandjean, & Kroemer, 1995; Vanwonterghem et al., 2012)

2.5.1.1. Overexertion theory

The theory of overexertion states that WRMSD occurs when the level of effort applied to the task exceeds the physical and physiological tolerance of the individual, making them vulnerable to injury. The main risk factors identified that support this theory are exposure to force, posture, repetition and duration during tasks. Several studies have stated that when one or more of these factors or a combination of them are present in work systems, then the risk of WMSD is higher (Bridger, 2018c; EU-OSHA, 2019; Helander, 2005b; Punnett & Wegman, 2004; Putz-Anderson et al., 1997)

Force: Muscles can resist loads when the maximum voluntary contraction (MVC) is less than 15%. Between 15 to 20% of MVC static contraction can be maintained indefinitely when contraction levels are maintained. However, when these limits are exceeded, muscles lose oxygen nutrients and form lactic acid stimulating the onset of fatigue (Kroemer & Kroemer, 2020). Nevertheless, most jobs do not usually involve static postures but combined and repetitive actions in cycles or established patterns so that the static criterion could be limited. Based on that perspective, Kumar & Mital (1992) suggested establishing a mixed criterion that involves physiological aspects and includes workers' perception of preference for establishing acceptable levels of work. Psychophysical perception patterns have proven to be very reliable and valuable in establishing safe work limits and are relevant in establishing risk-neutral work and a valid criterion for decision-making in work redesign for the reduction of WRMSD (Fox et al., 2017; Kumar, 2007; Sharples & Cobb, 2015; Snook & Ciriello, 1991).

Posture: The forces, geometry and arrangement of muscles, tendons, and bones can vary depending on the arrangement of the segments in space (Kumar, 2007). The ranges of motion can vary due to different factors; however, the best mechanical and physiological advantage occurs when the joint is mid-range. Different authors state comfort angles (Grandjean & Kroemer, 1995; Kee & Karwowski, 2001; Porter & Gyi, 1998) that describe mid-range in each joint segment. Kumar (2007) defines this range as approximately 20% of the joint range of the segment, although it may depend on the worker's perception. By exceeding the limits, musculoskeletal tissues can be strained beyond their physiological limits and precipitate injury.

Repetition: There are two main criteria to establish if there is a risk of WRMSD due to repetitiveness; 1) if the average work cycle duration is less than 30 seconds, and 2) if tasks require the same pattern of movements for more than 50% of the work cycle time (ISO, 2007; Silverstein & Armstrong, 1986). In normal conditions, with breaks of 50 minutes per hour and strength less than 5% of MCV, it is possible to sustain up to 30 technical actions/minute (Occhipinti, 1998).

Duration of exertion: The duration of exertion depends on variables such as the type of muscle contraction, the magnitude of contraction, the recovery period, and the repetition of the activity. The more duration with negative factors involved, the more fatigue in the muscle, diminishing the activity's endurance. The recovery time after a great exertion can vary according to the exertion and the onset of the anaerobic cycle. Åstrand (2003) suggests five minutes after a significant exertion to recover oxygen and regulate the aerobic process.

The measurement of these risk factors and their presence in the workplace has served as a basis for ergonomists as input to measure risk through different ergonomic tools such as NIOSH (Waters et al., 1994), REBA (Hignett & McAtamney, 2000), RULA (McAtamney & Nigel Corlett, 1993) and other assessment methods. Other factors in the work system that are present and act as synergistic factors to the biomechanical factors on the risk of WRMSD are physical and/or environmental factors**.** For instance: localised compression in any segment of the body due to the use of tools or other artefacts; exposure to heat or cold (temperatures close to 10° Celsius); hand tool vibrations; personal protective equipment that restricts movement; continuous grasping or manipulation of tools, such as scissors, tweezers or similar (Marucci et al., 2000; Occhipinti, 1998; Park et al., 2015).

Finally, psychosocial factors also play a relevant role in the genesis of WRMSD. The literature reveals different associative studies between psychosocial factors in WRMSD, with the main factors being: poor job control, job dissatisfaction, monotonous tasks, lack of compensation and social support, among others (Menzel, 2007; Putz-Anderson et al., 1997; Rodriguez Rojas et al., 2021).

The literature review generally shows that MSDs are not of unusual origin but have a multicausal and multifactorial nature, so the term work-related disorder is more appropriate than "occupational disorder", which corresponds to disorders due to a specific cause.

2.5.2. Work-related musculoskeletal disorders in laparoscopic surgery

Alleblas et al. (2017) performed a systematic review on WRMSD in laparoscopic surgeons, compiling HICs literature revealing a mean prevalence of WRMSD of 74% (95% CI = 65%-83%). Assuming that people who reported no symptoms never had physical complaints, the percentage would be 22% (95% CI = 16-30). This same study also concluded that the segments mainly affected in surgeons with discomfort or pain were the neck with 53% (95% CI = 42-63%), back with 51% (95% CI = 34-68), shoulders with 51% (95% CI = 41-60) and hands with 33% (95% CI = 14-55).

A recent study conducted by Gutierrez-Diez et al. (2018) determined a prevalence rate (during the last 12 months) of 90% among 140 laparoscopic surgeons in Spain. The prevalence was reported to be high in the lower back (54%), neck (51%), upper back (44%), lower limbs (42%), right shoulder (29%) and right hand (28%). This study applied the Nordic questionnaire by interviewing surgeons directly to reduce bias. Hence, the literature concludes that laparoscopic surgeons of different medical specialities have a high prevalence of WRMSD that exceeds 60% of the population and reaches margins of up to 90% of the population evaluated. The segments mainly affected were the back, neck, and shoulders.

Epstein S et al. (2018) conducted another systemic review on WRMSD in surgeons from different specialities to assess the prevalence of WRMSD. The main conclusions were that orthopaedic surgeons have the highest prevalence of WRMSD injuries, such as degenerative cervical spine disease, rotator cuff pathology, and degenerative lumbar spine disease. In contrast, laparoscopic surgeons have fewer diagnoses highlighting degenerative lumbar disease (9%) and carpal tunnel syndrome (4%). On the other hand, the meta-analysis also concluded that surgeons who practice laparoscopy have musculoskeletal symptoms above 60% in the upper limb regions, which is higher than that of orthopaedic surgeons and other specialities. It is noteworthy in this study that the laparoscopic technique generates many symptoms in surgeons. However, surgeons did not report clinical diagnoses, which may be caused by a lack of risk awareness in operating rooms.

All the studies had in common that questionnaire-based surveys were applied using self-report techniques, except for the study by Gutierrez-Diez et al. (2018), which used a direct interview to apply the questionnaires so that the bias could be reduced. The studies were mainly conducted in European countries (Netherlands, Germany, Spain, United Kingdom, Italy); (Asia, Korea, China, Hong Kong) and the United States. There were no records of prevalence studies in Latin American countries.

For the measurement of WRMSD, the Nordic questionnaire for musculoskeletal symptoms or modified versions were mainly used due to its high reliability and international validity (Dickinson et al., 1992). However, some of the studies conducted on surgeons did not clearly define WRMSD, often assuming symptoms, pain, complaints, stiffness, traumatic diagnosis or fatigue as WRMSD, which generates inconsistency in the final data and a lack of clarity in establishing the questions adequately. This may explain the high WRMSD range across studies. Also, it highlights the importance of establishing a framework based on ergonomics and systems to validate the results. Despite the limitations, it is clear that the WRMSD prevalence is high in laparoscopic surgeons. However, there are no records in the literature on the prevalence of WRMSD in surgeons operating in deficient work systems such as Peru.

2.5.2.1. Impact of WRMSD on patient safety: A review

Whilst the prevalence of WRMSD in surgeons is high, not many studies have focused on the impact of WRMSD on patient safety or surgical performance. Among the studies that considered the impact, it was concluded that approximately 16-34% of surgeons believed that their musculoskeletal symptoms could affect their laparoscopic surgical performance or activity (Adams et al., 2013; Esposito et al., 2013; Ruitenburg et al., 2013).

The impact of WRMSD was also reported in the reduction of the number of cases attended (caseload) to operate by laparoscopy, the number of complex cases, emergency surgeries and minor cases reaching from 6.7% to 17 (Adams et al., 2013; Hignett et al., 2017; Szeto et al., 2009). WRMSD somehow impacted the choice of operative approach modifying the laparoscopic surgical technique. According to studies, these modifications were reported by 25% to 65% of the surveyed surgeons (Bagrodia & Raman, 2009; Plerhoples et al., 2012; Villa et al., 2019). Franasiak et al. (2012) evidenced that surgeons in general (including those using robotic surgery, open and laparoscopic surgery) as a coping strategy to reduce pain changed positions during surgeries (79%), limited the number of cases attended per day (14%), spread the cases throughout the week (6%) or limited the number of cases per day (6%). This can be detrimental to the patient because the selection of surgical techniques should be guided by technical criteria and not by possible discomfort or injury to the surgeons.

On the other hand, complex laparoscopic surgeries have a high risk of error because they require more training and technique, leading to muscle fatigue in the upper limbs and loss of functionality in the surgeons. Kaya et al. (2008) found that 44% of laparoscopic surgeons had tremors in the hands, impacting their manipulation of tools. Cass et al. (2014) identified that disc protrusion injuries in surgeons also made it difficult for them to manipulate laparoscopic instruments. Despite the evidence found in the different studies, not enough studies report direct impacts on the patient or specific complications related to musculoskeletal symptoms.

2.5.2.2. Factors associated with WRMSD in laparoscopic surgery

Physical factors

Several studies revealed associations between the physical elements of operating rooms and WRMSD. One of the main elements was the regulation of the operating table which was associated with injuries in the neck and shoulder regions (Hignett et al., 2017; Lee et al., 2017; Manasnayakorn et al., 2009; Wauben et al., 2006).

Wauben et al. (2006) stated that more than half of surgeons (70%) found the table height too high and recommended lowering it to a more acceptable level, while Wolf et al.(2000) noted that 61% tried to lower the table as much as possible to alleviate discomfort.

Regarding the monitor display, the possibility of height adjustments was associated with neck symptoms mainly (Lee et al., 2017; Lucas-Hernández et al., 2014) but not the type of monitor or the mounting system used in operating rooms (Lakatos Andras, 2012; Lee et al., 2017; Park et al., 2015). To ensure comfortable viewing, adjusting the monitor height about 15° below the surgeon's eye level is recommended, avoiding neck extension. The distance between the surgeon and the monitor depends mainly on the size of the monitor. It should be far enough to avoid the accommodation of the eye and extreme contraction of the extraocular muscles (Zachariou, 2019).

The placement of trocars in the patient's abdomen was associated with the risk of WRMSD due to surgeons' postures, especially when they are positioned contralateral to the surgeon (on the opposite side) (Hignett et al., 2017a). Similarly, trocar placement was associated with the symptomatology of the hands (fingers) (Lee et al., 2017).Pedals allowing diathermic energy activation were associated with foot symptoms mainly (Van Veelen et al., 2003; Wauben et al., 2006)

Franasiak et al. (2012) and Lucas-Hernández et al. (2014)) found a higher prevalence of WRMSD in surgeons when the size of laparoscopic instrument handles was larger than surgeons' hands (measured by glove size). Likewise, Berguer & Hreljac, (2004) noted that 26% of surgeons with pre-existing symptoms reported difficulty using laparoscopic instruments (graspers and staplers), whilst van Veelen et al. (2004) indicated that the manipulation of laparoscopic instruments caused discomfort in the head, neck, shoulders, arms, back and hands.

Organizational factors

Several studies have linked surgeons' lack of ergonomics training to an increase in WRMSD. Villa et al. (2019) noted that surgeons who did not receive ergonomics training had a higher risk of WRMSD than those who did.

Shepherd et al. (2016) identified that 32% of surgeons associated WRMSD with a lack of ergonomics training. Similarly, Hignett et al. (2017) identified an association between lack of ergonomics training and overall WRMSD in laparoscopic gynaecologists.

Other relevant factors evidenced in the literature were the complexity and duration of surgeries associated with WRMSD. Cass et al. (2014) identified that vertebral disc protrusion injuries were associated with higher complexity of laparoscopic surgery and working hours per week. The long duration of laparoscopic surgeries without established breaks was associated with a higher prevalence of WRMSD (Shepherd et al., 2016).

Different laparoscopic techniques, such as SILS (single incision laparoscopy), were associated with a higher prevalence of WRMSD than conventional laparoscopic surgeries (Esposito et al., 2013). Likewise, Plerhoples et al. (2012) found that laparoscopic surgeries were more associated with higher rates of WRMSD in the upper back (41.4%) and shoulders (33.2% and 27.7%) than open and robotic laparoscopic surgery. However, neck and lower back symptoms were mainly associated with open surgery.

Personal factors

Several studies pointed out that women have a higher risk of WRMSD in laparoscopic surgery than men, so gender is a relevant risk factor (Adams et al., 2013; Dianat et al., 2015; Franasiak et al., 2012; Hignett et al., 2017; McDonald et al., 2014; Stomberg et al., 2010; Sutton et al., 2014). The upper limbs, neck and back were the segments most associated with female surgeons (Sutton et al., 2014).

Despite these results, there are also contradictory studies finding no gender differences, especially when compared to general surgery (Szeto et al., 2009). Surgeons with fewer years of experience (<5 years) and younger were more predisposed to develop WRMSD (Sari et al., 2010; Shepherd et al., 2016). Nevertheless, some studies stated that age and work experience increase risk. Park et al. (2010) did not establish a relationship between WRMSD and age but found a strong association between the number of cases attended and symptoms in the neck, right hand, upper limbs and lower limbs, concluding that the number of cases per year could be a strong predictor. Later, this was corroborated by Liang et al. (2013), who also evidenced a high association of symptomatology in hands, wrists, and back when surgeons operated on more than 250 surgeries per year.

Work-family conflicts are one of the main psychosocial factors reported in surgeons associated with high levels of WRMSD in different body segments but with greater emphasis on shoulders and knees (Dianat et al., 2015). This factor is related to the phenomenon of "double presence"; workers (in this case, surgeons) are concerned about what happens at home while working.

2.6. A systematic approach based on Ergonomics to redesign surgical systems

2.6.1. SEIPS model as thesis framework

As shown in the previous section, many healthcare studies focus on analysing surgeons' problems without having a clear vision of the work system. The studies were mainly focused on detecting possible occupational health problems of surgeons such as WRMSD from a physical and epidemiological approach without extending its application to the possible impact on patients' safety. From this perspective, the System Engineering Initiative of Patient Safety (SEIPS) model was born as a valid alternative based on the principles of Ergonomics and work systems that seek benefits for both patients and healthcare workers as well as to improve the quality of healthcare (Carayon et al., 2014; Hignett et al., 2013).

The SEIPS model was developed considering the principles of ergonomics and human factors described by Dul et al. (2012). Its structure responds to an adaptation based on the Donabedian model, the structure of the SPO model (Structure-Process-Outcome) of Donabedian's theory (Moore et al., 2015) and the work system model of Carayon & Smith (2000). In the SEIPS model, the central core is the person who interacts dynamically with the other work system's elements so that the system adapts to the person's limitations and capabilities.

SEIPS also highlights how the design of the work system (structure) is directly linked to the safety of patients and healthcare workers (outcomes) through the care processes (process) (Xie & Carayon, 2015). The model focuses not only on the caregiver, patients or healthcare workers like other models, but also on the interactions across the system (Hignett et al., 2013).

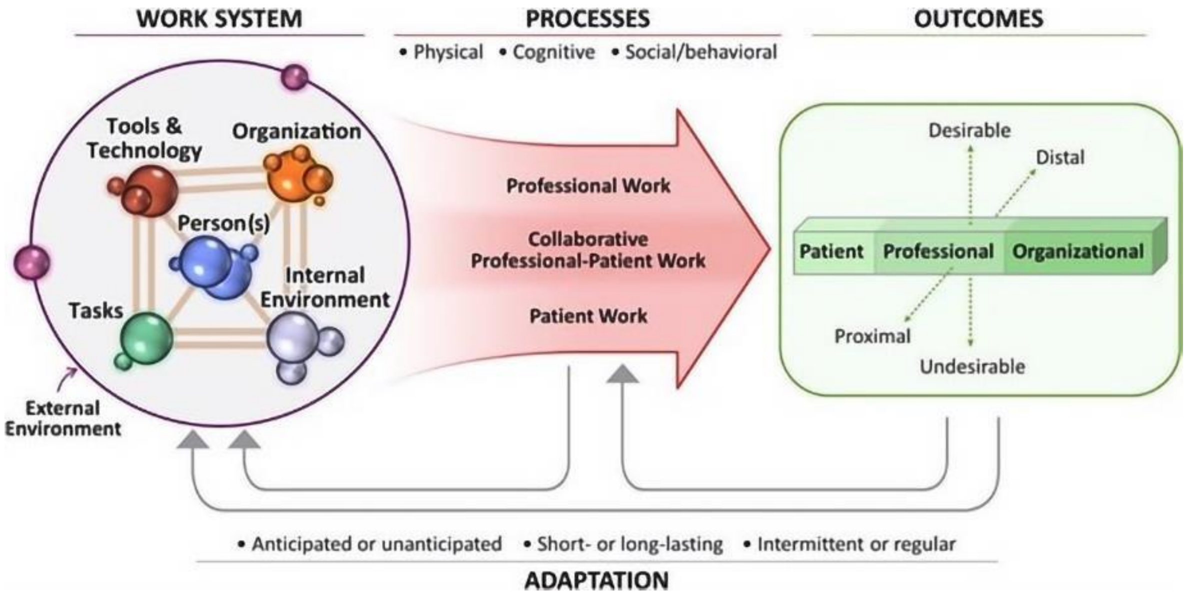
For this reason, SEIPS takes a macro ergonomics approach to understand the interactions between each of the elements that make it up and can thoroughly guide the analysis with a focus on the redesign of the system (Carayon et al., 2014; Carayon et al., 2006; Wilson, 2000). Thanks to the SEIPS model, it is possible to identify the negative and facilitators factors among the work system elements, understand their dynamics, and prioritise them to design or redesign systems following an anticipatory ergonomics approach. In this way, the model avoids understanding the problem from a reactive view but understands the failures and hazards that may increase the likelihood of harm to patients and injuries to healthcare workers.

During the literature review, a diversity of published works using the SEIPS model as the basis for safeguarding patient safety were evidenced. Even in the current Covid-19 pandemic, studies, analyses, and letters to the editor (Carayon & Perry, 2020; Escobar-Galindo, 2020) have been presented using this model as a basis for identifying barriers and facilitators in critical systems such as intensive care and trauma units (Gurses et al., 2012, 2020; Hignett et al., 2013; Holden et al., 2013; Werner et al., 2021; Wetterneck et al., 2014; Xie & Carayon, 2015). The application to different contexts and environments ensures that SEIPS has sufficient external and internal validation for its application in the thesis.

The SEIPS model has evolved over time as research has developed, including up to three versions: SEIPS, SEIPS 2.0 and SEIPS 3.0 (Carayon et al., 2020; Carayon et al., 2006; Holden et al., 2013). However, all versions have the same core components and only vary by including new concepts, broadening the definition of the components clarifying some aspects, and considering multi-system elements, including the patient journey. Recently an abbreviated version called SEIPS 101 was launched to simplify its application (Holden & Carayon, 2021).

2.6.2. SEIPS model description

The SEIPS model comprises three components; the work system, the work process and the outcomes. This means that the work system in which healthcare is provided affects both the work and the clinical process, ultimately impacting patients, workers and the organisation (outcomes), as shown in Figure 2.5.



Note. Figure extracted from Holden et al. (2013)

Figure 2.5 SEIPS model versión 2.0

Work system

The work system comprises six elements, the person, the tasks, the organisation, the tools and technologies, the internal environment and the external environment.

The person is the system's centre and is represented by healthcare workers, caregivers, patients, and even work teams. Tasks are the attributes or characteristics of tasks such as difficulty, complexity, variety, ambience and sequence.

Tools and technologies are the objects that people use to work and help people do something.

Organisation refers to the structures external to people but placed by people in the workplace related to time, resources and activities.

The internal environment refers to the physical work environment and includes illumination, noise, temperature, vibration, physical layout, available space, and air quality.

Finally, external factors incorporate external macrolevels such as the economy, politics, and ecological factors outside the organisation (Carayon et al., 2014; Holden et al., 2013).

Work Process

The work process is a set of tasks performed to change inputs into outputs intrinsically related to the work system (Carayon et al., 2020). The SEIPS distinguishes three types of performance in the process: (a) professional work-process (the workers are the main actors performing the process); (b) patient work-process (patients or caregivers are the actors in the process); (c) collaborative professional and patient work process (both healthcare workers and patients and/or relatives participate in the work-process) (Holden et al., 2013).

Outcomes

Outcomes are the states or conditions resulting from the work process that impact healthcare workers, caregivers and patients and can even encompass the organisation. Outcomes resulting from the work process can be immediate (proximal) or long-term (distal). WRMSD in surgical teams and patients harm are examples of outcomes (Holden et al., 2013)

Adaptation

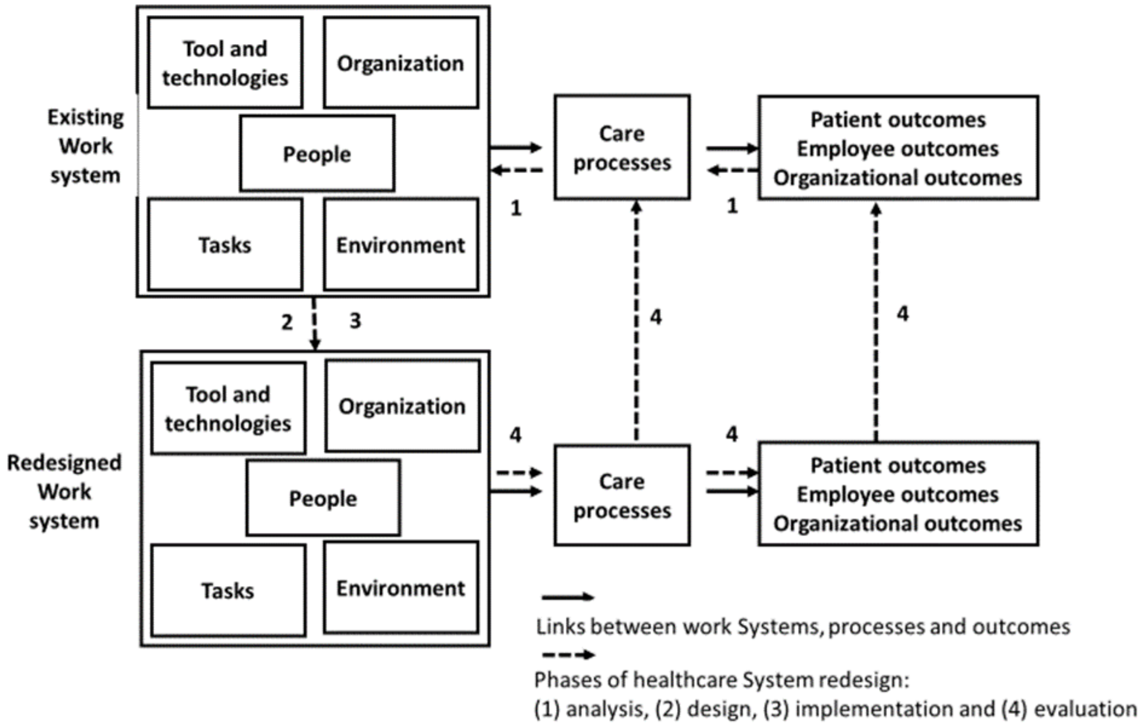
Adaptations are how the work system is regulated by comparing actual and ideal functioning (Carayon et al., 2020). Systems regulate themselves by supervising the work process and outcomes; therefore, they are fundamental for learning and continuous improvement of the system. Adaptations can be planned (anticipated) or long-lasting and reactive or short-lasting. Ideally, adaptations are better to be long-lasting and anticipated to optimise performance without impacting health (Holden et al., 2013).

2.6.3. System redesign based on Human Factors Ergonomics using the SEIPS model

Healthcare system redesign based on Ergonomics can be defined as the deployment of ergonomics tools, knowledge and practitioners in the analysis, design, implementation and evaluation of changes in the healthcare work system to improve care processes and patient, employee and organizational outcomes (Xie & Carayon, 2015). Implementing ergonomics strategies such as participatory ergonomics can be fruitful in finding solutions for redesign, especially when healthcare professionals, patients, family and stakeholders are involved in the process (Xie & Carayon, 2015). Therefore, system redesign aims to intervene in the physical, cognitive and organizational problems related to ergonomics that can affect the quality of care and patient safety (Carayon, 2006, 2016).

Among some physical problems, for example, are mismatches between the requirements of the tasks and the physical characteristics of healthcare professionals, technologies used in the healthcare system with physical dimensions and physical environments that do not facilitate the development of clinical tasks (Xie & Carayon, 2015). From this perspective, WRMSD in healthcare workers results from a hostile work process and a work system with poor interactions that directly affect the health of patients and healthcare workers. Thus, attention should be paid to the system's dynamics and the work process to redesign the healthcare system successfully.

Therefore, ergonomics-based system redesign is distinguished from a regular quality of care improvement process because it incorporates the principles of ergonomics application throughout the analysis process supported on a systems model (see Figure 2.6).



Note. The dotted lines in the opposite direction at the top represent how the negative outcomes are the product of deficiencies in the care process and turn, of poor interaction in the work system. The lower part of the Figure represents the redesign and work surveillance to improve the system. This Figure was extracted from Xie & Carayon (2015)

Figure 2.6 Ergonomics-based system redesign

2.6.4. Ergonomics application in laparoscopic surgery systems

Studies focusing on healthcare systems redesign are limited, especially in operating rooms. During the literature search, different studies with a systems approach to ergonomics in operating rooms were identified with particular emphasis on critical areas such as cardiac surgery, which is complex, long duration and with high workloads (Barach et al., 2008; Catchpole et al., 2006; Palmer et al., 2013; Parker et al., 2010; Parker, 2010).

However, only the study conducted by Gurses et al. (2012) employed the SEIPS model to identify factors based on a novel pairwise analysis to establish the harmful elements of the system. The authors conducted a qualitative study to identify and categorise patient safety hazards in cardiovascular operating rooms using an interdisciplinary approach based on the SEIPS model. The data collection consisted of participant observation in 20 cardiovascular surgeries in five hospitals in the USA. As a result, a total of 58 categories of hazards were identified related to the person (e.g. practice variations); tasks (e.g. elevated workload); tools and technology (e.g. Poor usability); physical environment (e.g. cluttered workspace); organisation (e.g. Top-down communication); and hazards and opportunities for improvement in patient safety in the process of care in operating rooms. The study concluded with recommendations to reduce the risk for patients and surgical teams, but there was no surveillance of changes.

On the other hand, studies related to ergonomics-based systems approach interventions in laparoscopic surgery are limited. The reviewed studies use human error, human reliability and patient safety approaches from a systems perspective and focus mainly on organizational and cognitive factors (Catchpole et al., 2008; Joice et al., 1998; Malik et al., 2003; Mishra et al., 2008).

The only study in laparoscopic surgery analysing the system from the SEIPS perspective was the one developed by Kolodsley (2016). The study was a thesis with a resilience approach (safety II) applying the SEIPS model to identify risk safety threats during long-term laparoscopic surgeries and resilience supports in a Canadian hospital. The study consisted of observing 19 laparoscopic surgeries (mainly gastric bypass and cholecystectomies) through a camera placed inside the operating rooms to observe the interaction of the surgical team. To categorise the threats and resilience supports, they used the SEIPS model by numbering the observations using a mixed approach to treat the information. Twenty-five threats and nineteen resilience supports were identified and categorised based on the SEIPS model.

Factors in organizational (e.g. safety culture deficiencies) and environmental elements (e.g. suboptimal workspace design) were the most frequent threats. Resilience supports were mainly in the person category (e.g. anticipatory action). Tools and technology were one of the categories with more safety threats highlighting poor device ergonomics, unintuitive design, dangerous design elements and technological malfunction.

Applied studies with a systems approach in LMICs, especially in laparoscopy, are scarce. Santos et al. (2016) conducted a qualitative study in Haiti that aimed to identify safety challenges in the technology used in operating rooms. Many of the challenges encountered were similar to those of HIC hospitals. However, the lack of services and equipment in operating rooms was evident, and safety standards were practically not applied in the healthcare systems. The author explains the need to apply a "community ergonomics" approach, defined as an action-oriented strategy involving the participation of actors involved in the issues identified in a system. In this way, businesses and companies can adapt their products to the needs of the community in order to achieve an efficient technology transfer process.

One of the studies recently published in a peer review journal on ergonomics was conducted by Ordóñez-Ríos et al. (2019), developed in Cuenca, Ecuador. This study reports on the importance of the anthropometric characteristics of Ecuadorian surgeons and the medical equipment used in Operating rooms of Ecuador. The study concluded that Ecuador had mismatched issues with surgeons' characteristics, poor disposition of the elements of the operation room, the lack of ergonomically designed instruments and limited space in operating rooms. It also concludes that there is no precise and reliable information on related studies in Ecuador and Latin America. Although the study has limitations, such as the sample size (only seven surgeons to determine the anthropometric chart) was a good precedent for paying attention in this area.

Finally, no studies related to the development of WRMSD in surgeons and assistants were found to redesign healthcare systems based on Ergonomics, especially in Latin American countries and much less in Peru.

Many studies in the literature involved ergonomic interventions aimed at reducing WRMSD in surgeons but not comprehensively. The vast majority of the studies had a physical factors approach using the exposure-dose-response model by identifying a specific system element and analysing posture, duration, and overexertion. Among the studies were interventions applied to diagnose deficiencies and improve equipment and technology design in surgery.

The interventions allowed designers and users to take action on the equipment and tools used in laparoscopy. For instance, the positioning of the visualisation screens (Brown et al., 2003; Haveran et al., 2007; Matern et al., 2005; Muratore et al., 2007; Uhrich et al., 2002), the regulation of operating tables (Berquer et al., 2002; Manasnayakorn et al., 2009; Matern et al., 2001; Van Veelen et al., 2002), the positioning of trocars (Fingerhut et al., 2010; Hignett et al., 2017; Lee et al., 2017) and the manipulation and design of surgical instruments(Berguer & Hreljac, 2004, 2004; Lucas-Hernández et al., 2014). However, many studies have reached conclusions that have not solved the underlying problems, such as operating tables, which are still used by surgeons today without relevant modifications despite being designed for open surgery (NHS, 2009).

These studies allowed the development of specific assessments such as checklists (van Veelen et al., 2004; Wauben et al., 2006) and specific guidelines of recommendations to reduce physical and mental overload on surgeons and assistants (Supe et al., 2010; Zachariou, 2019). These guidelines supported designers and medical technology manufacturing companies in developing surgical equipment for laparoscopic surgery. Despite the diversity of the research globally, the majority were developed in HICs.

The standards and medical equipment were designed to consider the HICs populations, limiting the integration of other non-developed countries. New technology developed in many cases is inapplicable in LMICs. For example, new laparoscopic tools were developed with flexible handles whose cost exceeded the regular price of tools (Anderson et al., 2016); or special seats for laparoscopic surgery with mounted systems would be impossible to place in operating rooms with little space and not prepared (Takayasu et al., 2019).

On the other hand, research also focuses on improving robotic laparoscopic surgery, such as The Da Vinci system. This technology has not yet reached Peru despite more than 20 years of implementation in HICs. (Cornejo et al., 2019).

2.7. Summary

Laparoscopic surgery is a minimally invasive surgery beneficial for patients but physically and mentally demanding for surgeons due to sensory and motor restrictions that limit direct manipulation of the structures for surgery.

Peru is classified as an LMIC with severe limitations in the healthcare system. It has deficient healthcare spending, a fragmented system that weakens administration, and a restricted patient safety culture. Operating rooms have severe deficiencies that may limit patient quality care, putting them at risk. Likewise, these conditions make it possible for surgeons to have a high probability of WRMSD. In addition, the ergonomic approach is limited in Peru, which restricts the possibilities for system change.

WRMSDs are prevalent in laparoscopic surgeons and are associated with physical, organizational, psychosocial, and personal factors. The impact of WRMSD on patient safety is not clear in the literature. There is no evidence of studies on WRMSD in laparoscopic surgeons in Latin America and even less in Peru. The studies were mainly conducted in HICs using quantitative methodologies without a clear framework.

Ergonomic intervention studies to reduce WRMSD are numerous in HICs literature but limited in LMICs. Furthermore, the approach in the literature is mainly quantitative without collecting opinions from surgeons directly through qualitative or mixed approaches.

It is concluded that no studies can be used to aid in redesigning work systems based on ergonomics in laparoscopic surgery in Peru that aim to reduce WRMSD and improve patient safety, and therefore, the focus of this PhD research was to gather such information.

Chapter 3. Research Philosophy

3.1. Chapter overview

This chapter aimed to establish the methodological foundations and the strategies used to develop the research presented in the thesis. This chapter describes the research paradigm, approaches, designs, and methods.

3.2. Overall research approach

The thesis adopted a framework of research studies built upon previous findings, including some elements of the action research approach in healthcare systems (Koshy et al., 2010). These elements included a participatory character with a focus on people and their simultaneous contribution to science (knowledge) and social change (practice), taking into account the particular context in which the facts emerge (Koshy et al., 2010). In this way, the thesis proposes formal research that generates knowledge and research that allows for action of change in the Peruvian healthcare system.

Three studies were carried out in parallel to address the first aim, and the integration of results provided conclusions regarding factors affecting WRMSD for surgeons in Peruvian operating rooms. These conclusions were then used to define two further studies that address the second aim. Although the first aim of the thesis was identified, the second aim was flexible depending on the results of the first part of the study, so the methods selected in the second part depended on the first results.

3.3. Thesis theoretical framework

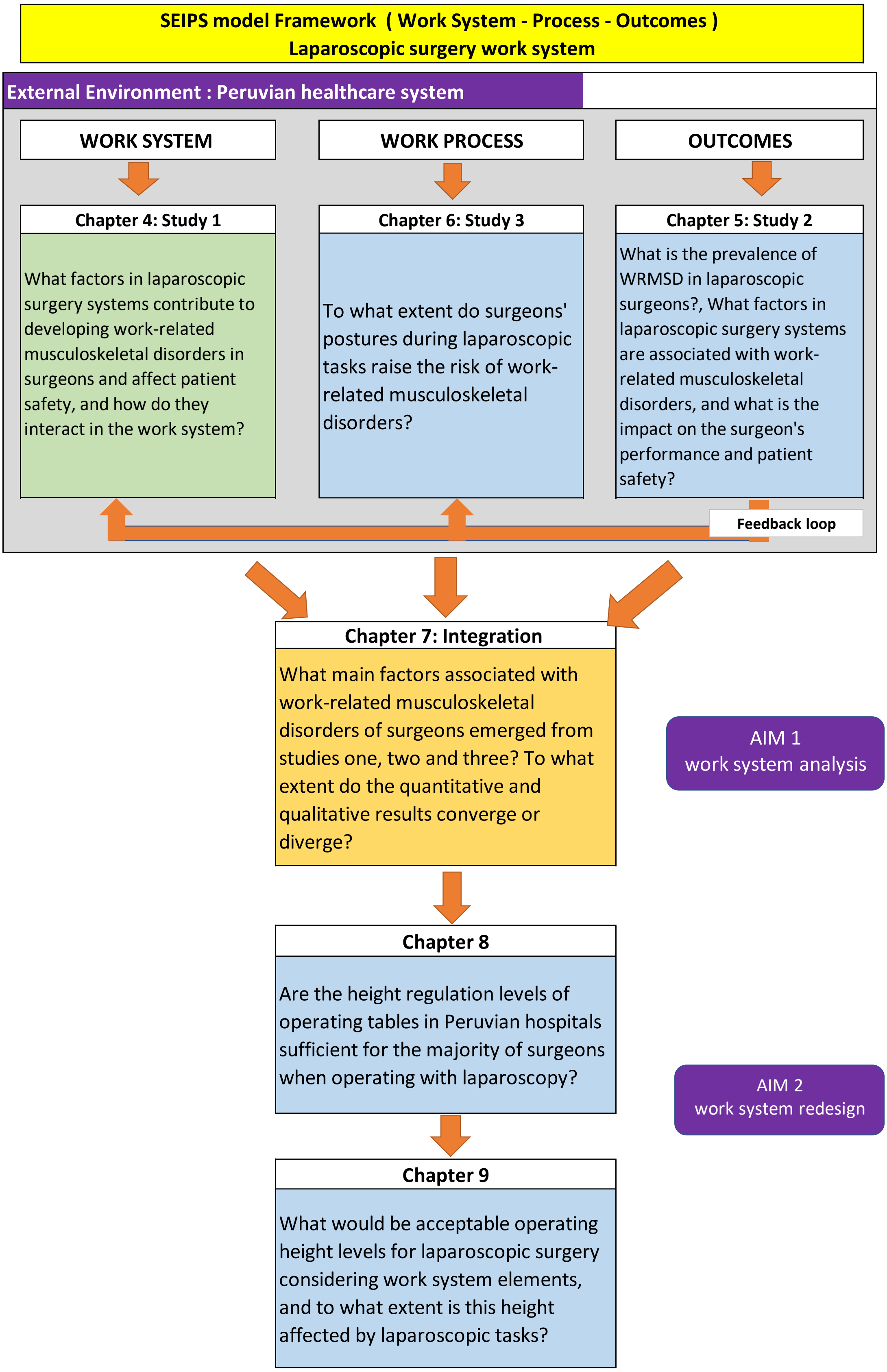
The thesis was developed using a theoretical framework based on the SEIPS model. For more details on the SEIPS model, see chapter two, section 2.6.1. The thesis had two primary stages: the laparoscopic surgery work system analysis and work system redesign to establish recommendations based on the analysis (Carayon et al., 2014; Holden et al., 2013). From this analysis, the main factors that hinder the system and impact the work process and outcomes (aim 1) are identified to plan the following actions for intervention and redesign (aim 2).

Therefore, to fulfil the first aim of the thesis, four research questions were formulated and answered in three studies (chapters four, five and six), representing each component of the SEIPS model and a chapter on the integration of results. Study one encompassed the analysis of the work system through a qualitative and participatory view of the workers (chapter four); study two quantified the outcomes translated into possible effects on the workers (WRMSD prevalence) and the patient (impact on the system and patients) and possible associations with the elements of the system (feedback loop) (chapter five). Study three quantified the risk of WRMSD in the postures adopted by surgeons due to the interaction with the elements of the system (chapter six). In chapter seven, the results from the three studies were integrated to determine the main factors affecting the system. This also directed the following lines of action to achieve the second aim of the thesis (see Figure 3.1).

To achieve the second aim of the thesis, two additional research questions were formulated to establish recommendations for redesigning the system taking into account the surgeons' characteristics and preferences (chapters eight and nine) and the laparoscopic surgery work system to reduce WRMSD and maintaining patient safety in Peruvian hospitals. Figure 3.1 illustrates the overall design of the thesis by identifying the main research questions, the theoretical framework and the objectives.

3.4. Research framework

Description of the research approach, designs and methods used was developed following the model by Creswell & Creswell (2017). In this model, the researcher must reflect on the paradigm or worldview that he/she brings to the study, the research design that fits this vision and the specific research methods or procedures that allow the approach to be implemented.



Note. Green box: qualitative approach; blue box: quantitative approach; orange box: Integration. Pragmatic paradigm

Figure 3.1 Theoretical framework research questions and studies to achieve aims

3.4.1. Research approach and design to achieve the first aim

Issues in Healthcare systems are complex and need to be analysed in their context (Carayon, 2006; Dul et al., 2012). A healthcare system can have multiple elements to assess and interactions that can jeopardise patient safety. For example, many clinical and non-clinical staff in outpatient and acute care interact with different physical and environmental elements in a healthcare system, creating significant challenges that potentially risk harming patients (Hignett et al., 2013). This becomes even more relevant in healthcare systems in LMIC, such as Peru, where deficiencies can increase the complexity of providing quality and safe care to patients. Thus, the investigation of complex systems merits using multiple data sources and data collection methods to assess the numerous aspects of the working systems and their outcomes for both patients and healthcare professionals.

For this reason, the thesis adopted a mixed research approach that allows a broader and more profound assessment of ergonomics-related problems in healthcare systems to safeguard patient safety and healthcare professionals. In mixed or multi-strategy research design (Robson & Mc Cartan, 2016a), the researcher combines quantitative and qualitative research approaches to broaden understanding and corroboration (Johnson et al., 2007). This approach is based on the understanding that quantitative and qualitative designs have biases and weaknesses that are compensated for during qualitative and quantitative data collection by mutually excluding their weaknesses (Creswell & Clark, 2017).

The use of mixed research approaches involves using a pragmatic paradigm or worldview. In this paradigm, the researcher uses whichever philosophical or methodological approach best works for the research problem (Robson & Mc Cartan, 2016a). It is focused mainly on the research question and the search for an answer by delving into qualitative and quantitative approaches. In pragmatism, concerns focus primarily on applications (that works) and problem-solving rather than methods or designs (Creswell & Creswell, 2017). Combining quantitative and qualitative data would provide a better picture of the problem and facilitate redesigning the work system by reducing overload and improving patient safety (Carayon et al., 2015).

This thesis mainly adopted the convergent or parallel research design developed through three studies (one qualitative and two quantitative) and a chapter dedicated to integrating results. The convergent mixed design was the most suitable research design because it allowed the researcher to merge quantitative and qualitative research data to analyse the research problem comprehensively (Creswell & Creswell, 2017). The researcher collects quantitative and qualitative data simultaneously and establishes general interpretations of the results by integrating the results through joint displays and mind maps (Fetters, 2019).

This type of mixed research is most commonly used in Ergonomics studies applied to healthcare systems. In particular, to assess the relationship of technologies with users as well as to identify barriers and facilitators within complex healthcare systems (Bekhet & Zauszniewski, 2012; Casey & Murphy, 2009; Jones & Hignett, 2007). Different studies addressed this strategy, including joint displays and mind maps mainly to perform across triangulation (Carayon et al., 2015; Carayon & Perry, 2020; Rochais et al., 2013).

3.4.1.1. Deductive and inductive approach

The use of quantitative approaches demands mainly a deductive approach, while qualitative approaches are predominantly inductive (Saunders et al., 2009). This does not mean that the deductive approach is exclusive to the quantitative approach, but it can also be applied in qualitative research, albeit to a limited extent (Saunders et al., 2009). In the deductive approach, the researcher seeks to explain causal relationships between variables by establishing hypotheses and collecting data to test them. In addition, the deductive approach allows generalisation as long as sufficient samples are taken to achieve this objective. On the other hand, in the inductive approach, the researcher begins collecting data and then analyses them to develop a theory, thus comprehensively understanding the nature of the problem (Saunders et al., 2009).

The thesis employed deductive and inductive approaches to achieve the objectives and respond to the research questions. For example, in study two (chapter five), a study was conducted to establish an association between the risk factors of the surgeon's work system and musculoskeletal symptoms in a sample of 144 surgeons surveyed. This study allowed for establishing causal or associative relationships between the variables to open subsequent studies using a deductive approach.

Study one (chapter four) was a qualitative study that aimed to analyse the work system of surgeons to determine risk factors contributing to the development of musculoskeletal disorders. A predominantly inductive but also deductive strategy was used to collect information. From the surgeon's testimonies and participant observations, categories were established and framed within the SEIPS model using an inductive approach. However, as the SEIPS framework already established specific definitions of the meaning of the categories, then the thematic analysis results were also analysed with the SEIPS categories using a deductive approach.

3.4.1.2. Quantitative approach in studies two and three (chapters five and six)

Studies two and three (chapters five and six) adopted mainly a quantitative approach. The quantitative approach uses a post-positivist paradigm where the researcher collects data through an instrument that measures the problem. The information is analysed using statistical procedures and testing hypotheses. This paradigm is referred to as "the scientific method" or "doing science research" (Creswell & Creswell, 2017).

The quantitative design to answer the research questions in studies two and three was non-experimental, adopting a cross-sectional correlational design because the data were taken once at a specific time. In this design, the researcher uses correlational statistics to describe and measure the degree of association (or relationship) between two or more quantitative variables (Robson & Mc Cartan, 2016b).

Study two adopted this design mainly to associate risk factors in the work system and WRMSD, whilst study three applied this design to associate postural risk with work system factors.

3.4.1.3. The qualitative approach in study one (chapter four)

Study one (chapter four) primarily adopted a qualitative research approach to explore the work system of laparoscopic surgeons within Peruvian hospitals and identify factors that contribute to the development of WRMSD in surgeons and affect patient safety. This approach was based on the constructivist or interpretivism paradigm, which aims to understand and interpret motives, meanings, reasons, and other subjective experiences linked to time and context in human behaviour and social interactions rather than predict causes and effects. Research in this paradigm is developed "from the bottom up," considering the perspectives of individuals to expand patterns and knowledge (Denzin, 2017).

Several studies in ergonomics and human factors use the qualitative approach to explore work systems and identify barriers and factors that put patients at risk (Carayon et al., 2015; Carayon & Perry, 2020; Gurses et al., 2012). This is because it allows for a deeper assessment of problems by evaluating the reasons, identifying potential risks and how the workload of healthcare workers may affect patients in a specific context (Carayon et al., 2015). This approach, therefore, provides greater flexibility in data collection and facilitates the use of methodologies that allow the perspective of stakeholders to be gathered with flexible questions and real observations (Hignett & Wilson, 2004).

3.4.2. Research approach and design to achieve the second aim

In order to achieve aim two, it was first necessary to know the results of the integration process of the previous study, establishing two new research questions which were responded to through a quantitative or fixed approach. The research question of study four (chapter eight) had primarily a quantitative component that first determined the percentage of surgeons who matched the height of the operating tables. Therefore, a quantitative or fixed approach was used with a mainly non-experimental design, and according to the research purpose, it was mainly descriptive and cross-sectional. This is because the aim was not to generate correlations but to describe the results through a quantitative analysis which would serve as a basis for answering a subsequent research question.

Study five had two main objectives: to determine the acceptable operating table height and the extent to which heights are affected by laparoscopic tasks. Therefore, a quantitative descriptive design was adopted to meet these objectives and answer the research question, but with components of a quasi-experimental study for within-subjects (repeated measures). In this study, the same participant is asked to respond to different stimuli of an independent variable to determine a response and define a common height. However, it is not a complete experiment since the variable is not manipulated, and no randomisation was generated (Robson & Mc Cartan, 2016b).

3.4.3. Thesis research methods and thesis design

The research methods used in the thesis and their explanation are detailed in each chapter. Table 3.1 illustrates the research questions posed in the study and the respective research paradigms , designs and methods adopted throughout the thesis.

Chapter	Research question	Paradigm	Research design	Research method
4 Study 1	What factors in laparoscopic surgery systems contribute to developing work-related musculoskeletal disorders in surgeons and affect patient safety, and how do they interact in the work system?	Constructivist (part of pragmatic)	QUAL (flexible) exploratory phenomenology	Interviews (semi-structured, face-to-face)and participant observation
5 Study 2	What is the prevalence of WRMSD in laparoscopic surgeons? What factors in laparoscopic surgery systems are associated with work-related musculoskeletal disorders, and what is the impact on the surgeon's performance and patient safety?	Postposititvism (part of pragmatic)	QUAN (fixed) explanatory, correlational cross-sectional	The questionnaire-based survey, Self-completion (online and paper format distribution)
6 Study 3	To what extent do surgeons' postures during laparoscopic tasks raise the risk of work-related musculoskeletal disorders?	Postposititvism (part of pragmatic)	QUAN (fixed) descriptive cross-sectional	Observational method: Postural analysis Hierarchical task analysis
7 Integration	What main factors associated with work-related musculoskeletal disorders of surgeons emerged from studies one, two and three? To what extent do the quantitative and qualitative results converge or diverge?	Pragmatic	Multistrategic mixed-method Convergent Design	Integration or merging techniques using joint displays
8 Study 4	Are the height regulation levels of operating tables in Peruvian hospitals sufficient for the majority of surgeons when operating with laparoscopy?	Postposititvism	QUAN (fixed) descriptive cross-sectional	Anthropometric survey Method of limits adapted from fitting trials using anthropometric data available and criteria to design working heights
9 Study 5	What would be acceptable operating height levels for laparoscopic surgery considering work system elements, and to what extent is this height affected by laparoscopic tasks?	Postposititvism	QUAN (fixed) Quasi-experimental within-subject	Psychophysical techniques: Users' preferences by Fitting trial

Note. QUAN: quantitative; QUAL: qualitative

Table 3.1 Summary of research design and methods carried out in the thesis

3.5. Summary

This chapter presented the research methodology developed during the thesis, describing the different paradigms, research designs and methods used to achieve the aims.

The thesis is divided into two stages: the analysis of the laparoscopic surgery work system and the recommendations for the system's redesign based on the SEIPS conceptual framework. The research approach used in the first stage was mainly pragmatic, having a post-positivist and constructivist vision using different quantitative and qualitative methods. In the second stage, the thesis adopted mainly a positivist approach, developing quantitative research designs in the last two studies. The practical aspects of each method are explained in more detail in each chapter throughout the thesis.

Chapter 4. Study 1: Ergonomics in laparoscopic surgery: a work system analysis in Peruvian hospitals

4.1. Introduction

As previously concluded in the literature review, surgeons are at constant risk of WRMSD, especially when performing laparoscopic surgery, due to the physical and sensory restrictions demanded by the task. This is evidenced by high rates of WRMSD and different risk situations mainly investigated in HICs under a physical ergonomics approach. However, there is scarce literature that analyses laparoscopic surgery as an integrated system of interacting components. In addition, there is no background of reliable research on ergonomics in laparoscopic surgery carried out in LMICs such as Peru, which has significant deficiencies in their healthcare systems. The absence of this data will be the starting point for exploring the laparoscopic surgery system in Peruvian hospitals from a qualitative approach.

This chapter presents the work system analysis of laparoscopic surgery in operating rooms of Peruvian hospitals using a qualitative approach. The study was intended to answer the qualitative research question:

RQ1: What factors in laparoscopic surgery systems contribute to developing work-related musculoskeletal disorders on surgeons and affect patient safety, and how do they interact in the work system?

4.2. Methods

4.2.1. Study design and sampling strategy

A qualitative study was the most suitable approach to explore surgical work systems and achieve the study's aims.

Direct observation of operating rooms in five Peruvian hospitals, complemented by interviews with laparoscopic surgeons, enabled a detailed exploration of the system and provided a classification scheme for the main risk factors based on the SEIPS model.

The criteria for choosing the hospitals were based on purposive sampling, which considered the number of patients, hospital size, geographical location, volume of laparoscopic surgery and interest in the study, and included five hospitals. Four hospitals were located in different parts of Lima, and one was a regional hospital in Piura, northern Peru. All five hospitals received students and residents, and one was exclusively for emergencies. The sampling strategy to recruit surgeons in the hospitals followed two steps. First, purposive sampling was performed to contact surgeons with expertise in laparoscopic surgery, who acted as gatekeepers and provided access to the surgical staff. Second, snowball and opportunistic sampling occurred to contact new surgeons, considering their contacts and the unexpected flexibility to participate (Hignett, 2016).

As a result, 18 surgeons who performed laparoscopic surgery and 14 surgical residents participated in the study. All 18 surgeons participated in interviews. Sixteen surgeons (twelve male and four female) and 14 surgical residents (nine male and five female) participated during observations of laparoscopic surgeries.

4.2.2. Data collection

A semi-structured interview was applied to surgeons that consisted of 15 questions about different topics related to possible work-related issues in laparoscopic operating rooms. Beforehand, the study was explained to the surgeons, who signed the consent form before participating. Interviews were carried out in surgeons' offices or specific rooms in the hospitals designed to avoid distractions or noise.

The interviews opened with questions related to their work in operating rooms, followed by questions about factors related to the use of technology, organization, laparoscopic tasks and the physical environment that may increase surgeons' musculoskeletal overload. Furthermore, the interviews included questions about possible incidents or events that could occur during surgeries and may affect surgeons and patients. The final set of questions asked surgeons to describe the possible musculoskeletal symptoms or health issues resulting from their work. Interviews were conducted and recorded in Spanish (since the Peruvian language is Spanish) and then transcribed verbatim. The recorded interviews were assigned an identification code to quote examples (for instance: I-02). The coding process was carried out in Spanish following the iterative process. Once the process had finished, the final factors identified, outcomes and the main testimonies and observations were translated into English.

In total, 20 laparoscopic surgeries were observed across the five hospitals. The type of surgeries observed was described in Table 4.1. The protocol for participant observations consisted of the researcher filming the laparoscopic surgery from the beginning of the surgery (the preparation of the patient was not included). A SONY XR camcorder was used to film the process positioned at an angle to capture the interaction and movements of the surgeons and assistants and the surgical procedures in the operating room.

Patients were not filmed or photographed during surgeries. Before surgery, surgeons were informed about the study and its implications before signing the consent form. Then, according to the surgery scheduled, patients were informed about the procedure and the study's aims, emphasising that their identities would be protected and they would remain anonymous in the research should they choose to participate. Participant observations were conducted after the perioperative period, starting when the patient was ready to be operated on and ending immediately when the surgeon finished the surgery.

The researcher observed the process in the real context without interviewing surgeons and annotated all the relevant information, such as postures adopted, gestures, movements and interactions between surgeons and assistants during surgery.

Table 4.1 Surgeries observed during the research

Surgeries observed	Laparoscopic surgery observed	Average time in minutes (min and max)	Brief description
15	Cholecystectomy	50 (30-90)	Surgical removal of the gallbladder
2	Inguinal Hernia Repair	68 (67-68)	Surgery that allows the return of the bulging tissue to the abdominal wall with sutures and protective meshes.
1	Appendicectomy	102	Surgical removal of the appendix
1	Sigmoidectomy	134	Surgery removes all or part of the sigmoid colon
1	Cholecystectomy with complication	156	Surgical removal of the gallbladder with bile leak and bleeding
1	By-pass Y roux stomach surgery	212	Bariatric surgery. Surgeries that involve procedures that make changes to the digestive system to help lose weight

During surgery, surgeons explained the process and surgical tasks performed aloud. Spontaneous verbalisations or comments from surgeons and assistants during the surgeries were recorded with a voice recorder and then transcribed. Observations were coded with the number of surgery observed (for example, S-03 refers to surgery three).

4.2.3. Data analysis and development of classification

4.2.3.1. Proposed multilevel scheme

The data analysis was based on the SEIPS model (Holden et al., 2013) following the classification scheme suggested by Gurses et al. (2012), where an iterative approach was established, a three-tiered categorisation.

This categorisation consisted of a classification scheme based on three levels. The highest level (top) included the elements of the SEIPS model (person, tasks, tools and technologies, organization, internal environment and outcomes). The second level (subcategory) included more detail on the highest category and was classified as a "general factor", while the third level defined in more detail the factor identified and was called a "detailed factor". These last two categories emerged from the data collected.

4.2.3.2. Data coding process

A qualitative data content analysis was performed to condense the raw data into general and detailed factors following the proposed classification scheme based on the SEIPS model. Both deductive and inductive approaches were used to analyse the qualitative data. The factors that emerged from the surgeons' observations and testimonies were developed inductively and then classified according to the categories of the SEIPS model (deductive). This combined approach allowed considering a work system's categories (elements) and their interactions against the SEIPS model framework. Using theoretical frameworks is an accepted data management method in the coding process (Miles et al., 2020).

Annotations from observations and transcriptions of interviews were entered into the NVivo software, and a first visual recognition of the data was performed. The analysis began by generating initial codes within the raw data, including sentences, words or specific paragraphs from the transcripts. A library of basal codes with brief definitions was obtained at the end of the process. Data saturation was considered when generating new codes was not possible, thus ending the coding phase.

The base codes that emerged from the iterative analysis were grouped according to their affinity and similarity with others to obtain categories (factors) and descriptions. The categories formed should have internal homogeneity (similarity) and external heterogeneity (different and distinct from other descriptions) (Braun & Clarke, 2006). Codes that did not fit into any category were temporarily put aside, and at the end of the process, they were reviewed, and a specific category was proposed. Categories were sorted against the theoretical framework of the SEIPS model following the proposed multilevel classification scheme. This way, an inductive process was carried out to capture the information collected from the surgical field and testimonies and a deductive process to group the codes following the SEIPS model categories. As a result, it was obtained that main categories (top-level SEIPS categories), subcategories included the identified factors (second level-subcategories), and a third level provided details about the identified factors (third-level-detailed factors). Outcomes of the work system interaction were categorised into the patient, system, and professional outcomes and proximal /distal (immediate and overtime) (Holden et al., 2013).

Table 4.2 Example of coding analysis and categorization process

First level	Second level	Third level	
SEIPS Category	**Subcategory General factor**	**Detailed factor**	**Observation/interview**
Tools and technology	Lack of Availability of suitable tools and equipment	Insufficient surgical tools and technology in the operating room	"Assistants and surgeons see the same screen because there is no other one available. Assistants rotate and extend their necks to see the screen." (S-02).
Tasks	patient´s characteristics	Shape and size of patients (obese, adult, or child)	"When we have super obese patients, even though the table is down to the floor, the patient has an abdomen like this (makes the gesture of an obese person), we have to work like this…its harder when the patient is chubby."(I-01)

4.2.4. Research ethics consideration

The study was approved by the Faculty of Engineering Ethics Committee at the University of Nottingham (see appendix 12.24) and approved by authorities of hospitals visited.

4.3. Results

The results presented as categories and subcategories extracted from the analysis of the interviews and direct observations highlight the main issues relevant to the Peruvian context. A total of 15 general factors (subcategories) from the five top-level categories emerged from the analysis, and 33 detailed factors were identified related to the surgical work system (see Table 4.3). More details that include the complete list, definitions, and examples are available in appendix 12.5. Due to the interdependence of work systems, outcomes can be caused not only by exposure to one factor but also by a combination of other factors; however, each factor (category) is presented individually for the purpose of analysis. Surgeons' testimonies were identified with numbers (for example, I-01 refers to interviewee one) and direct surgical observations with the identification number of the surgery (for example, surgery one is labelled S-01).

4.3.1.1. Persons: surgeons and assistants

Clinician characteristics

The study found that the surgeons' physical characteristics, such as height, somatotype, and gender, were essential factors. Surgeons with short statures were the most affected, predominantly female surgeons, because laparoscopic surgery requires operating at a raised working height. Even though this is a common issue found in other countries, it might be more pressing in Peru due to the population's short stature extending the problem to women and men.

"Height influences a lot, and few people realize it (I-13)". "When the patient is well-built or overweight, it is more difficult, especially when the surgeon does not have the right stature." (I-06)

Table 4.3 General and detailed factors based on SEIPS models analysis found in the study

1. PERSON

Clinician's characteristics :

- ✓ *Sensorial issues that include Low vision and the use of bifocal glasses,*
- ✓ *Different statures of surgeons and assistants*
- ✓ *Surgeons and assistants overweight*
- ✓ *Advanced age of surgeons and assistant*

The surgical team have inadequate or insufficient knowledge of LAPS:

- ✓ *Inadequate and/or insufficient training in LAPS and ergonomics*
- ✓ *Surgical staff's (camera assistants, scrub nurses, anaesthetists) lack of experience and skills*

Surgical teamwork issues:

- ✓ *Poor communication among surgical team members*
- ✓ *Coordination before and during surgery is not assertive, and support among members is limited*

2. TASKS

Patient's characteristics:

- ✓ *Shape and size of patients (obese, adult, and child patients)*
- ✓ *Anatomical variants that changed the normal procedure*

Long duration and complexity of surgery:

- ✓ *The complexity of LAPS depends on the patient's status and job demands (type of surgery, intracorporeal suturing tasks, other complex tasks)*
- ✓ *Since the complexity and other factors of the system, surgery may last a longer time than planned*

Laparoscopic surgery demands and workload:

- ✓ *Unexpected situations during surgery (surgery complications, unexpected events)*
- ✓ *Laparoscopic tasks shared with the assistant that demand specific skills (e.g. Laparoscopic camera driving)*
- ✓ *The location of LAPS changes the position of surgeons and assistants. French position (between the patient's leg), American (standing patient's side), and others (contralateral, etc.)*

3. TOOLS AND TECHNOLOGY

Poor design of tools and surgical equipment:

- ✓ *Mismatch issues with tools and technology (e.g. Operating table with poor adjustability to fit surgeons and assistants)*
- ✓ *Design restriction of surgical stools*

Lack of Availability of suitable tools and equipment:

- ✓ *Use of unsuitable equipment in surgery*
- ✓ *Insufficient surgical tools and technology in OR (e.g. Insufficient number of screens for surgeons and staff)*

The poor state of equipment in operating rooms:

- ✓ *Systems damaged and equipment that fails during real LAP surgeries*
- ✓ *Signs of wear on equipment and/or surgical instruments that difficult the performance of tasks.*

4. ORGANIZATION

Poor ergonomics and safety culture:

- ✓ *Hierarchical top-down system*
- ✓ *Limited efforts to identify and mitigate ergonomics and patient safety risks*

Limited education and training opportunities:

- ✓ *Lack of adequate training policies*
- ✓ *Lack of physical spaces prepared for LAPS training with appropriate coaches*

Poor organization of surgeries:

- ✓ *Lack of control over the pace of work. Surgeries programmed continuously without sufficient rest*

5. INTERNAL ENVIRONMENT

Deficiencies of environmental system regulation:

- ✓ *Poor state of heat regulation systems*
- ✓ *Low illumination level into OR and illuminations systems damaged*

Distractor sounds and noise:

- ✓ *Distraction due to external stimulus (e.g. External staff into OR)*
- ✓ *Disturbing sounds*

Limited physical workplace:

- ✓ *Poor disposition of equipment in ORs that difficult the performance of tasks*
- ✓ *Small spaces and/or poor layout in OR that make difficult the distribution of equipment and transit (e.g. messy cables on ORs, small size operating rooms)*

Note. SEIPS Categories (capital letters) , subcategories (Factors) and detailed factors (in italics)
LAPS (laparoscopic surgery); OR (Operating room)

Limited laparoscopic surgery training

Participants indicated an explicit limitation in accessing proper laparoscopic surgery training. Surgeons expressed difficulty accessing simulators and mock-ups to develop the necessary surgical skills. In many cases, surgeons hone their expertise directly in real surgeries with the support of experienced surgeons, limiting the development of their psychomotor skills and compromising patient safety.

"There are many surgeons that never learned intracorporeal suture, so Laparoscopic surgery is being taught in the patient's belly and very little in the laboratory when it should be 95% in the laboratory and 5% in patients." (I-12)

Teamwork issues

Teamwork was affected by poor organization and communication among surgical staff, increasing the surgery time and the fluidity of communication. This was evident during several surgeries, mainly when team members performed surgery with different levels of laparoscopic experience. The following lines are an observation made during a laparoscopic surgery in which communication was affected:

"The surgeon again asks the nurse for tools and anticoagulants, and she told him that was not available because she forgot to ask to the logistic area, increasing the surgeon's discomfort due to the situation" (S-05)

The surgeon said, " these are the problems when you do not work as a team ".... "(S-05)

Interaction among team members of different statures (person) was complicated and could affect the performance of surgery because the surgical teamwork needs to work with the same tools and equipment, such as the operating table (tool)

"When a short surgeon has to work with a much taller surgeon ….wow… who really suffers is the shorter surgeon because he has to work on that position (shoulder elevation) …?" (I-17)

4.3.1.2. Tasks

Long duration and complexity of surgery:

Laparoscopic surgery may become more complex and longer-lasting depending on different factors specific to the task, such as the type of surgery, skills required, and severity. The surgeons indicated that surgeries could turn more complex when a patient has complications in the emergency.

"If it were an emergency surgery in which the gallbladder is inflamed, or the appendix is inflamed, it makes the dissection more laborious and requires more force, i.e., pushing and manoeuvring."

On the other hand, some surgeries demand advanced skills that can further complicate the procedure, increase surgery time, and, in many cases, adopt awkward positions, perform complex tasks, and use special equipment. The main laparoscopic task identified as complex was laparoscopic intracorporeal suturing.

"Transabdominal preperitoneal hernia …, you have to enter the cavity and open the peritoneum, make the preperitoneal space, place the mesh, and then close the peritoneum (using laparoscopic suture), then this technique is more difficult, higher learning curve."

Patients' characteristics

It was a recurrent factor observed in several surgeries. Many surgeons considered that operating on obese patients increased their workload because of the elevation of working height. In addition, the patient's characteristics interact directly with other factors such as operating table height adjustability, length of tools used, and surgeon and assistant stature.

"(*About elevated operating table height) …That is also associated with the patient's height because sometimes there are very thick (obese), very thick patients … and his body is very bulky then it is also a bit difficult, especially when the surgeon does not have the right stature." (I-06).*

Laparoscopic surgery demands and workload: camera conduction.

Depending on the type of laparoscopic surgery, the position of the surgeons and assistants may change. These positions may alter the posture dynamic when operating and interacting with the surgical team. Surgeons explained that operating may depend on surgeons' previous training or experience and perception of comfort when operating.

"In my case, the French position (between the patient's leg position) is more anatomical. I can see the structures, it seems more familiar to me, but the American style is not comfortable because I look like a bullfighter (torero) working at the side of the patient ...; instead of in the French position, you are in the middle of the patient and cover the gallbladder frontally... , so I may work with laparoscopic triangulation "(I-10).

The role of camera conduction is especially relevant in the Peruvian context because, in many surgeries, this role was assumed by inexperienced students and residents. During operations, the assistant had to adapt their position to the surgeon's working height and space, frequently adopting awkward, highly static postures. Consequently, fatigue and a lack of experience meant it was difficult for the camera conductors to keep up with surgeons throughout the surgeries (see Figure 4.1a)

"During a bypass surgery, the main surgeon worked with an elevated shoulder for a long time, and the assistant held the camera in a poor position; at the end of the surgery, an evident discomfort was observed and confirmed by surgeons." (S-12)

4.3.1.3. Tools and technology

Poor design and usability of surgical instruments and technology

Several design issues on technologies and tools were identified, mainly in operating tables, surgical tools, and screens. A recurrent factor mentioned by surgeons and observed was the limited ability to reduce operating tables to a suitable height for surgeons.

a

b

c

d

Note. A. camera assistant trying to follow surgeon; B. the screen above eye level; C. surgeon operating adopting a side position and raising upper limbs since operating table height ;D. Surgeon operating in a seated position

Figure 4.1 Examples of risk factors identified

In some cases, the poor state of the adjustability mechanism of the table and the lack of remote control to regulate heights were observed. However, in most cases, it was due to the limitation of adjustability of the table design.

"The table is limited … so I have to work with shoulders elevated or use a surgical stool, and I have to stand on it and my assistant too, but it is not always available." (I-01)

The poor state of equipment in operating rooms

A recurrent issue observed in two hospitals was the use of disposable tools as reusable tools. After a sterilisation process, the tools were reused and could lose their properties, such as grasping or cutting. Reusable tools had similar issues due to the lack of a correct maintenance program, observing signs of wear which limited their functionality.

"Each time the tool is removed, the carbon dioxide is out, and the medicine intern helps by covering the trocar hole with his finger since, as they refer, is broken." (S-12)

Lack of Availability of suitable tools and equipment

Due to the lack of surgical tools in Peruvian hospitals, surgeons are forced to use different tools, which may increase the surgeons' workload and tool manipulation issues. Consequently, some surgeons switched to open surgery without planning it, increasing operating time.

"Some graspers are not ideal, for example, when gripping intestines;... Our grasper is not ideal for grasping the intestine, but we have to use it … the right ones are not available..." (I-08)

Most hospitals had only one screen fixed in a tower placed in front of the surgeon constraining the gaze of assistants (see Figure 4.1b). Different screen positions were observed, finding some even outside the viewing angle of assistants and staff, forcing them to turn their necks. Only one hospital had two screens working; one had three but only used one.

"As it is a fixed tower, we must try to put it in a good position, but sometimes it is impossible … The ideal thing would be to work with two monitors all the time, but when only one is available, we work with only one monitor." (I-03)

4.3.1.4. Organizational

Poor ergonomics and safety culture

Only five surgeons indicated that they knew about ergonomics in surgery and guidelines about laparoscopic and ergonomics but considered it challenging to apply in their realities. Only two surgeons were aware of ergonomics' importance. One was a laparoscopic instructor, and the other was a surgeon who learnt ergonomics to reduce pain because of tendonitis. However, hospitals were not involved in identifying and mitigating factors.

"We have a lot of ergonomic errors, so look, I would say that 95% of surgeons have permanent ergonomic errors from standing, neck position, monitor heights…but hospitals do not seem to care about improving this situation, so the *training is necessary to correct these errors."(I-13)*

Surgeons reported a top-down communication and lack of awareness regarding safety and ergonomics culture between hospital managers and surgical staff. They reported that poor communication was reflected in the delay and purchase of inadequate surgical instruments without considering the specifications required by surgical staff.

"Unfortunately, this eh, we depend a lot on a budget but a budget that is not handled by the doctor…. it is handled by a manager who sometimes does not understand medicine ... Therefore, he does not understand our requirements, sometimes he prioritizes other things that are not necessarily a priority."(I-11)

Poor organization of surgeries

Poor organization of surgeries is a recurrent factor that increases surgeons' and assistants' workloads. It was observed in two hospitals with fewer operating rooms prepared for laparoscopic surgery.

"Two gastric bypasses were programmed on the same day. The surgery took more than 3 hours to be completed, and 30 minutes later, another one was programmed with the same team." (S-12)

4.3.1.5. Internal environment

Limited physical workspace:

Poor equipment distribution was observed in the space in four operating rooms, especially when they were small-sized. The limited space forced assistants to adapt their spaces by moving equipment, screen, and tables, constraining their movements and visual field. Also, cables impeded transit in the operating area.

"Lack of space to transit freely since the poor disposition of equipment in rectangular operating rooms. There is no space to store surgical equipment and supplies. The lack of space limited the main entrance to the OR when the surgeon needed to use the C-Arc. Furthermore, the insufficient space limited the entrance of other staff members into the operating room". (S-09)

Deficiencies in environmental system regulation:

The temperature and lighting systems in the two operating rooms were damaged.

"During two surgeries, two surgeons claimed the raise of temperature expressing discomfort, and the nurse indicated that air conditioning was damaged." (S-05)

The illumination systems failed in many surgeries creating difficulties to operate; for example, in one surgery, the system failed, being difficult to turn on the lights again, and the surgeon could not be able to continue the surgery due to the lack of light, many technicians tried to repair at the moment, but it took more than 10 minutes until the system worked." (S-12)

4.3.1.6. Interaction of work system elements and adaptation

As explained above, numerous factors interact dynamically among work system elements rather than acting individually. For instance, a female surgeon adopted awkward postures in upper limbs (person), especially in complex surgeries (tasks) when operating on an obese patient (tasks) due to the raised height of operating tables (tools) and the poor spaces available (environment) (S-10) (see Figure 4.1c).

The SEIPS model divides adaptation into planned and reactive adaptations to manage demanding systems. A recurrent, planned, long-lasting adaptation related to the height of operating tables was the use of surgical stools to offset the elevated working height differences. However, surgical stools were limited in operating rooms and had limitations, which impeded the adaptation.

"The problem when using the stool is that there is not enough space for pedals (for electric) and nobody fit the height when we use it, feeling a sense of instability."(I-14)

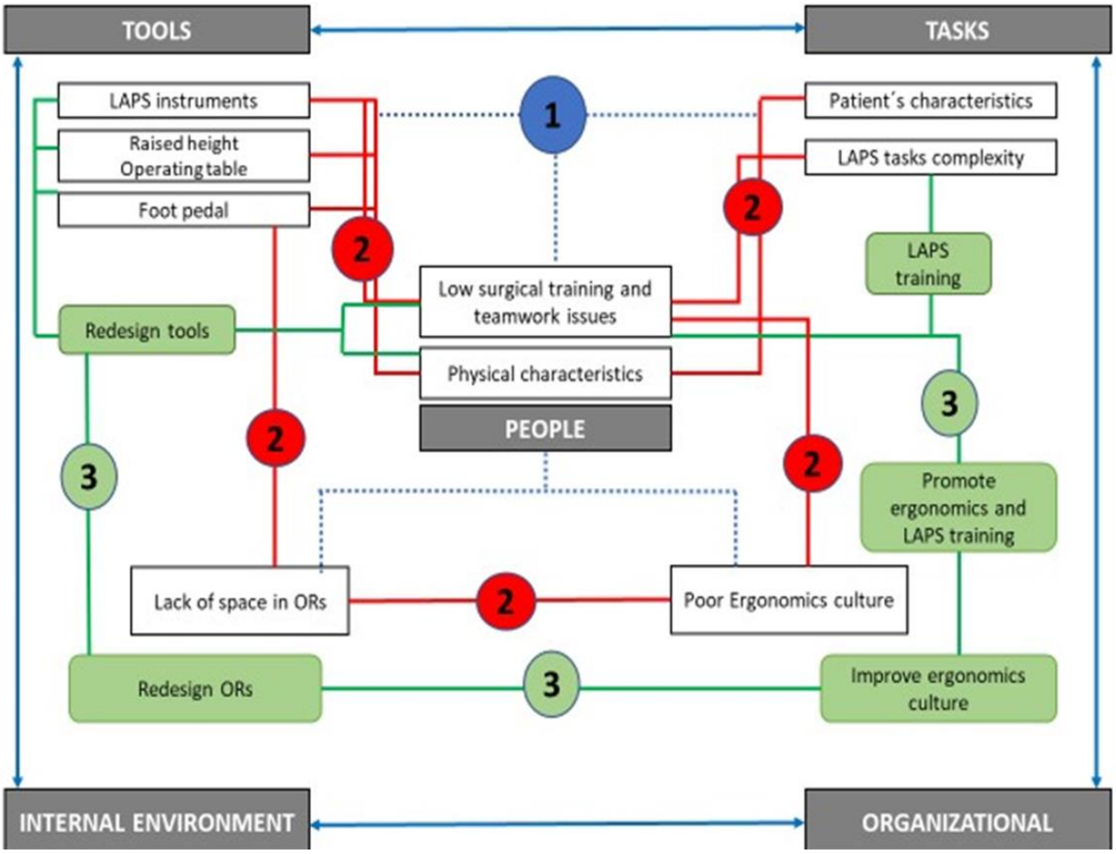
The use of unsuitable equipment when the desired equipment is not available forces surgeons to perform tasks in other ways, raising the level of exertion or adapting new movements to achieve their goals.

"…I think we basically adapt (to the surgery), that is, if we do not have a suitable grasper or we do not have a grasper that we need, we try to adapt in some other way, right? Sometimes we don't have the monopolar, we use the bipolar, things like that, that is, we try to adapt…" (I-9) "but then… we have to work with what is available, there is nothing else to do…" (I-12)

One experienced surgeon operated in a seated position (see figure 4.1d), raising their shoulders and adapting their posture to alleviate musculoskeletal symptoms in their ankles and feet. The surgeon indicated that he only adopted the seated position in cholecystectomy surgeries because of the low complexity and the possibility of positioning in front of the patient. According to the surgeon, sitting favours the precision of the technique and reduces stress on the lower limbs.

"The assistant got me a little stool which I have there, then there was the possibility to operate sitting down, I settled down and positioned the patient in front of me... When I operate sitting down, I pull the patient well down, the buttocks go down, the pelvic cavity opens up, the intestines fall down, and I don't have to do much fowler (incline the table). This changed my life, my ankle pain disappeared to such an extent that I operate sitting only gallbladder appendix no, I have to operate standing, hernias I also have to operate standing, except gall bladders and bile ducts since the position in front of me" (I-13)

Figure 4.2 illustrates the interaction among work system elements and factors identified with an example of observations. Work system interventions were also described in the figure to understand the impact on mitigating risk factors.



1	A female surgeon with a stature of 155 cm carried out a complex laparoscopic surgery on an obese patient that lasted more than 2 hours adopting awkward postures in upper limbs since the raised height of the OT. The surgeon works with a novice assistant to conduct camera. The surgeon works with a novice assistant to conduct camera.
2	Interaction among factors that are controllable and uncontrollable in the work system threaten the performance of laparoscopic tasks and/or the use of equipment that may raise the WRMSD risk and affect patient safety.
3	Designed System interventions may balance and mitigate these risk factors. For instance, by promoting LAPS training (e.g deconstructive learning) and redesigning equipment and tools to be used by many surgeons and assistants (e.g developing stools that fit for surgeons). The ergonomics awareness may improve the organization and task performance.

Note. The red line represents the interaction among factors identified in the study. Green boxes and lines represent interaction among possible design system interventions illustrating how interaction improves the work system. Blue dotted lines represent the main interaction of surgeons and assistants with the system. LAPS: laparoscopic surgery; ORs: Operating rooms: OT: operating table. The author elaborated on the figure by adapting the example provided by Holden & Carayon (2021)

Figure 4.2 Example of work system interaction with several factors identified during the study

4.3.1.7. Outcomes

Outcomes were divided into two categories: those that impacted the surgeons' musculoskeletal health and the patient's safety. These were further divided into proximal (immediate as a result of the work process) and distal (emerging over time or following complications). A list of outcomes is summarised in Table 4.4.

Several surgeons claimed to have musculoskeletal symptoms in their upper limbs when performing laparoscopic surgery, and two surgeons revealed that they were diagnosed with musculoskeletal injuries. One of them was diagnosed with De Quervain's tendonitis attributed to the poor design of the surgical tool and repetitive motions, and the other one with ankle/feet tendonitis due to the hours spent standing.

" The handle of instruments had two holes, I used these holes to deploy the instrument, putting my finger on it, however, during the time that I used and the repetitive motions I had a terrible tendonitis and wow … it was terrible…" at the end of the month, I ended up with a terrible de Quervain´s tendinitis, and I had to go to rehabilitation, but I try to take care of myself."(I-17)

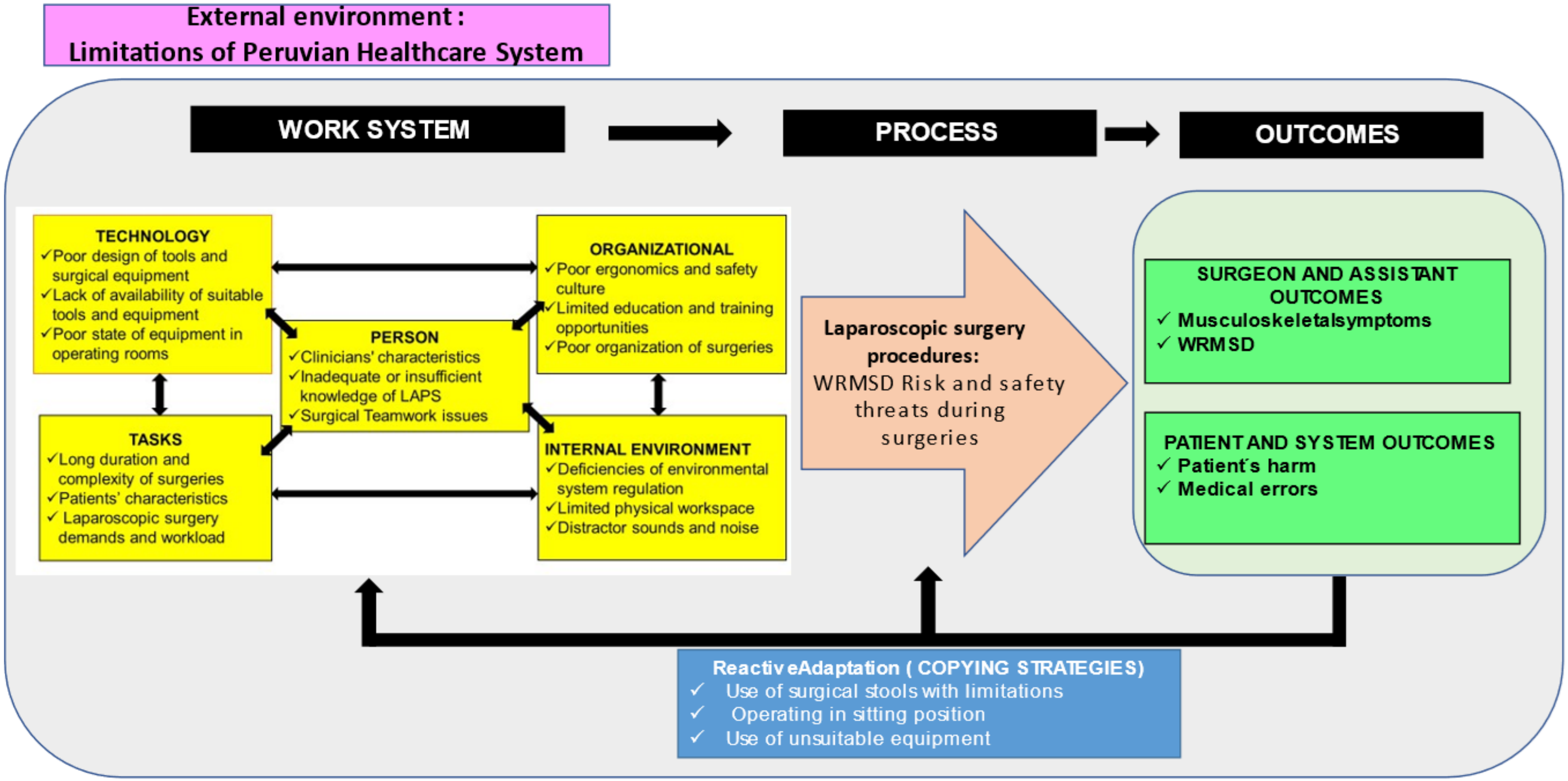
One camera assistant experienced physical discomfort after prolonged use of the camera. For instance, a bypass surgery lasted about three hours. Consequently, the assistant endured terrible pain in their right shoulder and upper back due to the high position and awkward postures.

"I have a great muscle spasm because of the adopted position due to the use of the camera during this surgery." (I-12)

Finally, Figure 4.3 summarises the work system's whole analysis, including the factors identified and the dynamic among elements, including outcomes.

Table 4.4 Outcomes as a product of analysis in Laparoscopic surgery

Proximal outcome	Distal outcomes
Professional Outcome	
Musculoskeletal discomfort on different segments: ✓ Shoulder discomfort as a product of keeping static postures while holding the camera (e.g. I-01; I-11) ✓ Upper limb pain after a high exposition (I-07) ✓ Neck and upper back pain (e.g. I-07) ✓ Hand pain after manipulating tools (I-06; S-01,02,03) ✓ Hands tremors due to a prolonged time in surgery (I-10; I-17; I-18; S-2; S-10)	***Undesirable outcomes*** ✓ Work-related musculoskeletal disorders: Quervain tendonitis, rotator cuff syndrome, ankle tendonitis (I-07) ✓ Fatigue (e.g. I-07; I-11; I-12) ✓ Stress (I-04; I-06; I-16)
Patient and system outcomes	
Errors related to the use of technology ✓ Cutting of structures that produced bleeding extending the time of surgery. Bleeding of surrounding structures due to poor manipulation of dissectors (S-05; S-06) ✓ Spread of bile after cutting the cystic conduct (gallbladder) (S-06) ✓ Anatomical structures burned related to the use of diathermy (S-6; S-12; S-13) ✓ Clips dropped off into the patient's abdomen after using the clipper ✓ Difficulties in keeping the grasp of structures (I-02) ✓ Possible patient's fall when the operating table was adjusted (I-09; I-11)	***Undesirable outcomes*** ***Patient's harm:*** ✓ Increase the operating time ✓ Internal haemorrhage (S-12) ✓ Damage to anatomical structures (e.g. gallbladder) (I-04; I-11; S-09)
Reduction of internal visibility (non-visualisation of surgery): ✓ Release of carbon dioxide (from trocars) reducing internal visibility (I-05; I-12; I-15; I-18; S-11; S-12) ✓ The screen turned off due to an external input that pulled off the cables. Non-visualisation of the instrument (S-04) ✓ Not focus on the surgery site due to poor manipulation of the camera (I-06; S-02; S-10) ✓ Camera front fogging due to poor manipulation of the camera (S-11; S-12) ✓ Frequent removal of the camera outside the patient's abdomen to try following the surgeon since fatigue (S-11; S-12)	***Medical errors:*** ✓ Surgical skills are affected by the reduced quality of care
Outcomes related to surgeon organization and team interaction ✓ Conversion of Laparoscopic surgery to open surgery (I-04) ✓ No availability of materials due to poor organization (A nurse had not prepared the material necessary for the surgery, increasing surgery time) (S-02; S-03)	



Note. Work system (yellow box-input) factors identified that interact dynamically with each other and affect the laparoscopic surgery (red arrow-process) impacting surgeons and patients (green box-outcomes). To face up to issues and reduce overload, surgeons adopt different strategies (blue box- reactive adaptation). Interactions occur in the Peruvian healthcare system with limitations (purple box). Figure adapted from SEIPS model (Carayon, 2014)

Figure 4.3 Laparoscopic surgery work system in Peruvian hospitals

4.4. Discussion

The study was the first analysis of the laparoscopic surgery system in Peruvian operating rooms from a systemic perspective. The SEIPS model was a helpful tool that allowed exploring and identifying factors within laparoscopic surgery systems, not focusing only on one particular factor but also the work system as a whole dynamic system. As a result of studying the interacting factors, a detailed list of outcomes related to surgeons (WRMSD) and patients (proximal and distal) has been identified. As explained in chapter two, studies about healthcare system analysis in Peru are scarce, especially in operating rooms where the most critical tasks are carried out and concerned directly with patient safety. Thus, the present study explored the Peruvian laparoscopic system to identify influencing factors and propose recommendations beyond changing human behaviour but intervening in the system.

The study revealed several interconnected factors that have the great potential to affect surgeons, assistants and patients. These issues are probably representative of most Peruvian hospitals due to the standardisation of laparoscopic surgical procedures but may be more pertinent in regions where the limitations of the healthcare system are evident (Defensoría del Pueblo, 2019; Nogoy et al., 2021).

Several factors found were not unique to the Peruvian context and have been reported in the literature pertaining to HICs (Armijo et al., 2018; Gurses et al., 2012; Matern, 2009; Supe et al., 2010; Wauben et al., 2006; Zachariou, 2019), for instance, screen position, patients' characteristics or teamwork issues. However, these factors could have a more significant impact on Peruvian systems due to the limitations of the healthcare systems (WHO, 2020), differences in the anthropometry of Peruvians (Escobar-Galindo, 2020; NCD, 2016), the lack of ergonomics and safety culture in hospitals (Arrieta et al., 2017), deficiencies in laparoscopic training and a poor technologic transfer process (Cornejo et al., 2019).

The height of the operating tables was a recurring factor during the study because its range of adjustment was limited in achieving an optimal position for surgeons. One surgeon explained that current operating tables were designed mainly for open surgery, not specifically for laparoscopy. Due to the long length of the instruments and the restriction of visual perception and movement in laparoscopic surgery, working height requirements for both types of surgeries are different (Wauben et al., 2006). The short stature of Peruvians, who are one of the shortest populations in the world (NCD-RisC, 2016), added to the risk factors associated with patient´s characteristics such as obesity and insufflation (process to inflate with carbon dioxide in the patient´s abdomen to increase the workspace (see chapter 2, section 2.3.1) made it even more difficult for clinicians to interact with the table, forcing surgeons to work with their shoulders elevated and abducted.

These postures complicated the positioning of instruments, which not only increased the clinicians' physical discomfort but could affect the performance of more complex tasks (Matern, 2009). In addition, the study identified that tables are shared with camera assistants and that on several occasions, the height demands were different, mainly to the detriment of the assistant.

The study revealed that assistants had great difficulty conducting the camera because most were inexperienced students or residents with limited training in camera conduction. Besides, the raised static load and prolonged maintenance of the awkward postures required to follow surgeons are highly associated with WRMSD. Zihni et al. (2016) determined a high activation of upper back muscles in camera assistants, emphasizing the necessity to analyze other strategies to reduce their physical load. Park et al. (2010) suggested that robotic cameras should be used instead to improve conduction, but their implementation is not yet possible in Peru (Cornejo et al., 2019). Training camera conduction and possible low-cost devices to support the camera and reduce upper arm fatigue may be helpful strategies to consider in the short term.

The lack of suitable surgical equipment forced surgeons to use whatever equipment was available, some of which was in poor conditions (such as having broken handles) and designed for other functions (for example, tools with a lock system were used to manipulate anatomical structures and not just to hold them). Reusing disposable instruments and/or using reusable instruments without periodical maintenance were recurrent practices across some hospitals. Dunn

(2002) stated that it is not clear if reusing disposable instruments in poor conditions may cause patient injuries, but the possibility exists and is high. A worn or torn instrument may affect a surgeon’s skills to operate safely since it may increase the exertion of deploying the instrument and raise the pressure on surgeons´ hands. Besides, the lack of sharpness to cut anatomical structures may affect their psychomotor skills and increase the WRMSD, also putting the patient's safety at risk. Further studies should be carried out to understand the impact of this practice.

Reusable instruments are more expensive than disposable ones because they require periodic maintenance to guarantee optimum functionality (Adler et al., 2005). However, the high prices are offset by their prolonged use duration, calculated to be about ten years (Alfa-Wali & Osaghae, 2017). This issue has also been identified in other LMICs as a recurrent problem that endangers patients (Adler et al., 2005; Chao et al., 2016). However, using these will not solve this problem since the instruments are expensive and not inclusive for the medical population. Thus, designers and manufacturers should consider developing instruments that can be cheaply maintained and suit the population. Setting up a proper procurement process would save much money and improve ergonomics.

Surgeons demanded more participation in the purchasing process of medical instruments, which indicated problems with communication with managers, which tends to be top-down communication from hospital managers. Most surgeons explained that managers usually work alone, failing to select suitable equipment without considering the surgeons’ recommendations. Hence, adopting a more bottom-up approach is highly recommended, wherein the surgical team analyses their problems and proposes responsible solutions to managers, working together as a team (Budnick et al., 2012; Carayon et al., 2006; Gurses et al., 2012). This approach will help reduce the costs associated with purchasing unnecessary and inappropriate equipment by optimizing the limited resources of the Peruvian healthcare system.

The study revealed that many surgeons opted for self-assisted learning systems, which involved purchasing their simulators or following online tutorials without any follow-up. Rabee et al. (2015) stated that learning surgery through unsupervised video tutorials is a recurrent practice that does not benefit patients and may increase surgeon physical overload since they may learn manoeuvres detrimental to surgical skill development. This is not trivial, as inappropriate learning can end up harming patients and adopting inadequate skills that can be taught to other residents, forming a vicious cycle of learning. In addition, malpractice can increase surgeons' risk of WRMSD because they learn inappropriate movement patterns. It was consistent with testimonies of surgeons interviewed which confirmed that surgeons generally adopt inappropriate postures because they learn inappropriate movement patterns.

In Peru, a surgeon graduates after completing three years of medical residency (Penny & Collins, 2018) in contrast to other countries such as Uruguay, which takes five years (Universidad de la República, 2016), while HICs such as the UK take six years due to the need to complete accreditation courses in laparoscopic surgery (RCS, 2019).In addition, Peruvian residents usually learn laparoscopic techniques in hospitals based on the Hasteld method, which consists of observing, performing, and teaching on the patient (Rodríguez-Sanjuán et al., 2010).

Chinelli & Rodriguez (2018) explained that learning by self-training and the Hasteld method might jeopardize patient safety and increase surgeon fatigue due to the poor technique learnt and the high exposition to surgeries. However, some studies claimed that this learning method could be developed as long as a trained surgeon supervises students (Thorpe, 2004). Therefore, it is necessary to implement training based on deconstructive learning and advanced simulations to guarantee training with less physical overload for surgeons while safeguarding patient safety. However, the medical training scheme would have to change in Peru if laparoscopic training by simulation were introduced as part of the medical residency since the surgical residency also contains open surgery training and other care activities inherent to medical training (Penny & Collins, 2018).

The consequences of a flawed system increase the barriers that put the surgery at risk. Despite these deficiencies in the system, surgeons and the surgical team have not detected them as risk factors for the patient. This was evidenced in the testimonials, where only two surgeons were aware of the importance of ergonomics and formal training in laparoscopic surgery. Therefore, although the system's deficiencies are numerous, it is essential to establish a clear awareness of the importance of ergonomics in the laparoscopic work system. This point marks a difference concerning HICs since the culture of ergonomics, systems, and patient safety is still incipient in Peru, as evidenced by the study. Current Peruvian regulations on patient safety are limited and very little used in surgery (Palomino-Sahuiña et al., 2020), so it is a great challenge to introduce ergonomics from the early stages of medical training.

4.4.1. Study limitations

Snowball sampling could reduce diversity in selecting suitable participants and affect the generalisability of the results. However, the purposive sampling to select the hospitals tried to choose the most representative of Peru, including one in the regions.

Some surgeons were more reluctant to give information in the interviews and were very brief and concise in their answers. However, some surgeons gave additional details during the observation period by speaking aloud. At the end of the surgeries, many were happy to talk and discuss the problems encountered and explain new anecdotes that contributed significantly to the research.

Although there may have been some bias during the participant observation period due to the Hawthorne effect (Bridger, 2018b,Adair, 1984), the researcher reduced this possibility by avoiding interrupting surgeries and not carrying cumbersome equipment, such as film cameras or tripods, and reducing their participation to a minimum. The surgical team in many hospitals reported that they were used to recording their surgeries for teaching and continuous improvement purposes. Hence, the presence of an external evaluator or camera in operating rooms was not unusual in their activities.

4.5. Key summary

The SEIPS model was valuable for identifying risk factors for WRMSD among surgeons and patient safety issues due to system interaction. Also, SEIPS explored the dynamics of the system factors in laparoscopic surgery, being the first precedent in a Latin American country, such as Peru, which has several limitations in its healthcare system. As a result, the study identified 15 interacting factors sorted in SEIPS work system categories that contribute to the development of WRMSD and a list of frequent outcomes in system tasks.

Most surgeons reported the existence of WRMSD, and even two reported diagnoses that demanded medical attention and related it to the work system. It is presumed that more surgeons may have needed medical attention but did not report it due to a lack of awareness of the importance of ergonomics in work systems. Many of the errors committed in surgeries are caused not only by aspects related to the surgeon but also by the system as a whole, so it is necessary to use approaches that go beyond improving the behaviour of health personnel and influencing the system as a whole.

It is needed to promote interventions considering the participation of the surgical team, the search for local solutions with the support of authorities and institutions to promote a culture of patient safety and well-being for workers, and embedding ergonomics as an essential element to improve laparoscopic surgery.

The height of the operating tables was a recurring theme during the study because its range of adjustment was limited to achieve an optimal position for the surgeon. Several surgeons claimed discomfort when operating at the current tables due to the raised height and the inability to reduce their heights. Factors related to the surgeon´s stature, team interaction, tasks demands, design of tools, and environment were factors interconnected that increased the WRMS risk

4.6. Implications for the subsequent studies

The thesis uses the SEIPS model as the primary theoretical approach to explore the work system of laparoscopic surgeons. The central dynamic of the work consisted of analysing the three components depicted in the SEIPS model in healthcare systems: *Work system, Process and Outcomes*. This study responded to the first research question related to the *Work System* analysis, and subsequent studies will respond to research questions related to the other components of the system.

This first study identified 15 factors that contribute to the development of WRMSD and affect patient safety. The approach was qualitative through interviews and participant observations. A system analysis was conducted, and interactions were described, concluding that the deficiencies of the Peruvian system had an impact on surgeons and patients. The following chapters will expand the knowledge through a quantitative look at the other working system components to achieve the thesis's first aim.

Chapter 5. Study 2: Work-related musculoskeletal disorders and associated factors in Laparoscopic surgeons of Peruvian Hospitals

5.1. Introduction

Chapter four identified factors in the work system that contribute to WRMSD in laparoscopic surgeons through a qualitative approach. Among the main outcomes identified were WRMSD, which also impacted patient safety.

The following study analysed system outcomes by focusing on WRMSD and its association with laparoscopic surgeons' work system factors. Unlike the previous study, the proposed approach was quantitative through a questionnaire-based survey, following the convergent mixed approach design.

The aim of the study was focused on responding to the second research question:

RQ2: What is the prevalence of WRMSD in laparoscopic surgeons?, What factors in laparoscopic surgery systems are associated with work-related musculoskeletal disorders, and what is the impact on the surgeon's performance and patient safety?

5.2. Method

5.2.1. Participants

A descriptive cross-sectional study was carried out from 2018 to 2019, applying a survey to Peruvian surgeons with accredited experience in Laparoscopic surgery recognised by the Peruvian medical college. Only certified surgeons were recruited to complete the survey because they represented the target group with expertise in laparoscopic surgery. Hence, the study excluded students, residents, and physicians still in training.

5.2.2. Survey design and development

As explained in chapter three, using a quantitative, cross-sectional approach, the questionnaire-based survey was the best means of rapidly collecting information on risk factors and WRMSD in surgeons. The survey was designed primarily to be completed online through a server authorised by the University of Nottingham. However, the paper format was also used when it was not possible to use the online format.

The advantages of using an online version were the low cost for application, the speed of data collection since the servers allow processing the information in real-time, and the possibility of using different designs with visual aids to develop any question (Robson & McCartan, 2016c). However, among the disadvantages is the possibility of a low response rate, the lack of internet access and the difficulty for some people to complete the questions electronically (Robson & McCartan, 2016c). It may be relevant, especially because many surgeons are older and unfamiliar with the technology. Also, some may work in Peruvian regions where internet access is limited. For this reason, it was decided to apply a mixed application approach, using both online and paper format surveys to obtain a more significant number of participants. This strategy ensured a high response rate.

The online version was designed in the JISC survey server (Bristol online survey)™ with the support of the University of Nottingham. Participants had to fill out the survey by themselves, read the questions, and respond, marking an alternative. A hyperlink was provided to participants to complete the survey via phone or pc by clicking the link. The paper format consisted of printing the survey on both faces on a maximum of three paper sheets.

The survey consisted of six sections: 1) participant's information sheet and consent form; 2) demographic data; 3) WRMSD divided into body regions; 4) work system factors in laparoscopic surgery; 5) impact on surgeons; and 6) general questions about interaction and training.

In the first section, there was a brief description of the survey, the target population addressed, and the study's objectives. The ethical aspects were also informed, including the possibility of voluntary withdrawal at any time (not completing the survey) and the anonymity of responses. At the end of the introduction, participants were consulted on whether or not they consented to participate in the study. A page that thanked them for their interest in the study was displayed if they did not agree to participate.

Section two contained general demographic information: gender, age (a range of age), medical speciality, time as a surgeon performing laparoscopic, workplace, and workplace location in Perú.

Section three included questions of WRMSD based on the standard Nordic Questionnaire developed by Kuorinka et al. (1987) and adapted by Dickinson et al. (1992). This questionnaire had high reliability and validity in detecting musculoskeletal symptoms in workers in several studies (Dickinson, 1998; Epstein S et al., 2018; Gutierrez-Diez et al., 2018). Besides, this instrument offers the possibility of comparing the results with other studies applied to laparoscopic surgeons (Adams et al., 2013; Giberti et al., 2014; Hignett et al., 2017; Wauben et al., 2006) due to its extensive use in the scientific community (López-Aragón et al., 2017).

Section four presented a list of work system factors based on the SEIPS model related to WRMSD in laparoscopic surgeons of HICs (see chapter two). There was no evidence of similar Peruvian studies that addressed this problem, and very few were found in Latin America.

The work carried out by Hignett et al. (2017) was used as the basis to construct the questionnaire that comprised several factors associated with WRMSD in laparoscopic surgery in the UK, such as operating table height, use of suitable laparoscopic surgery tools, the position of the screen, among others. These results were combined with other factors from the review of studies in HICs described in the literature review chapter (chapter 2; section 2.5.2.2). The selected factors were classified according to the categories of the SEIPS model and presented randomly to the participants, asking them about their level of contribution to WRMSD.

This rating divided these into three levels: high-contributing, low-contributing, and no contributing factor. Participants only had the option of marking one response for each factor.

The questions in sections five and six were about the impact of WRMSD on the surgeons' work, the surgeons' level of training and interaction with team members. There was one multiple choice question on the impact of their work and two yes or no questions. An open-ended question was also asked for surgeons to indicate the most physically and mentally challenging laparoscopic surgery and how long it took. The last question was open to including any other comment about their work as laparoscopic surgeons. The answers were ranked based on the similarity and frequency of surgeries with the support of a surgeon.If participants agreed at the end of the survey, they could leave their email to be contacted for further studies related to the present thesis.

A first pilot was conducted with ten surgeons to check for clarity, accuracy and ambiguity in the questions and determine the time taken to complete the entire survey. Before applying this, two professional ergonomists made several suggestions to improve the questionnaire. Since Peru is a Spanish-speaking country, the author translated the survey into Spanish following a regular translation. After reviewing, the final questions were formulated in Spanish and applied later to surgeons. Table 5.1 presents the survey structure, including the factors and variables considered in the study.

The final version of the survey was created on the JISC online platform, getting a final online link later shared with participants (see appendix 12.6). The total number of questions was 17 (only two were open questions), with an average ten-minute completion time. The internal consistency reflects the extent to which the instrument items are inter-correlated or consistent for the same construct measured (Tsang et al., 2017). To determine the instrument's internal consistency was used, Cronbach's Alpha. A pilot test was applied to 30 surgeons to calculate Cronbach's Alpha to carry out the measurement. The results showed an internal consistency of 0.85, concluding that the questionnaire had an adequate internal consistency (Tsang et al., 2017)(see appendix 12.7)

Table 5.1 Survey structure

	Working conditions - Factors	Responses
I. Introduction		
1	Description of the survey, consent form	
II. Demographics factors		
1	What is your gender?	S
2	How old are you?	S
3	What is your stature?	O
4	What is your medical speciality?	S
5	How long have you been performing laparoscopic surgery?	S
6	What is the common duration of surgical procedures you perform with Laparoscopic surgery? *<60 minutes , 1-2 hours , 2 or more hours*	S
7	Do you perform laparoscopy surgery in rural areas?	S
8	could you specify where your hospital is or where you work frequently?	S
9	Where do you perform Laparoscopy surgery	S
III. Work-related musculoskeletal symptoms		
10	Have you experienced work-related musculoskeletal symptoms (aich, pain, discomfort) in any part of your body?	S
11	If your answer is " yes", please indicate the part of the body by ticking boxes for each alternative: neck, shoulders, elbows, wrist/hands, upper back, lumbar back; hip/thighs; knees; ankle/feet)	S
IV. Work system factors		
12	What factors do you think have contributed to your work-related symptoms?	S
	Inadequate operating table height; lack of training of surgeons; duration of surgery; position of the monitor display; complexity of surgery; patient shape and size; use of disposable graspers and/or scissors more than once; time pressure (cases on the list); lack of suitable equipment; lack of illuminance; use of Foot pedals and /or hand switch; use of double gloves (or unsuited gloves); position to work; lack of microbreak during surgery; lack of practice; lack of shoulder support; poor distribution of shifts ; poor handle design ;	S
	Mention another one	O
V. Impact on surgeons and patients		
13	Could you explain the most challenging Laparoscopic surgeries that you have performed in terms of physical and mental fatigue?	O
14	Have you ever changed your work because of musculoskeletal symptoms?	S
14a	*If yes, how have you changed?*	M
VI. General questions about training and interaction		
15	*Have you experienced any difficulties with your work team during Laparoscopic surgery that might affect your performance? (please select)*	S
15a	If you have responded "yes", Choose the possible factors by ticking the boxes	S
16	Have you received ergonomics training or formal training on optimizing your operative technique?	S
17	Do you want to add any further comments about your work as a Laparoscopic surgeon?	O

Note. S= Single answer, M=multiple selection available, O= open

5.2.3. Procedure

The survey was distributed to 320 surgeons with the support of the Peruvian Endoscopic Surgery Society through the associated members. In addition, surgeons of six Peruvian hospitals, with the prior permission of authorities, were invited by sharing the survey through their emails. To promote a higher response rate, the survey was resent to participants after one week as a reminder to participate. Furthermore, the researcher distributed the paper and online surveys through assistants of two national congresses of laparoscopic surgery in two regions in Peru who voluntarily wanted to participate in the study with the authorization of organizers (Peruvian Endoscopic Surgery Society).

5.2.4. Data analysis

Results were imported from the online webpage of JISC to Microsoft Excel and then processed in SPSS v.24™. The Descriptive statistical analysis of categorical variables was presented in frequency and proportions and arranged in tables, and the numerical variables were summarised in averages and standard deviation (e.g. stature). The chi-square test of independence and Fisher's exact test was used to analyze associations.   Associations were presented in tables with total prevalence and divided into body regions with specific working conditions factors. To determine statistical significance, p-values of < 0.05, < 0.01, and 0.001 were considered, bearing in mind that the lower the value, the greater the certainty that the association is true (Field, 2018). Responses to the open-ended questions were analyzed by copying all responses into an Excel spreadsheet, coding each response into categories, and counting the number of participants who matched each proposed category.

5.2.5. Ethics approval

The Faculty of Engineering Ethics Committee of the University of Nottingham approved the study (see appendix 12.25).

5.3. Results

A total of 140 surgeons responded to the survey. Participants were mainly men (76%) with a range of age between 30-60 years old (87%), more than five years of experience (57%) and a medical speciality in general surgery (92%). The mean stature of surgeons was 169 (SD=5.6) cm for men and 161 (6.3) cm for women. The majority of surgeons worked in different hospitals in the city of Lima (45%), and the rest were from different regions of Peru (55%) (see Table 5.2). For more details, see Table 5.2

Figure 5.1 illustrates the number of cases attended according to the duration of laparoscopic surgery. Half of the respondents indicated that several cases operated on per week lasted about 1 to 2 hours (50%; N=70), whilst almost half of surgeons reported that they never operated on cases for more than two hours (49%). Forty-four per cent indicated that operating one case per week last about one to two hours and more than two hours. Surgeons reported that most cases were treated in hospitals (100%), while 28.5% worked in hospitals and private clinics.

The prevalence rate of WRMSD was 89%, of which more than half of surgeons (56%) claimed symptoms in more than three body regions. Reported symptoms were higher in shoulders (59%) and neck (51%), followed by the hand/wrist (41%) and upper back segment (41%), while lower back (36%), elbows, and lower limbs had the lowest proportion of reports. There was no statistical difference between male and female surgeons($p>0.05$) (see Table 5.3).

The prevalence rate of 12-month WRMSD was also high. Of the total, 37% and 36% of surgeons reported a high prevalence of WRMSD on shoulders and the neck, respectively. It was followed by the hand/wrist (24%), upper back (20%), and lower back (22%). On the other hand, participants who reported 7-day symptoms were considerably lower, reaching the maximum rate in shoulders and upper back (21%) followed by hand/wrist (16%) and neck (15%) (see Figure 5.2).

Table 5.2 Demographic data

Demographic data	Total of responses	
	n	%
Age group		
< 40 years	**65**	**46%**
41-60 years	58	41%
>60 years	13	9%
Gender		
Male	**107**	**76%**
Female	33	24%
Time as a laparoscopic surgeon		
< 1 year	9	6%
1-2 years	20	14%
2-5 years	29	21%
> 5 years	**80**	**57%**
Stature (mean) (SD) in centimetres		
Male	**169**	**5.6**
Female	161	6.3
Total population	166	6.7
Medical speciality		
General Surgeon	**131**	**94%**
Gynaecologist	1	1%
Oncologist	2	1%
Other	6	4%
Provenance		
Lima	**63**	**45%**
North	46	33%
South	14	10%
Centre	17	12%

Note. Bold: higher percentage and mean

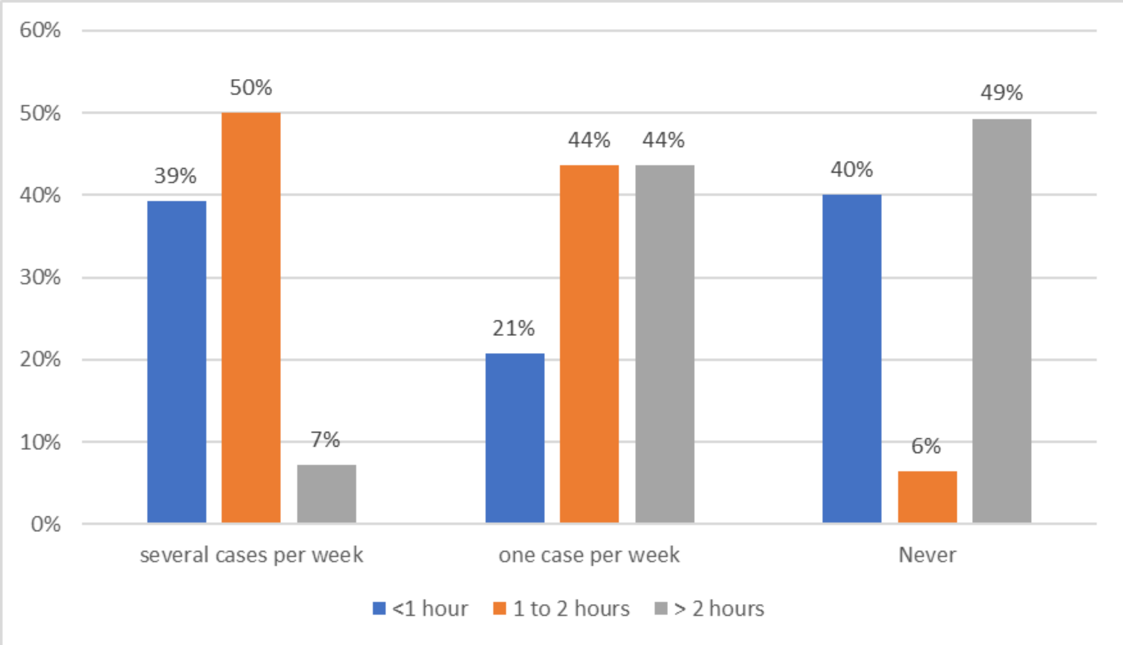


Figure 5.1 Duration of Laparoscopic surgery and number of cases

Table 5.3 Work-related musculoskeletal disorders reported by surgeons.

	Total prevalence		**Female=33**		**Male=107**		
	n	**%**	**n**	**%**	**n**	**%**	***p***
Body regions							
Neck	72	51%	16	48%	56	52%	*0.69*
Shoulder	82	59%	22	67%	60	56%	*0.28*
Elbow	18	13%	5	15%	13	12%	*0.65*
Hand/wrist	57	41%	11	33%	46	43%	*0.32*
Upper back	57	41%	13	39%	44	41%	*0.86*
Lower back	50	36%	12	36%	58	54%	*0.92*
Hip/thighs	9	6%	4	12%	5	5%	*0.12*
Knee/Legs	36	26%	9	27%	27	25%	*0.81*
Ankle/feet	36	26%	11	33%	25	23%	*0.25*
Body regions with complaints							
None	16	11%	5	15%	10	9%	0.72
More than one	124	89%					

Note. P: Chi-square test of independence and Fishers's exact

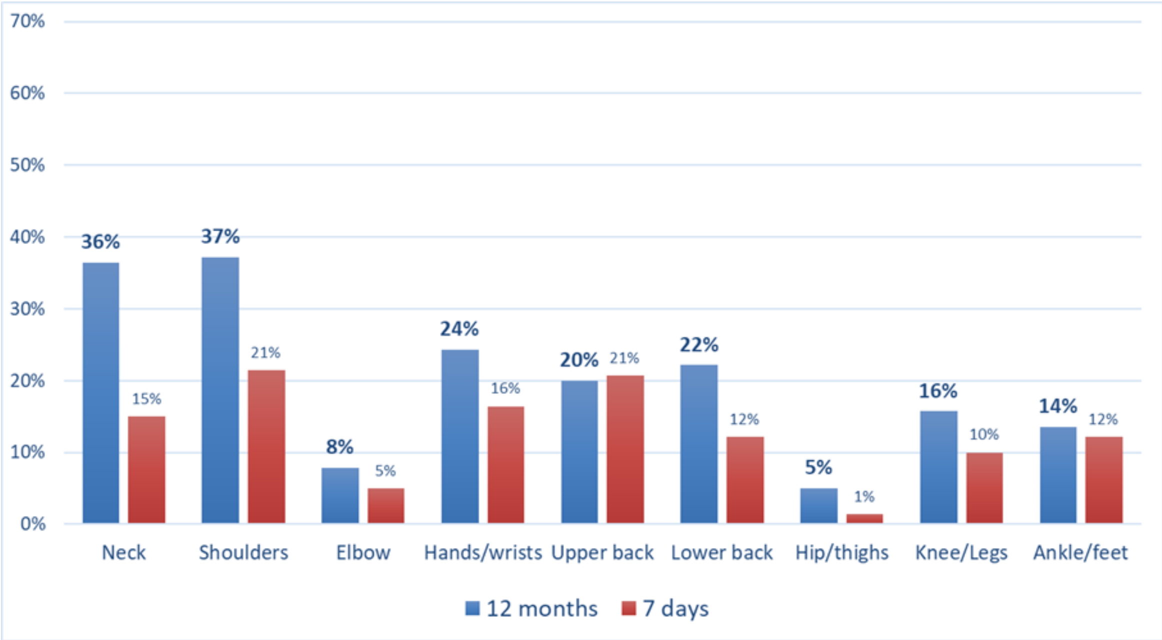
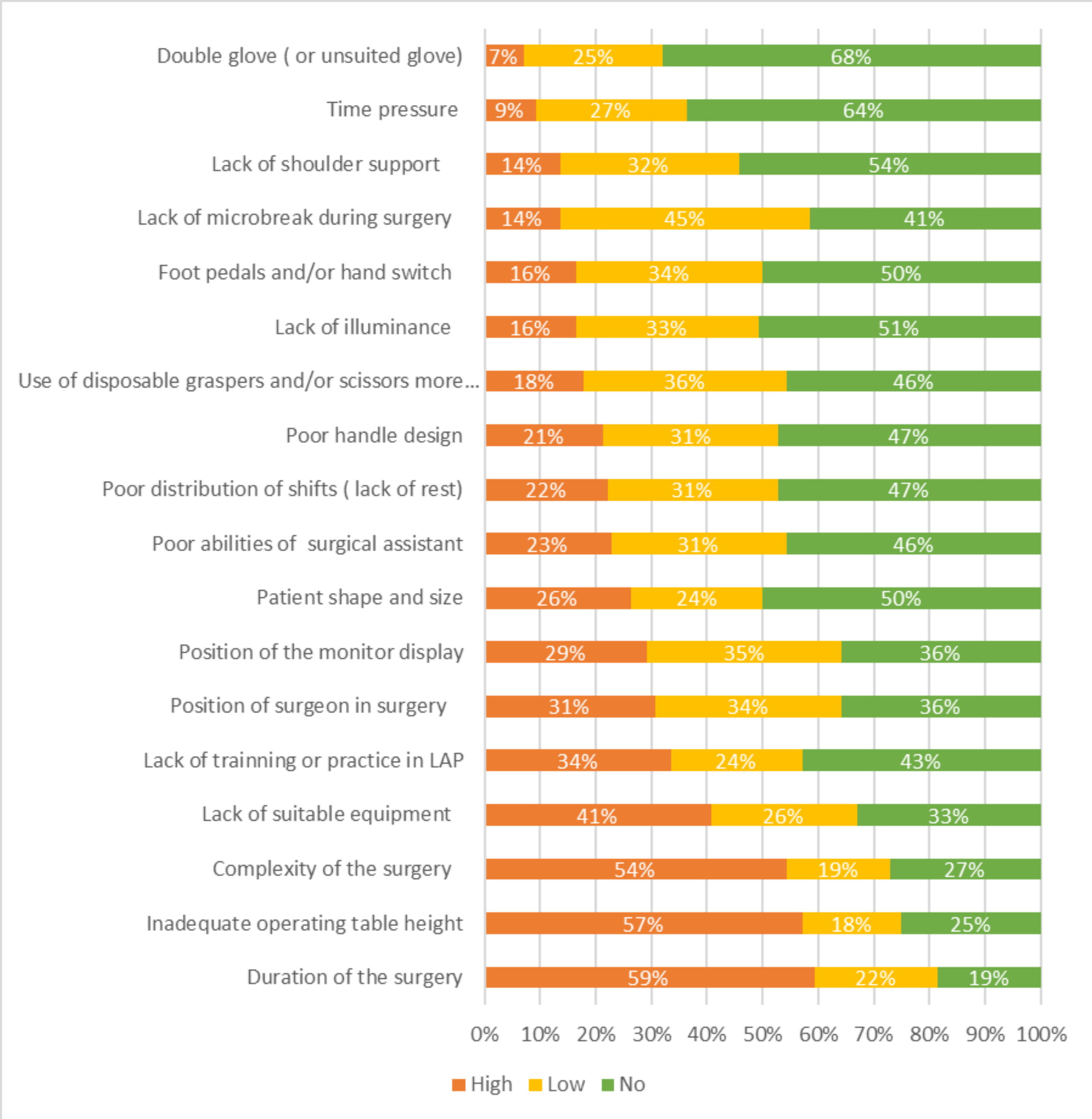


Figure 5.2 Prevalence of WRMS of surgeons by 12-month and seven-day reports

5.3.1. Work system factors and level of contribution to the presence of WRMSD

Figure 5.3 illustrates the frequency of 18 work factors based on the opinion of surgeons and the level of contribution to WRMSD. Over half of surgeons reported the duration of surgery (59%), inadequate operating table height (57%), and the complexity of the surgery (54%) as highly contributing factors. Lack of suitable equipment (41%), lack of training in Laparoscopic surgery (34%), the position of surgeons (31%), the position of monitors display (29%), and patient's shape (26%) were the second group more frequent with more than quarter of surgeon surveyed. Conversely, the majority perceived the time pressure (62%) and the use of double gloves (68%) as non-contributing factors. The lack of microbreaks (45%) and use of disposable tools (36%) were perceived mainly as small-contributing factors



Note. High, Low, No: level of contribution to WRMSD

Figure 5.3 Work factors and level of contribution to the presence of WRM

The study revealed an association between WRMSD and time as a laparoscopic surgeon ($x^2_{(1)}$ = 10.3; p<0.05), especially in the upper back segment ($x^2_{(1)}$= 20.5p<0.001). Several work factors were associated with the total prevalence of WRMSD such as: duration ($x^2_{(1)}$=21.1;p<0.001) and complexity of surgeries ($x^2_{(1)}$=9.84;p<0.001), lack of suitable equipment ($x^2_{(1)}$=22.1;p< 0.001), inadequate table height ($x^2_{(1)}$=8.0;p<0.01), the position of monitor display ($x^2_{(1)}$=10.4;p< 0.01), reuse of disposable tools ($x^2_{(1)}$=7.4;p<0.01), position to operate ($x^2_{(1)}$=8.5;p<0.01) and lack of microbreaks during surgery ($x^2_{(1)}$=10.3;p<0.01). Neck, shoulders, and upper back were the main body regions with a high number of associations with work factors. The three main factors identified (>50%) were associated with shoulders, wrist/hand, and upper back (see Table 5.4). Elbow/forearm symptoms were the regions with the lowest associations.

Table 5.4 Work factors and associations with WRMSD by body regions

Work system factors	Body regions (p-value)							
	Total	Neck	Shoulders	Elbow/ Forearm	Wrist/ hands	Upper Back	Lower back	Ankle /feet
Demographics factors								
Age group						*		
Time as a laparoscopic surgeon	*	*	*			***		*
Work factors								
Duration of the surgery	***	*	**		*	*		**
Inadequate operating table height	**		*		***			
The complexity of the surgery	**	**	**			**		
Lack of suitable equipment	***	**	**	*	***	***		**
Lack of practice or training	*	**	**		*	**		*
Position of the surgeon in surgery	**	*	**			*		
Position of the monitor display	**	***	***		**			**
Patient's shape and size	*	**	*			*	**	*
Lack of surgical assistant								
Poor distribution of shifts	*	*	**			*		
Poor handle design		*	**					
Reuse of disposable tools more than once	**	**	***		**	*		*
Lack of illuminance	*	**	**	*	*	**		
Foot pedals and/or hand switch		**	**			**	**	***
Lack of shoulder support		**	***					*
Lack of microbreak during surgery	**	*	**			**	*	
Time pressure			**			*	*	
Use of Double glove or unsuited glove								

Note. Chi-squared and Fisher's exact test of independence, P<0.05* ;P<0.01** ;P<0.001***

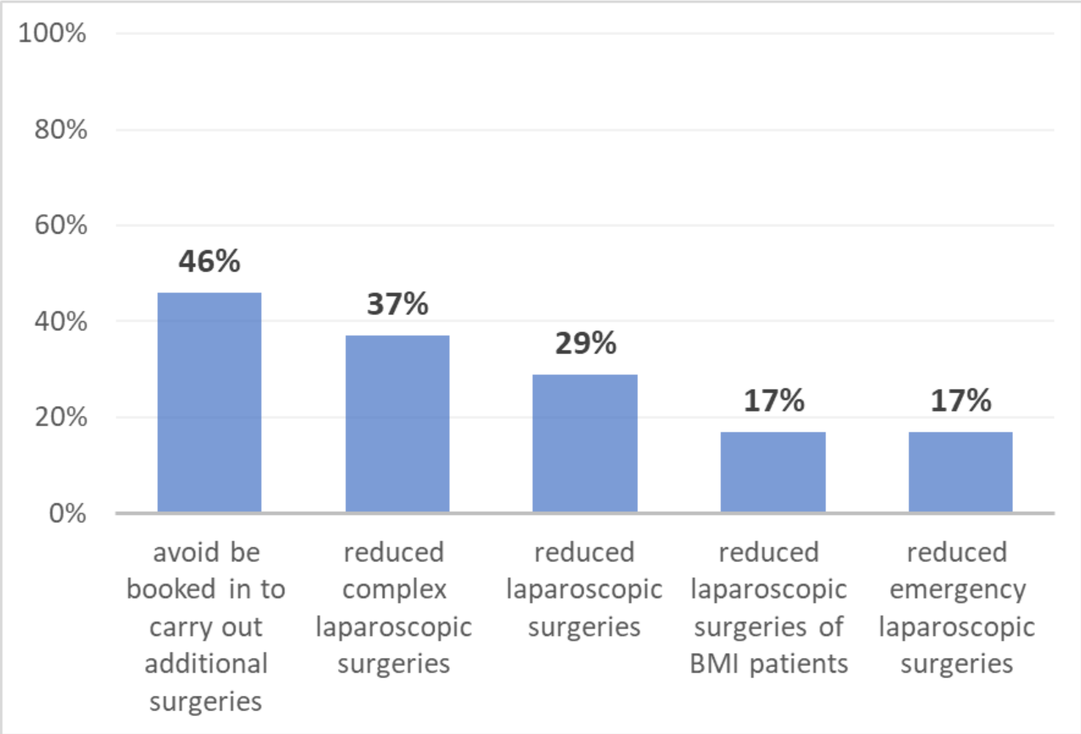
Furthermore, surgeons reported that cholecystectomy with complications (26.3%), complex appendicectomy (16.3%), inguinal hernia repair (16.3%), and bariatric surgery (Whipple bypass) (8.8%) were the more complex procedures that required more than one hour and a high physical and mental demand.

5.3.2. Impact of WRMSD on surgeons

Regarding organizational factors, 41% of participants stated difficulties interacting with surgical staff such as nurses, assistants, and residents. The most recurrent factors affecting surgical performance were the lack of collaboration with the team (34%) and inexperienced residents (44%).

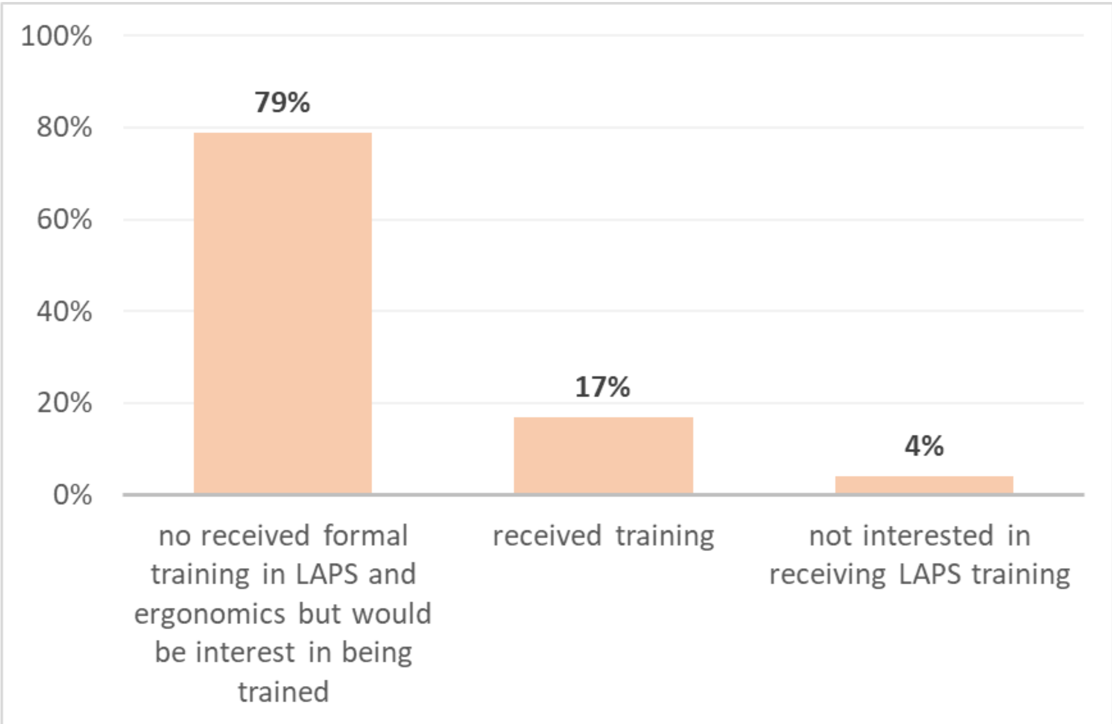
Within the survey, 25% of surgeons reported changing the way of working in the following ways. For example, 46% of surgeons avoided being booked in to carry out additional surgeries, 37% reduced the number of complex laparoscopic procedures, and 29% reduced their workload by reducing the number of surgeries they carried out. Also, 17% of surgeons reduced the number of high Body mass index (BMI) patients and emergency laparoscopic surgeries (see Figure 5.4).

More than three-quarters of surgeons (79%) indicated that they did not receive formal training in Laparoscopic surgery and ergonomics but would be interested in being trained. In comparison, 17% reported that they had received training and 4% said they would not be interested (see Figure 5.5). In addition, the high rate of WRMSD was associated with the lack of training in laparoscopy and ergonomics. ($x^2{}_{(1)}$=5.27;$p<0.05$).



Note. BMI: Body Mass Index

Figure 5.4 Impact of WRMSD on surgeons and laparoscopic surgery training



Note. LAPS: laparoscopic surgery

Figure 5.5 Laparoscopic surgery and ergonomics training

5.4. Discussion

A total of 140 surgeons responded to the survey reaching a response rate of 43.7%, higher than other similar studies in Laparoscopic surgery using surveys in HICs (Hignett et al., 2017; Park et al., 2010). Men predominantly answered the survey with a low response rate from women, representing almost a quarter of the sampled population (24%). This is consistent with Quispe-Arminta & Shu-Yip (2021), who stated that female representation in Peru is as high as 26% in gynaecological surgery and 12% in general surgery, indicating a lower but increasing female representation in Peruvian operating rooms. Compared to other similar studies on WRMSD in laparoscopic surgeons of HICs, they also established a low female presence in their surveys and an age range below 50 years, similar to this study (Park et al., 2010; Shepherd et al., 2016; Wauben et al., 2006). Furthermore, as in other studies, the sample did not focus on just one region of the country but on different regions to obtain variability in responses.

The total rate of WRMSD was 89%, of which more than half of surgeons reported symptoms in more than three body regions. It suggested a high rate of WRMSD, exceeding other at-risk occupational groups, such as skilled agricultural forestry, assemblers or plant operators (EU-OSHA, 2019) and rates of surgeons from HICs (Alleblas et al., 2017; Gutierrez-Diez et al., 2018).

Shoulders and neck symptoms (51%), wrist/hands, and upper back (41%) were reported as the most prevalent body segment and associated with almost all system factors, being similar to results from other studies in laparoscopic surgery (Alleblas et al., 2017; Epstein et al., 2018; Gutierrez-Diez et al., 2018). Furthermore, neck, shoulders, upper back, and hand wrists represented more than 80% of the reported WRMSD and were associated with highly contributing factors to WRMSD, such as lack of adequate equipment, complexity, duration of surgeries, and lack of laparoscopic training. However, a lower frequency of lower back pain was found in the sample, reaching 36% of surgeons, in contrast to similar studies in laparoscopic surgeons of HICs, where the prevalence exceeded 50% (Epstein S et al., 2018; Gutierrez-Diez et al., 2018). In addition, lower back pain had fewer significant associations than upper back pain. This could be explained by a possible underestimation of the responses or because surgeons perceive the problem mainly in the upper body regions minimizing other body regions.

Over half of surgeons indicated that three main high contributing factors were complexity and duration of the surgery (related to tasks elements) and the inadequate height of the operating table (related to tools and technology elements) to perform laparoscopic surgery. At the context or system level, these include factors related to "tasks" such as the difficulty of performing surgery and the physical environment where surgeons operate, such as the poor working height due to inadequate operating tables (Carayon, 2016). These results align with the dose-response model explained by Armstrong et al. (1993), who argued that WRMSD results from excessive job demands that may exceed the capacity limits of individuals.

Duration and complexity of surgery are factors related to the nature of tasks (Carayon et al., 2006). High duration is related to the complexity of surgeries and possible unanticipated events during the procedure, which may prolong the surgeon's exposure (Gurses et al., 2012). For example, emergency surgery requiring advanced techniques increases the intraoperative time and, thus, the total duration of surgery. Thus, training skills development is imperative to improve surgical technique and reduce surgery time and resulting discomfort (Fried, 2008; Perez-Cruet et al., 2002). Based on the survey results, only a few surgeons are considered adequately trained in laparoscopic surgery and ergonomics (17%), so hospitals and universities should set up a formal program to respond to this urgent necessity.

The long duration of surgeries may increase the WRMSD due to the high exposure to physical factors such as awkward postures, overexertion, and repetition (Bridger, 2018c; Kumar, 2007). It was observed, for example, in the high frequency of ankle/feet symptoms due to surgeons keeping standing for a long time without standing support and when used of foot pedals to activate electrocautery.

Matern (2009) observed that the bending movements of ankles to activate pedals and the instability on one foot increased the physical overload on ankle/feet, especially in overweighted surgeons triggering symptoms of numbness and pain

The average height of surgeons in this study (166.9 cm) is above the average of the Peruvian population by approximately 4 cm (Asgari et al., 2019) but below the general population of HICs (Pheasant, 2003). In other similar studies of laparoscopic surgeons in the European Union and the United States, the average height was greater than the average height of the general population (Franasiak et al., 2012; Sutton et al., 2014; Wauben et al., 2006), so this trend is also confirmed in this study. However, when height is segmented by gender, as is to be expected, the difference between males and females increases. Although they were taller than the general population, the difference could make interaction with technologies and tools more challenging. For example, the screen's position was associated with WRMSD in the neck because, in many hospitals, it was above the surgeons' line of sight.

Sutton et al. (2014) argued that female surgeons are more at risk in the operating room than male surgeons since their shorter stature. However, in the case of Peruvians, although their height is indeed relatively greater than the general Peruvian population, the average height is lower than that of the male and female population of HICs, so the problem of interaction with technology may be even more accentuated. In addition, the lack of anthropometric standards for the Peruvian population limits the possibility of finding solutions that adapt to the characteristics of the population (Escobar-Galindo, 2020). So, further studies should focus on the medical population's anthropometry and its relationship with the surgical system.

The raised height of the operating table was reported as the primary contributor factor related to technology. This result contrasts with other studies in HICs that found that operating table height was not the priority factor in operating rooms (Park et al., 2010; Wauben et al., 2006). Two aspects may explain these differences with HICs. On the one hand, the operating tables were limited adjustable, designed mainly for open surgery but not for laparoscopic surgery. On the other hand, the short stature of Peruvians increases the risk of mismatching with the operating table height that exceeds surgeons´ working height. Current clinical guidelines on ergonomics in laparoscopic surgery recommend working heights based on the anthropometric measurements of people in HICs, forcing Peruvian surgeons to adapt to these standards (Matern, 2009; Zachariou, 2019).

Furthermore, patients' shape and size (related to the TASK element of the system), such as obese patients who raise the working height, may trigger physical discomfort for surgeons, especially in the upper extremities. This may explain why more than half of the surgeons indicated this factor contributes to WRMSD and is associated with neck and shoulder pain. Overall, these results may largely explain the high rate of WRMSD in the shoulders, neck, and upper back because they are related to working heights and precision tasks (Pheasant & Haslegrave, 2006d).

More than 50% of surgeons reported that a lack of microbreaks with stretching was a minor contributor to WRMSD and that it is highly associated with symptoms in all body regions. Studies in HICs evidenced the importance of setting up microbreaks during Laparoscopic surgeries to reduce pain, fatigue, and stress and improve physical performance (Park et al., 2017). In Peru, many companies adopt microbreaks as part of their occupational health and safety programs (Cáceres-Muñoz et al., 2017). However, hospitals do not have well-established safety programs, which may make their implementation difficult (Mejia et al., 2015).

WRMSD can directly affect the acuity and accuracy of tasks and directly or indirectly affect patient safety (Alleblas et al., 2017; Hignett et al., 2017). Several studies indicated that more than 25% of surgeons reported that WRMSD could impact surgical performance (Adams et al., 2013; Esposito et al., 2013; Ruitenburg et al., 2013). The various symptoms such as pain, fatigue, stiffness, or numbness can directly impact the surgeries, requiring a leave of absence, early retirement or modification of surgical practice reducing the number of surgeries (Epstein et al., 2018).

The current study found that a quarter of surgeons surveyed had opted to reduce the number of surgeries as the primary measure to reduce the risks of the tasks involved, notably complex laparoscopic surgeries and obese patients. This reduction in caseload was higher than other studies on HICs that reported a range between 6.7% to 17 (Adams et al., 2013; Hignett et al., 2017; Szeto et al., 2009). This significant caseload reduction can negatively impact the choice of operative technique by putting the patient at greater risk. For example, a surgeon switches from laparoscopic surgery to open surgery because of pain, fatigue, or patient condition (obesity) and not for a technical surgical criterion. This change may be more significant if other factors, like lack of training and ergonomics awareness, interact. This association between lack of training and high rates of WRMSD was evidenced in the study and the impact on reducing the number of surgeries.

The lack of formal training can dangerously increase the risks of WRMSD to levels that can cause injury to surgeons and patients and can lead to tremors and localized fatigue that can disrupt surgery (Kaya et al., 2008). Furthermore, Park et al. (2010) found that surgeons had little awareness of ergonomics when they were not adequately trained. In this study, although 79% had no formal training in laparoscopy and ergonomics, they were interested in completing formal training if available. This is an important finding since the motivation for change from the person is a fundamental element for redesigning the system (Carayon, 2016). Thus, formal and adequate training in laparoscopic surgery techniques with ergonomics topics would help generate awareness to improve risk control in the system. Hence, Ergonomic interventions to reduce WRMSD should be focused on the training and education of surgeons in surgical techniques and ergonomics to create greater awareness and participation in system improvement.

Finally, It is necessary to rethink and redesign the work system and eliminate or reduce exposure to system factors that contribute to high WRMSD rates, such as the elevated height of the operating table, high duration and complexity, among others that can significantly impact patient safety.

5.4.1. Study Limitations

One study limitation was the focus on surgeons, not assistants and nurses. Although one of the questions was related to the interaction with the team, there were no specific questions to assess the impact of factors on assistants such as second surgeons or nurses. Nurses were not considered since they were not the focus of this research. The possibility of including a specific questionnaire for assistants should be considered for further studies.

Although in a self-reported questionnaire, participants have time to think about their answers and submit them at a given time, there is a risk that they may not reflect reality and therefore have the possibility of bias (Robson & Mc Cartan, 2016c). However, several studies have pointed out that self-reported surveys have similar results to expert examinations regarding the presence of WRMSD (Perreault et al., 2008; Takekawa et al., 2015).

The survey development had a primarily online format; however, there was a risk that the response rate would be limited because not all surgeons were familiar with online technology. For this reason, the study considered the possibility of also completing the survey in paper format. This also made it easier to collect information from surgeons at the scientific congresses they attended. Hence, the survey was adapted to a written form, which could be completed from a mobile phone or computer.

5.5. Key summary

The study found a prevalence rate of WRMSD of 89%. Of this total, more than half of the surgeons (56%) reported symptoms in more than three body regions. Reported symptoms were higher in shoulders (59%) and neck (51%), followed by the hand/wrist (41%) and upper back segment (41%), while lower back (36%), elbows and lower limbs had the lowest proportion of reports. All system factors were associated with WRMSD, mainly the duration and complexity of laparoscopic surgery, inadequate operating table height, and lack of suitable equipment in operating rooms.

Inadequate operating table height was one of the main factors associated with the symptoms of shoulder and wrists/hands. Almost a quarter of surgeons reported the patients' size and shape as a contributing factor complementing operating table issues. The raised height of the operating tables, coupled with the patient's size and shape (a factor related to the TASK), raised the working height to operate, overloading the upper segments.

Twenty-five per cent of surgeons reported changing the way of working by reducing the number of surgeries as the primary measure to reduce the risks of the tasks involved, notably complex laparoscopic surgeries and obese patients. These values were higher than other reported studies. In addition, the high rates of WRMSD were associated with a lack of training in laparoscopic surgery and ergonomics. The lack of ergonomic awareness could be attributed to a lack of a comprehensive training program. This may impact WRMSD rates and raise the probability of affecting patient safety.

The introduction of ergonomics in laparoscopic surgery training is necessary to increase ergonomics awareness in the surgical team. This could improve surgical techniques to reduce time and exposure to musculoskeletal risk factors. It is also essential to develop ergonomics guidelines in laparoscopic surgery based on the limitations of Peruvian hospitals and their application. Including microbreaks with muscle stretching during surgeries may be a short-term solution, especially when the surgery takes more than one hour.

Further studies should focus on all roles, such as surgeons and assistants and all other system factors of the Peruvian context within the system, especially analysing the WRMSD risk during laparoscopic surgeries tasks, to improve conditions and reduce physical risk factors and WRMSD.

Chapter 6: Study 3- Ergonomics risk of surgeons and camera assistants during real laparoscopic surgeries in Peruvian hospitals

6.1. Introduction

Chapters four and five identified several factors within Peruvian hospitals' work systems that affected surgeons and patient safety when performing laparoscopic surgeries. As a result, a high prevalence of WRMSD was determined in which associated factors such as awkward postures and overexertion played a preponderant role. However, it is still unknown to what extent the posture adopted by surgeons in Peruvian surgical environments, as a product of the factors identified during previous studies, increases the risk of WRMSD. Therefore, it is necessary to analyse the "work process" and identify the main postures during laparoscopic tasks to determine the risk of WRMSD at work.

Additionally, surgeons participate directly in the surgery and the camera assistants, usually residents or surgeons in training, act as the surgeons' eyes. For this reason, they are part of the laparoscopic surgical work team, and their work directly may impact the surgeon's work. However, literature related to the risks of WRMSD of assistants in surgical systems is scarce, so it is crucial to analyse the risk from their perspective.

On the other hand, observational studies have focused on analysing the surgeon's work from the simulation without understanding their behaviour in real laparoscopic surgeries (Alamoudi, 2020; Dabholkar et al., 2017; Khan et al., 2020; Lee et al., 2005; Zihni et al., 2014). These analyses do not capture the real essence of the surgery, reducing representativeness and generalisation to understand the dynamics of the process and identify the risk of fundamental tasks (Hollnagel et al., 2015). From a systems perspective, the work process analysis is fundamental to understanding how the factors within the work system can impact the activity, the people, and the performance of the tasks (Wilson, 2000). This becomes even more relevant if the work system presents deficiencies that can directly impact surgeons and patients, such as in the Peruvian healthcare system. For this reason, it is essential to understand the work system by analysing the work process of laparoscopic surgery in the Peruvian systems.

Based on the SEIPS model, this chapter aimed to analyse the "work process" and respond to the third research question related to the work process of laparoscopic surgery:

RQ3: To what extent do surgeons' postures during laparoscopic tasks raise the risk of work-related musculoskeletal disorders?

6.1.1. Objectives

1. To identify postures with the highest risk of WRMSD during laparoscopic surgeries.
2. To determine the level of risk of musculoskeletal disorders during the different levels of complexity in laparoscopic surgeries
3. To determine the laparoscopic tasks that contribute to a higher risk of WRMSD

6.2. Method

This study complemented results from study one (chapter four), following the convergent mixed-method approach to achieve the first aim of the thesis. The study followed a cross-sectional design based on observations of real laparoscopic surgeries in Peruvian hospitals. The study was carried out from October 2018 to March 2019. A total of 19 laparoscopic surgeries were observed in five different Peruvian hospitals and included: Cholecystectomy (13); Transabdominal preperitoneal (TAPP) inguinal hernia repair (2); sigmoidectomy (1); appendicectomy (1), Single Anastomosis Sleeve ileal Bypass (SASI) (1) and Cholecystectomy with complication (1).

6.2.1. Participants

Surgeons from Peruvian hospitals were invited to participate in the study responding to the invitation 16 surgeons. The target sample group was surgeons with experience in laparoscopic surgery and registered in the Peruvian medical college (Colegio Medico del Perú). Residents were excluded from the role of the primary surgeon since their lack of experience and training in Laparoscopic may bias the results. However, residents and medical students were accepted to participate in the study as camera assistants because this was the typical role assumed during laparoscopic surgeries in Peru. The total of residents and medical students that participated was 14. All participants accepted voluntarily, were informed about the research, and signed the consent form to participate.

6.2.2. Materials and equipment

In order to capture details of laparoscopic surgeries, surgeries were recorded with three cameras located on different planes of reference. Camera A consisted of a small live-action camera with HD resolution, camera B was an iPad pro 10.5" camera with HD resolution, and camera C was a SONY XR camcorder with a memory card.

6.2.3. Procedures

6.2.3.1. Data collection during surgeries

Camera A was situated in front of the surgeon (under the screen) in the frontal plane. Whilst camera B was placed on a tripod in a higher view in the lateral plane to capture a general plane of the surgeon's and assistant's interactions. Camera C was placed in the direction of the screen to record the surgical procedure. The video recording started when surgeons insufflated the patient's abdomen and continued up to finish closing up the patient.

6.2.3.2. Data process

Analysis of frames

The video recordings were processed in Camtasia software, unifying the views from each camera into a single video. These views were: one in front of the surgeon (lateral plane, camera A), the second in the sagittal plane (camera B) and the third (camera C) with zoom in the screen to observe details of the task (see Figure 6.1). The VLC video converter software was used to extract the frames every 30 seconds of the surgeries by storing them directly in a folder with the name of each surgery.

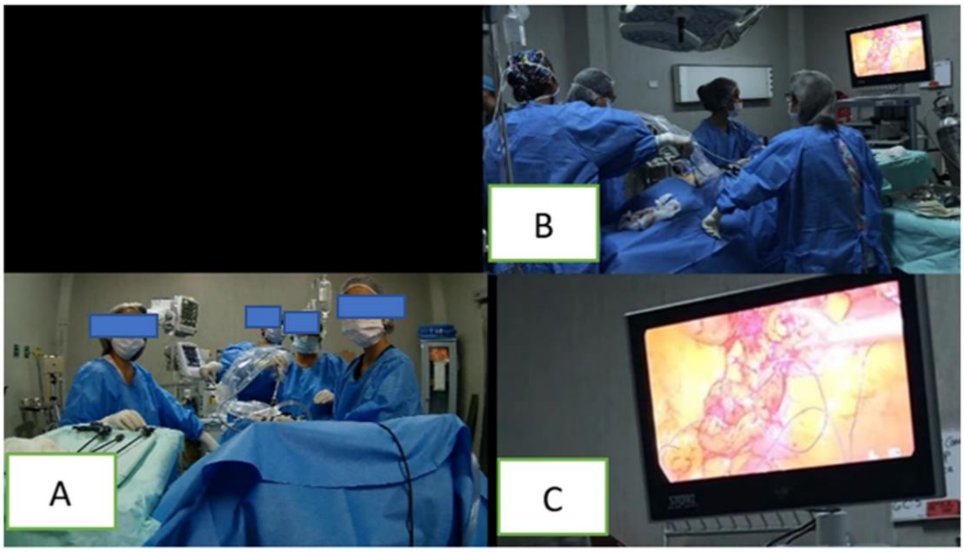
The extracted frames were reviewed to determine the quality of the image. If the frame showed a blurred, unobservable, out-of-focus image, or some external factor that made the analysis difficult, it was discarded and not considered in the sample for analysis. The frames were extracted at regular 30-second time intervals throughout the laparoscopic surgery to capture greater detail in the postures adopted by the surgeon and greater precision for risk assessment. The number of postures observed decreases the estimation error approaching an error limit of 10% to 5% (with a 95% probability when more than 80 postures are observed) (Diego-Mas, 2015). Then, a postural analysis was carried out from frames to determine the risk of WRMSD adopted by surgeons and assistants and identify different movements in surgical tasks.

Task analysis

The surgeries were divided into specific tasks following the hierarchical task analysis (HTA) approach described by Kirwan & Ainsworth (1992). Two surgeons were invited to analyse video recordings of their surgeries and describe the main tasks performed following a timeline. From the surgeons' observations and testimonies, the tasks were named sequentially according to the activities necessary to complete the surgery. The surgeons also provided details about the tools, specific tasks performed, and the most common positions to complete the task.

For the analysis, the goal of the HTA was to accomplish the laparoscopic surgery (e.g. Cholecystectomy), and the task list started from creating the pneumoperitoneum to the close-up patient's abdomen. Only one level of analysis was developed for postural analysis, presenting the results of the HTA in a table. Once the HTA was completed, surgeons were asked to make the necessary corrections to complete the analysis. Then, video frames of the recorded surgeries were categorised according to the HTA developed , identifying the beginning and end of each task.

Finally, the laparoscopic tasks with the highest exposure for each surgery were regrouped into specific laparoscopic tasks using common surgical tools and techniques.



Note. A: frontal view; B: sagittal and general view; C screen view

Figure 6.1 Example of video frame extracted to be analysed

Work-related musculoskeletal disorder risk analysis

The RULA method was applied to determine WRMSD in laparoscopic surgeries. RULA is validated to be applied in tasks where people have a risk of neck and upper-limb loading combined with force, time and repetitiveness (McAtamney & Nigel Corlett, 1993). RULA provides a template with different postures divided into two groups. Group A includes upper-arm (flexion/extension, degree of abduction and elevation), lower arms (flexion/extension) and wrist (flexion/ extension deviation and twisting), whilst Group B includes neck (flexion/extension, twisting and inclination), trunk (flexion /extension, twisting and side-bending) and legs (supported or unsupported).

Using the tables associated with the method, a score is assigned to each body zone (legs, wrists, arms, trunk) and based on these scores, overall scores are assigned to each group (A and B). Subsequently, global scores of groups A and B are modified according to the type of muscular activity performed and the force applied during the task performance.

Finally, the final score is obtained from these modified global values. The final scores are categorised into action levels (AL), ranging from AL 1 or low-risk level to AL 4 or high-risk level of WRMSD (see Table 6.1). For the study, the AL3 and AL4 were considered High-risk levels of WRMSD

The procedure to use RULA comprised: (a) identifying postures to be assessed on the right and left side; (b) postures are scored using the scoring sheet and body-part diagrams, and (c) converting final scores to one of the four Action levels (AL) and categories of risk (Stanton et al., 2004).

Table 6.1 Final RULA score and action level scheme classification

WRMSD RISK	RULA score	Action Level	Description
Low	1-2	AL 1	Posture is acceptable if it is not maintained or repeated for long periods
Medium	3-4	AL 2	Further investigation is needed, and changes may be required
High	5-6	AL3	Investigation and changes are required with some immediacy
High	7	AL 4	Investigation and changes are required immediately

Because of the large number of observations captured in the video recording, a Microsoft Excel spreadsheet was prepared with RULA method formulas divided into body regions to calculate the musculoskeletal load risk score and action levels (see Figure 6.2). The percentage of body postures scores based on RULA was used, arranging the information in final graphs with representative postures of both surgeons and assistants.

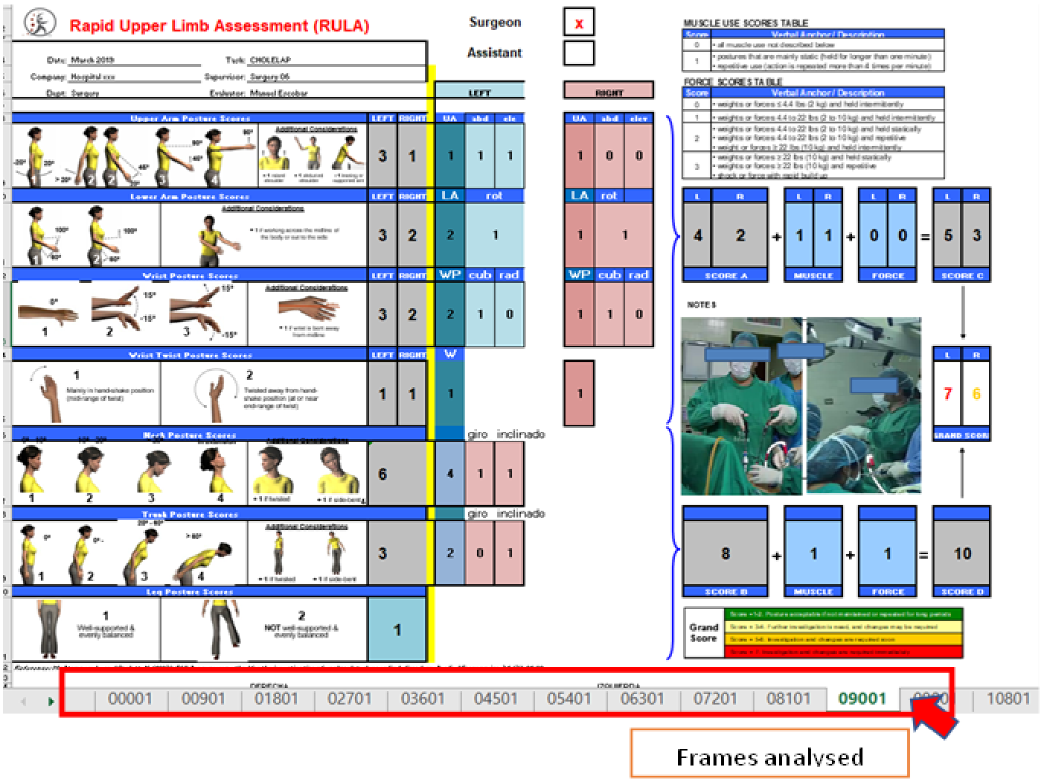


Figure 6.2 Example of Spreadsheet to analyse frames with RULA method

Posture considerations

The surgeon's position technique was assessed according to the preferences of surgeons. Based on observations and testimonies of surgeons during study one and posture classification referred to in the literature review, three specific frequent positions were observed: patient supine and the surgeon standing on the patient's left (American position), patient in lithotomy position and the surgeon stands between the patient's leg (French position) and patient supine with the surgeon at the side of the patient with the camera at patient's feet position (side position)

6.2.4. Research approvals

The study was approved by the University of Nottingham, the Faculty of Engineering Ethical Committee, and the head of the surgeries department of the hospitals visited (see appendix 12.24).

6.2.5. Statistical analysis

The statistical analysis of data was processed using the IBM SPSS statistics software package version 24.0. The frames represented the postural observations made in the field and were subsequently analysed with the RULA method to define AL and WRMSD risk. The analysis results were categorised into three groups of WRMSD risk (low, medium and high) in cross-frequency tables. In case there are no low-risk postures, only Medium and High-risk postures were considered for the analysis.

The two-way chi-square test (x^2) was used to establish associations among independent variables. The accepted level of significance was $p< 0.05$. Adjusted standardised residuals were also used to establish differences in preferences that could be considered significant. A value beyond the range of +-1.96 was considered a significant contributing value to the chi-square, while lower or negative values were not accepted as high contributing.

Differences in RULA final scores in the laparoscopic tasks were determined using the nonparametric Kruskal Wallis test with Dunn's correction pairwise. Representative scores were distributed as medians and plotted on graphs of lines to represent the final RULA score distribution by laparoscopic tasks. Since the non-normality of the distribution was applied, a nonparametric test

The final tasks were regrouped according to the skills and tools necessary to perform laparoscopic surgery. The Pearson chi-square test was used to establish the association among tasks, sorting the postural observations made according to the risk of WRMSD. Finally, the RULA scores were categorised into body segments representing groups A and B and the frequency of postures for each group was recorded. The differences in postures between surgeons and assistants were also recorded, and the data were analysed using a two-way chi-square test.

6.2.6. Inter-rater reliability

An inter-rater reliability assessment of RULA was conducted after the complete analysis. A total of 39 frames were randomly drawn from all surgeries to obtain 78 postures to be analysed (left and right side). All postures were qualified by two professional ergonomists with experience in physical ergonomics and compared with the results of the researcher. Before the analysis, the experts were informed of the study's objectives, the RULA-based rating tools and the criteria used to familiarise them with the study methodology. The experts were asked to rate the randomly selected frames using the excel template. The results were compared with the researcher's results to determine the level of inter-rater reliability of the action levels using Cohen's kappa analysis. More than 90% of the agreement for the AL was acceptable for inter-rater reliability (Jones & Hignett, 2007), and Kappa score above 0.78 was a strong concordance (McHugh, 2012).

The final results indicated a high agreement to determine the action level (>90%) and acceptable levels of Kappa (>0.78), achieving high inter-rater reliability. More details were given in appendix 12.8

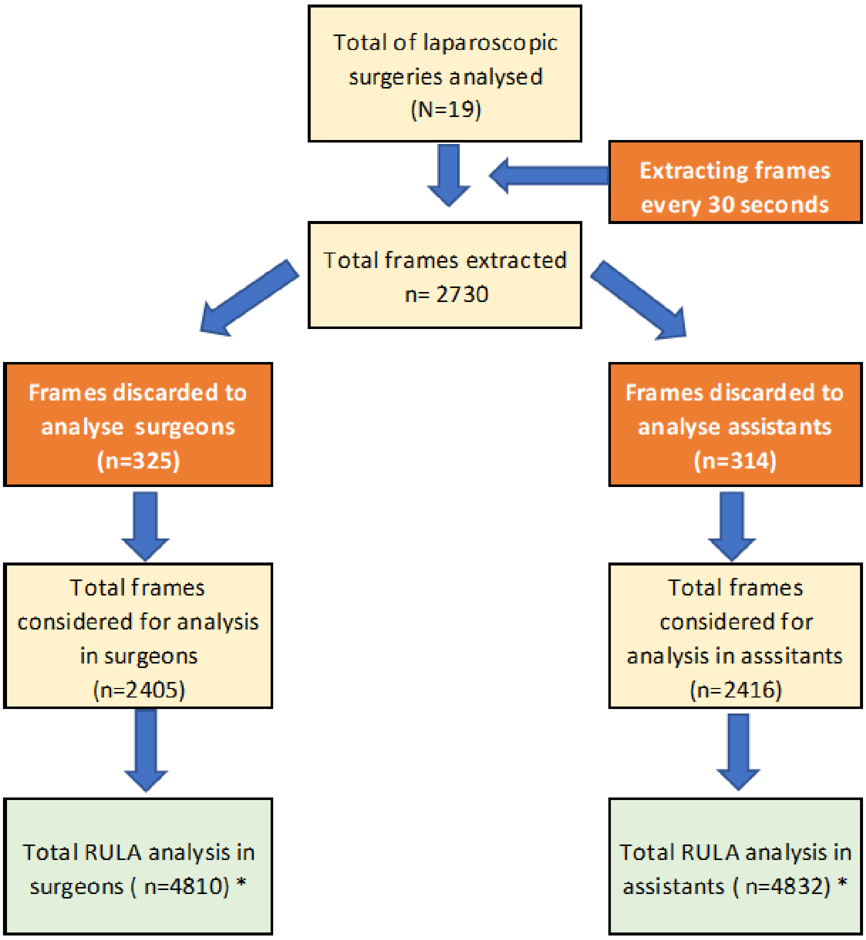
6.3. Results

6.3.1. Study population

Sixteen surgeons participated in the study, of which 13 were men (81.2%) and three were women (18.8%). In the role of assistants were one medical student (6.7%), 13 residents (86.6%) and one surgeon (6.7%), of which three were women. Residents were excluded when they worked as the main surgeon. The mean stature of male surgeons was 174 cm (SD=6.4), and assistants were 170 cm (SD=6.2) , whilst female surgeons had a mean of 162cm (SD=6.0) c, and assistants were 155.2 cm (SD=0.9). Surgeons were aged between 31 – 64, with a mean age of 48 years, and assistants were aged between 25 -36, with a mean of 32 years. Surgeons' mean years of experience in laparoscopic surgery was 16.4 years, ranging from 3 – 25 years. All surgeons and residents were full-time workers in hospitals.

6.3.2. Total number of frames to analyse

From the total number of surgeries observed (N=19), 2730 frames were extracted, of which 325 and 314 frames (surgeons and assistants) were discarded for not meeting the inclusion criteria related to image quality (see section 6.2.3.2). As a result, 2405 frames were included for analysing surgeons and 2416 for camera assistants. Each frame permitted analysis of postures on the right and left sides; therefore, 4810 postural analyses were conducted for surgeons and 4832 for assistants. Figure 6.3 illustrates the process of selecting frames for analysis.



Note. (*) included right and left side

Figure 6.3 Flowchart with the distribution of frames used to analyse WRMSD risk in surgeons and camera assistants

6.3.3. RULA results by factors

Final RULA scores

Over half of the frames analysed resulted in a RULA score corresponding to AL 4 for both surgeons (60%) and camera assistants (52%), followed by AL3 32% for surgeons and 45% for camera assistants. These action levels represented 92% of postures observed at high risk for surgeons and 93% for camera assistants. None of the frames analysed was classified as AL 1 (0%). The risk of WRMSD of surgeons and camera assistants is high in both cases without significant differences ($x^2_{(2)}$=3.89; p=0.05) (see details in Table 6.2).

Table 6.2 WRMSD risk in surgeons and assistants

Role	WRMSD risk		Total	x^2 (df)	*p*
	Medium	High			
Surgeons	381 (8%)	4429 (92%)	4810	3.89 (2)	0.05
Assistants	332 (7%)	4500 (93%)	4832		

Note. X^2 . Chi-square of Pearson (degrees of freedom) ; p-value : p<0.05* ; p<0.001** ; Medium : AL2; High: AL3+AL4

RULA scores by type of surgeries

Inguinal hernia repair surgeries and Cholecystectomy mostly had postures in AL 3 and AL4 (48% and 47%, respectively), while complex surgeries mostly reached AL 4 (76%) and AL 3 (19%). Barely 11% of observations were classified in AL2 in the cholecystectomy group, while other complex surgeries included only 5%. None of the frames analysed reached AL 1. These action levels represented more than 90% of postures observed at high risk for inguinal hernia repair and complex surgeries, being the riskiest surgeries for surgeons ($x^2_{(2)}$=50.28; p<0.001).

On the other hand, camera assistants mostly adopted postures in AL 3 (56% and 51%) when assisted during Cholecystectomy and Inguinal hernia surgeries, while complex surgeries mostly reached AL 4 (66%). In the three groups, less than

10% of postures were classified in AL2. None of the frames analysed reached AL 1. Thereby, inguinal hernia repair and complex surgeries represented the riskiest surgeries for assistants ($x^2_{(2)}$=50.28; p<0.001). Therefore, inguinal hernia and complex surgeries represented a higher risk of WRMSD than cholecystectomies for both surgeons and assistants ($x^2_{(2)}$=118.66; p<0.001) (see Table 6.3)

Table 6.3 WRMSD risk and type of surgery

Role	**Type of surgery**	**WRMSD risk** Medium	**WRMSD risk** High	**Total**	**x^2 (df)**	**p**
Surgeon	Cholecystectomy	**240 (11%)**	1956 (89%)	2196	50.28 (2)	< 0.001*
	Hernia inguinal repair	29 (6%)	**479 (94%)**	508		
	complex surgery (>90 min)	112 (5%)	**1994 (95%)**	2106		
Assistant	Cholecystectomy	**221 (10%)**	1951 (90%)	2172	73.68 (2)	< 0.001*
	Hernia inguinal repair	8 (2%)	**492 (** 98% **)**	500		
	complex surgery (>90 min)	103 (5%)	**2057 (** 95% **)**	2160		
Total	Cholecystectomy	**461 (11%)**	3907 (89%)	4368	118.6 (2)	< 0.001*
	Hernia inguinal repair	37 (4%)	**971** (96%)	1008		
	complex surgery (>90 min)	215 (5%)	**4051** (95%)	4266		

Note. X^2. Chi-square of Pearson (degrees of freedom), (*) significant difference; Bold (>1.96), adjusted standardised residuals; Medium: AL2; High: AL3+AL4

Final RULA scores by gender

Over half of frames observed in male surgeons corresponded to AL 4 (65%) and female surgeons (54%), whilst more than a quarter of male surgeons adopted postures in AL 3 (28%) and almost 40% in female surgeons (37%). Similarly, male and female camera assistants exceeded half of the frames observed in AL4 (54% and 58%, respectively). None of the frames analysed reached AL 1. Therefore, female surgeons adopted higher-risk postures than male surgeons in both surgeons

($x^2_{(1)}$=27.07; p<0.001) and assistants ($x^2_{(1)}$=69.99; p<0.001) and total observations ($x^2_{(1)}$=89.43; p<0.001). Details are given in Table 6.4

Table 6.4 WRMSD risk by gender

Role	Gender	WRMSD risk		Total	x^2 (df)	p
		Medium	High			
Surgeon	male	**197 (10%)**	1690 (90%)	1887	27.07 (1)	< 0.001*
	female	184 (6%)	**2739 (94%)**	2923		
Assistant	male	**214 (10%)**	1842 (90%)	2056	69.99 (1)	< 0.001*
	female	118 (4%)	**2658 (96%)**	2776		
Total	male	**411 (10%)**	3531 (90%)	3942	89.43 (1)	< 0.001*
	female	302 (5%)	**5397 (95%)**	5699		

Note. X^2. Chi-square of Pearson (degrees of freedom), (*) significant difference; Bold (>1.96), adjusted standardised residuals; Medium: AL2; High: AL3+AL4

Final RULA scores by the position of surgeons in the surgery

Of the 19 surgeries, nine were performed with surgeons positioned in the American position, four in the French position and six at the patient's side with the screen at feet level (inguinal hernia repair and sigmoidectomy) (see Figure 6.4). The American, French and side positions exceed half of the postures observed in AL 4 (58%, 55% and 67%, respectively), followed by postures in AL 3 (32%, 43%,28%) and less than 10% in AL2. Hence, the side standing position was associated with postures with a higher risk of WRMSD (96%) than the American and French positions, which were not significantly different from each other ($x^2_{(2)}$=45.38; p<0.001). Details are given in Table 6.5

Table 6.5 WRMSD risk by positions of surgeons adopted in laparoscopic surgery

Role	Position	WRMSD risk		Total	x^2 (df)	p
		Medium	High			
Surgeons	American	**205** (10%)	1820 (90%)	2025		
	French	**97** (9%)	927 (91%)	1024	45.38 (2)	< 0.001*
	Side	79 (4%)	**1682** (96%)	1761		

Note. X^2. Chi-square of Pearson (degrees of freedom), (*) significant difference; Bold (>1.96), adjusted standardised residuals; Medium: AL2; High: AL3+AL4

(a) American position

(b) French position

(c) Side position

Figure 6.4 Examples of surgeons' positions adopted in surgery

6.3.4. RULA results by laparoscopic surgical tasks

Final RULA scores by tasks in laparoscopic Cholecystectomy

Figure 6.5 illustrates the level of risk of 12 cholecystectomies, and table 6.6 shows the detail of the analysis with corresponding action levels. Surgeries were analysed and finally decomposed into eight tasks described in contingency sequence at one level, starting with creating pneumoperitoneum up to closing patients' abdomen. The mean duration of surgeries was 60 minutes. RULA scores of surgeons and camera assistants were qualified as" high risk", varying scores from AL3 (Mdn=6) to AL4 (Mdn=7) without finding a "low risk" score.

Tasks demanded that surgeons adopt static postures holding the diathermic electric hook, activated by foot pedals placed under the table. As the surgery progresses, surgeons' postures increase the risk of WRMSD. Tasks four and five (Mdn=7) resulted in a higher risk than the other tasks with a combined exposure of 23% ($x^2_{(7)}$=118.1; p<0.001); however, all represented a high risk of WRMSD for surgeons. Although the assistants had lower AL scores than surgeons, the risk values were just as high as those of the surgeons.

The close-up patient's abdomen tasks were high risk because they involved trunk flexion postures and were performed by the surgeons (Mdn=7) rather than the assistants (Mdn=6).

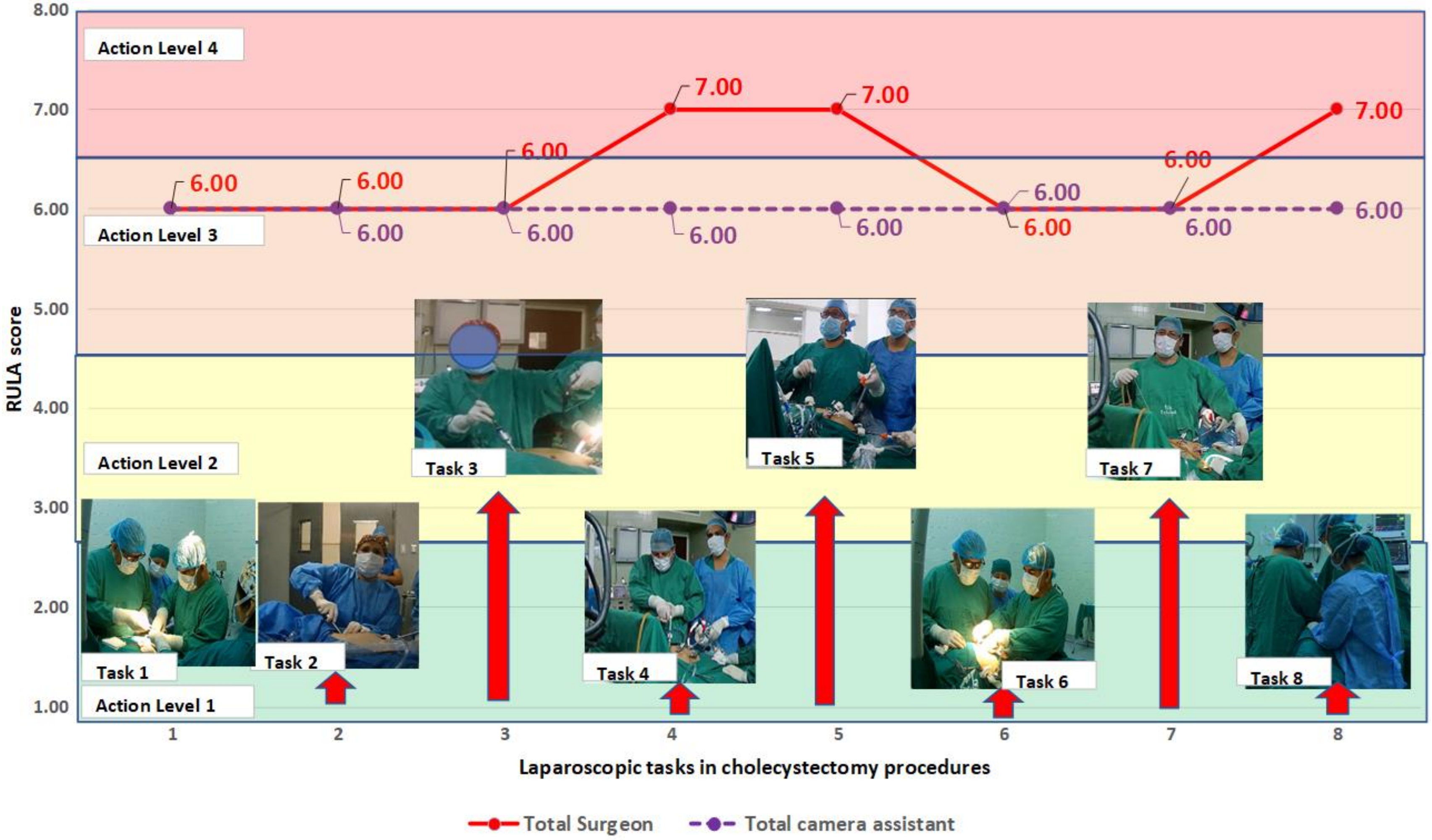


Figure 6.5 Musculoskeletal disorder risk of surgeons and camera assistants during Cholecystectomy

Table 6.6 Task analysis and RULA scores of cholecystectomy surgery

Tasks	Goal: Cholecystectomy	Surgical skills and tools used	Exposition	RULA*	AL	Risk
	Surgeon					
1	Create Co2 Pneumoperitoneum	Non laparoscopic task	6%	6	3	High
2	Insert access port (trocars)	Place trocars applying exertion	7%	6	3	High
3	Dissect and expose CA and CD	Hook (electrocautery) activated by foot pedals, dissectors	34%	6	3	High
4	Secure CA and DC	Staplers and dissectors	7%	7	4	High
5	Transect DC and detach the GB from the liver bed	Hook (electrocautery) activated by foot pedals. Use of dissectors and scissors	16%	7	4	High
6	Extract the GB	Use of dissectors	14%	6	3	High
7	Final check and irrigation	suction (irrigation suction and dissectors)	6%	6	3	High
8	Close up patient	Suture with open surgery	10%	7	4	High
	Assistant					
1 to 2	Peumoterineum assistance	N/A	13%	6	3	High
3 to 7	camera conduction	endoscope/laparoscope	77%	6	3	High
8	Close-up patient assistance	Non laparoscopic task	10%	6	3	High

Note. *RULA scores (median); AL: action level ; CA:cystic artery ; CD: Cystic Duct ; GB:Gallbladder

Final RULA scores by tasks in inguinal Hernia Repair

The surgery was decomposed into ten tasks described in contingency sequence at one level, which started with creating pneumoperitoneum up to close the patient's abdomen. Figure 6.6 shows the distribution of RULA scores and AL, whilst Table 6.7 describes the HTA of inguinal hernia repair (TAPP) and WRMSD risk. The lowest score was achieved when the surgeon prepared the mesh on a separate table (Mdn = 3; AL2), whilst the assistant held the endoscope in the operating area until the surgeon returned (Mdn= 7; AL3). The mean duration of the surgery was 68 minutes for an average male patient.

Tasks three, seven and eight were the riskiest and demanded surgeons' different skills (Mdn=7; $x^2_{(9)}$=221.76 ; p<0.05). Opening the peritoneum above the inguinal foramen to create space on both sides (bilateral hernia) (task three) and the individualisation of structures (task 4) demanded that surgeons use dissectors and scissors during 24% of the total surgery, adopting postures at a high level of risk (Mdn=7).

The suture of the peritoneum with intracorporeal suturing demanded more than 30% of time exposition at very high risk (Mdn=7). In addition, tasks three, four and eight exceeded 50% of the surgical exposure with surgeons operating in high-risk postures. These tasks positioned the surgeon at the patient's side and across the midline, with the screen located at the patient's feet. Similarly, the camera assistant achieved high scores during camera conduction (Mdn= 7; AL4), being the riskiest assistant task ($x^2_{(2)}$ = 160.36; p<0.001).

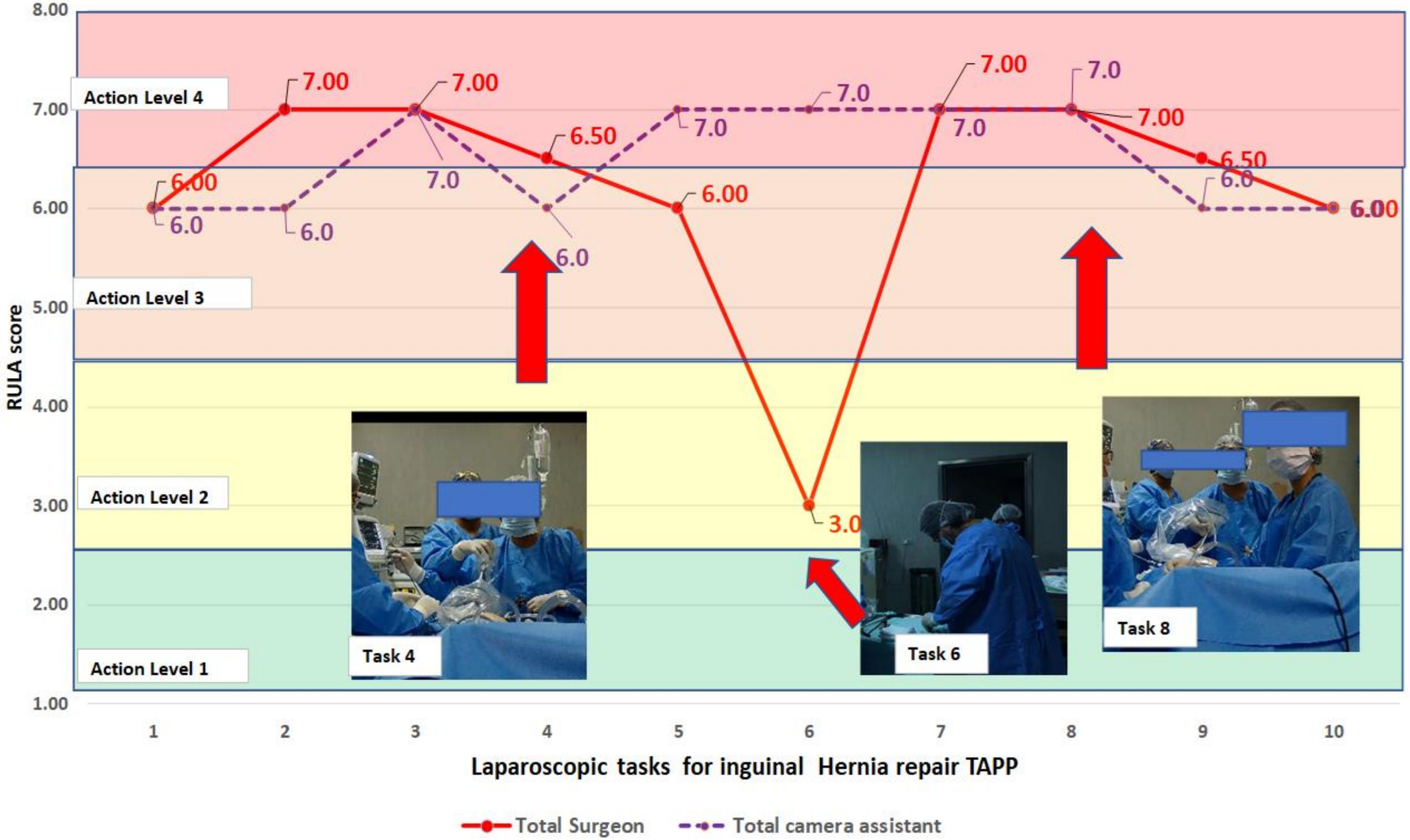


Figure 6.6 Example of Postural risk analysis of surgeons and camera assistants that perform a laparoscopic inguinal hernia repair TAAP (surgery 15)

Table 6.7 Task analysis and RULA scores of a TAPP inguinal Hernia Repair

Tasks	Goal: Hernia Inguinal repair TAPP	Surgical skills and tools used	Exposition	RULA*	AL	Risk
	Surgeon					
1	Create Co2 pneumoperitoneum	Non laparoscopic task	19%	6	3	High
2	Insert access port (trocars)	Place trocars applying exertion	2%	7	3	High
3	Create the peritoneal flap	Graspers, dissectors and scissors	13%	7	3	High
4	Individualization and dissection of structures and identification of cooper ligament	Use of dissectors and scissors	11%	6.5	4	High
5	Preparation of space to place the mesh	Use of dissectors and graspers	4%	6	4	High
6	Mesh Preparation	Non laparoscopic task	2%	3	3	High
7	Mesh placing and fixation in the posterior wall	Use of dissectors, graspers and mesh fixatives	6%	7	3	High
8	Suture and close of peritoneum	Intracorporeal suturing with the needle driver	30%	7	4	High
9	Final check and irrigation	suction (irrigation suction and dissectors)	2%	6.5	4	High
10	Close up patient	Suture with open surgery	11%	6	3	High
	Assistant					
1 to 2	Peumoterineum assistance	N/A	21%	6	3	High
3 to 9	camera conduction	endoscope/laparoscope	68%	6	3	High
4	Close-up patient assistance	Non laparoscopic task	11%	6	3	High

Note. *RULA scores (median); AL: action level

Final RULA scores by tasks in complex surgery: Bypass gastric surgery

Figure 6.7 represents the RULA analysis by tasks of SASI (complex surgery), and Table 6.8 the detail of final scores by tasks. The surgery was decomposed into 12 tasks described in contingency sequence at one level, starting and ending similar to other surgeries. The mean duration was 212 minutes, and the patient operated on was an obese man (raised working height). Most tasks (tasks four to ten) related to the surgery process obtained a high score (Mdn=7; AL4).

The SASI surgery demanded advanced skills such as intracorporeal suturing with needle drivers to complete the suture line and anastomosis of the ileum and gastric line. All observed postures involving intracorporeal suturing tasks were high risk, with exposure close to 50% of the total duration of surgery (45%). Furthermore, the vertical gastrectomy required that the main surgeon use mechanical suturing, applying a great exertion to activate the tool repetitively with poor mechanical advantage (94% high-risk postures).

The postures adopted in tasks three to ten accounted for 94% of the entire surgery and were the riskiest tasks ($x^2_{(10)}$=258.58; p<0.001), so changes need to be made soon. None of the tasks was categorised as low risk. Likewise, the assistant camera adopted high-risk postures during most of the surgery, mainly when conducted the camera assisted the surgeon in closing up the patient ($x^2_{(2)}$=515.30;p<0.001).

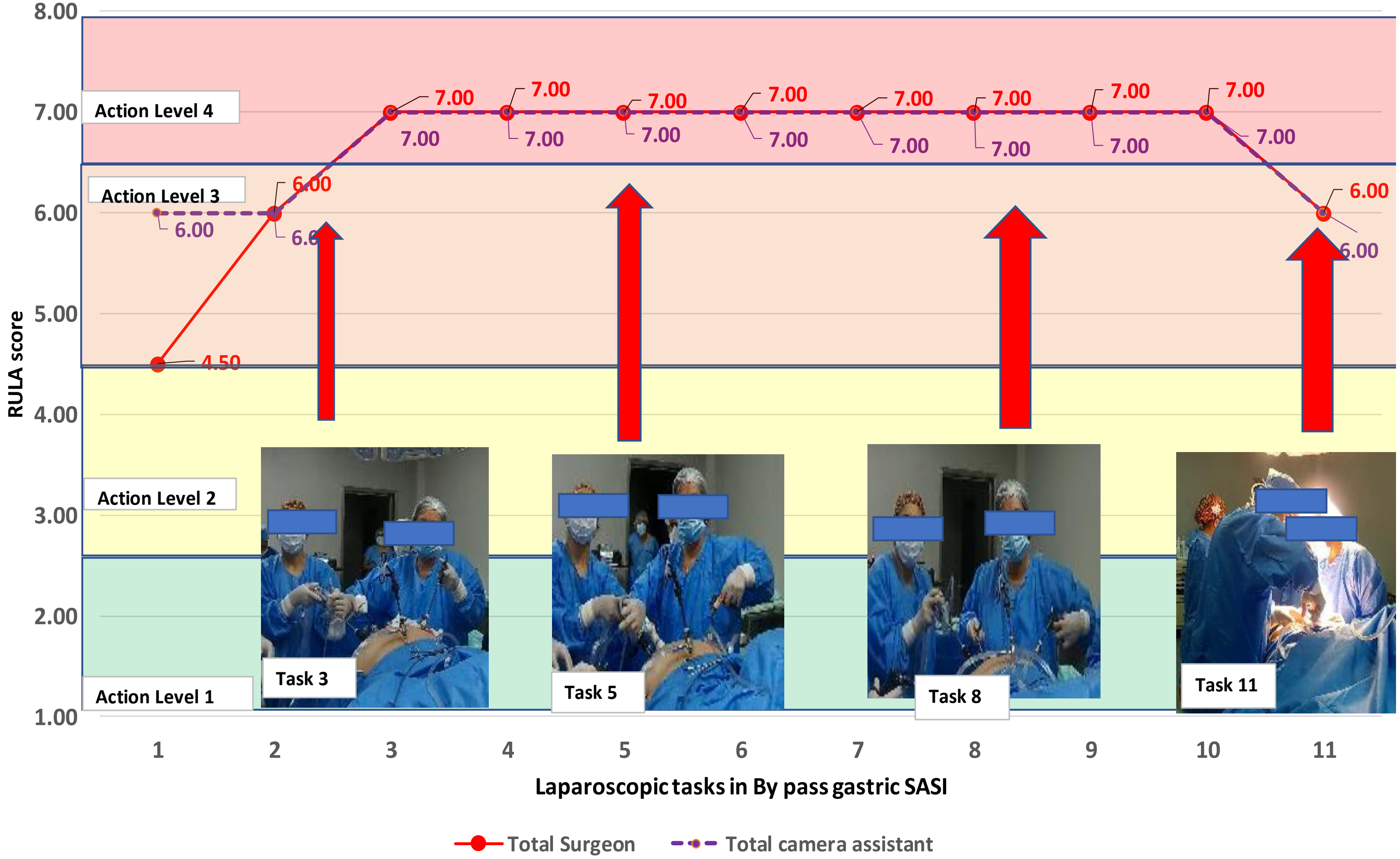


Figure 6.7 Postural risk of surgeons and camera assistants in a laparoscopic Bypass gastric SASI

Table 6.8 Task analysis of Bypass gastric SASI surgery and RULA scores of surgeons and assistants by tasks

Tasks	Goal: By pass Gastric SASI	Surgical skills and tools used	Exposition	RULA*	AL	Risk
	Surgeon					
1	Create Co2 pneumoperitoneum	Non laparoscopic task	1%	4.5	3	High
2	Insert access port (trocars)	Place trocars applying exertion	2%	6	3	High
3	Release of the omentum from the greater curve of the stomach	use of vessels sealer with dissectors	14%	7	4	High
4	Place calibrating tube on the minor curve of the stomach	Use of dissectors and scissors	2%	7	4	High
5	Vertical gastrectomy	mechanical suturing	25%	7	4	High
6	Omentum partition and placing the intestine	Dissectors, graspers	4%	7	4	High
7	Suturing of the stomach and jejunum anastomosis	intracorporeal suturing with a needle driver	12%	7	4	High
8	Lateral anastomosis between the stomach and jejunum	intracorporeal suturing with a needle driver	35%	7	4	High
9	Pneumatic test and drain placement	suction (irrigation suction and dissectors)	2%	7	4	High
10	Final check and irrigation	suction (irrigation suction and dissectors)	1%	7	4	High
11	Close up patient	Suture with open surgery	3%	6	3	High
	Assistant					
1 to 2	Peumoterineum assistance	N/A	3%	6	3	High
3 to 10	camera conduction	endoscope/laparoscope	94%	6	3	High
11	Close-up patient assistance	Non laparoscopic task	3%	6	3	High

Note. *RULA scores (median); AL: action level

Final RULA scores by tasks in complex surgery: laparoscopic sigmoidectomy

Figure 6.8 shows the distribution of final RULA scores and ALs, whilst table 6.9 describe the RULA analysis by tasks of a laparoscopic sigmoidectomy (complex surgery). The surgery was decomposed into 15 tasks described in contingency sequence at one level, which starts with creating pneumoperitoneum up to close patient's abdomen. The mean duration of the surgery was 134 minutes.

Tasks three to twelve got the highest WRMSD risk and corresponded to tasks related to performing intracorporal and extracorporeal suturing at the patient's side (Mdn=7; $x^2_{(14)}$=245.09; p<0.001). None of the tasks was in AL1. It is concluded that this is the surgery with a higher risk than the previous ones, mainly due to the amount of exposure to the laparoscopic suture and high coordination demanded to perform the surgery. As with the previous surgeries, the camera conduction proved to be a high-risk task for assistants ($x^2_{(2)}$=193.91; p<0.001).

The close-up patient task did not involve laparoscopic tasks per se because the surgeon performs sutures using an open technique; however, it represents a significant risk concerning the other positions that must be considered.

Final WRMSD risk of tasks

As a result of surgeries analysis, the common tasks in the different surgeries were summarised, considering the skills and tools used (see Table 6.10). Overall, an association was found between laparoscopic tasks and the risk of WRMSD, with dissecting tasks, cutting tasks (including diathermic energy) and intracorporeal suturing contributing significantly to higher risk ($x^2_{(4)}$=37.5; p<0.001). Furthermore, the table shows the final results of the risk of WRMSD in the three tasks of assisting the surgeon in the main laparoscopic surgeries assessed. The results showed an association between the assistants' tasks and the risk of WRMSD, concluding that camera conduction was the task more frequent and contributed to the high-risk level ($x^2_{(4)}$=29.4; p<0.001).

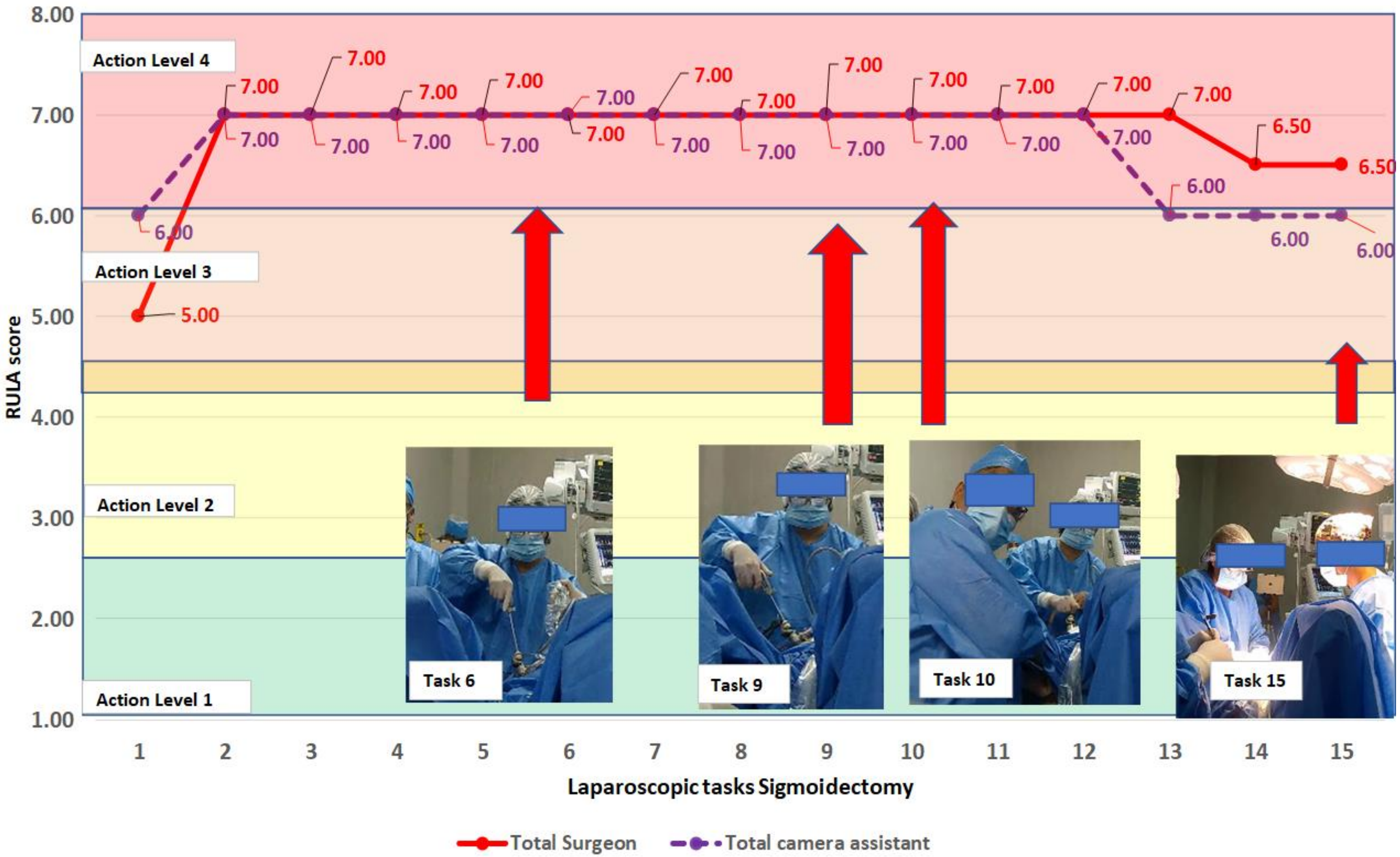


Figure 6.8 Postural risk of surgeons and camera assistants in a laparoscopic Sigmoidectomy

Table 6.9 Task analysis of laparoscopic sigmoidectomy surgery and RULA scores of surgeons and assistants by tasks

Tasks	Goal: By pass Gastric SASI	Surgical skills and tools used	Exposition	RULA*	AL	Risk
	Surgeon					
1	Create Co2 pneumoperitoneum	Non laparoscpic task	9%	5	3	High
2	Insert acces port (trocars)	Place trocars applying exertion	4%	7	4	High
3	Marking section line and opening of mesosigmoid releasing left told fascia	Dissectors, scissors	11%	7	4	High
4	Clip the artery	Staplers and dissectors	17%	7	4	High
5	Dissection of the sigmoid junction at the rectus sigmoid level	Dissectors, scissors	6%	7	4	High
6	Purse-string suture of the distal stump (colon)	intracorporeal suturing with a needle driver	11%	7	4	High
7	Opening of the mid-infraumbilical incision wall and removal of the operative piece	Dissectors, scissors	6%	7	4	High
8	Placement of anvil (extracorporeal) and abdominal wall closure	intracorporeal suturing with a needle driver	4%	7	4	High
9	Search and closure of the purse around the anvil suture	intracorporeal suturing with a needle driver	15%	7	4	High
10	Colon anastomosis and mechanical suture assembly	intracorporeal suturing with a needle driver	2%	7	4	High
11	Closure and firing of suture	intracorporeal suturing with a needle driver	1%	7	3	High
12	Check the two colon lines	Dissectors, scissors	3%	7	4	High
13	Pneumatic test and drain placement	Dissectors, graspers	6%	7	4	High
14	Final check and irrigation	suction (irrigation suction and dissectors)	2%	6.5	4	High
15	Close up patient	Suture with open surgery	3%	6.5	4	High
	Assistant					
1 to 2	Peumoterineum assistance	N/A	13%	6	3	High
3 to 14	camera conduction	endoscope/laparoscope	70%	6	3	High
15	Close-up patient assistance	Non laparoscopic task	1%	6	3	High

Note. *RULA scores (median); AL: action level

Table 6.10 Frequent Laparoscopic surgery tasks and WRMSD risk

Laparoscopic tasks	WRMSD risk Moderate	WRMSD risk High	Total	x2 (df)	*p*
Surgeon´s tasks					
Insert trocar into patient abdomen	9 (6%)	143 (94%)	152		
Dissecting and cutting tasks (diathermic)	41 (3%)	**1300 (97%)**	**1341**		
Irrigation and suction	11 (9%)	113 (91%)	124	37.50 (4)	p<0.001*
Intracorporeal suturing	2 (0%)	**558 (100%)**	**560**		
Mechanical suturing	12 (6%)	178 (94%)	190		
Assistant´s tasks					
Assist surgeons with trocar placement	38 (9%)	369 (91%)	407		
Camera conduction	105 (4%)	**2717 (96%)**	**2822**	29.40 (2)	p<0.001*
Close-up patient assistance	24 (7%)	326 (93%)	350		

Note. X^2. Chi-square of Pearson (degrees of freedom), (*) significant difference; Bold (>1.96), adjusted standardised residuals; Medium: AL2; High: AL3+AL4

6.3.5. Percentages of postures cumulated by body segment

In almost half of the observations, surgeons and assistants positioned upper arms between 20-45° flexion (48.1%; 47.7%), with shoulders raised (79.3%; 81.5%) and mainly rotated (65.8%; 64.8%) without statistical differences ($x^2_{(1)}$=0.09; p>0.05). More than two-thirds of surgeons (72.1%) and 65% of assistants positioned lower arms out of mid-range (<60°->100°), as well also wrist at 0-15° (63.1%; 60.5%) with ulnar deviation mainly in surgeons (73.5%). Surgeons had significantly higher percentages of high-risk postures than assistants in wrists ($x^2_{(1)}$=54.57; p<0.001). Half of the observations showed the trunk mainly kept erect in surgeons and assistants (50.1%; 49.7%) and almost two-thirds twisted (64.7%; 60.3%), while the neck remained mainly in extension (64.6%; 71.3%) and twisted (40.4%;53.9%).

Final high-risk trunk postures were significantly greater in surgeons than assistants ($x^2(1)=54.57$; $p<0.001$), but the neck was higher in assistants ($x^2(1)=54.57$; $p<0.001$). Many surgeons held their feet on the foot pedal over an unstable surface, especially when performing tasks with electrocautery in Cholecystectomy (11%) (See Appendix 12.11).

The final scores of the body segments with low-risk score (1) did not exceed 25%, while the scores higher than one (high risk) exceeded in all segments by more than 80%, which evidences the postural risk of surgeons and assistants.

6.4. Discussion

Laparoscopic surgery demands a high risk of WRMSD for surgeons and camera assistants, so further investigation and changes are required soon. The results were in line with other similar studies where the ergonomic risk of laparoscopic surgeons was measured, concluding that surgeons work mainly adopting awkward and non-ergonomic postures that somehow affect their work. However, study results carried out in controlled environments such as virtual simulators or physical environments with box trainers; the risk could be underrated or overrated (Alamoudi, 2020; Dabholkar et al., 2017; Khan et al., 2020;Lee et al., 2005; Zihni et al., 2014) due to a lack of exposure to real factors within the laparoscopic system. For instance, (Dabholkar et al., 2017) found that surgeons were at moderate risk when they had experience and high risk when they were novices. However, the study results indicated that experienced surgeons had high risks exceeding more than 90% of postures at high risk.

On the other hand, Pazouki et al. (2017) conducted a study in Iran with surgeons in real laparoscopic surgeries, determining a RULA score of 4 with an AL 2 (47.8%), by selecting the worst posture during laparoscopic surgeries, which differed substantially from this study where results exceeded 60% of postures observed in AL 4 and reached 92% of high-risk postures. .

Most studies selected the most representative posture, usually the worst posture of the entire surgery, to rate the surgeon's overall posture (Alamoudi, 2020; Dabholkar et al., 2017; Khan et al., 2020; Pazouki A et al., 2017). However, it may be at greater risk of making errors of omission, as it is possible to miss postures that may pose a real risk in surgeries. For this reason, the study's methodology consisted of selecting the postures every 30 seconds, reducing the margin of error and the measurement with acceptable reliability ranges.

The study identified that female surgeons had a higher risk of WRMSD than male surgeons. The high scores can be explained by the participants' height, which was smaller than the males. This is a real trend in the general population, where the differences in stature make it challenging to adapt surgical systems to women because they were designed mainly for men (Sutton et al., 2014). Despite these differences, both groups were exposed to high-risk postures, which could also be associated with the short stature of the Peruvian population compared to HICs (Escobar- Galindo, 2020).

There was no evidence of postures in action level 1 in surgeons and assistants. This is evidence of surgeons' exposure to high-risk factors in the system that increase postural overload. The lowest scores were reached when surgeons were not performing proper laparoscopic tasks such as creating pneumoperitoneum or inserting trocars; however, they remained in the moderate and high-risk categories. To create pneumoperitoneum, surgeons did not demand high physical effort. They mainly needed to be attentive to the amount of Co2 insufflated in the patient and control the flow, getting relatively lower scores (AL2-3). On the other hand, preparing hernia mesh requires basic skills such as measuring with a ruler and cutting on a table (not laparoscopic). Thereby, these tasks did not demand a significant effort.

The neck was one of the main segments that increased the risk of WRMSD since the screens in most operating rooms were outside the surgeon's and assistant's viewing angle. This relationship was evidenced in several studies (Matern et al., 2005; Park et al., 2010; Wauben et al., 2006). More than 60% of the postures involved neck extension and rotation, which generated risky exposure considering the long duration of the surgeries. However, not all the time surgeons visualise the screen because they must also do other tasks that involve observing the patient and open surgery techniques, although in a lower percentage.

On the other hand, this study differs from other studies in that it considers the level of complexity in real surgeries. This analysis started from frequent surgeries such as Cholecystectomy that did not require advanced laparoscopy skills and more complex surgeries such as inguinal hernia repair or emergency surgeries, concluding that have a high risk of WRMSD.

The analysis identified that complex tasks demand significant surgical skills and experience, such as intracorporeal suturing and mechanical suturing. Unlike dissecting and cutting with scissors and graspers, the suture requires a needle driver with axial handles, demanding "extreme" movements in upper limbs. Axial handles tend to bend the wrist outward (ulnar deviation), stretching tendons of the forearm muscle on one side, raising the likelihood of WRMSD (Bridger, 2018c). This may explain the high percentage of wrist deviation identified in this study and the high prevalence of hand/wrist discomfort reported by surgeons in study two (chapter five). Besides, a higher working height or a reduced space could increase the ulnar deviation of the wrists and therefore increase the effort required, reducing the efficiency of movement and increasing discomfort (Croce & Olmi, 2000; Matern et al., 2001; Supe et al., 2010).

Finally, the more complex surgeries demand the surgeon to be positioned side-standing and often in a "bullfighter" position, significantly increasing the risk of WRMSD such as hernia inguinal repair and sigmoidectomy identified in this study.

Camera conduction tasks were typical of the surgeon's assistant and, as the surgeon's tasks, had a high risk of WRMSD. In several surgeries, the assistants held the cameras and held the tissues statically with the other limb, so they were also directly involved in the surgery and could injure the patient in case of poor manipulation. Unlike other studies where the risk of the assistant was lower (Pazouki A et al., 2017; Van Veelen et al., 2002), the study determined a high postural risk in upper limbs that may increase over surgery time due to a lack of muscle oxygenation exceeding the response capacity of surgeons (Armstrong et al., 1993). Also, the continuous adaptation of the assistants to the surgeons' needs increases the risk of awkward postures, so a work team approach is necessary to redesign the system.

The study evidenced that shoulders were mainly raised, upper arms were between 20 ° and 45° (>45%) and elbows out of mid-range, which did not match with the recommended position to work comfortably in laparoscopic surgeons (Berguer, 1999; Zachariou, 2019). These awkward postures, mainly static and added to the long exposure, are strongly associated with working height issues. Pheasant and Haslegrave (2006d) stated that when a working height is too high, shoulders and upper limbs will be raised, triggering fatigue and strain in muscles of the area. For this reason, recommendations for manipulative tasks with precision, such as surgery, suggest that working height should be 5-10 cm above the elbow. However, due to the length of the laparoscopic instruments (35 cm length) and the patient's size, this distance should be less to keep upper limbs in more suitable postures. In the case of surgeries, working heights are regulated in the operating table, so the height adjustment levels should be sufficient to achieve suitable heights. Further studies should be carried out to address this issue and establish appropriate recommendations.

Finally, the most-risk laparoscopic tasks were dissection, cutting, laparoscopic intracorporeal suturing and camera conduction. Although there were other risky tasks, these tasks were the most frequent and present in almost all surgeries. According to Fried (2008), dissecting and intracorporeal suturing tasks are the main tasks for developing skills in laparoscopic surgery and therefore require specific training and are necessary to achieve operating basic and complex surgeries. At the same time, camera conduction is essential for visualising the patient's interior and is crucial for the surgery's success (Muratore et al., 2007).

6.4.1. Limitations and strengths of the study

The presence of an external observer could change how surgeons perform tasks due to a possible Hawthorne effect (Adair, 1984). To minimise this effect and facilitate the work, the researcher contemplated using a small-sized camera placed in front of the surgeon's screen, avoiding the sensation of being observed. The researcher with the second and third cameras was positioned outside the surgeon's visual field to avoid being observed directly. In addition, surgeons previously indicated that they commonly record their surgeries, so it was a routine activity. At the end of the surgery, many surgeons stated that they worked comfortably without feeling invaded.

There were specific factors that the RULA method could not consider, for example, the slippery floor that could increase the postural overload of the surgeons and assistants when they performed Laparoscopic tasks. This factor was also observed in study one, where one surgeon constantly slipped on the wet floor of the surgery area. It is essential to assume this overload as part of the possible instability when standing.

The use of cameras in different planes improved the perspective for the analysis to apply the RULA method; however, some operating rooms had limitations in the infrastructure and organization, presenting difficulties for the recording process. For example, when the operating room was small, the researcher had to adjust the camera and the tripod to achieve better vision, limiting the visualisation of the posture and losing frames. As the frames were later excluded from the analysis, this may have limited the observation of relevant postures.The foot pedal could not be correctly assessed because it was under the table, so it was assessed in the surgeries in which the foot pedals could be evidenced.

The study's main strength was the analysis of real laparoscopic surgeries that allowed postural analysis while performing laparoscopic tasks. Furthermore, surgeries included cholecystectomies, the most frequent and less complex laparoscopic surgeries, and more complex surgeries such as Gastric Bypass or sigmoidectomy that lasted longer than two hours and demanded more advanced skills. This made it possible to obtain representative information to determine a range of WRMSD risks of working in laparoscopic surgery, unlike in the literature.

6.5. Key Summary

The research question was responded to by concluding that there is a high postural risk of having WRMSD in surgeons and assistants when performing laparoscopic surgeries, including complex surgeries. The findings supported the following conclusions:

- According to the RULA method, the action levels were greater than 3, classifying laparoscopic surgeries as high risk, so immediate investigations and changes are required. The results indicate a higher level of risk than scores reported in the literature on HICs.

- Complex surgeries demand surgeons and assistants to adopt greater high-risk postures than frequent surgeries such as Cholecystectomy. However, overall, laparoscopic surgeries demand high-risk postures for developing WRMSD.

- Female surgeons and assistants adopted significantly more high-risk postures than males; however, both groups had a majority of high-risk WRMSD postures.

- The laparoscopic tasks with the highest risk postures were dissection, cutting tasks (including diathermic tools), intracorporeal suturing and camera conduction.

- Among the main factors that conditioned postures were:
  - The neck extension was the most frequent and highest-risk posture observed, mainly related to the raised screen's position.
  - The raised working height may explain shoulder raised, upper arm postures between 20-45° and out mid-range posture of the lower arm.
  - The laparoscopic tasks, such as intracorporal suturing tasks, demand surgeons to operate with axial handles that prompt the ulnar deviation on the wrist.

Chapter 7: Studies integration

7.1. Introduction

The study presented the results of the integration studies developed in chapters four, five and six to determine the main factors associated with WRMSD across surgeons. Likewise, the study also aimed to determine the extent to which qualitative and quantitative studies integration converges or diverges following the SEIPS model approach.

This study intended to respond to the fourth research question

RQ4: What main factors associated with work-related musculoskeletal disorders of surgeons emerged from studies one, two and three? To what extent do the quantitative and qualitative results converge or diverge?

7.2. Method

As was explained in chapter three, integrating qualitative and quantitative data is crucial for mixed research since it may comprehensively explain a phenomenon. The primary method used to integrate the results of studies was triangulation with a complementary approach (McCrudden et al., 2021). Researchers investigate the same elements of a specific phenomenon with triangulation by corroborating data from different sources. In a complementary approach, researchers use one strand to illustrate or clarify the findings from another strand by focusing on similar and distinct aspects of the same phenomenon. However, Creswell and Clark (2017) stated that the term triangulation could be misleading because it is also used to validate qualitative research data. Thereby, they proposed "integration of results" as an alternative, so this study used the term integration or merging dataset to achieve the aims.

The method used to integrate studies results was the "across method", in which quantitative and qualitative procedures were combined simultaneously to achieve the completeness of data (Bekhet & Zauszniewski, 2012; Casey & Murphy, 2009). "QUAL1" was used to refer to the study (chapter four), "QUAN2" for study two (chapter five) and "QUAN3" for study three (chapter six).

7.2.1. Procedure

The strategies used to integrate the data responded mainly to a comparison model that included matching and expansion. The main purpose of the comparison is to examine how the two types of data (quantitative and qualitative) relate to each other (Fetters, 2019). Matching responds to an attempt to collect data from the same domain, constructs and ideas so that the information from both strands (qualitative and quantitative) can be compared and establish closely related findings (Fetters, 2019). The other strategy was expansion, which referred to broadening information on a specific topic (Greene et al., 1989). Hence, the results of the quantitative studies and the qualitative study were compared, looking for convergence (similarity or closeness of the results), divergence (in case the results do not coincide) and expansion (where the qualitative study will allow the expansion over a quantitative domain and vice versa).

The procedure for integrating the results aimed to achieve transferability and generalizability of the data. These aspects consider the participants' results in the study to take it to a broader population to understand better the phenomenon of interest, the context, or the theory (Creswell & Clark, 2017; Fetters, 2019). This concept is analogous to the generalisation of data in quantitative research or external validity (Hignett, 2016), which seeks to extend findings and conclusions through comparison with larger samples.

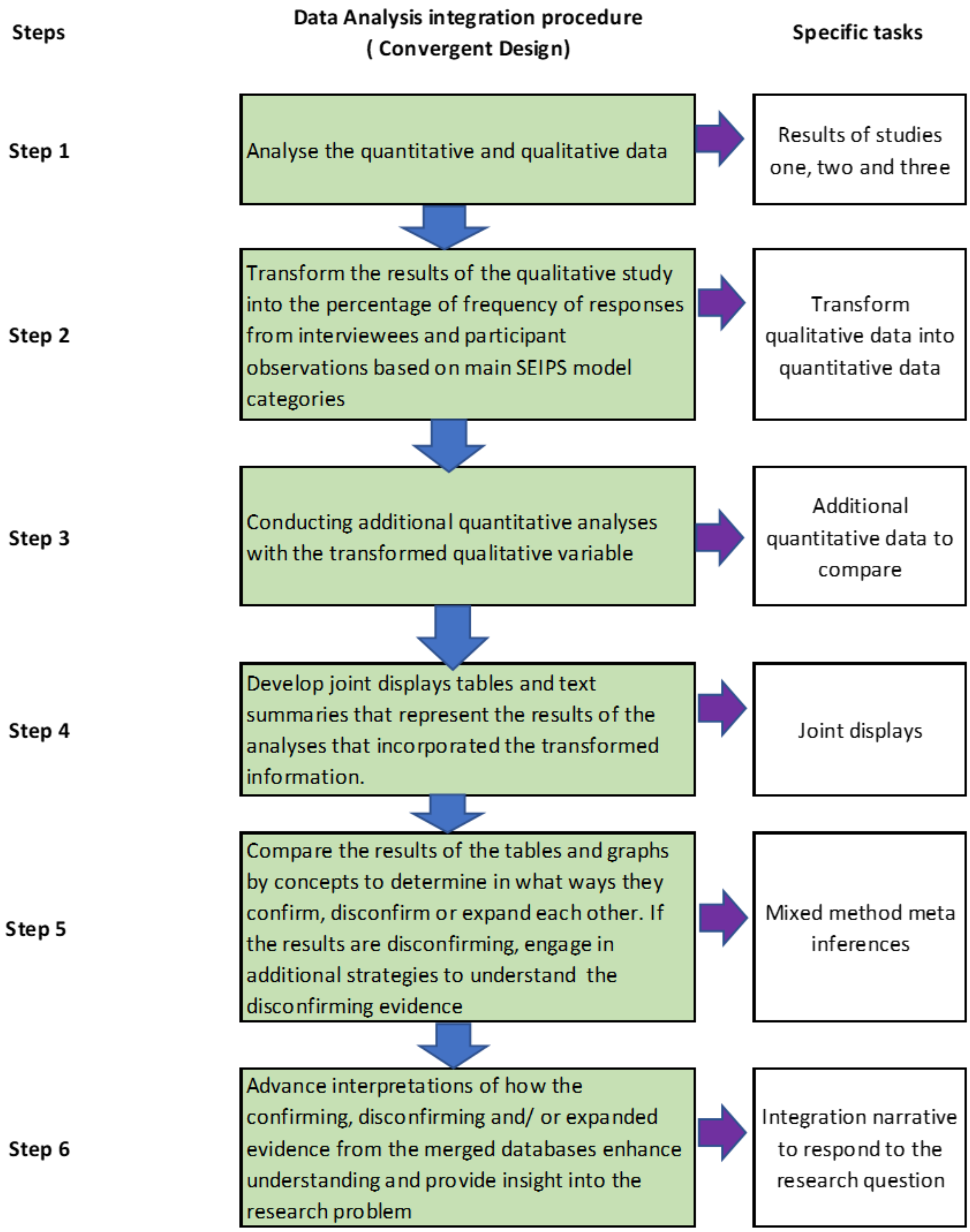
Primary data analysis integration procedure

The study compared the datasets by separating the results of the two strands of datasets, the qualitative (QUAL1) and two quantitative studies (QUAN2, QUAN3), using the classical joint display for mixed convergent designs (comparing in parallel). The theoretical scheme used to perform the comparison was the SEIPS model, so the central theme of comparison and organization of the data was based on this model. The detailed process is described in Figure 7.1.

The first stage to make data integration was by transforming the results of the QUAL1 dataset into quantitative data to establish priorities. Transformation of the data involved reducing the final factors to numerical information using dichotomous categories, i.e. indicating whether or not a factor described was present in each participant's testimonies. The quantification results were presented in total percentages of people where a particular factor was identified and ordered according to the categories of the SEIPS model. The next step was to create a joint display for convergent design in which one column had the results of the qualitative study (QUAL1), and another column had the results of the quantitative studies (QUAN2 and QUAN3). Finally, the results were compared and determined how the results converge, diverge or expand each other. This integration allowed to establish narratives that supported the answer to the research question.

Work interaction narrative

The "system story tool" suggested by Holden & Carayon (2021) was used to explain interactions among the SEIPS factors. This tool is a story frame or logical model that explains how the factors interact within a system according to the SEIPS model using a narrative argument. In this narrative, the dynamics of the main factors identified and how they impact the work process resulting in different outcomes affecting surgeons, assistants, patients, and the system, are described through a story.



Note. The author elaborated on this graph by adapting the procedure stated by Creswell & Clark (2017)

Figure 7.1 Procedure to integrate QUAL and QUAN results to respond to research questions

7.3. Results

The results of the data integration process were presented through Joint displays in order of priority according to the SEIPS model (see appendix 12.12). Table 7.1 represents a joint display that summarizes the studies' main convergences and knowledge expansion. The most frequent categories mentioned among the studies were ranked according to the structure of the SEIPS model.

The SEIPS categories where most surgeons and observations converged were mainly Tools and Technology, Tasks, and Persons, so the main risks were within those categories. However, this does not mean that the other factors are less important; on the contrary, they served as a basis for prioritizing and answering the research question and determining how these factors interact with each other and how they could have impacted each other. Thus, the most frequent factor was related to the technology and equipment used by the surgeons, emphasising issues related to operating table height regulation (Figure 7.2). Issues related to operating table height area contained in each SEIPS category were the main factor observed across surgeons.

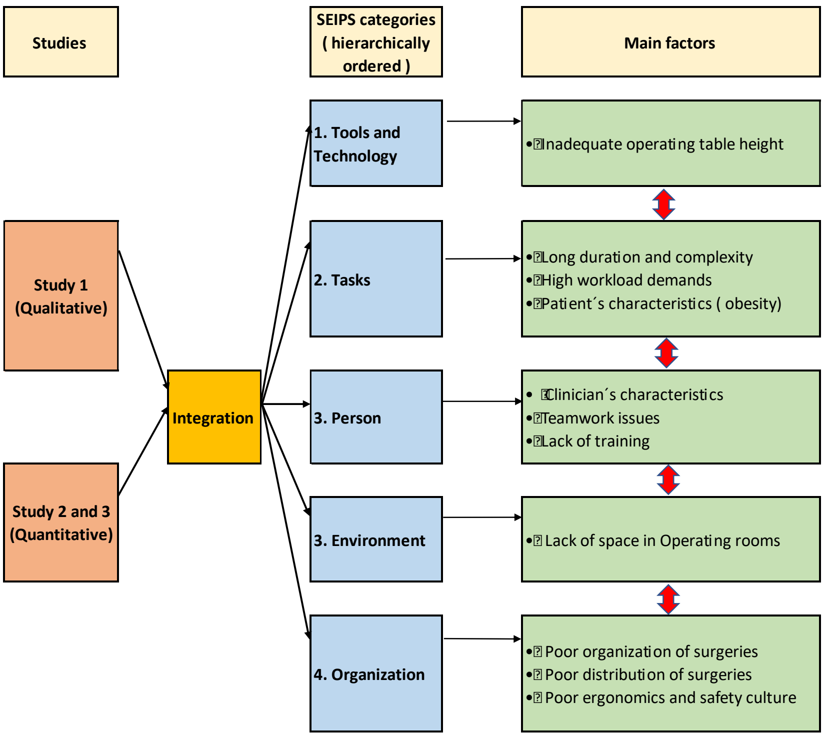


Figure 7.2 Main factors identified in the integration process

Table 7.1 Joint display with main convergences and expansion across studies

SEIPS CATEGORY (ordered)	Converge and expansion (QUAL1 , QUAN2 , QUAN3)
1. Tools and technology (QUAL1 = 92%) (QUAN2 = 87%)	✓ Inadequate operating table height was the most frequently reported factor associated with WRMDS in QUAN2 and QUAL1. QUAL1 and QUAN2 converge that problems related to inadequate equipment and poor tool design are top priorities for more than 50%. ✓ The WRMSD rates identified in QUAN2 were associated with operating table height issues ($p<0.05$) confirmed in QUAL1. ✓ The most frequent postures adopted by surgeons (QUAN3) converge with problems related to raised working heights and the manipulation of laparoscopic tools (QUAL1 and QUAN2). ✓ QUAL1 expanded knowledge of the operating table issues by including factors related to the lack of suitable equipment (surgical stools) and the poor state of equipment in operating rooms (broken tables) identified as the most contributing factors
2. Tasks (QUAL1 = 74%) (QUAN2 = 86%)	✓ WRMSD were highly associated with the duration and complexity of surgeries (QUAN2). It converged with testimonies and observations of QUAL1 and results of QUAN3. ✓ QUAL1 identified patient size as a factor that increases working height and risk of WRMSD. Surgeons also pointed out that obese patients can break the tools because of the fat mass in the abdomen. Also, the patient's size in QUAN2 was identified as a relevant contributing factor to WRMSD for 50% of surgeons. Bypass surgery (complex surgery) had a high risk of WRMSD (QUAN3 and QUAN2) ✓ QUAL1 described how challenging laparoscopic tasks are (camera conduction and intracorporeal suturing). Dissecting, cutting, intracorporeal suturing and camera conduction were associated with high postural risk when surgeons operating at current tables heights (QUAN3)
3. Person **(QUAL1 = 68%)** **(QUAN2 = 78%)**	✓ The women's short stature impacted their tools' working height and size (QUAL1 QUAN2 QUAN3). ✓ The mean stature of participants in QUAL1, QUAN2 and QUAN3 was similar ($p<0.005$), below the international population average and relatively higher than the Peruvian average. ✓ QUAN3 established that women surgeons had higher risk postures than men. QUAN1 also pointed out that anthropometric differences were a relevant factor when operating on patients (raised height of operating table) ✓ QUAL1 expands on the results of QUAN3 and QUAN2 by pointing out the problems that shorter surgeons have in surgeries, especially when working in teams with taller surgeons because they have to adjust the heights of the taller surgeons.

4. Internal Environment (QUAL1 = 68%) (QUAN2 = 68%)	✓ QUAL1 and QUAN 2 converged that factors related to the limited physical workplace were the most frequent factors. ✓ QUAL1 explained that limited space within the operating room forced surgeons to operate, adopting awkward postures and restricting their movements. QUAN3 found that the surgeon's position (lateral side) has a higher risk of WRMSD.
5. Organizational (QUAL1 = 46%) (QUAN2 = 70%)	✓ Lack of microbreaks during surgery was reported by almost 60% of surgeons in QUAN2, which QUAN3 and QUAL1 confirmed. During participant observations, there was no evidence of any microbreak during surgeries ✓ Surgeons indicated that shifts are sometimes poorly organized, forcing them to operate two complex surgeries, increasing fatigue and the risk of WRMSD (QUAL1 and QUAN3). This can also have consequences for patients (QUAL1). ✓ QUAL1 indicated that surgeons are not knowledgeable about ergonomics. QUAN2 indicated that although more than 70% of surgeons have no formal training, they are willing to receive it. Lack of training limits the possibility of improving workplace organization. The risk of awkward postures at an elevated table increases the risk of WRMSD.

Work system interaction factors by narrative review

The dynamics of the working system resulting from the integration analysis and the results of the laparoscopic surgery process are depicted using the SEIPS model as a basis in Figure 7.3. This figure configures how the main factors interrelate and impact patients and surgeons. A narrative was developed below to understand how the factors are interrelated and what outcomes they may have had on the work system.

The main factor related to the SEIPS category Technology that contributed to the development of WRMSD was "the inadequate operating table height". This factor converged with the results of all three studies and interacted with different factors identified.

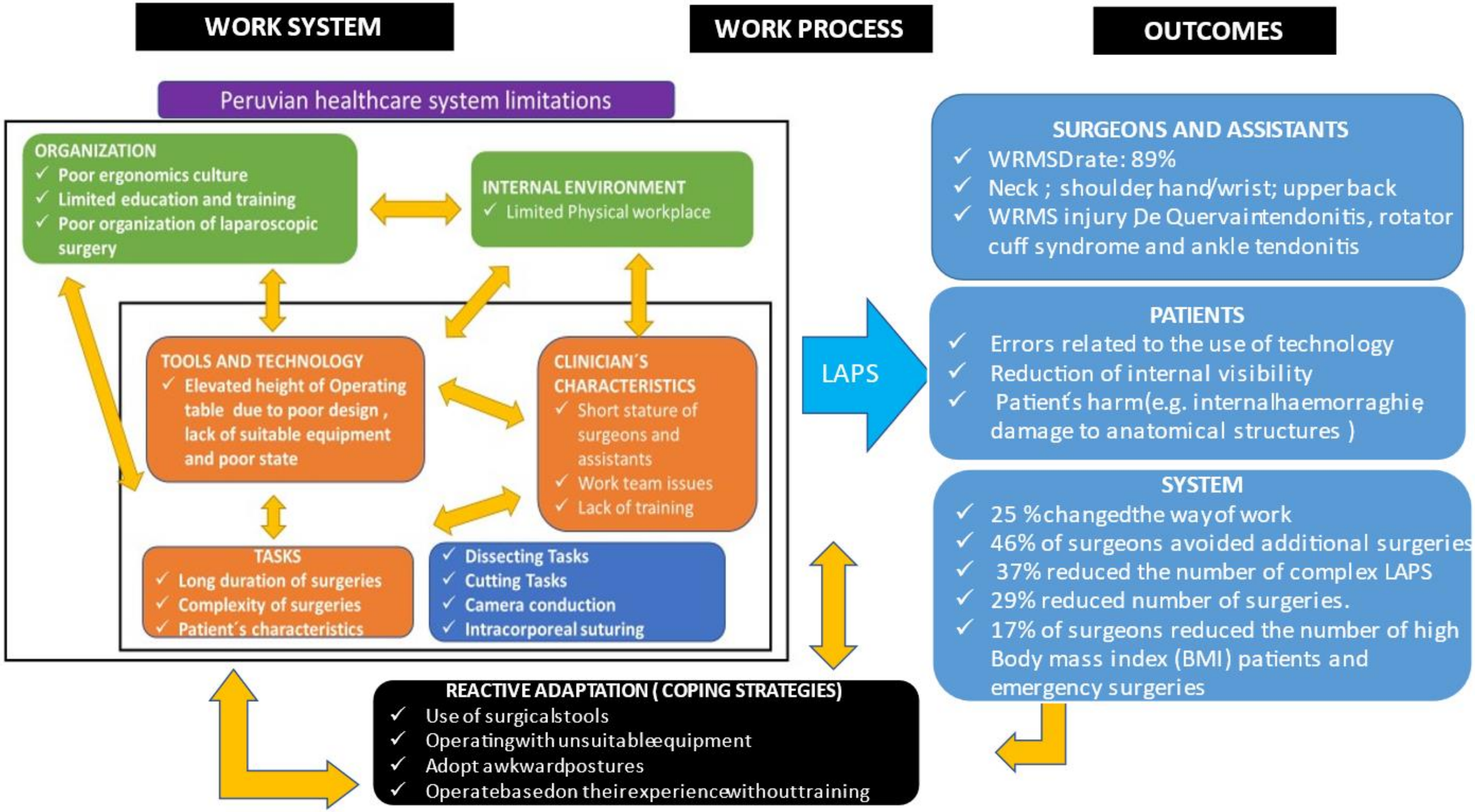


Figure 7.3 Final graphic as a result of the integration process based on the SEIPS model

Due to design constraints, operating tables in Peruvian operating rooms were limited in their adjustability. Yet, many were in poor condition and had a broken height adjustment system or damaged remote control to adjust heights. This meant that the height had to be adjusted in constraining ranges. While the operating table issues were a factor related to poor design and poor equipment condition, it was also related to the lack of suitable equipment. Thereby, the lack of surgical standing stools in the operating rooms was a factor that prevented surgeons from reaching the raised heights required to work on the operating tables, whose minimal adjustment was not sufficient to accommodate the surgeons. The surgical stools functioned as a reactive adaptation or coping strategy to reach raised working heights. On the other hand, the few operating rooms with surgical stools had limitations since the stool height was insufficient to reach the heights, and the surface space to keep standing was too small to place foot pedals, which created instability for the surgeon.

The operating table height issue was directly related to the factors identified with the second most frequent category, "Task". The elevated operating table height, coupled with operating on large and obese patients (patient's characteristics), further raised the working height, forcing surgeons to adopt awkward upper limb postures. Exposure to these postures was also affected when surgeries were of long duration and complex. This exposure increased the physical burden on surgeons because it contributed significantly to adopting awkward postures. Complex surgeries demanded surgeons to operate with more advanced surgical techniques involving laparoscopic tasks such as intracorporeal suturing, dissection and cutting (scissors and diathermic energy).

The short stature of the surgeons was an anthropometric factor that increased the risk of WRMSD because when interacting with raised operating tables and heights and operating on obese patients, they were at greater risk of adopting inappropriate postures. Furthermore, operating in teams with shorter surgeons increased the risk because assistant surgeons had to adjust to the height of the taller surgeon. In addition, women were at greater risk as they were shorter than men, but the short stature of Peruvians put both genders at risk.

Fatigue due to the raised working height caused trembling and difficulties for assistants when conducting cameras that did not allow them to focus correctly on the operative field. The camera assistants' task was high risk because they maintained static postures for extended periods holding the camera following the surgeon and pointing out the surgeon's field of vision inside the patient. Moreover, they had to follow the surgeons during the whole surgery, adopting forced and often restrictive postures to follow him. The working dynamics could be altered when the surgeons were of different statures and exposed to raised working heights.

The surgeons' lack of formal training in laparoscopic surgery and ergonomics interacted with the problems of working heights because many were unaware of the factors in the system and the possibilities of adopting more suitable postures using planned and anticipated adaptation strategies. In addition, the lack of training increased the possibility of errors and adverse events, which increased the length of surgery and the risk to the patient. The inexperience of surgeons was associated with more significant postural overload and the possibility of surgeon error.

The limited space in operating rooms forced surgeons to adopt working positions that could be restrictive. In addition, lack of space or disorganization within operating rooms could force surgeons to change their operating position. This factor also interacted with surgeons' and assistants' lack of formal ergonomic training because choosing an appropriate operating position requires formal training, not just experience.

Finally, the factors of the organizational category interacted indirectly with the other factors. Surgeons with knowledge of ergonomics were very few, and those who knew about ergonomics stated that applying ergonomic recommendations in laparoscopic surgery in Peruvian operating rooms was a significant challenge. The lack of specialized laparoscopic training centres and the lack of an ergonomic culture limited the training possibilities for surgeons and assistants. The main outcomes as a result of the interaction among system factors were summarized in Figure 7.3

7.4. Discussion

The integration of the results mainly established that inadequate operating table height was one of the factors that contributed most to the occurrence of WRMSD. This finding was even more prioritized than other relevant factors, such as the design of the laparoscopic tools, which was one of the prioritized factors in HICs (Lucas-Hernández et al., 2014; Park et al., 2010; Wauben et al., 2006). Therefore, these results differ in the level of priority concerning HICs and determine a relevant finding to guide the redesign of the Peruvian surgical system.

The integration study provided more detail about the factors that limited the possibility of reaching adequate heights. The lack of adequate equipment in operating rooms, such as surgical stool, was not a reasonable solution because the surface area and space were limited for working with foot pedals. Furthermore, the fixed height constrained short surgeons from reaching higher operating heights. Matern (2009) expanded on this point by stating that surgical stools created instability for the surgeons due to the poor support base and therefore endangered the patients. On the other hand, the table adjustment systems in several rooms were faulty and did not allow the tables to be adjusted to the desired heights, so surgeons had to settle for a fixed height or adjust them to safe heights. This shows the importance of working on periodic preventive maintenance of medical equipment, a safety policy not usual in Peruvian operating rooms (Defensoría del Pueblo, 2019).

The studies available in the literature addressing the issue of working heights and operating tables in laparoscopic surgery are few and limited. The studies that specifically addressed this issue are more than 20 years old since their last publication (Berquer et al., 2002; Matern et al., 2001; Van Veelen et al., 2002) and are still used today in clinical ergonomic guidelines for laparoscopic surgery (Rubin & Bettolli, 2009; Zachariou, 2019). This information gap and the limited availability of devices or systems demonstrate the low priority of HICs in addressing this issue.

Hignett et al. (2017) pointed out that operating laparoscopically on an obese patient is quite exhausting for a surgeon because of the increased working height and, thus the overload on upper body segments. However, if the surgeon were of short stature and had to operate on an obese patient, the risk could be much more significant, and the height requirements could be different. This was evidenced across studies where surgeries with obese patients were found to be more challenging for surgeons and assistants. Also, laparoscopic tasks require operating with various instruments with different deployment systems, which may alter the manipulation of the instrument at different working heights. This is consistent with Matern et al. (2001), that stated that the height requirements decrease when holding instruments with different handles

The SEIPS model states the importance of considering the person not as an individual user but as the individual or a set of individuals in a team with common goals, which are part of the process and the working system (Carayon et al., 2006; Holden et al., 2013). This lack of team vision has limited the recommendations to the surgeon, and there are no recommendations in the literature that guide the regulation of working heights in the surgical team, especially when working with the camera assistant. Study three identified that the risk of WRMSD of the surgeons was as significant as that of the assistants, and the camera conduction tasks proved to be the highest risk for the assistant. Thus, the data integration results allowed to delve deeper into this problem and make visible the importance of the assistant's tasks in laparoscopic surgery, an indispensable part of the work system.

Wiklund & Weinger (2011) stated that the anthropometric characteristics of the target population should be considered in the development of medical devices. The lack of anthropometric information available on the medical population limits the decision-making process for medical equipment design, and even more so when there are no anthropometric references on the general population, as is the case with the Peruvian population (Escobar-Galindo, 2020). An operating table will only be used by a specific occupational group, such as physicians and nursing staff, so setting general population criteria may lead to extreme measurement biases that are unnecessary for laparoscopic reality. It is necessary to carry out anthropometric studies of this occupational group to have more accurate data and establish appropriate recommendations.

Finally, limited space in many operating rooms can force surgeons to adopt positions that increase physical overload and thus trigger WRMSD (Worksafe, 2007). Overbooking surgeries were frequent in Peruvian operating rooms, increasing surgeons' exposure to WRMSD risk factors. For this reason, the redesign should consider mainly the relation between technology, person, and tasks and how internal factors such as organizational and internal environment can be controlled to reduce exposure to risk factors.

7.5. Key Summary

- The chapter responded to the research question by determining that the three previous studies converged with similar results revealing that Technology, Tasks, and People were the main categories based on SEIPS that increased the risk of WRMSD.

- The main factors that emerged from the studies were mainly the inadequate operating table height (Tools and Technology), complexity and duration of tasks, high workload demand of laparoscopic tasks and patient's characteristics (Tasks), clinicians' characteristics (Person), and lack of training (Person). Secondly, the lack of operating space (Environment), limited training opportunities, poor shift distribution, and poor ergonomics and safety culture (Organization).

- The emerged factors from QUAL1, QUAN2, and QUAN3 expanded the understanding of the factor dynamics in the work system and their interrelationships at different levels, converging findings and establishing divergences. When comparing the studies, many convergence areas and a few divergence areas were identified. This process supports the transferability of qualitative data and the process of generalisation by confirming the results of the studies and extending the results for better understanding.

Chapter 8. Study 4: Match analysis between operating table height and surgeons' anthropometrical characteristics in Peruvian hospitals

8.1. Introduction

The previous chapter integrated the results of QUAL and QUAN studies to respond comprehensively to the fourth research question concluding that the elevated height of the operating table was the main technology-related factor identified as a high contributor to WRMSD. Besides, the working height issues are interconnected with other work systems factors such as task, person, internal environment, and organization, raising the WRMSD risk (chapter 7).

As discussed in the literature review (chapter two), Peru is not a medical technology manufacturer, so the regulation systems of operating tables may not respond to the real needs of users. Also, the stature of Peruvians is one of the lowest in the region and the world (Escobar-Galindo, 2020), being complex to reach levels of adjustability sufficient to accommodate the majority of the population to the medical technology mainly designed and manufactured with standards from HICs (Hsiao et al., 2002). In the literature, few studies have investigated issues related to working height in laparoscopic surgery, apart from two studies carried out more than 20 years ago (Catanzarite et al., 2018; Madhu Shankar et al., 2017; Rubin & Bettolli, 2009; Sánchez-Margallo, 2017). One study was carried out by Berquer (2002), who set up the working surface height 10 cm below elbow height, whilst Van Veelen et al. (2002) suggested design as a proportion of the standing elbow height (0.7 and 0.8).

The previous chapter also explained that surgeons use surgical stools as a coping strategy to offset working heights, but it had limitations. Based on testimonies, the fixed height was insufficient to compensate for the high working height, especially for short surgeons. Also, the small stool space limited the positioning of the pedals on the surface, restricting the possibility of operating with diathermic energy. These issues are highly related to anthropometric characteristics of medical populations.

To set up an optimal match with current tables, designers aim to accommodate 90% of the population (Bridger, 2018a; Pheasant and Haslegrave, 2006b). However, the percentage of surgeons who could be affected by the raised heights of the operating tables is unknown. Also, the percentage of surgeons matching raised working heights is not precise when using stools, so possible recommendations to improve the redesign of the surgeon's workstation are unclear. These data could help search for possible solutions to regulate the working heights and know the magnitude of the problem to address possible design solutions.

Helander (2005) argued that it is necessary first to characterise the target population from an anthropometric analysis and then make precise recommendations to establish design references.

Thus, this chapter will respond to the fifth research question that is part of the second research aim:

RQ5: Are the height regulation levels of operating tables in Peruvian hospitals sufficient for the majority of surgeons when operating with laparoscopy?

8.1.1. Objectives

1. To estimate the anthropometrical characteristics of Peruvian physicians by establishing a reference of the medical population and emphasising measures related to working height design.
2. To calculate the percentage of surgeons that would match current operating table heights in Peruvian hospitals when surgeons operate on patients of different sizes and use surgical stools.
3. As a first reference, to recommend height adjustments based on the working heights necessary to accommodate 90% of surgeons.

8.2. Methods

To determine the percentage of surgeons that match with current working heights, the procedure for anthropometric design described by Helander (2005) was applied, following the method of limits (analogous to fitting trial) to determine the percentage of people that match a particular dimension (Castellucci et al., 2020; Pheasant and Haslegrave, 2006c). The process consisted of four steps (see Figure 8.1)

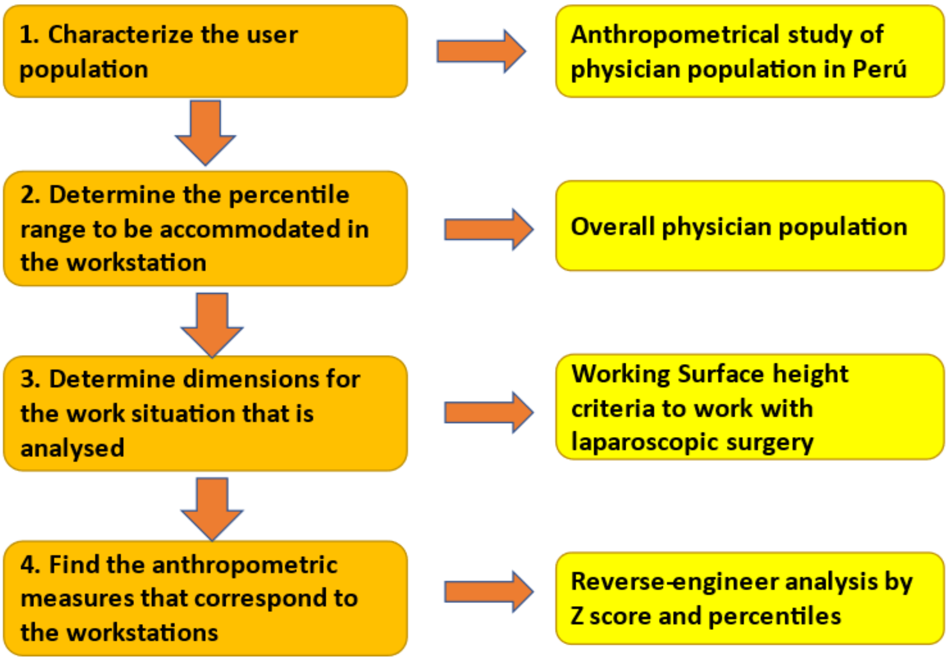


Figure 8.1 Four steps used to achieve the study aim

8.2.1. Characterise the user population.

Since there were no anthropometric tables available for the Peruvian population nor specifically for the medical population, the first step to respond research question was to determine anthropometric data of the medical population

8.2.1.1. Sampling and inclusion criteria

The sample size was determined following WHO recommendations and ISO 15535:2012, establishing a minimum of 200 individuals to be used as an anthropometric reference standard. This minimum ensures a 95% probability that the 95th and 5th percentile of the population will be calculated (Bridger, 2018; ISO, 2012; WHO, 1995). The study included physicians, surgeons, medical students of the last years and residents of medical specialities related to surgery in an age range of 25-65 years. Participants with deformities and disabilities or any physical state that could affect the nature of the data were excluded. Since stature is highly correlated to many anthropometric measures (Pheasant and Haslegrave, 2006c), it was used to compare and determine the representativeness of the sample compared with statures reported by surgeons in the survey carried out in study two (chapter five).

8.2.1.2. Technique

To collect anthropometric data, the direct manual measurement technique was used, which is the traditional, inexpensive and classical anthropometry broadly applied in several studies, especially in Latin America (Avila et al., 2007; Castellucci et al., 2019; Dianat et al., 2018; Estrada, 2001; Gutiérrez & Apud, 1992). For taking measurements, an anthropometer GPM SWISS 100 (type Holtain) calibrated with an error margin of +-1 mm, taking measures of the human body such as breadth, height, and length measurements. Anthropometric measures were taken by the researcher who had experience in Ergonomics and Anthropometry studies in collaboration with an assistant (resident in occupational medicine and/or student in occupational therapy) who had an active role as a notetaker.

8.2.1.3. Data collection procedures

Anthropometric measures selected for the study were related to working height and reach in laparoscopic surgery. The operational definition of every measure selected for the study was according to the recommendations of ISO 7250:1:2017 and Pheasant (2003)(see appendix 12.13). Measures were taken with the subject in a standing positioning with the gaze parallel to the flat ground (Frankfurt plane) with light clothing and without shoes. Shoulders were relaxed and hanging with elbows extended. Elbow height was measured with elbows at 90°. The body was positioned against a flat wall taking it as a plane of reference for horizontal measures. Abdominal Depth was calculated using the ratio scale method

(Pheasant and Haslegrave, 2006b), considering the stature of the general Peruvian population (Asgari et al., 2019). Measures were taken in two different environments, university classrooms and hospital rooms, with enough space to carry out the study without restriction (see appendix 12.16). After data collection, the data were analysed to eliminate errors related to typing or incorrect measurement.

8.2.1.4. Data Analysis of the anthropometrical study

The information was processed in Microsoft Excel spreadsheets and SPSS v.25 (SPSS Inc, Chicago, IL). To establish the normality of the data, the Kolmogorov - Smirnoff test (KS) was used for each variable (n>50). The accuracy of the data was determined through the standard error (se) of the mean to then determine the confidence intervals at 95% (Bridger, 2018a). It was calculated as follows:

$$1.96\ (se) \qquad (8.1)$$

Once the normality of the anthropometric data was determined, the following were calculated: the mean ($\overline{X}$), the standard deviation(SD) and the 5th, 50th and 95th percentiles since they are the most common parameters for ergonomic design (ISO 7250:3, 2015). To calculate the percentiles, the following formula was used:

$$Percentile\%(x) = \overline{X} \pm SD*Z \qquad (8.2)$$

(Z=1.64 for 95th and 5th percentile)

The abdominal Depth was projected by scaling the measure of Chilean anthropometrical charts on the general population because of the lack of these data for the Peruvian population (Castellucci et al., 2019). The ratio scale method was applied to scale this measurement using the Chilean anthropometrical charts, which were selected due to similarity in terms of geography and population, to avoid a high discrepancy in data (Pheasant and Haslegrave,2006b).

8.2.2. Determine the percentile range to be accommodated in the workstation.

Since laparoscopic surgery is performed by both male and female surgeons, the overall population (mixed population) data was selected to carry out the study.

8.2.2.1. Determine dimensions for the work situation that is analysed.

The main dimensions analysed were working height, working surface height, operating table height and patient's abdominal Depth.

8.2.2.2. Working height and working surface height in laparoscopic surgery

To determine the optimum working heights, it was necessary first to know the criteria for designing the working height in laparoscopic surgery. The working height (WH) was determined by the reference point of the hand (HARP)(Helander, 2005b), which was located on the handles of laparoscopic tools.

The anthropometric reference used to define this height was the standing elbow height (EH) of the overall physician population. The main reference to determine the working height was the working surface height (WSH), which included the operating table height, the patient's abdomen depth and laparoscopic tools (tools and trocars). The working surface height in laparoscopic surgery was defined as the sum of the table surface height (TSH) plus the height of the patient's sagittal abdominal Depth (SAD) plus six centimetres of the insufflation process to make pneumoperitoneum (Pick et al., 2004).

The reference to define TSH was the surface of the operating table, so it was used as a synonym for operating table height (Figure 8.2).

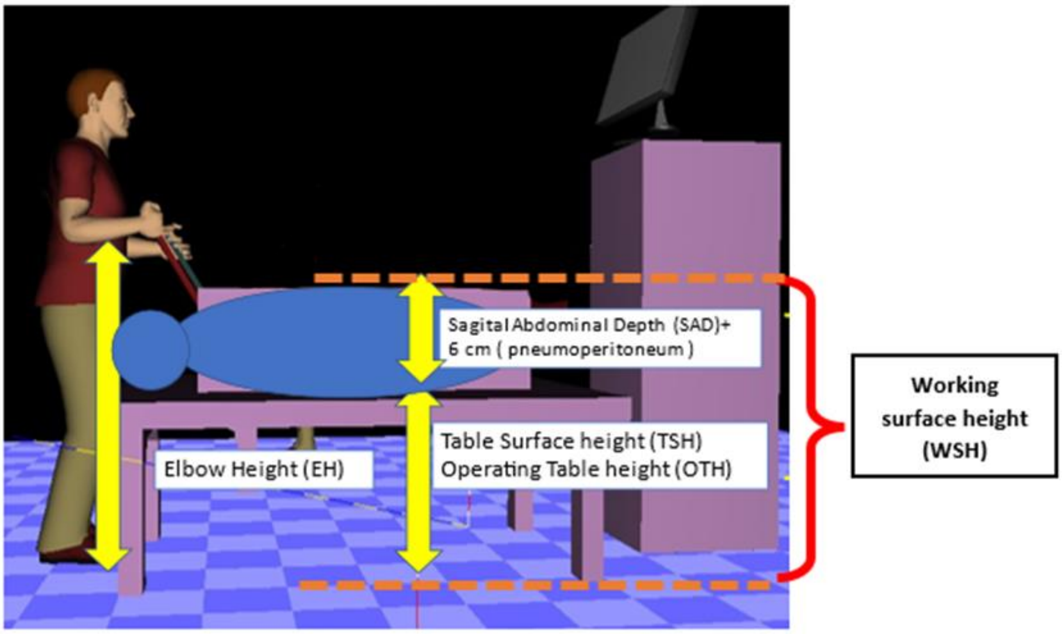


Figure 8.2 Working surface height and working height in laparoscopic surgery

8.2.2.3. Operating table height

Operating tables selected for the analysis were determined based on observations made in four Peruvian hospitals (developed during study one), identifying seven different models (see Figure 8.3). The models were grouped according to the similarity in their characteristics and regulation ranges, reducing to five operating tables used for the analysis (see Table 8.1). The technical specifications of each table were corroborated with the technical information of manufacturing companies available on their respective web pages.

Standard Surgical stool in Peruvian operating rooms (20 cm height)

Figure 8.3 Operating tables with brands and surgical stool with minimal heights in Peruvian hospitals

Table 8.1 Operating table considered for the study and height characteristics

Code	**Operating table brand**	**Height range (minimum, maximum)**
Table A	Medland_Amax	78-122
Table B	Saturn Trumpf	76-122
Table C	Alpha Maquet	74-116
Table D	Steris-Amsco ; Barfaab 683	73-117
Table E	Merivara-Promerix;Berchtold	70-120

8.2.2.4. Sagittal abdominal Depth of patients (SAD)

The SAD was used as a reference to determine the WSH. The measurements were extracted from the anthropometric table for the general population and represented three different types of patients: 5th percentile (thin patient), 50th percentile (average patient), and 99th percentile (obese patient) (see Table 8.2). The percentile 99th was calculated by the percentile formula previously explained.

Table 8.2 Sagittal Abdominal Depth height used for the study

Patient's characteristics	Anthropometric measure	Final measure(rounded)*
Obese patient (99th percentile)	35.4	41
Average patient (50th percentile)	26.2	32
Thin patient (5th percentile)	19.6	26

Note. Measures in centimetres(cm).* Anthropometric measure + 6 cm of pneumoperitoneum

8.2.3. Find the anthropometric measures that correspond to the workstations

Since the WH depends on the object being manipulated, tools employed, and nature of the task being performed, the optimum working height will depend on an appropriate WSH. To determine the WSH, the two most recurrent recommendations from current clinical guides in laparoscopic surgery were used, the Berguer and Van Veelen criteria (Berquer et al., 2002; Van Veelen et al., 2002) described as follows:

a) Berguer Criteria: WSH should be located 10 cm below the users' standing elbows height (WSH= EH -10 cm+SC),
b) Van Veelen Criteria: the working height is the result of a proportion of the elbow height (WSH= EH * 0.7+SC or WSH=EH * 0.8+SC)

*SC=shoes correction (2.5 cm)

As a reference, the shoe correction applied was 2.5 cm (Pheasant and Haslegrave, 2006c). Then, the ideal surgeons' EH was calculated to match WHS, so formulas were exchanged (see table 8.3).

Table 8.3 Formulas used to determine the working surface height

	Working surface height	Elbow height of users
Berguer criteria (Berquer et al., 2002)	WSH = EH-10 cm +SC	EH = WSH+10 cm -SC
Van Veelen	WSH = EH*0.8+SC	EH=WSH/0.8-SC
(Van Veelen et al., 2002)	WSH = EH*0.7+SC	EH=WSH/0.7-SC

8.2.4. Calculate percentiles in the normal distribution of elbow height

To assess the match level with the current working heights, a bivariate analysis was carried out between the stature and standing elbow height because of the necessity to have two measures for the analysis (Castellucci et al., 2019; Pheasant and Haslegrave, 2006c; Robinette, 1998). Because operating tables had a regulation system, the bivariate analysis was performed with the two extreme measures: the lowest and highest regulation height. These heights could vary depending on the characteristics and design of operating tables.

To calculate how many people matched with the working surface height, reverse-engineer analysis was applied using the Z score distribution. Z scores allowed determination for which percentile a measure was specifically designed. The Z score or Z distribution allowed measurement of standard deviations above or below the population means, thus determining the measure's position in the normal distribution. The value of Z score was obtained from the following equation

$$Z \text{ score} = (x - \overline{X}) / SD \qquad (8.3)$$

Where $\overline{X}$ es the mean of the measure (EH); X is the compared mean, and SD is the standard deviation of the measure

8.2.5. Determine the percentage of surgeons that match on current Working surface height

The EH equivalences of the lowest and highest WSH were converted into percentiles using conversion tables automatically calculated with Microsoft Excel©TM. Finally, the highest and lowest percentile values of the distribution were subtracted to obtain the percentage of people who matched the normal distribution of surgeons' EH (Figure 8.4 illustrates the process). Ellipses graphs represented the matching level as bivariate analysis (Robinette, 1998) using EH and the stature of the overall physician population. The criteria to determine an acceptable level of accommodation in the population was 90% (Bridger, 2018a; Pheasant and Haslegrave, 2006d)

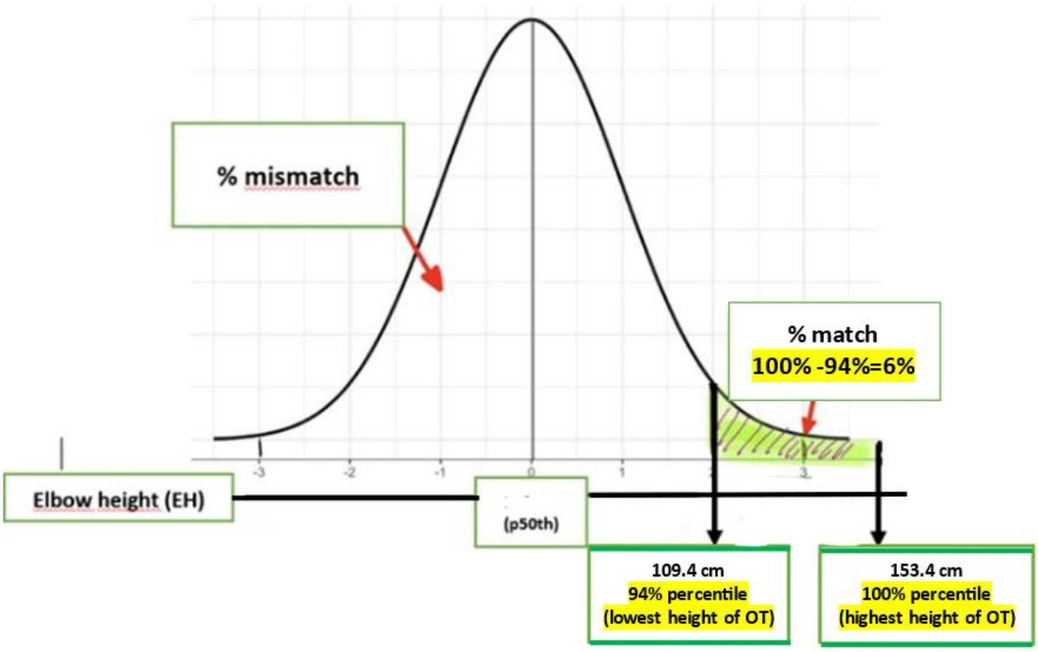


Figure 8.4 Example of analysis to determine the percentage of surgeons who match with current Working surface height

8.2.6. Research ethics consideration

The study protocol and data collection method (see appendix 12.24) were approved by the Faculty of Engineering Ethics Committee at the University of Nottingham. Before collecting information, participants were informed about the research and signed informed consent.

8.3. Results

8.3.1. Anthropometrical study of medical population

A total of 211 participants took part in the study, of which 101 were women and 110 were men. The mean age of participants was 28 years (SD=7.6), distributed mainly in a group of < 30 years (n=173; 82%). The sample comprised of medical students, residents (n=192;91%) and physicians (n=19; 9%). The main place of birth of participants was Lima city (n=130;61.6%), and more than one third from regions of Peru (n=82; 38.9%), not only concentrating participants from Lima but also from different regions (see Table 8.4).

Table 8.4 Characteristics of participants in the anthropometrical study

General characteristics	n	(%)
Gender		
Male	111	52.6
Female	101	47.9
Place of birth		
Lima	130	61.6
Out from Lima	82	38.9
Participant		
Resident and medicine students	192	91.0
Physician	19	9.0
Age		
> =30 years	39	18.5
< 30 years	173	82.0

The number of people recruited for the study was sufficient to obtain low levels of standard error (<1.3), which allowed for greater accuracy to calculate percentiles (see Table 8.5). In addition, with the standard error, it was possible to report the 95% confidence intervals, i.e. the probability that the population mean is in a specific range with 95% certainty.

Table 8.5 Accuracy of anthropometric data and confidence interval

	Anthropometric dimension	Accuracy	CI 95%
1	Stature (ST)*	1.2	163.1-164.2
2	Eye height (EyH)*	1.1	152.0-154.3
3	Shoulder height (SH)*	1.0	135.3-137.4
4	Elbow height (EH)*	0.8	100.6-102.2
5	Umbilicus height (UH)*	0.9	96.8-98.6
6	Knuckle height (KH)*	0.7	73.5-74.8
7	Grip Reach (GR)*	0.7	69.0-70.3
8	Elbow grip reach (EgR)*	0.4	35.1-35.8

Note. KS test (p>0.05; normal distributed)*

Compared with the survey carried out in study two, where surgeons self-reported their statures, there was no statistical difference in the results of the survey (M=166.9; SD=6.7) and the sample of the present study (M=164.2, SD=5.7; p>0.05), so it can be assumed that the anthropometric table account for the Peruvian surgeon population (see Figure 8.5).

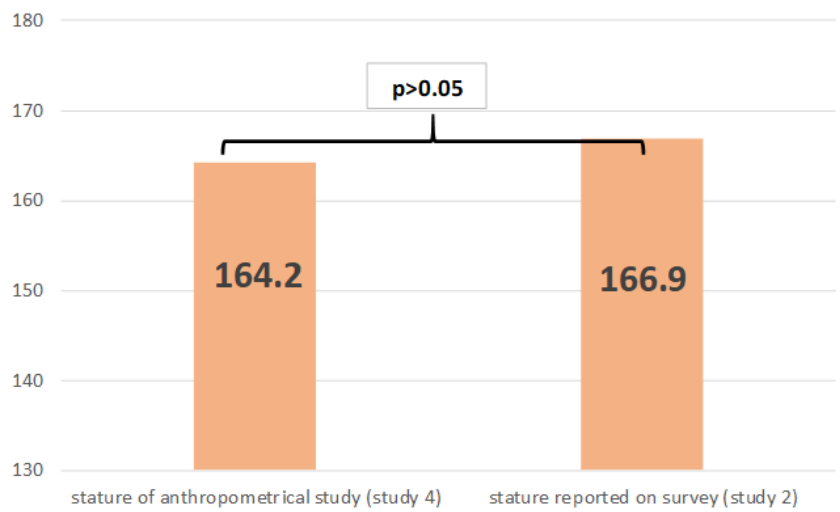


Figure 8.5 Stature differences between study 2 and study 4

Table 8.6 sets out the final chart with nine anthropometrics measures divided into the overall physician population, male and female population (as a reference). The abdominal depth measure was calculated from the general population, not specifically from the medical population.

The mean stature of the sample was 164.2 cm (8.8), with percentiles ranging from 151.1 cm (p5th) to 178.3 cm (p95th). By gender, the mean stature of the male physician was 170.0 cm (SD=6.7), and for females, 158.1 cm (SD=5.7). Thus, on average, the male surgeon population was 12 cm taller than female surgeons. The stature, shoulder and eye height represented measures with a high standard deviation (7.7 to 8.8), followed by elbow height, umbilicus, and knuckle height (5.2 to 6.2). The measure of umbilicus height (M=97.6; SD=6.5) and elbow height (M=101.4; SD=6.5) differed on 3.8 cm being statistically different ($t_{(210)}$ =15.9; p=0.001). All the anthropometric measures correlated with stature ($r>0.7$; $p<0.05$).

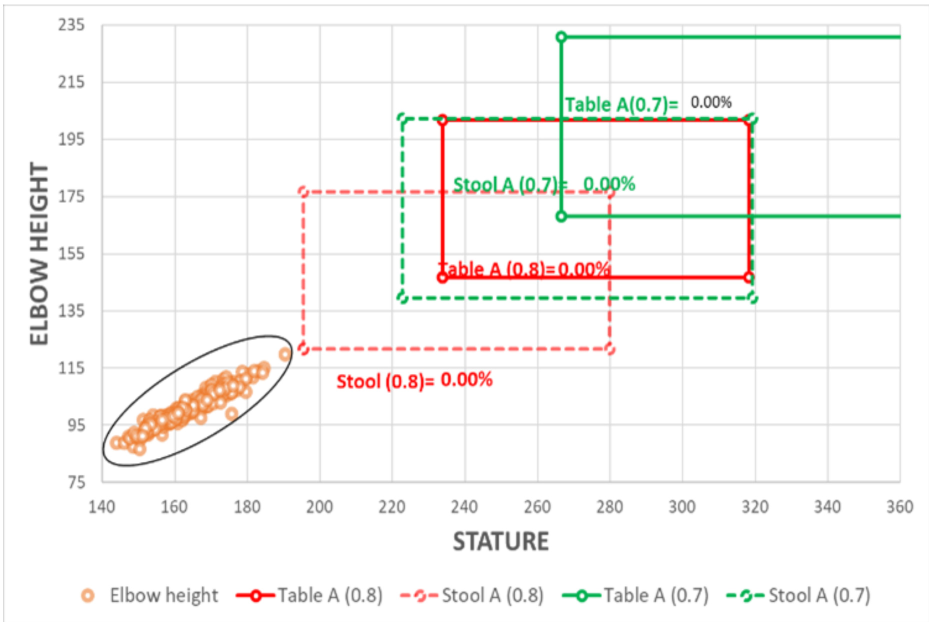
8.3.2. Match analysis

Figures 8.6, 8.7, and 8.8 account for matching percentages of surgeons plotted in ellipses graphs. The elbow height and stature data were presented in a bivariate graph of the overall population (raw data); the rectangles were drawn to represent the maximum and minimum system regulation of operating table heights, including SAD. Dotted rectangles account for the height that surgeons would reach when using a surgical stool (20 cm height) with the final correction to elbow height. As observed, the percentages of acceptability were variable with both criteria. However, none of the situations reached 90%. None of the operating tables assessed would have enough adjustment range to accommodate the working surface at a suitable height, especially when operating an obese patient (0% acceptance).

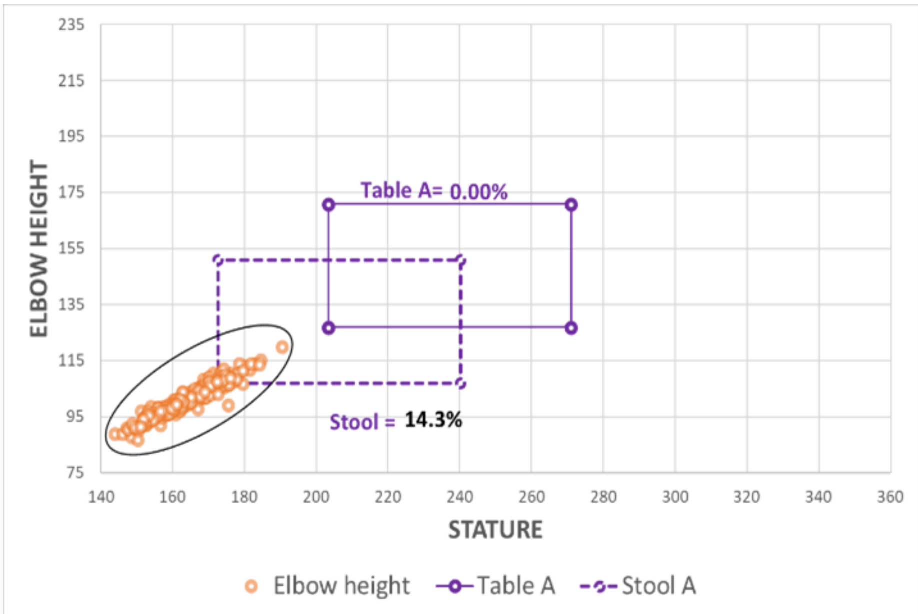
Table 8.6 Anthropometrical dimensions of Peruvian physicians

		Overall physician sample (mixed) (n=211)					Male physician sample (n=110)					Female physician sample (N=101)				
				Percentiles					Percentiles					Percentiles		
		Mean	SD	P5	P50	P95	Mean	SD	P5	P50	P95	Mean	SD	P5	P50	P95
1	Stature	164.2	8.8	151.1	163.5	178.3	170.0	6.7	159.7	170.0	181.6	158.1	5.7	148.6	158.0	168.7
2	Eye height	153.2	8.5	140.1	152.5	166.6	158.8	6.5	147.9	159.4	169.6	147.2	5.6	138.5	147.2	157.6
3	Shoulder height	136.4	7.7	124.6	136.0	147.7	141.3	5.9	131.8	141.5	151.2	131.1	5.1	122.6	130.5	139.0
4	Elbow height	101.4	6.0	91.9	101.0	111.3	105.2	4.8	97.7	105.6	113.6	97.3	4.1	90.6	97.0	104.3
5	Umbilicus height	97.7	6.6	86.9	97.5	108.3	101.1	5.5	92.6	101.5	109.8	94.0	5.4	85.1	94.2	102.4
6	Knuckle height	74.2	5.2	67.2	73.0	78.0	76.9	4.7	70.1	76.5	84.1	71.1	3.6	65.3	71.2	77.9
7	Grip Reach	69.7	4.9	62.3	69.8	77.8	72.5	4.2	64.8	73.0	79.4	66.7	3.2	62.0	66.0	72.9
8	Elbow grip reach	35.4	2.8	31.0	35.2	40.0	37.1	2.4	33.3	37.0	40.4	33.7	1.9	30.6	34.0	37.0
9	Abdominal Depth	25.7	3.7	19.6	25.7	31.8	25.8	4.0	19.2	25.8	32.4	25.6	3.7	19.6	25.6	31.7

Note. KS (p>0.05) normal distribution. Measures in centimetres



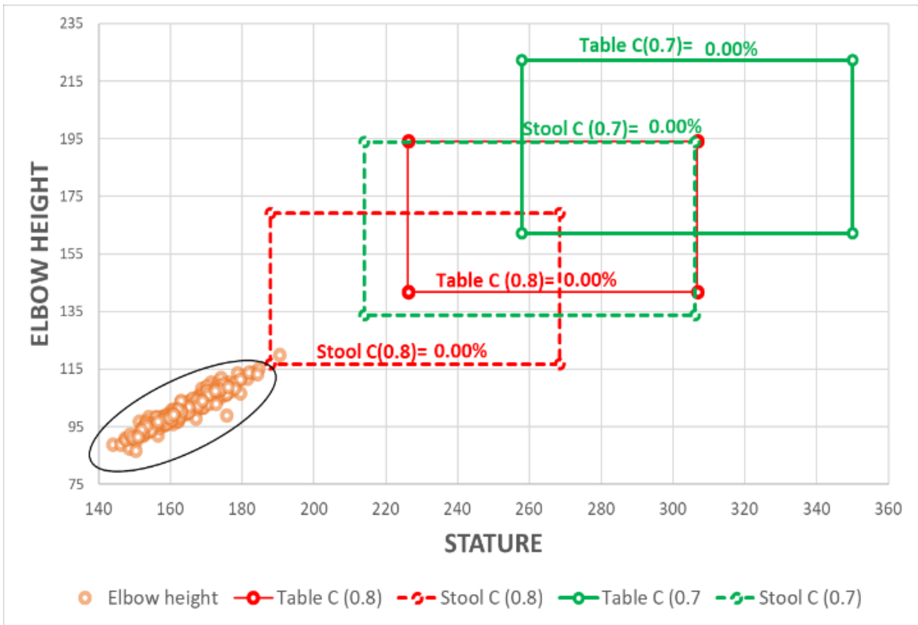
Van veelen Criteria (EH*0.8 ; EH*0.7)-red and green



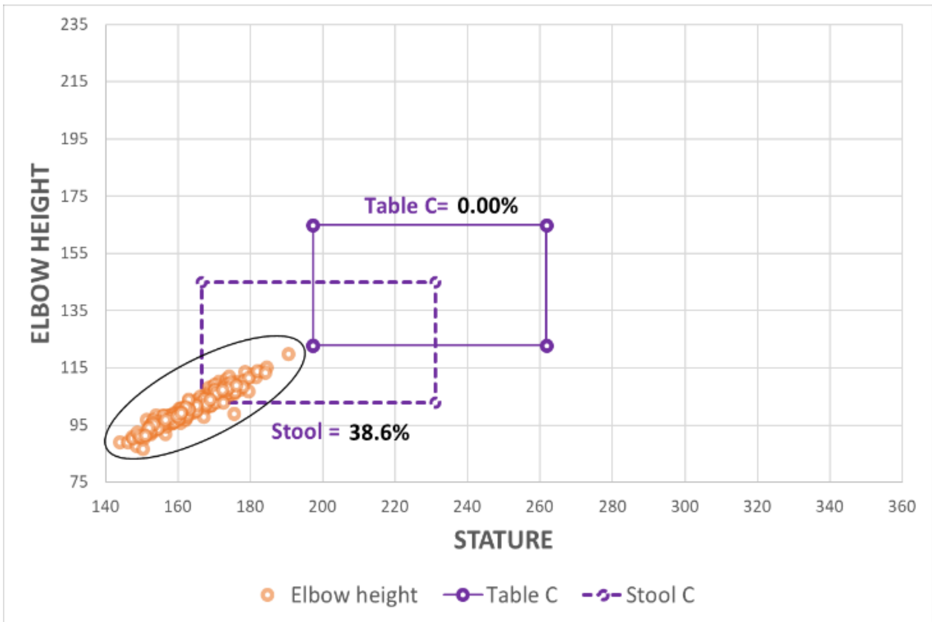
Berguer Criteria (EH-10) -purple

Operating Table (A) 78-122 cm

Figure 8.6(a) Ellipses graph that represents the percentage of surgeons that fit with three different working heights (TABLE A)while operating on obese patients (continue)



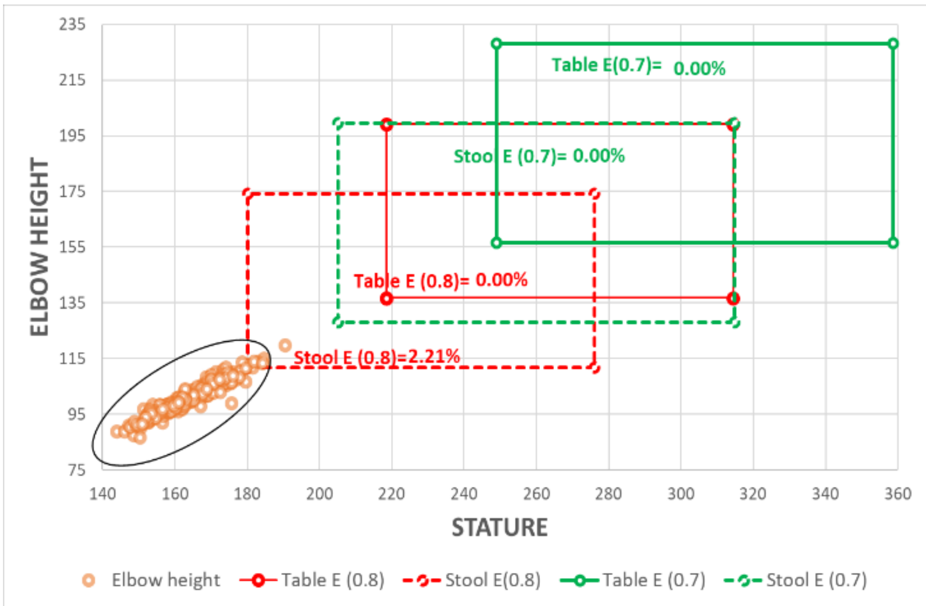
Van veelen Criteria (EH*0.8 ; EH*0.7)-red and green



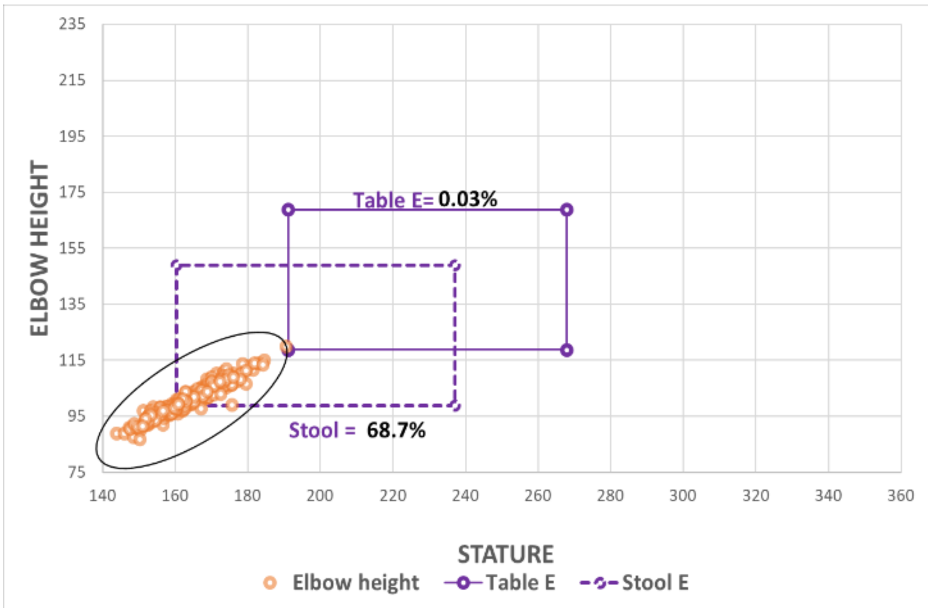
Berguer Criteria (EH-10) -purple

Operating Table (C) 74-116 cm

Figure 8.6(b) Ellipses graph that represents the percentage of surgeons that fit with three different working heights (Table C) while operating obese patients (continue)



Van veelen Criteria (EH*0.8 ; EH*0.7)-green



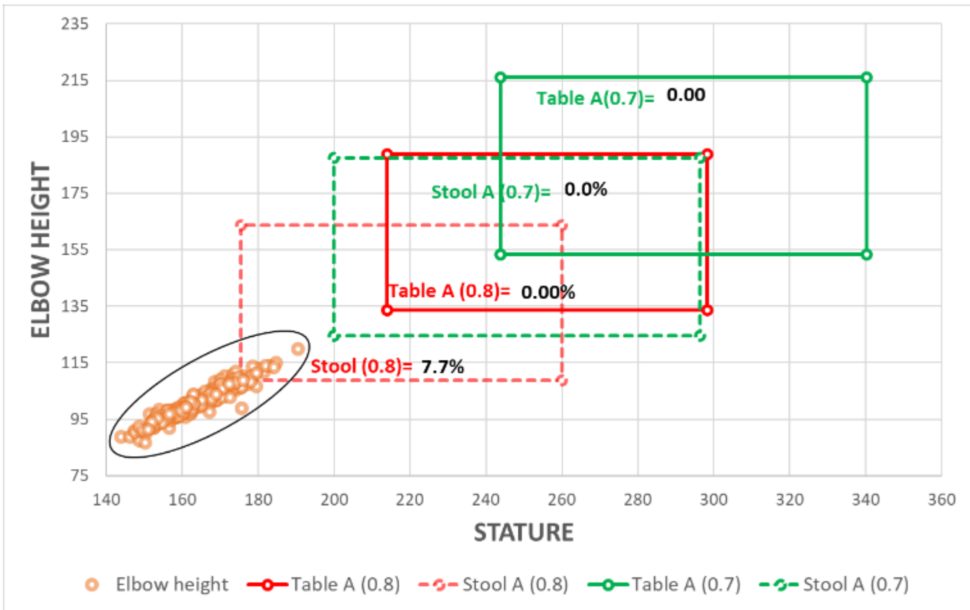
Berguer Criteria (EH-10) -purple

Operating Table (E) 70-120 cm

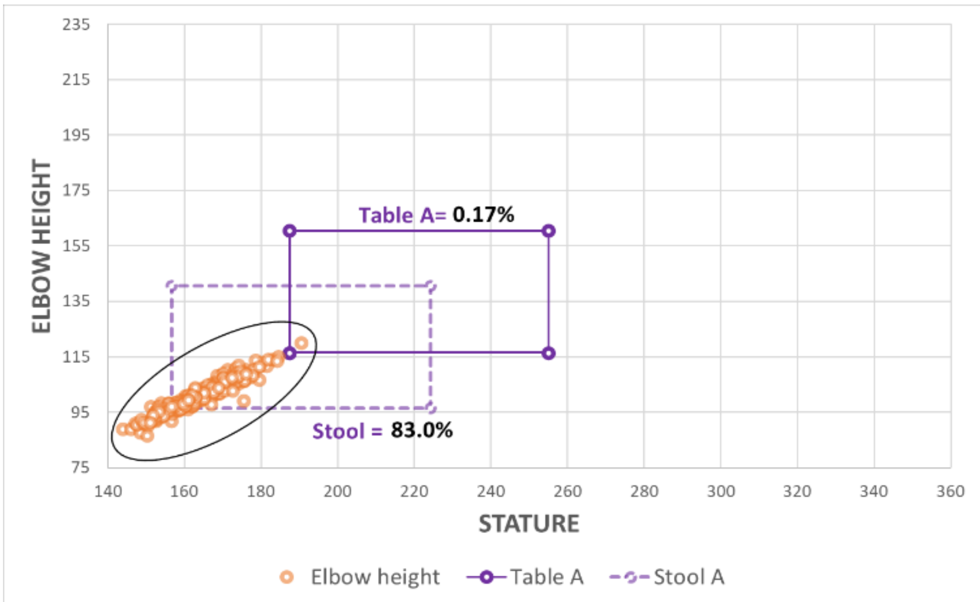
Note. Van Veelen criteria to determine working height (green = EH*0.7 ; green dotted line= EH*0.7 +20 cm of stool ; red line= EH*0.8 ; red dotted line=EH*0.8+ 20 cm of stool).

Berguer Criteria (purple line= EH-10 ; purple dotted line=EH-10 + 20 cm of stool)

Figure 8.6(c) Ellipses graph that represents the percentage of surgeons that fit with three different working heights (TABLE E) while operating obese patients



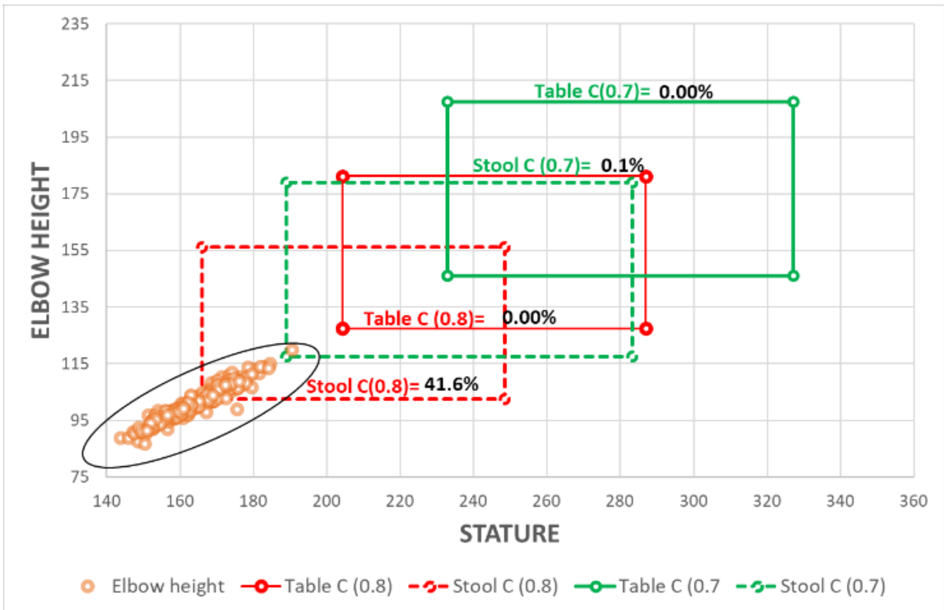
Van veelen Criteria (EH*0.8 ; EH*0.7)-green



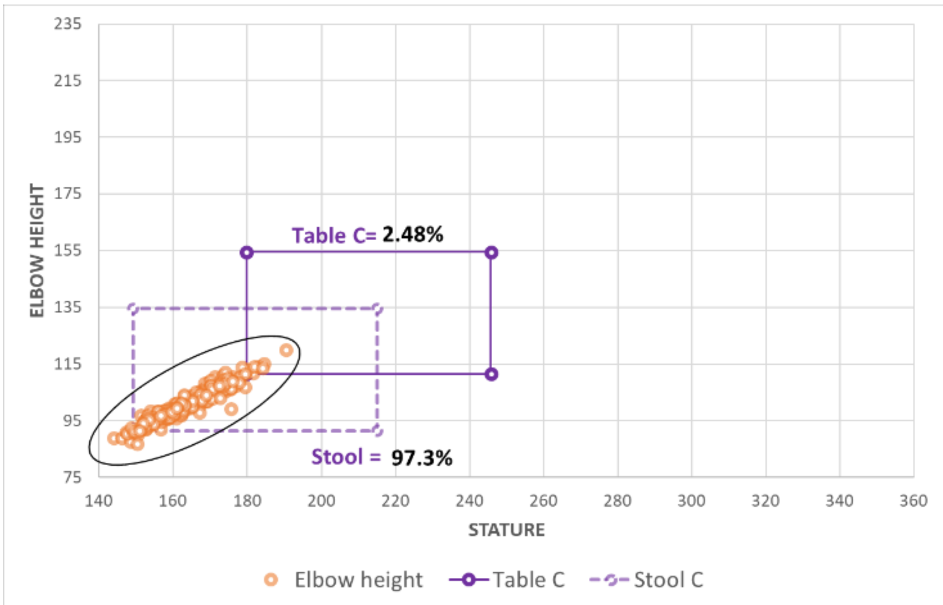
Berguer Criteria (EH-10) -purple

Operating Table (A) 78-122 cm

Figure 8.7(a) Ellipses graph that represents the percentage of surgeons that fit with three different operating table heights (Table A) while operating an average patient *(continue)*



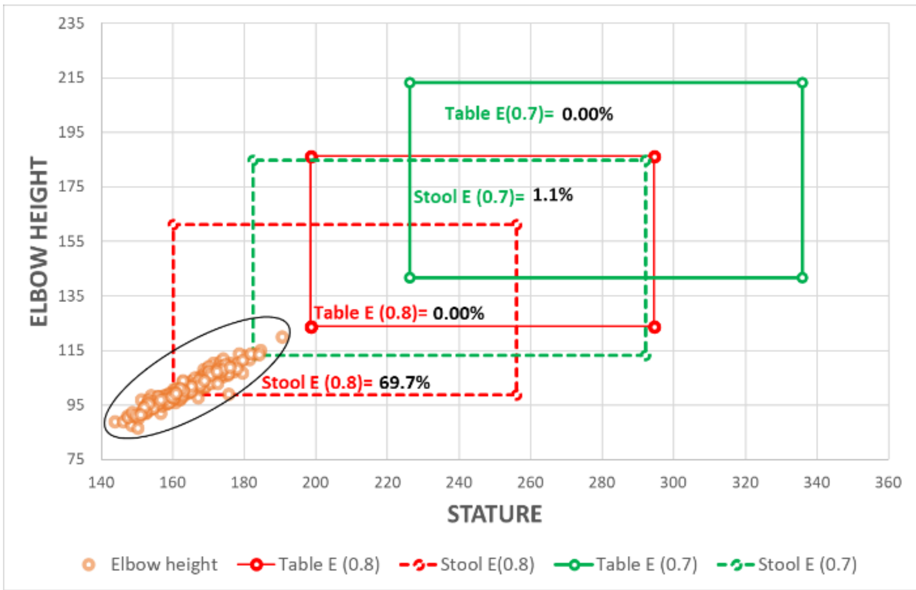
Van veelen Criteria (EH*0.8 ; EH*0.7)-green



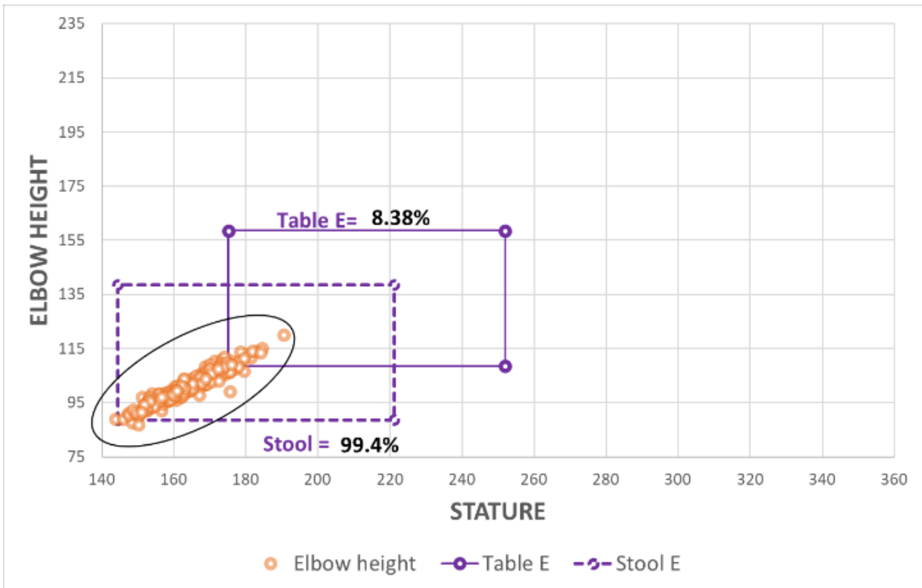
Berguer Criteria (EH-10) -purple

Operating Table (C) 74-116 cm

Figure 8.7(b) Ellipses graph that represents the percentage of surgeons that fit with three different operating table heights(Table C) while operating an average patient Continue)



Vann veelen Criteria (EH*0.8 ; EH*0.7)-green

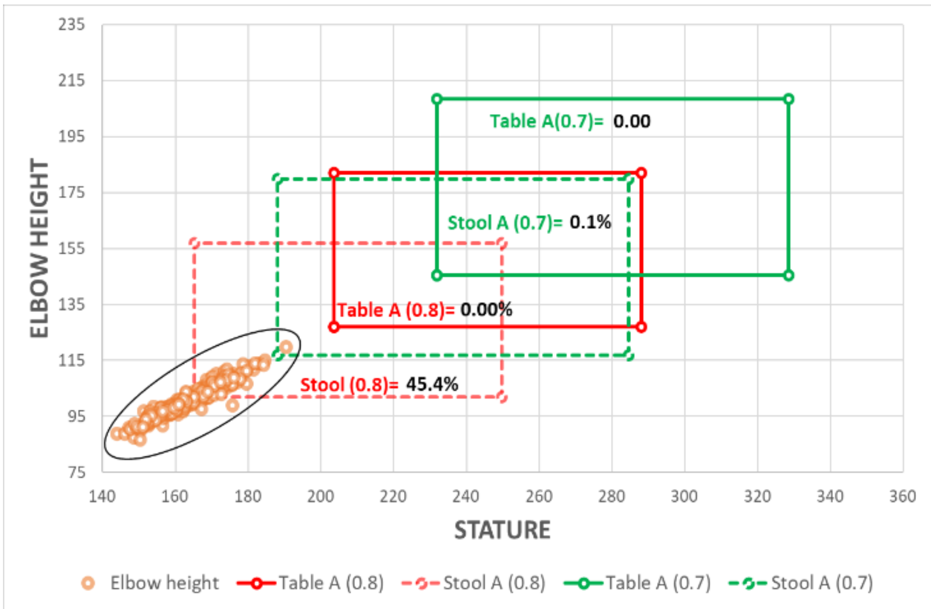


Berguer Criteria (EH-10) -purple

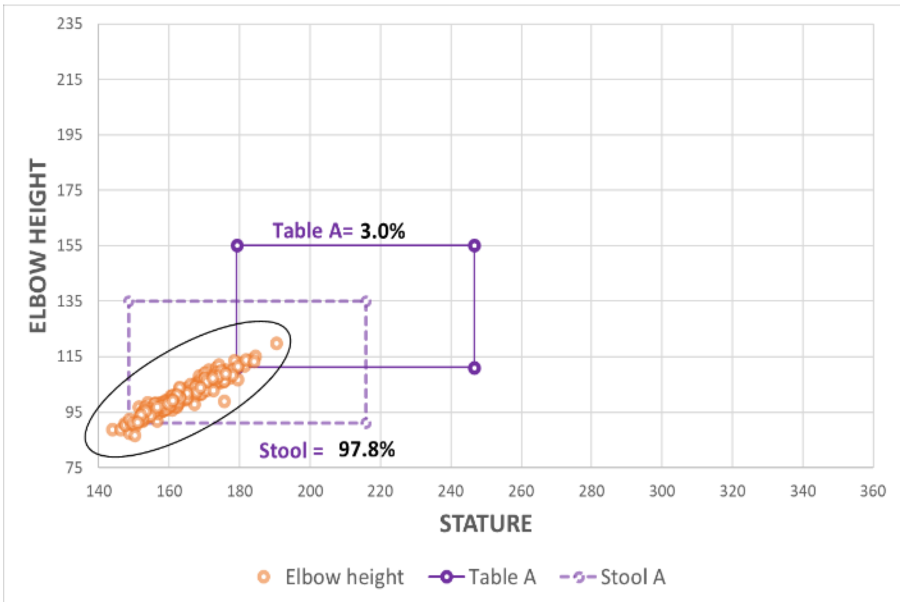
Operating Table (E) 70-120 cm

Note. Van Veelen criteria to determine working height (green = EH*0.7 ; green dotted line= EH*0.7 +20 cm of stool ; red line= EH*0.8 ; red dotted line=EH*0.8+ 20 cm of stool). Berguer Criteria (purple line= EH-10 ; purple dotted line=EH-10 + 20 cm of stool)

Figure 8.7(c) Ellipses graph that represents the percentage of surgeons that fit with three different operating table heights (Table E) while operating an average patient



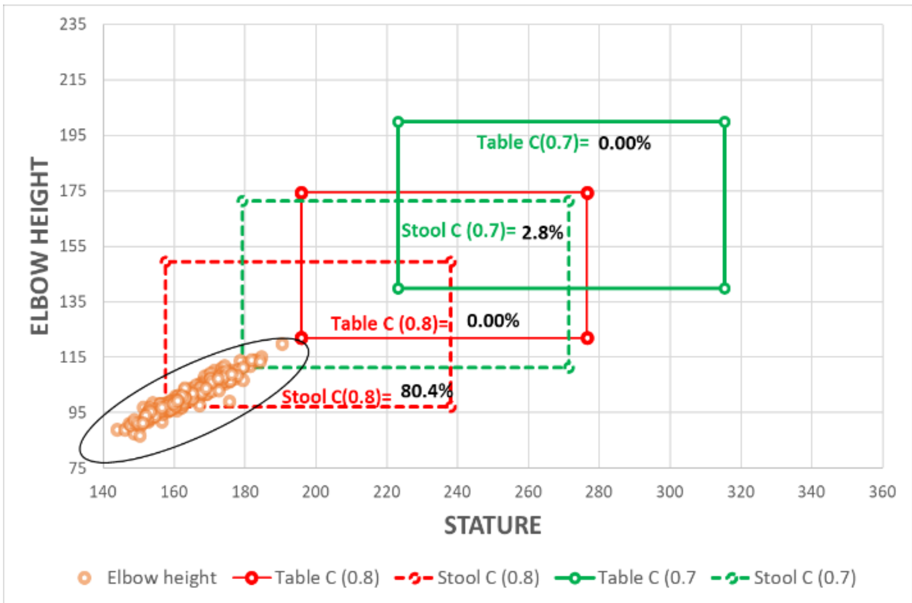
Vann veelen Criteria (EH*0.8 ; EH*0.7)-green



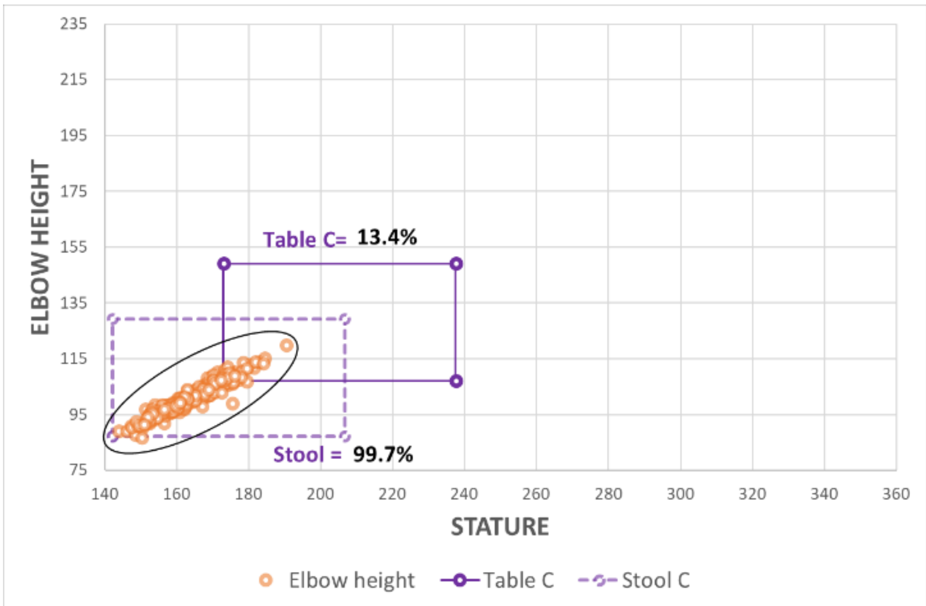
Berguer Criteria (EH-10) -purple

Operating table (A) 78-122 cm

Figure 8.8(a) Ellipses graph that represents the percentage of surgeons that fit with three different operating table heights (Table A) while operating a thin patient in the lowest percentile *(continue)*



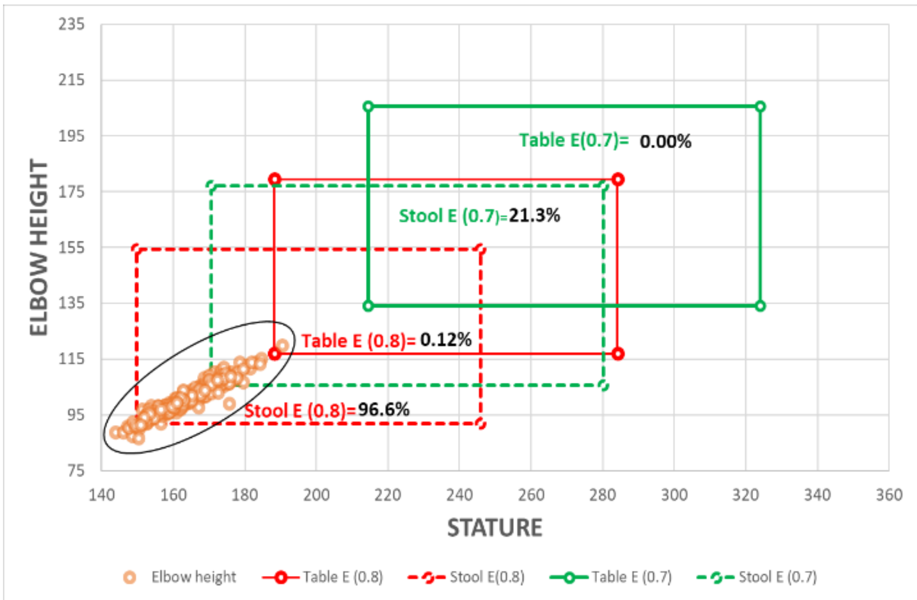
Vann veelen Criteria (EH*0.8 ; EH*0.7)-green



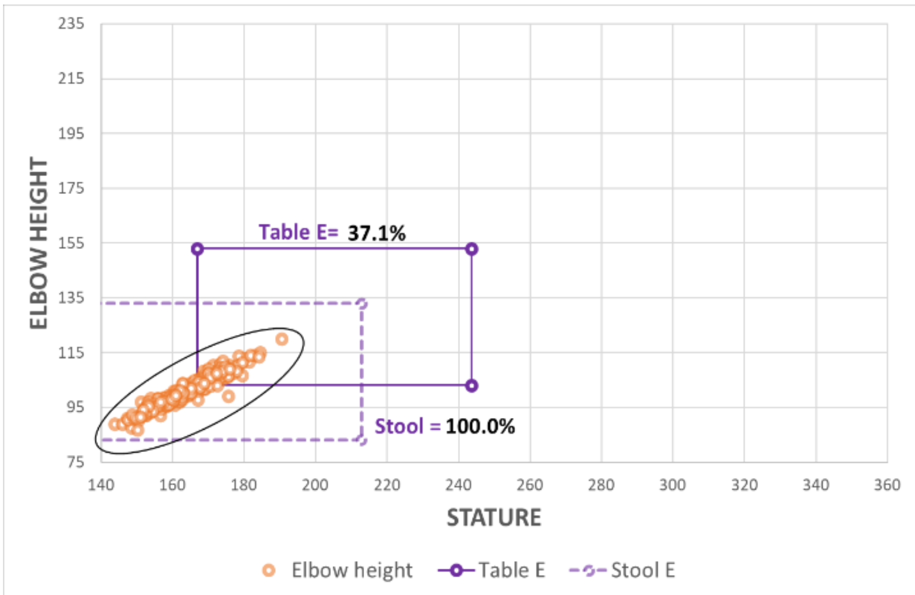
Berguer Criteria (EH-10) -purple

Operating table (C) 74-116 cm

Figure 8.8 (b) Ellipses graph that represents the percentage of surgeons that fit with three different operating tables (Table C) heights while operating a thin patient in the lowest percentile(continue)



Vann veelen Criteria (EH*0.8 ; EH*0.7)-green



Berguer Criteria (EH-10) -purple

Operating table (E) 70-120 cm

Note. Van Veelen criteria to determine working height (green = EH*0.7 ; green dotted line= EH*0.7 +20 cm of stool ; red line= EH*0.8 ; red dotted line=EH*0.8+ 20 cm of stool). Berguer Criteria (purple line= EH-10 ; purple dotted line=EH-10 + 20 cm of stool)

Figure 8.8 (c) Ellipses graph that represents the percentage of surgeons that fit with three different operating table (Table E) heights while operating a thin patient in the lowest percentile

The summary of the percentage of surgeons that match current operating table heights with and without surgical stools is presented in Table 8.7

Applying Van Veelen's criteria, no operating table would have sufficient adjustment to reach an acceptable working height. With Berguer's criteria, an operating table with a minimum height adjustment of 70 cm (Table E) and thin patient SAD (percentile 5th) could accommodate 37.1% of surgeons, being less than half of the population

If surgeons use a surgical stool of 20 cm, the match percentage improves, depending on table height and patient. When using Van Veelen's criteria to operate on an obese patient, only 2.2% of surgeons would match with a minimum operating table height (70-120 cm), whilst with Berguer's criteria, up to 68.7% of surgeons (see Figure 8.6c). When working with the highest operating table (78 - 122cm table), with Van Veelen's criteria, no surgeon would match, but with Berguer's criteria, 14.3% could match with a 20 cm height stool support.

Depending on the criteria, the heights would be sufficient to accommodate a large number of the population when operating an average patient and using surgical stools. With the Van Veelen criterion, 69.7% of surgeons could match the lowest operating table height (70-120 cm), whilst with Berguer's criteria, 99.4% (Figure 8.7c). Using Berguer's criteria could accommodate 91% of surgeons operating an average patient on an operating table with 76 to 116 cm height. In comparison, Van Veelen's criteria indicate that only 17.3% could be accommodated.

With Van Veelen's criteria, when a thin patient is operated on, the match level is much higher, reaching up to 86% of acceptability on an operating table with a height of 73-117 cm and exceeding 95% on the lowest height (70-120 cm). In contrast, Berguer's criteria would exceed 95% accommodation in all operating tables. In all cases, the maximum operating table height adjustability would match with a percentile 100th surgeons' elbow height. Van Veelen's criteria differ enormously from Berguer, so the results must be taken cautiously. The best match levels were achieved when was used the 0.8 criteria.

Table 8.7. Percentage of surgeons that fit with current operating tables with and without using a surgical stool

Operating table and WH criteria	Percentage of fit			Percentage of fit with surgical stool (20 cm)		
	Obese (p99th)	Average (p50th)	Thin (p5th)	Obese (p99th)	Average (p50th)	Thin (p5th)
Table A (78-122 cm)						
VV (0.8)	0.0%	0.0%	0.0%	0.0%	7.7%	45.4%
VV(0.7)	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
BG	0.0%	0.2%	3.0%	14.3%	83.0%	**97.8%**
Table B (76-116 cm)						
VV (0.8)	0.0%	0.0%	0.0%	0.0%	17.3%	64.5%
VV(0.7)	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%
BG	0.0%	0.5%	6.7%	24.8%	**91.0%**	**99.2%**
Table C (74-116 cm)						
VV (0.8)	0.0%	0.0%	0.0%	0.1%	41.6%	80.4%
VV(0.7)	0.0%	0.0%	0.0%	0.0%	0.1%	2.8%
BG	0.0%	2.5%	13.4%	38.6%	**97.3%**	**99.7%**
Table D (73-117 cm)						
VV (0.8)	0.0%	0.0%	0.0%	0.3%	41.6%	86.4%
VV(0.7)	0.0%	0.0%	0.0%	0.0%	0.1%	5.2%
BG	0.0%	2.5%	18.1%	46.2%	**97.3%**	**99.9%**
Table E (70-120 cm)						
VV (0.8)	0.00%	0.00%	0.10%	2.20%	69.70%	**96.60%**
VV(0.7)	0.00%	0.00%	0.00%	0.00%	1.10%	21.30%
BG	0.00%	8.40%	37.10%	68.70%	**99.40%**	**100.00%**

Note. VV = Van veelen Criteria EH*0.7 and EH*0.8 ; BG =Berguer criteria ; bold (>90% fit)

Table 8.8 sets out the recommended operating table height deeming patients SAD based on the percentiles of the overall medical population. Following the Berguer criteria, the minimum height that demands a percentile 5th surgeon to operate on an obese patient is 43.4 cm, whilst a percentile 95th surgeon to operate on a thin patient is 77.8 cm. On the other hand, Van Veelen's criteria may change depending on the multiplier factor. The minimum height of a percentile 5th surgeon to operate on an obese patient by multiplying 0.7 by elbow height is 25.8 cm. A percentile 95th surgeon to operate a thin patient multiplying 0.8 to elbow height is 65.5 cm. Finally, based on both criteria, we may conclude that a minimum of 26cm and a maximum of 78 cm would be necessary to include the majority of surgeons.

Table 8.8 Recommendations to adjust the operating table height to reach an acceptable working surface height

	Operating table height		Regulation span
Recommendation	**Thin (5th)**	**Obese (99th)**	**(rounded)**
Berguer			
percentile 5th	58.4	**43.4**	43 - 78
percentile 95th	**77.8**	62.8	
Van Veelen (0.7)			
percentile 5th	40.8	**25.8**	26 - 54
percentile 95th	**54.4**	39.41	
Van Veelen (0.8)			
percentile 5th	50.0	**35.0**	35 - 66
percentile 95th	**65.5**	50.54	

Note. Bold and orange: minimum and maximum value; values in centimetres (cm)

8.4. Discussion

The present study covered a relevant gap in understanding how current operating tables, initially designed for open surgery, were not manufactured to reach a suitable working height to operate with the laparoscopic technique. In addition, the study contributed relevant anthropometric information about the medical population, which will be helpful for future design purposes.

The first part consisted of an anthropometrical study to characterise the Peruvian medical population since the lack of information available. A total of 211 subjects participated in the study, reaching the recommended minimal validated sample size to represent a population (Bridger, 2008; WHO, 1995). No statistical difference was observed between the stature of the study participants and the self-reported sample of surgeons carried out in study two (N = 140), so the sample is considered to be a good representation of the population of Peruvian surgeons. The mean stature of the sample was surprisingly higher than other Peruvian references (Asgari et al., 2019; Escobar-Galindo, 2020), where the only measure detailed was stature. Male and female surgeons were taller by about 4.1 and 4.7 cm, respectively (Asgari et al., 2019; CENAN, 2014).

Since the operating table is used by male and female surgeons indistinctively, the analysis was based on a mixed population (Castellucci et al., 2020; Pheasant and Haslegrave, 2006c) (studies 1 and 2). However, the comparative analysis with mixed populations (overall population data) is more complex due to the lack of availability of mixed anthropometric charts, which required specific formulas to make comparisons (Castellucci et al., 2020; Pheasant and Haslegrave, 2006b). As a result, the mean of the mixed Peruvian population was calculated at 160 cm (Escobar-Galindo, 2020), while the study determined 164.2cm, being higher than the overall population.

However, the Peruvian population is significantly shorter than HICs, where medical equipment is manufactured. For instance, the mean stature of the North American mixed population is 170 cm and Dutch 174.3 cm (ISO, 2012; Pheasant, 2003). These populations exceed the Peruvian physician population by 6cm and more than 10cm for the overall population, which explains the mismatch with operating tables height. These differences may be attributed to several factors such as birth, age even occupation, or social status (Botha & Bridger, 1998; Hsiao et al., 2002).

Several anthropometric measures identified high dispersion levels (SD>5), such as eye height, shoulder height and elbow height, similar to other studies reported in the literature (Apud, 1997; Castellucci et al., 2019; Pheasant, 2003). These dispersions should be understood as possible difficulties in matching equipment to the population's physical characteristics. For instance, the physician population's elbow height had a standard deviation of 6cm, so a higher adjustment of the working surface height would be necessary to achieve optimal height for Peruvian physicians.

An essential contribution of the study was the development of an anthropometric standard database specifically on the Peruvian physician population, which will facilitate the possible development of future specialised designs addressed for this particular occupational group. The possible use of the ratio scale will be helpful to analyse other populations in Latin America (Botha & Bridger, 1998; Kroemer, 2020; Pheasant and Haslegrave, 2006b).

The match percentage of surgeons with current operating tables reached barely 37.1% when operating a thin patient on a table with a minimum height of 70 cm. Nevertheless, no surgeons could be accommodated when the Van Veelen criteria were used to regulate heights. These results confirmed findings of previous studies where the surgeon's posture was affected due to the elevated height of operating tables, considered to be a high contributing factor to WRMSD. Main awkward postures resulting from elevated working heights were broadly described in study three (chapter six), concluding that laparoscopic surgery has a high risk of WRMSD.

As a reference, current guides recommend a minimum operating table height of 29 cm to operate on an obese patient with a surgeon in the percentile 5^{th} (Van Veelen et al., 2002), while the Peruvian population demands a much lower height reaching up to 26 cm (Van Veelen's criteria). This difference psychophysically may be perceived by humans as a significant difference (Helander, 2005b). On the other hand, when using Berguer's criteria, the recommended height should be 43 cm, higher than the other criteria but similarly complicated to implement in real surgeries since limitations on regulations systems of operating tables. Other studies recommended a range of 29 to 70 cm (Matern et al., 2001). Despite the discrepancies, the guidelines still recommend regulating the tables according to these criteria, which puts surgeons and patients at risk. Therefore, these results show that the problem has not yet been solved and that LMICs are the most affected. This lack of interest in the HICs may be because laparoscopic surgery has evolved over time and now has new challenges, such as robotic surgery (Armijo et al., 2018).

Based on the study, operating tables in Peruvian operating rooms had a minimum height of 70 cm and a maximum of 122 cm. Also, many of them were damaged, reducing the range of adjustability, and being impossible to regulate to recommended heights (chapter seven). The NHS published a buyer's guide that compared different operating tables across ten manufacturers in the UK, finding that the minimum height across brands was 65 cm, which was not enough to accommodate the population (Clift et al., 2011; NHS, 2009). Wauben et al. (2006) determined after applying a survey to 284 surgeons from the Netherland that 70% of surgeons preferred the table to be lowered more, even when they are the highest population in the world. However, is it possible to design a new operating table with these height recommendations?

Surgeons and assistants commonly use surgical stools to offset greater heights. The study showed that 20 cm in height surgical stools would accommodate a significant percentage of surgeons, especially when using Berguer's criteria. With a table height of 76 cm and operating on an average patient, more than 90% of surgeons could fit the working surface height, while Van Veelen's criteria only fit such a range of the population with a table height of 70 cm. Hence, both criteria can fit the population when surgeons use a stool of 20 cm with a table height of 70 cm operating on a thin patient. However, to operate on an obese patient, a stool of 20 cm would not be sufficient. Following the recommendations, the stools should have a maximum height adjustment of 52 cm (Van Veelen criteria) or 35 cm (Berguer criteria) to operate on an obese patient with a minimum table height of 78 cm (the most extreme situation). However, available stools in Peruvian hospitals have a fixed height that reaches a maximum of 20 cm. Other higher stools available in the market may reach up to 43 cm but demand use handrail and two steps being quite large to be used in small spaces and limited to use with foot pedals.

8.4.1. Study limitation

Recommendations and percentages of surgeons´matching with work surface height using two criteria differ broadly, especially in the Van Veelen criteria, in which surgeons did not fit in any situation, whilst Berguer criteria reached up to 37.1%. However, the results are probably not realistic since they were obtained with static models. This situation can be even more complex considering that different factors specific to the laparoscopic work system may affect the performance of surgeries (chapter 7).

Another relevant aspect was if the camera assistant would need a specific height different from surgeons since the surgery demand teamwork. So, current criteria would not explain if working heights should be shared or designed individually depending on the role assumed during surgery (camera assistant or surgeon). If we analyse both criteria for design, they only assessed one task with one type of tool (e.g. shaft handle), testing only the performance during a task in a specific situation without giving surgeons the freedom to choose based on their experience. Further studies should encompass task performance to determine working heights among surgeons.

In this study, the method of limits was used as a first approximation; however, a fitting trial could give a more precise scope on the working height needs of surgeons in laparoscopy. The subsequent study should contemplate the anthropometry of people and the anthropometry-independent effects, such as preferences and comfort (Dianat et al., 2018; Molenbroek et al., 2011). Besides, the study should include work system factors identified in the previous chapter, improving the design proposals, especially if they are made in simulation environments closer to the surgical work system.

8.5. Key Summary

- Anthropometry measures of Peruvian physician populations were higher (164.4.cm) than the overall Peruvian population (160.0 cm) but lower than other HICs where medical equipment is imported, such as the USA (170.0 cm) and The Netherland (174.4 cm).

- No operating table available in Peruvian hospitals nor in the market would be suitable for 90% of Peruvian surgeons. The tables were too high to accommodate surgeons with optimal working surface height to perform laparoscopic surgery.

- The Peruvian population demands a minimum operating table height of 26 cm for a mixed population, resulting in a discrepancy of 3 cm in the minimum height adjustment regards current guides. These recommendations could be impractical for application in operating table design since other system factors, such as surgical tools or tasks, should be considered.

- Surgical stools (20 cm height) may accommodate 90% of surgeons operating on an average patient on a table height of 76 cm (Berguer's criteria) and 70 cm (Van Veelen's criteria). However, to operate on obese patients, a stool of 20 cm would not be sufficient.

- The design criteria for working surface heights currently used in the literature have methodological limitations since they only represent a specific task and focus on analysing physical factors.

- Since there are limitations of current criteria to determine suitable working surface heights, it is necessary to conduct psychophysical studies using fitting trials that reflect the surgeons' preferences, taking into account work system factors to give more realistic and accurate design recommendations.

Chapter 9. Study 5: Remote fitting trial to determine recommendations for designing operating table heights in laparoscopic surgery

9.1. Introduction

The previous chapter determined that a high percentage of surgeons would not match with current operating tables by anthropometric analysis. This match level reached 0% when surgeons operated on obese patients on tables with a minimum height adjustment above 70 cm. Also, surgeons could not adequately reach the working height even using surgical stools of 20 cm height, mainly when operating on obese patients.

Study four (chapter eight) also provided recommendations for redesigning working heights, recommending extreme span regulation ranges of height adjustment between 26 and 77 cm. The analysis was performed using the method of limits, which is analogous to fitting trials, using the static anthropometry of the users and criteria developed in literature without considering other essential elements of the laparoscopic working system (chapter seven)

Anthropometric data often provide accurate information about specific groups' body dimensions and functional abilities but do not determine how they interact with the design with the same degree of precision. It is difficult to illustrate a work situation using only static anthropometry, especially when the jobs involve greater dynamism and demand greater complexity in their tasks (Helander, 2005; Pheasant and Haslegrave, 2006c). Therefore, the final design of workstations, tools or equipment using static anthropometric projection is insufficient to establish accurate and reliable design criteria.

It is necessary to establish design guidelines by analysing tasks in a more realistic context using mock-ups and simulations that resemble the actual task (Feathers et al., 2015).

Psychophysical techniques such as fitting trials are a valid and reliable alternative to more accurately establishing design parameters. On the other hand, it is necessary to establish the tasks and the elements of the system to be represented to establish an appropriate protocol and respond broadly to the research question. Thereby, chapter seven provided a list of factors within the work system that should be considered that affect the working heights based on the integration of studies one, two and three.

The following study considered these elements to set up recommendations and respond to the last research question:

RQ6: What would be acceptable operating height levels for laparoscopic surgery considering work system elements, and to what extent is this height affected by laparoscopic tasks?

9.1.1. Objectives

1. To determine the preferred, lowest, and highest working surface height limits of acceptability to perform laparoscopic surgery based upon surgeons' preferences.

2. To determine whether the preferred, acceptable limits of working heights are similar when surgeons perform three different complex levels of laparoscopic surgical tasks.

3. To present the working surface height and operating table height limits of acceptability integrated into a tabular arranged data set, based upon the percentage of acceptability for surgeons, related to patients' characteristics, laparoscopic surgical tasks performed and suitable regulation height.

4. Based on current guides, compare acceptable working surface heights with international data and recommendations for Peruvian populations.

9.2. Method

9.2.1. Study design

The study followed a quantitative strand (fixed design) with a postpositivist paradigm and a type of quasi-experimental within-subjects design. The research method consisted of a fitting trial based on the classical psychophysical approach (Ciriello and Snook, 1978; Pheasant and Haslegrave, 2006c; Snook et al., 1995) and the adaptation made by Lin, Catalano, y Dennerlein (2016). The fitting trial is a study in which a sample of participants judges whether a particular dimension is too big, too small, or just right.

Several studies have confirmed the reliability and validity of fitting trials, so their results are valid for design purposes (Bahrampour et al., 2018; Garneau and Parkinson, 2011; Haslegrave et al., 1997; Jakob et al., 2012; Lin et al., 2016; Lin and Dennerlein, 2015; Molenbroek et al., 2011; Pheasant and Haslegrave, 2006c). The protocol was designed based on the previous analysis of laparoscopic work systems in Peruvian hospitals (chapter seven).

9.2.2. Study protocol

Due to the covid 19 pandemic, the study design had to be modified to reduce participants' exposure to potential covid-19 infection. For this reason, the original study, which consisted of a controlled psychophysical protocol using laboratory simulation, was modified to be conducted remotely in the participants' homes or workplaces, maintaining the study's objectives and controlling the variable as much as possible. The original protocol (protocol A) is detailed in summary form in appendix 12.18 to make the reader aware of the original structure planned to achieve the study's objectives.

Protocol B was the alternative to protocol A to be applied remotely to minimise the exposure of the participants and the researcher to Covid-19 and maximise the use of digital resources for data collection. Protocol B is described in detail in this study and was fully implemented to achieve the objectives.

9.2.3. Elements considered for the fitting trial design protocol

Work system elements

The protocol was designed considering most of the factors within the work system identified in chapter seven to have a broader scope in the final recommendations for designing working heights in laparoscopic surgeries (see Table 9.1).

Laparoscopic tasks

Standardising laparoscopic tasks is necessary to set up reliable tasks representing real laparoscopic surgeries. Thus, the Fundamentals of laparoscopic surgery (FLS) course training is one of the leading used test batteries to represent laparoscopic surgery tasks in simulated environments. Furthermore, the FLS has been widely used for ergonomics studies related to laparoscopic surgery and validated for medical education (Fried, 2008; Rodrigues Armijo et al., 2020; Siri et al., 2020), being a practical tool to represent laparoscopic surgery tasks.

The FLS practice skills section demands that surgeons complete five laparoscopic tasks; peg transfer, precision cutting, ligating loop, suture with an extracorporeal knot and suture with an intracorporeal knot. In this, the two extreme tasks were selected: the most basic (peg transfer) and the most advanced (intracorporeal suturing), to have a more comprehensive panorama of laparoscopic skills at different levels of complex surgeries.

Peg transfer tasks represent the basic skill necessary to perform laparoscopic surgery, whilst intracorporeal suturing represents a more advanced skill due to the high coordination necessary to handle needle drivers and knotting in the Penrose drain (Li et al., 2016). The camera conduction protocol was developed with a general surgeon following the protocols of the CEPCEA training centre (see Table 9.2).These tasks were selected because they represent the basic skills for performing laparoscopy according to the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) and represent the main high-risk tasks of WRMSD in laparoscopic surgery (chapters six and seven).

Table 9.1 Work system elements deemed for the study design

Factors	Protocol consideration
Person	
The short stature of surgeons and assistants	✓ Male and female experienced surgeons participated in the study. A sample of surgeons was considered to determine a normal distribution accounting for the surgical population.
Lack of surgeons' experience in laparoscopic surgery	✓ Anthropometric measures were taken to determine the level of representativeness of the sample with regard to the overall medical population
Work team issues	✓ The fitting trial considered camera conduction tasks usually performed by assistants (surgical work team). The final result determined whether the assistants demanded a similar working height to surgeons.
Tasks	
Patient's characteristics	✓ Final tables considered recommendations to design working surface heights based on patient characteristics, including obese, average and thin
Long duration of surgeries	✓ Participants were prompted to choose the preferred working surface height as if surgeons worked for a whole day performing laparoscopic surgeries in the Hospital.
Complexity of surgeries	✓ To simulate real surgeries, tasks were selected at different ranges of complexity: peg transfer (PT; basic task); intracorporeal suturing (IS; advanced task), and to simulate assistants' tasks, camera conduction.
Tools and Technology	
The elevated height of the operating table due to poor design, lack of suitable equipment and poor state	✓ Laparoscopic tasks were performed with the usual instruments. For peg transfer tasks, Maryland dissectors with a ring handle; intracorporeal suturing were used with two needle drivers with axial handles; an endoscope was used with a long tube or the dissector tool (used backward to simulate an endoscope). ✓ The operating table was simulated by adjusting the height through a regulated table system. The screen was positioned in front of the surgeon.
Organization	
Limited education and training opportunities	✓ Trials were performed with the knowledge and some degree of experience in laparoscopic surgical tasks. The exposure time was simulated during laparoscopic tasks. However, the adapted protocol (protocol B) did not consider this factor.
Poor ergonomics and safety culture	✓ The study design allowed participants to choose their preferred working heights based on their experience and comfort. Only participants with laparoscopic experience could participate.
Internal Environment	
Limited physical workplace	✓ Tasks were performed to simulate the lack of space available in operating rooms with similar conditions (protocol A). The protocol B did not take into account this aspect

Table 9.2 Description of laparoscopic tasks simulated

Task	General description
1. Peg transfer (PT)*	In this task, surgeons Transfer cubes with a dissector to different sides of a pegboard, repeating the action for each cube
2. Suture with an intracorporeal knot (IS)*	For this task, surgeons need to place a short suture through the two marks in a penrose drain and then tie three throws of a knot intracorporeally in order to close the slit in the penrose drain
3. Camera conduction	In this task, the surgeon holds the endoscope with two hands and simulates pointing to four points on the table. This action is repeated up to five times

Note. (*) Explanation of tasks are based on the description of "FLS manual Skills Written Instructions and performance Guidelines" (2014)

9.2.4. Participants

A total of 25 adult participants were recruited with no history of neck or upper extremity musculoskeletal injuries. Similar studies that used a psychophysical approach recruited a similar number of participants to set up population representation (Ciriello and Snook, 1978; Lin et al., 2016, 2016; Lin and Dennerlein, 2015; Wright and Mital, 1999), so the sample size is valid to represent the population. To be included in the study, participants were required to meet the following criteria:

- Participants should be medical residents in the training process to be surgeons and/or surgeon specialists with experience in laparoscopic surgery and/or knowledge of Fundamental Laparoscopic Surgical training tasks.
- Participants should have availability to participate in the whole test following the protocol statements
- Participants must not have or be diagnosed with an injury or musculoskeletal disorder that may affect their usual performance in the test.
- Participants must be able to source the study equipment list and use their laparoscopic training kit or construct the alternative kit suggested

9.2.5. Research approval

The University of Nottingham, Faculty of Engineering Ethics Committee, approved protocol B and data collection procedures (see appendix 12.26). Before collecting information, participants were informed about the research and signed informed consent.

9.2.6. Procedures

9.2.6.1. Call for participants

Participants were invited to the study in three ways:

(1) An email was sent inviting surgeons to participate in the study. Email addresses were obtained from the survey database during study two (Chapter five). Participants voluntarily left their email addresses to participate in "future studies".

(2) By emailing the call to the Peruvian Society of Endoscopic Surgery members (who previously were invited to collaborate with the study). Those interested were invited to write to the researcher's email address.

(3) The call was sent to CEPCEA (laparoscopic surgery training centre) to share with their trainees. Subjects interested could communicate directly with the CEPCEA coach or with the researcher.

9.2.6.2. Information Sheet and consent form

The information sheet and the consent form were developed through the JISC survey Online platform, and the link was shared with interested participants.

The participant information sheet detailed the study's objectives and the procedures for conducting trials. It included the ethical aspects of the study, being participants free to accept or withdraw from participating. If they accepted, a second page was displayed containing a link to redirect them to a virtual folder named "remote fitting trial". If they did not agree to participate, a second page thanked them for their time and consideration for participating. The study was anonymous and ensured the confidentiality of the information.

The virtual folder contained all the instructions to complete the trials successfully and included virtual data collection sheets and the participant's guide detailing the fitting trial protocols. Once participants completed the trials, all the information was uploaded to the virtual answer sheet, which was available by a link in the participant's guide. In addition, video tutorials were incorporated to facilitate understanding of the trials (see Appendix 12.19: Participant's Guide).

9.2.6.3. Procedure to complete protocol

The study consisted of general data, self-reported anthropometry, and the fitting trial protocol. General data included: age, gender, role (e.g. resident or surgeon) and level of experience in laparoscopy. Participants were asked to complete all protocol information by clicking on the virtual data collection sheet link attached to the virtual folder and the participant's guide.

9.2.6.4. Self-reported anthropometry: Procedure for taking anthropometric measures

Participants were asked to self-measure and report three anthropometric measures: stature, elbow height, and umbilicus height. These measures were requested since they are the main references to design working heights (Pheasant and Haslegrave, 2006d). All measures were taken in the dominant side segment of participants standing, facing forward, and keeping their sight on Frankfurt's plane. Videos with the procedures were included in the" remote fitting trial file" to facilitate the explanation process. To carry out this process, participants were asked to opt for one of the two alternatives:

a) Self-reported: A plastic tape measure is stuck on a wall surface 30 cm from the floor and extended straight along the wall. Instructions were given to participants to take the three anthropometrical measures themselves, deeming the different points of reference.

b) Assisted: A second person takes measures and annotates measures to be posteriorly uploaded in the data collection form. The second person should preferably be someone who works or lives with the participant to avoid unnecessary contact with others due to any Covid 19 restrictions.

The measurement procedure followed the directives of ISO 7250 (ISO, 2017) and Pheasant and Haslegrave (2006c) instructions, similar to study four (chapter eight) (see Figure 9.1).

Note. (A) self-reported: A simple plastic tape measure may replace the tape on the wall; (B) assisted by a second participant.

Figure 9.1 Example of two alternatives to take measures

9.2.6.5. Fitting trials

Trials aimed to determine the acceptable lowest working surface height, the acceptable highest working surface height and the preferred working surface height to carry out three simulated tasks. Participants were advised to simulate the patient's sagittal abdominal Depth height with a pelvis box trainer or a cardboard mock-up supported on an adjustable chair or tripod with a height regulation system to represent the working surface height in laparoscopic surgery.

The working surface height was determined as the height measured from the ground to the top of the box trainer representing the patient's insufflated abdomen. Similarly, as in study four (chapter eight), the working surface height was defined as the sum of the operating table height plus the height of the patient's sagittal abdominal depth plus pneumoperitoneum (+6 cm).

Participants were allowed to use their laparoscopic tools, which included: two Maryland dissectors with ring handles and two-needle drivers with axial handles, but if they did not have the tools, they were given alternatives to building tools with home material (see participant's guide, Appendix 12.19).

9.2.6.6. The process of defining heights

Participants were prompted to choose their preferred working surface height with the following instruction:

"Adjust the height to minimise discomfort as if you were to work in this posture for a whole day performing laparoscopic surgeries in the Hospital. You may continue to make as many adjustments as you like, even in the middle of your task, whenever you feel you would like to, and even if you have not made any adjustments for some time. At the end of the trial, you will be asked to set the simulated table to the lowest and highest heights that you consider acceptable and to your own personal preferred optimum height."

These instructions are an adaptation of classical recommendations on psychophysical experiments of Snook and Ciriello (Ciriello et al., 1990) that recommended: "Adjust the amount of weight until it represented the maximum they could handle for eight hours without straining themselves or becoming usually tired, weakened, overhead or out of breath".

Participants were free to adjust the chair or tripod until reaching the desired height. The action was repeated as many times as necessary until reaching an acceptable height where the person perceives it as the most comfortable and suitable for work. Once participants had ended each trial, they measured the preferred working surface height, the lowest acceptable working surface height and the highest acceptable working surface height (see Figure 9.2)

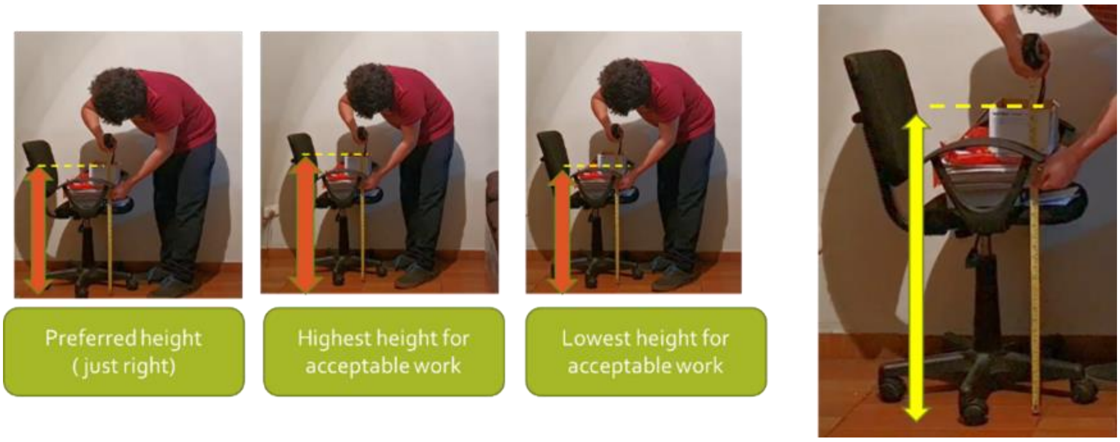


Figure 9.2 Procedure to record the working surface heights for each task

Participants were free to include photographs of their experience in the study by attaching a virtual link in a specific section of the data collection sheet. Precise instructions were given in the participant's guide to attaching photographs using different virtual drives. However, the photographs were voluntary, and they were free to complete the trials without having to attach them to the datasheet.

9.2.7. Statistical analysis

Means and standard deviations were calculated for the participant's upper and lower limits of the working surface heights chosen for each task activity. Normality tests were performed using the Shapiro-Wilk test (because the sample was smaller than 50 participants) and by observing the distribution graphically (normal distribution and Q-Q graph). The one-way ANOVA within-subjects test was used to establish whether there was a difference between surgeons' preferred heights according to the task performed because the same surgeons repeated the same trial, similar to other psychophysical studies (Ardiyanto et al., 2019; Lin et al., 2016; Wu & Chang, 2010). In addition, the assumptions of homogeneity of variances and normality of the data were considered. In case of differences, pairwise comparisons were made to establish differences. IBM SPSS v.24 software was used for the statistical processing of the data

9.2.7.1. Fitting trial statistics

Data processing was performed following the recommendations made in psychophysical experiments. A normal curve of acceptability and satisfaction is plotted from other normal distributions (facing each other) by subtracting their summed values from 100% (Nicholson & Ridd, 1988; Pheasant & Haslegrave, 2006c).This process is explained in the following paragraphs:

Once the normality of the sample was established, percentiles and Z values were calculated as follows:

$$Z\ score = (x - \overline{X}) / SD \qquad (9.1)$$

$$Percentile\%(x) = \overline{X} \pm SD*Z \qquad (9.2)$$

Where $\overline{X}$ is the mean of the working surface height chosen; x is a given height, and SD is the standard deviation of the measure

Ogives (cumulative distributions) were plotted to determine the threshold limits of "too low" and "too high" working surface height dimensions. For instance, if 73 cm was the lowest acceptable height for the 5%ile user, for 95%ile user this was "too low". The purpose of plotting the distribution in ogival curves is to determine the percentage of users who could accept a given measure to make design decisions. In this way, it is possible to identify the percentage of users that could accept a given working surface height (Pheasant & Haslegrave, 2006c). Then, a third distribution was plotted named as "acceptable or satisfactory", which represented the percentage of people for whom a given height was neither "too low" nor "too high". This distribution was calculated as follows:

A height given = " too low(%)" + " too high(%)" + " Acceptable (%)" = 100% (4.3)

Acceptable (%) = 100 % - "too low (%)" – "too high (%)" (4.4)

The curve of "acceptable" working surface heights was plotted by placing the heights on the x-axis (horizontal) and the percentage of users on the y-axis (vertical) to plot a final curve representing the percentage of users who would find it acceptable to work at a given height or range of heights. For example, at a working surface height of 94.5 cm, 90.2% of users would find it neither too low nor too high and, therefore "acceptable" or "satisfactory".

94.5 cm : 7% (too low) +2.8 % (too high) +Acceptable % = 100 %

Acceptable (%) = 90.2 %

The heights rated as acceptable represent the distribution of a population whose height meets their needs but not necessarily of a specific individual or group; thus, some participants would find these heights optimal or preferred. The distribution of preferred heights "just right" was derived directly from their responses without calculating cumulative distributions by rounding off responses to the nearest 5 cm to compare final responses (Pheasant and Haslegrave, 2006c). The final heights were plotted similarly to the "Acceptable" or satisfactory distribution. Calculations and graphs were performed in Microsoft Excel

The results were summarised in tables showing the acceptability ranges according to the percentage of users who would accept a given height or range of heights from the lowest to the highest limit. The percentages of users presented in the tables were 10, 25, 50, 75 and 90%, similar to those reported in other psychophysical studies (Snook and Ciriello, 1991). In other words, the acceptable working surface heights (according to the task performed) for 10, 25, 50, 75, and 90% of the Peruvian surgeon population. The criteria used in study four (chapter eight) were followed to classify patients as obese, average and thin, considering the abdomen's increase by pneumoperitoneum (+ 6cm). Also, a table with recommendations was presented with suitable regulation heights (SRH), which means the complementary height needed to reach a specific working surface height.

Finally, a summary results table compared the findings with study four (chapter eight) results and HICs recommendations.

9.3. Results

9.3.1. Study population

A total of 25 participants joined the study. The sample consisted predominantly of 68% male participants (n=17) and 32% female (n=8). Seventy-two per cent of participants were third and second-year residents in general and paediatric surgery, while the remaining 28% were general surgery specialists. On average, participants reported 5.6 years of experience in laparoscopic surgery, and twelve (48%) participants indicated that they had no formal FLS training but were aware of the contents and structure of the test.

Table 9.3 sets out the descriptive statistics of anthropometric measurements of participants. According to the Shapiro-Wilks test, the three anthropometric measurements followed a normal distribution (p>0.05). The mean stature of participants was 168.9 cm (SD=8.2), with a minimum of 154.4 cm, a maximum of 181.5 cm, and a 95% CI between 165.5 cm and 172.2cm.

Table 9.3 Descriptive statistics of anthropometrical measures

	Mean (DS)	Min-Max	95% CI	Shapiro Wilk test (*p*)
Stature	168.9 (8.2)	154.4 - 181.5	165.5 - 172.2	0.27*
Elbow Height	103.8 (8.8)	94.4 - 115	102.5 - 107.4	0.47*
Umbilicus Height	99.3 (9.8)	85.5 - 113.5	97.7 - 103.3	0.80*

Note. *Normal distribution (p>0.05)

Table 9.4 describes the comparison of heights between the different studies. The overall mean of the different studies ranged from 164.2 cm to 168.9 cm. The sample of this study was relatively taller than that of studies two and four, reaching a maximum difference of 4.7 cm concerning study four and 2 cm concerning study two. The main difference is observed in males (4.2 cm) while females maintain similarity between studies (2 cm). The proportion of females to males in the sample was less than 50% in all three samples. Moreover, the surgeons' heights in the present study were within previous studies' maximum and minimum parameters.

Table 9.4 Stature mean comparative among studies

	Stature	
Studies	**Mean (SD)**	**Min - Max**
Study 2		
Total (n=140)	166.9 (6.7)	150 - 188
Male (n=107)	168.8 (5.7)	155 - 188
Female (n=33)	161.1 (6.4)	150 -173
Study 4		
Total (n=211)	164.2 (8.8)	144 - 190
Male (n=110)	170.0 (6.7)	144 - 190
Female (n=101)	158.0 (5.7)	146 - 176
Study 5		
Total (n=25)	168.9 (8.2)	154 - 182
Male (n=17)	173.0 (5.8)	163 - 182
Female (n=8)	160.0 (4.3)	154 - 168

Note. Measures in centimetres

9.3.2. Fitting trials results: Distribution of working surface heights

Table 9.5 shows the final means, confidence intervals, normality tests and normal curve characteristics of the acceptable working surface heights obtained from the fitting trial. The Shapiro-Wilk test showed significant normality for all preference distributions (p>0.05). The lowest mean value among distributions was in the "optimal height" of the intracorporeal suture task (*M*=91.8cm, *SD*=5.9), and the highest values were reached in the "highest acceptable height" distribution of the peg transfer tasks and camera conduction (*M*=106.9 cm, *SD*=6.1; *M*=106.1 cm, *SD*=5.7). Furthermore, the results showed normality curves with skewness and kurtosis values very close to zero, demonstrating the normal distribution's symmetry.

Table 9.5 Final distribution of working surface height

Acceptable WSH	mean (SD)	95% CI	sk	ku	W	df	*p*
Task 1: peg transfer task							
Lowest	84.3(6.9)	[81.3, 87.2]	-0.2	-0.8	1.0	25.0	0.8
Just right	94.3(3.7)	[92.8, 95.8]	-0.3	-0.6	1.0	25.0	0.6
Highest	106.9(6.5)	[104.1, 109.4]	0.3	-0.2	1.0	25.0	1.0
Task 2:intracorporeal suturing							
Lowest	81.0(6.2)	[78.4, 83.6]	0.1	-1.4	0.9	25.0	0.1
Just right	91.8(5.9)	[89.3, 94.3]	0.4	-0.7	1.0	25.0	0.5
Highest	101.0(6.4)	[98.3, 103.7]	0.3	-0.4	1.0	25.0	0.6
Task 3: camera conduction							
Lowest	83.6(7.6)	[80.4, 86.8]	0.1	-0.1	1.0	25.0	0.8
Just right	94.4(5.9)	[91.9, 96.8]	-0.1	0.0	1.0	25.0	0.7
Highest	106.1(5.7)	[103.8, 108.5]	0.1	-0.4	1.0	25.0	0.8

Note. Measures in cm; WSH: working surface height; W: Shapiro Wilk – test, normality(p>0.05), Sk: Skewness, Ku: kurtosis, df: degree of freedom.

One-way ANOVA within-subjects analysis showed a significant difference between mean heights of the laparoscopic tasks when surgeons indicated the lowest ($F(2)=3.8, p=0.02$) and highest acceptable ($F(2)=13.7, p=0.001$) and preferred working surface heights ($F(2)=4.4, p=0.01$). Intracorporeal suturing (t2) was significantly the task with the lowest height demand among the preferred and highest condition except for the lowest acceptable surface height, where it was similar to the camera conduction surface height (t3)($p=0.05$). The camera conduction (t3) and peg transfer (t1) tasks had no significant differences at the three acceptable working surface height levels ($p<0.05$). For more details, see Table 9.6

Table 9.6 ANOVA one-way within-subjects analysis of the three acceptable working surface heights

Acceptable WSH	mean (SD)	w	Mauchly's test Spherecity	*F*	*df*	*p*
Just right (preferred)						
A. Peg transfer (t1)	94.3 (3.7)	0.80				
B. Suture (t2)	91.8 (5.9)	0.45	0.24	4.4	2	0.01[a]
C. Camera conduction (t3)	94.4 (5.9)	0.72				
Lowest acceptable high						
A. Peg transfer (t1)	84.3 (6.8)	0.64				
B. Suture (t2)	80.2 (6.1)	0.08	0.38	3.8	2	0.02[b]
C. Camera conduction (t3)	83.2 (7.6)	0.81				
Highest acceptable high						
A. Peg transfer (t1)	106.7 (6.4)	0.95				
B. Suture (t2)	101.0 (6.3)	0.57	0.7	13.7	2	0.001[c]
C. Camera conduction (t3)	106.1 (5.7)	0.83				

Note.W: normality test; ANOVA one-way within-subjects test

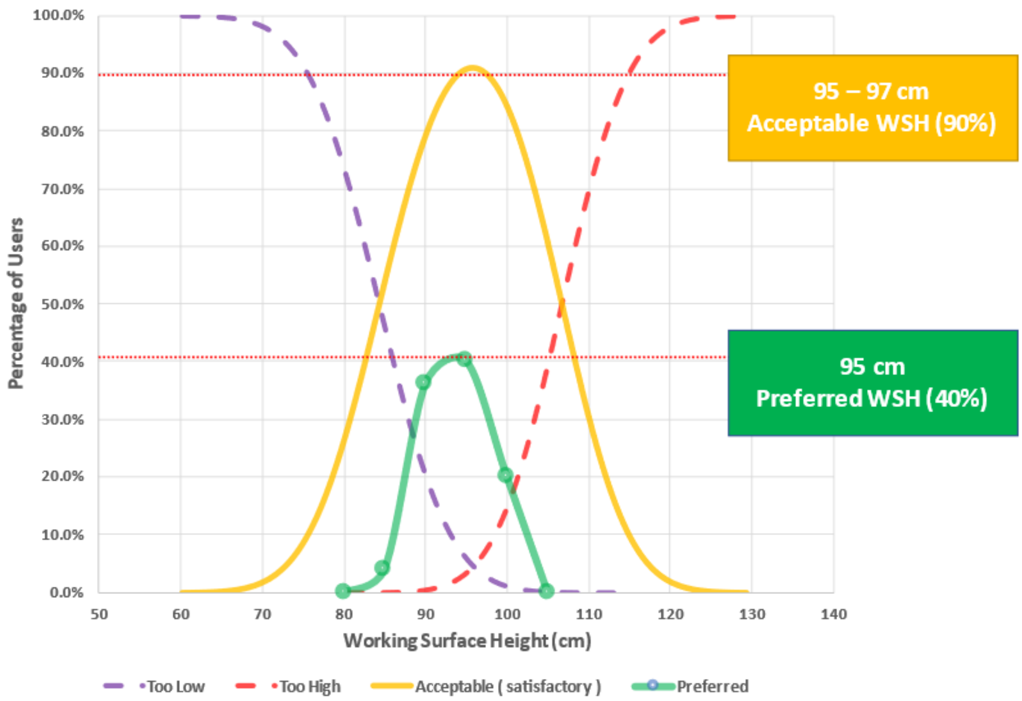
[a] t1 vs t2, p=0.001 ; t2 vs t3 , p=0.03; t1 vs t3, p=0.95

[b] t1 vs t2, p=0.001 ; t2 vs t3 , p=0.05; t1 vs t3, p=0.47

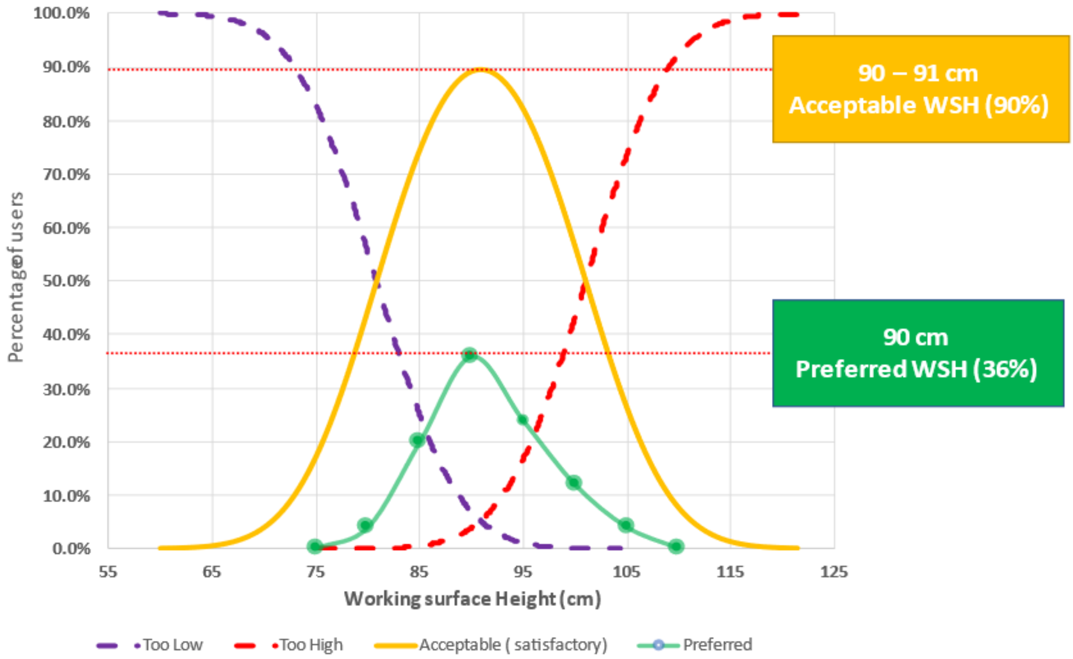
[c] t1 vs t2, p=0.001 ; t2 vs t3 , p=0.01; t1 vs t3, p=0.64

9.3.3. Acceptable and preferred working surface height limits

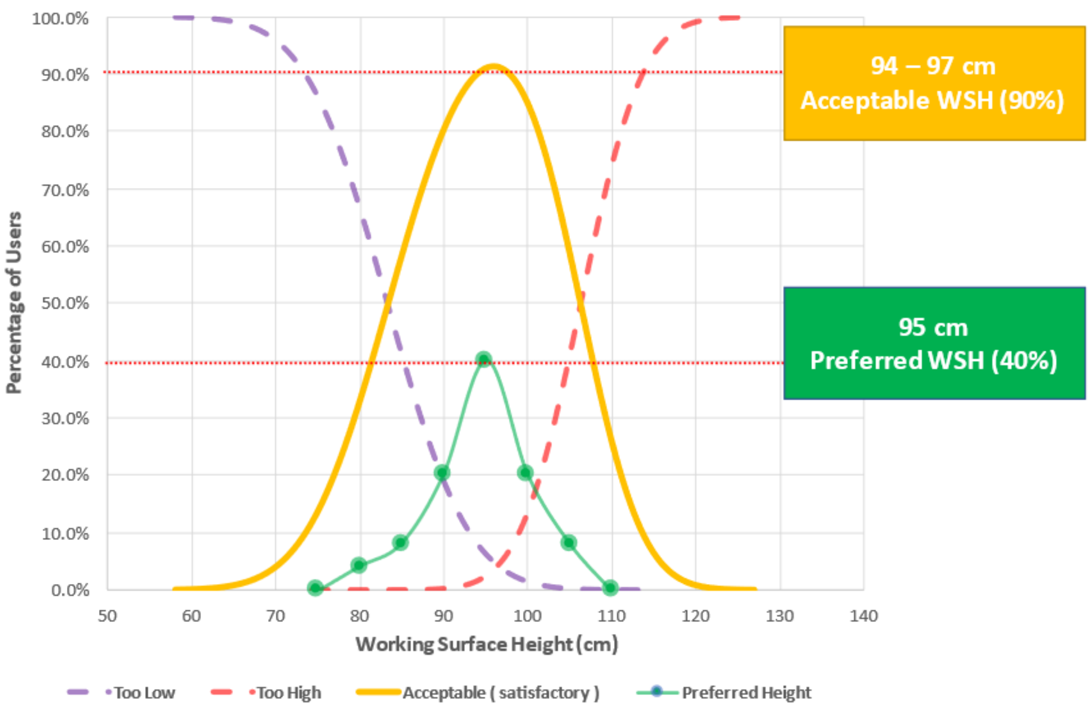
Figures 9.3a,b,c illustrate the fitting trials' results in laparoscopic tasks. The best estimates of the sampled participants' responses were represented by plots of cumulative distributions (red and purple dotted lines). The purple lines represent the ogive of the "too low" distribution, while the red lines are the "too high" distributions. These were pointed to as the threshold limits of the acceptable distribution. The yellow distribution represents the percentage of subjects who could accept a specific working surface height (satisfactory or acceptable). The green distribution represented the preferred working surface height and was plotted directly from the subjects' responses (without calculating the cumulative distribution) by rounding the final heights. Thereby, participants found working heights neither too low nor too high and, therefore, acceptable to work at a given height.



(a) peg transfer task (task 1)



(b) intracorporeal suturing task (task 2)



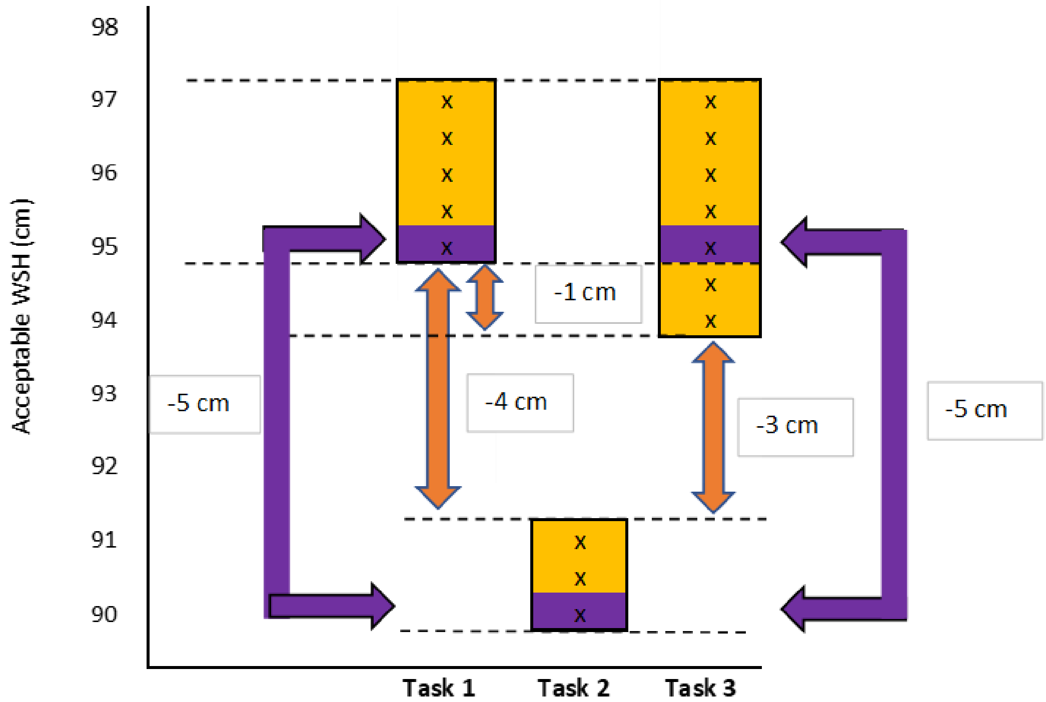
(c) camera conduction task (task 3)

Figure 9.3 Fitting trial results

The horizontal upper red dotted line shows the percentage of acceptability for the study, which in this case was 90%, while the lower horizontal red dotted line shows the maximum percentage of preferred height. Thus, all three tasks reached common points of acceptable and preferred heights without establishing amplitude ranges. The acceptable working surface height for 90% of the population in peg transfer and camera conduction tasks had similar ranges between 94 and 97 cm varying by one centimetre.

The maximum preferred height reached a maximum percentage of 40% for peg transfer and camera conduction tasks, while the maximum preferred height for suture tasks was 36%. The limit threshold of the "too low" and "too high "distribution during peg transfer and camera conduction tasks for 95% of surgeons were similar, reaching 73 cm and 71 cm (too low) and 117 and 116 cm (too high), respectively, while suturing tasks reached 71 and 111. To see the differences, the three results were compared considering the acceptable and preferred working surface heights for 90% by laparoscopic tasks (see Figure 9.4).

Intracorporeal suturing tasks demanded a lower working surface height than peg transfer (- 4 cm) and camera conduction (- 3cm). However, peg transfer and camera conduction demanded a similar height span that ranged from 95 to 97 cm, having the camera conduction task a bit lower tolerance acceptability range (-1cm) than the peg transfer task. The difference in preferred working height was similar for peg transfer and camera conduction tasks but 5 cm higher than the intracorporeal suture height.



Note. The purple boxes represent the surgeons' preferred working heights, and the purple arrows the differences in heights; the orange boxes with X represent a certainly acceptable measurement, and the orange arrows the differences in acceptable working surface heights between tasks.

Figure 9.4 Differences in acceptable working surface heights by laparoscopic tasks

Table 9.7 is a complementary summary of the results of fitting trials previously explained, presenting the acceptable working surface heights according to the percentage of benefited users and the task performed, highlighting the 90% of users (common fit).

In addition, the table presents the acceptable working surface heights at the lower limit that refers to the recommended heights to accommodate a certain percentage of users when the height was mainly too low for users, while the upper limit was when the height was too high. For example, if the working height is set to 76 cm or 115 cm in peg transfer tasks it would accommodate 10% of users. A height lower than 76cm or higher than 115cm would represent a lower proportion of users accommodated. Whereas 96 cm would accommodate 90%. However, this table does not provide more detail on operating table height and patient characteristics.

Table 9.7 Percentages of users accommodated and ranges of Acceptable working surface height in laparoscopic surgery tasks

Percentage of users	Acceptable working surface height		
	Task 1	Task 2	Task 3
Common fit range			
90%	**95 to 97**	**90 to 91**	**94 to 97**
Acceptable WSH (Lower limit)			
75%	89	85	89
50%	85	81	83
25%	80	77	78
10%	76	73	74
Acceptable WSH (upper limit)			
75%	102	97	102
50%	107	101	106
25%	111	105	110
10%	115	109	113

Note. Measures in centimetres (cm); Task 1: Peg Transfer; Task 2: Intracorporeal suturing; Task 3: Camera conduction

Table 9.8 sets out the recommended acceptable height of an operating table that satisfies a specific percentage of users according to the task performed and patients' characteristics. The tables represent the integer values of the heights in centimetres without setting specific ranges. The two measures (upper and lower limit) presented for each percentage of users represent the specific height that users would accept (similar to table 9.7) except at 90%, which was the minimum and maximum height range that 90% of users accepted as satisfactory (common fit).

The lowest acceptable height values for 90% would be reached when operating on an obese patient performing intracorporeal suturing tasks (49 to 50 cm). While the operating table height recommendations for camera conduction were similar to peg transfer differing by one centimetre at the lower limit of the measurement in the different patients. The acceptable measurements for 90% do not exceed a difference of three centimetres in the minimum and maximum range, being only one centimetre in suturing tasks in obese patients. Also, tables could be interpreted based on the percentage of users who would accept a given height according to the type of patient and task applied. For instance, if it is necessary to operate on obese patients, applying intracorporeal sutures on an operating table whose minimum height adjustment is 68 cm, the number of surgeons who could accept the given working height would be 10%.

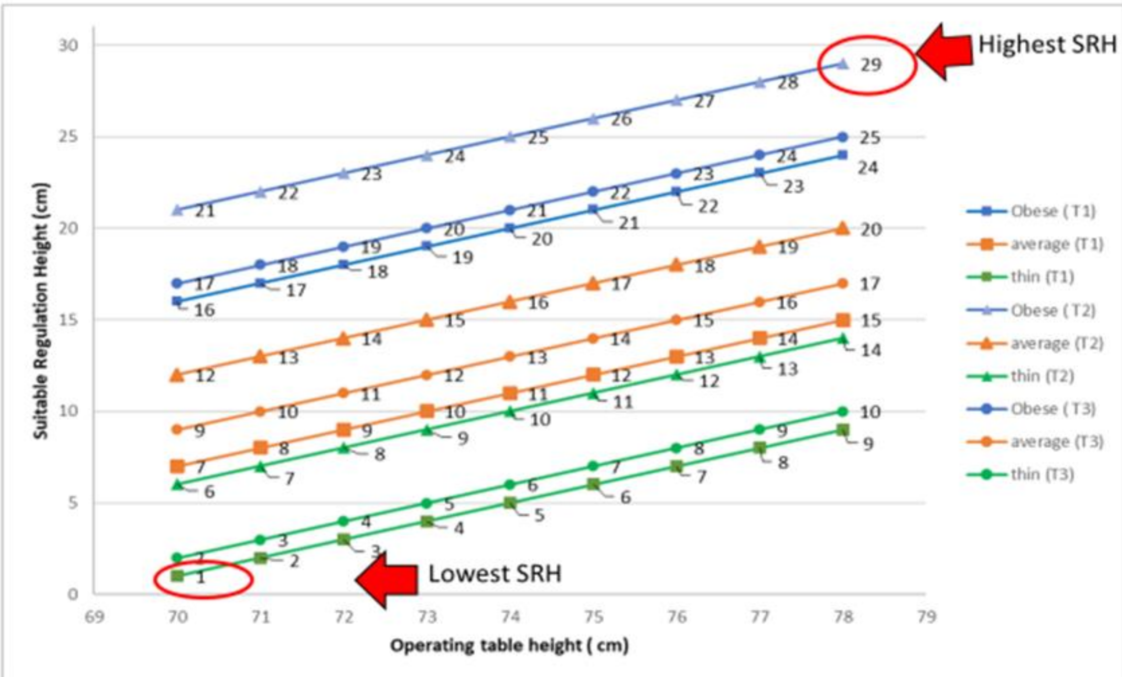
Table 9.8 Acceptable operating Table heights by patient's characteristics and percentage of users accommodated in laparoscopic surgery tasks

Percentage of users	Patients' characteristics								
	Thin			Average			Obese		
	T1	T2	T3	T1	T2	T 3	T1	T2	T3
Common fit (range)									
90%	**69-71**	**64-65**	**68-71**	**63-65**	**58-59**	**62-65**	**54-56**	**49-50**	**53-56**
Acceptable OTH	***(Lower limit)***								
75%	63	59	62	57	53	56	48	44	47
50%	58	55	57	52	49	51	43	40	42
25%	54	51	52	48	45	46	39	36	37
10%	50	47	47	44	41	41	35	32	32
Acceptable OTH	***(Upper limit)***								
75%	76	71	76	70	65	70	61	56	61
50%	81	75	80	75	69	74	66	60	65
25%	85	79	84	79	73	78	70	64	69
10%	89	83	88	83	77	82	74	68	73

Note. Measures in centimetres (cm); T1: Peg Transfer task; T2: Intracorporeal suturing task; T3: Camera conduction task; OTH: Operating table height. Common fit measures are ranges

Figure 9.5 presents the results of SRH, which was defined as the difference in heights between the current working height (considering the characteristics of Peruvian operating tables) and the recommended working height for 90% of users. The SRH would commonly be needed to design surgical stools or platforms. The highest SRH would be reached when surgeons operate on an obese patient on a 78 cm table (29 to 24 cm), and the upper limit would be reached when surgeons perform intracorporeal suturing tasks (29 cm). The lowest SRH would occur when operating on thin patients on an operating table 70 cm high (1 cm), with the difference being almost imperceptible.

On the other hand, if surgeons operate on a 70 cm table, the highest SRH to operate on an obese patient would be 21 cm for suturing tasks, 17 cm for camera conduction, and 16 cm for transfer tasks. Therefore, the higher the operating table and the larger the patient, the higher the SRH adjustment will be, reaching up to 29 cm for operating on obese patients.



Note. Laparoscopic tasks: (T1: peg transfer); (T2: intracorporeal suturing) ; (T3: Camera conduction).

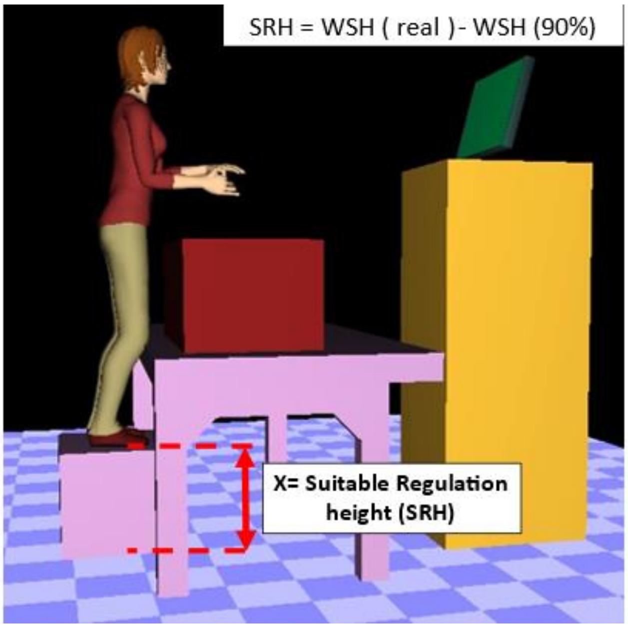


Figure 9.5 Suitable regulation height to accommodate 90% of surgeons by laparoscopic tasks, patients' characteristics, and operating table height

The minimum and maximum adjustability range of operating table heights to accommodate 90% of patients were presented in Table 9.9 and its comparison with the results of study four. The table height of the study differs from study four, in which heights were determined by using anthropometric criteria described by Van Veelen and Berguer criteria (see chapter eight). The difference was 22 cm regarding the lowest and highest positions (49 and 71 cm), while study four found differences between the lowest and highest positions of 40 cm and 35 cm, respectively. There were no available measures of table height based on tasks performed in HICs literature, so this space in the table was blank.

Table 9.9 Acceptable operating table heights compared with the Peruvian criteria determined in study 4

	Operating table height recommendations (90%)				
	Task 1	Task 2	Task 3	Total	Difference
Study results					
Fitting trial results	54 - 71	49 - 65	53 - 71	49 - 71	-22
Peruvian criteria (study 4)					
Van Veelen	-	-	-	26 - 66	-40
Berguer (EH-10 cm)	-	-	-	43 - 78	-35

Note. Measures rounded in centimetres

Measures were considered considering patients' characteristics

9.4. Discussion

The study determined the acceptable working surface heights for 90% of the surgeon population and preferred heights, concluding that laparoscopic surgery demands different working surface heights. Surgeons may accept a specific range of heights to work without considering anthropometric reference criteria, so it is possible to design devices that may satisfy the surgeons' preferences in a range of heights determined.

The acceptable working surface heights for 90% of surgeons to carry out peg transfer and camera conduction tasks were similar, ranging from 94 cm to 97 cm, with a preferred height of 95 cm (for 40% of users sampled) differing in only one centimetre for camera conduction tasks (94-97 cm). In contrast, suturing tasks demanded a lower working surface height of 90 -91 cm and a preferred height of 90 cm. These acceptability ranges mean that 90% of surgeons would accept or be satisfied to work at those heights, and a percentage of people within that range would find it "just right." Hence, surgeons could accept a narrow range of heights for a given task even though most heights within the range were not ideal for them.

Yet, it is necessary to understand how great the range of acceptability is to set up specific adjustment measures for design.

Helander et al.(2000) stated that individuals do not have the sensitivity to judge sitting height changes of less than three centimetres because the proprioceptive receptors are not sensitive to small changes. Hence, surgeons would not perceive differences among the acceptable height ranges of laparoscopic tasks because the ranges varied by a maximum of three centimetres for camera conduction tasks and one centimetre for suturing. Furthermore, the preferred height of the three tasks was within the range of acceptability.

The narrow margin of acceptable ranges for working heights at 90% demonstrates that surgeons can choose heights from a common fit range despite their anthropometric differences at the extreme percentiles. The extreme percentiles were considered in the sample recruiting a female and male surgeon of 154 cm and 181.5 cm in height, so the preferences variability of the extremes was covered. However, these ranges of variability in working heights increase when determining operating table heights if the characteristics of the patients are considered.

Intracorporeal suturing tasks demanded a lower working surface height of approximately 4 to 5 cm than the other two tasks. Matern et al. (2001)found a similar finding in a study conducted with two users, one in the 95th percentile and the other in the 50th percentile, using four types of laparoscopic tools simulating the optimal working position. To manipulate a tool with an axial handle (used for intracorporeal suturing tasks), a lower working surface height was recommended (70 cm), being up to 20 cm lower than the height recommended in this study. However, although the results differ notably in their final recommendations, both studies concluded that suturing tasks require lower working surface heights. A likely explanation is that using an axial handle for suturing with needle drivers forces surgeons to deviate their wrists for long periods increasing their discomfort (Lucas-Hernández et al., 2014; Park et al., 2010).

It may also explain the high wrist deviation found in chapter six.Surgeons may lower the working height to facilitate better wrist positioning when manipulating the needle driver as a copy strategy.

The variation in final results regarding Matern's experiment might be explained by the methodological approaches used to determine working heights. Matern's study only involved two participants and focused on finding the working height by positioning the participants in an "ideal posture" and not on a specific simulation of the task as was done in this study.

The study revealed that camera conduction tasks demand a working surface height of 94 to 97 cm to accommodate 90%, being similar to surgeon needs when performing peg transfer tasks. This finding is essential since current laparoscopic surgery guidelines only recommend regulating surgeons' heights (Catanzarite et al., 2018; Madhu Shankar et al., 2017; Soueid et al., 2010; Supe et al., 2010; Zachariou, 2019) but not for camera assistants who also require similar heights as surgeons. However, in real surgeries with current operating tables, when camera assistants worked with tall surgeons, the risk of WRMSD increased due to the need to adapt the assistants' posture to tall surgeons' working height needs. This was evidenced in study one (chapter four), where surgeons reported that the shorter assistant that conducted the camera was most affected when assisting a taller surgeon.

Although it seems contradictory, this could be explained because the range of acceptability of a tall surgeon at a given working height is higher at the upper limit than a short surgeon. Thus, when a tall surgeon adjusts the table height to a level that satisfies him or her, a shorter surgeon would not reach that range because the table has a minimum range favouring the taller surgeon. This would explain why the height discrepancy produces a higher risk of WRMSDs in assistants due to the limited minimum adjustment of the operating tables, even though both can reach a common acceptable working height. Based on the study's five results, both could set the table height to a maximum of 71 cm but only when operating on a thin patient, which is possible with specific operating tables that reach this minimum level (e.g. Merivara, Berchtold models).

The study also determined recommendations to calculate the suitable regulation height necessary to design a stool or platform that surgeons would need to reach the recommended surface height in the current working conditions. The highly suitable regulation height was 29 cm (to operate on obese patients in suturing tasks), while study four determined 52 cm and 35 cm (Van veelen and Berguer criteria, see chapter eight). These differences were mainly due to the working height criterion established by Van Veelen being significantly lower than the Berguer criteria, which established a closer height to the study results differing by six centimetres.

Nevertheless, these suitable regulation heights exceed the average height of a surgical stool in Peruvian operating rooms (20 cm high, see chapter eight), explaining the difficulties surgeons and assistants experience in reaching working heights. Possible design studies could include new adjustment systems that consider the 29 cm height as a possible starting point for developing adjustable technology. Yet, the focus should not only be on searching for the suitable height but also on the ideal working surface size, which should be associated with the working height. A smaller surface with greater height can create postural instability (Matern, 2009).

On the other hand, international recommendations suggest regulating operating tables with a height adjustment from 29 to 69 cm (including obese patients) (Van Veelen et al., 2002) and from 64 to 77 cm (Berquer et al., 2002). Similarly, current guides adopt these standards (Sánchez-Margallo, 2017; Soueid et al., 2010; Supe et al., 2010; Yeola et al., 2019; Zachariou, 2019) This difference, especially in the minimum height, concerning the results of this study could be because variables of the work system such as anthropometrical characteristics of surgeons, tasks, and tools were not considered to define working heights, which was taken into account in this study. In addition, Berger's criteria considered an average patient in his analysis and not obese patients, which could have widened the minimum adjustment range recommended.

Thus, the study offers ready-to-use tables (Table 9.7 and 9.8) that facilitate the choice of acceptable heights for 90% and assesses the impact measurement could have on surgeons' margins of acceptance without making complex calculations. This is relevant because the recommendations available in the literature require calculations that can be complex for designers (Ranger et al., 2019) and, as explained above, may be biased due to the time elapsed.

The tables present the working height according to laparoscopic tasks requiring different design tools (endoscope, needle driver, grasper). The surgical tools would be related to the "*tools and technology"* category, while the tasks (camera conduction, suturing, and peg transfer) and patient size (obese, average, and thin) would be associated with the "*task"* category. Likewise, the proportion of people suitable for the heights would represent the "*person"* category. These proportions determine the 10, 25, 50, 50, 75, and 90% fit rates of the similar population to Snook and Ciriello's psychophysical studies (Potvin et al., 2021). Although the tables are developed considering the Peruvian medical population, they could also be used for other populations, especially with conditions similar to those in the Peruvian context. However, the recommended heights should be taken with caution, not as an absolute and fixed value for design but as a starting point in the search for user-centred design. Future designs and studies could be developed by validating the data recommended in the table.

However, some limitations must be taken into account. If a height is not contemplated in the table, choosing the height closest to the most restrictive percentage of users is recommended to protect the user. For example, if the operating table is 72 cm high and an average patient is being operated on with camera conduction, the acceptance rate would be 50%. This is a recommendation based on the principle of user protection to avoid that a system can generate damage and seek to improve the design in favour of workers.

When comparing the height settings of operating tables, the recommendations of the fitting trial were found to be lower than operating tables available in the market (NHS, 2009) and Peruvian operating rooms (chapter seven). The exception was operating tables with 70 cm height, which could be used for camera conduction and transfer tasks but only for thin patients. Thus, the range of the tables would be limited.

Usually, the measures obtained from users' preference methods, such as fitting trials, are not linear or predictable as in static models, so the same person of a certain height may have another height preference (Christiaans & Bremner, 1998). Therefore, the preferences of the extremes may not necessarily be the most extreme but may share common ranges of satisfaction in smaller margins. Garneau & Parkinson (2011) supported this statement, stating that methods focused on user preferences are more accurate and valid for determining a design parameter because they consider human variability.

Castellucci et al. (2020) stated that measurements obtained from anthropometric tables or percentile-based criteria for designing artefacts or products require fitting trials because the theoretical matches do not necessarily coincide with the user's preferences. Similarly, Wiklund & Weinger, (2011) established as a principle of medical equipment design the need for fitting trials due to the complexity of human movement in three dimensions that could not be fully or accurately addressed through anthropometric research analysis. Thus, the final results may better represent the real height needs based on the surgeon´s preferences than anthropometrical projections.

Finally, with these results, we can begin to develop possible solutions to help redesign the laparoscopic work system in the Peruvian medical population and at the international level due to the variability of the sample and the elements of the system considered. Using these measures with caution is suggested, not assuming them as a fixed reference but as a starting point for the design process.

9.4.1. Study limitations

The study's main limitation was that the trials were conducted remotely without attending to participants in the laboratory. As explained in the methods section, the Covid-19 pandemic restricted in-person participation due to the high probability of contagion.

The protocol changed to be carried out remotely. However, remotely applying psychophysical studies is not a new topic in the literature and has been accepted due to its high reliability (Li et al., 2018, 2020; Reinecke & Gajos, 2015). The difficulty in many cases was recruiting participants who accomplished the inclusion criteria and were available to participate, especially when the pandemic was worsening in Peru. For this reason, the study took seven months to complete the required sample size.

The study adopted some measures to reduce possible biases in the results, such as:

(a) The recruiting process was coordinated with the Peruvian Society of Endoscopic Surgery and the heads of hospitals.

(b) Most of the trials were carried out in their hospitals in the training or simulation areas where, as part of their daily routines, they could carry out the trials with the support of a medical supervisor.

(c) Prior coordination and conversation with the trainees (remote) to guide them through the trials and answer their doubts.

Another limitation was the difficulty of simulating tasks considering all the system factors, especially those related to the organization and the environment. In regular conditions, it would have been possible to simulate the task in a controlled environment and control the pauses in trials as proposed in protocol A. However, the factors related to people, tasks and technology were considered within the protocol, and the results represent an approximation of the surgeon´s reality in operating rooms.

9.5. Key Summary

- This chapter finally concludes by answering the research question and establishing recommended regulatory limits considering the analysis of the laparoscopic work system and, above all, the surgeons' preferences.

- Surgeons may accept a specific range of working surface heights to satisfy 90% of the surgeon population work without considering elbow height proportions.

- Recommendations were based on the analysis of the Peruvian work systems by considering the main risk factors evidenced in previous studies. According to the results operating tables should be adjusted for:
  - Intracorporeal suturing tasks: 54 to 71 cm (working surface height: 90 - 91 cm)
  - Peg transfer tasks: 49 -65 cm (working surface height: 95 - 97 cm)
  - Camera conduction: 49 - 71 cm (working surface height: 94-97 cm)

- Intracorporeal suturing tasks demand a lower acceptable working surface height than the camera and peg transfer tasks. Camera assistants demand a similar working surface height to surgeons, so recommendations should be used to accommodate surgeons and assistants as a surgical team.

- The study results confirm the findings of study four (chapter eight), where the recommended working surface heights of 90% were lower than the operating tables available.

- Study results differ from study four, suggesting operating table heights between 49 to 71 cm (22 cm) being higher than recommended in study four (26 to 78 cm). Compared with international standards, the recommended heights for operating tables (49 - 77 cm) in laparoscopic surgery were higher than standards attributing these differences to the use of the psychophysics approach and work system variables.

Chapter 10. Discussion

10.1. Introduction

This chapter summarises the thesis results and discusses the key findings. It also includes the thesis's limitations, sets up recommendations, describes future research opportunities, and ends with the conclusion statement.

10.2. Summary of findings

The first aim of the thesis was to investigate the main factors that contribute to the development of WRMSD in laparoscopic surgeons that have the potential to affect patient safety in Peruvian hospitals using a systems approach based on the SEIPS model. From these findings, the second aim was to propose recommendations for redesigning the work system to reduce the risk of WRMSD in surgeons in Peruvian surgical systems. The following sections summarise the main findings of the thesis in accordance with the objectives proposed in chapter one to achieve the aims of the thesis.

Figure 10.1 summarises the main findings of the different studies using the SEIPS model as a theoretical framework, adopting a pragmatic convergent mixed research design (aim one) and a quantitative design (aim two).

10.3. Discussion of findings

The discussion of the main findings was divided into the analysis of the working system and WRMSD in surgeons and the redesign of the working system to improve working heights.

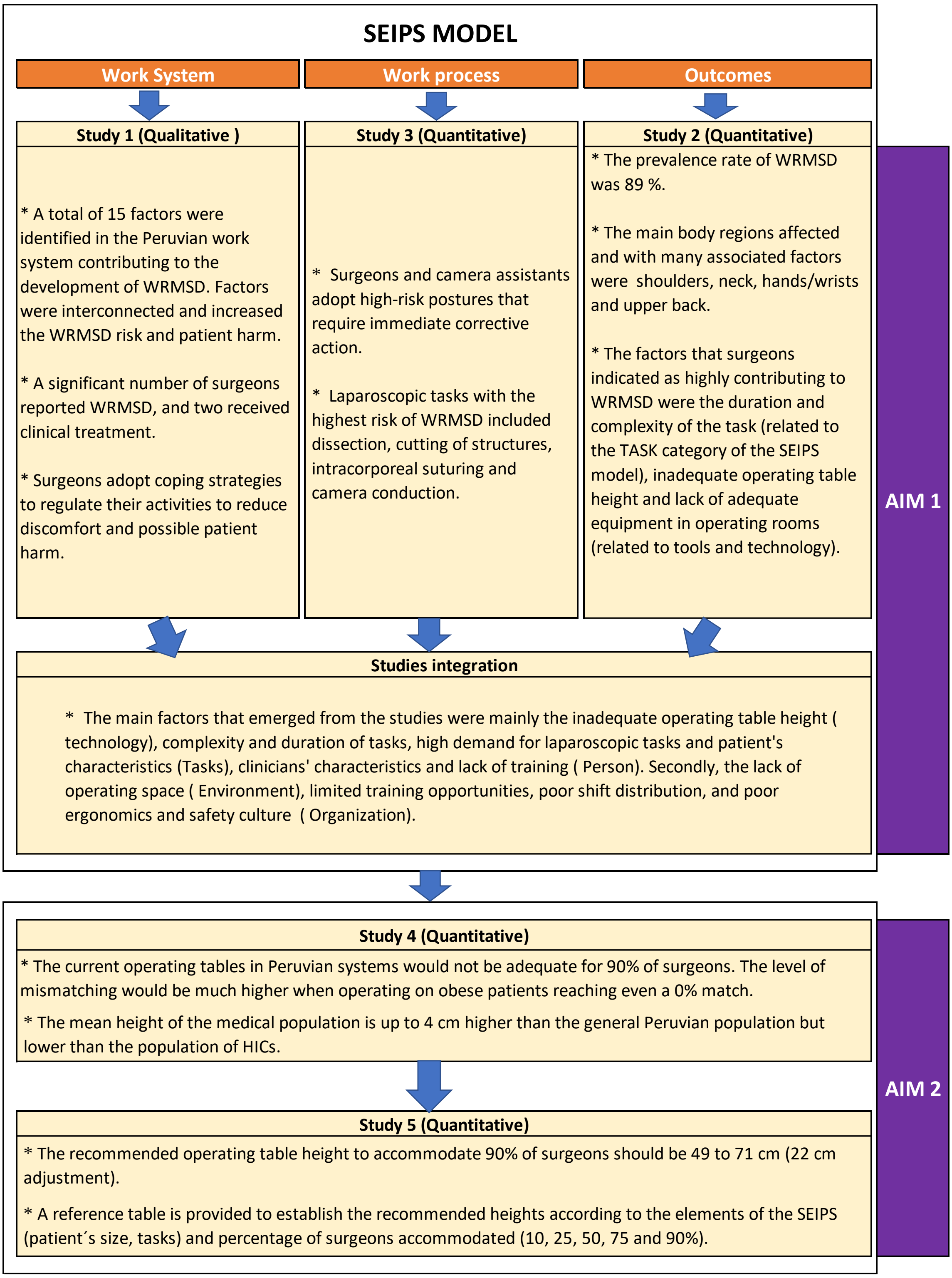


Figure 10.1 Summary of main findings to achieve aims one and two

10.3.1. External factors and factors internal to the work system

Study one identified 15 internal factors and 33 detailed factors within the work system that increased the risk of WRMSD among surgeons and could affect patient safety. These findings confirm many conditions observed in different operating rooms in Perú, which impacted surgeons, surgical teams, and patient safety (Condori, 2018; Defensoría del Pueblo, 2019; Nogoy et al., 2021). These studies revealed the limitations and deficiencies of the Peruvian system in terms of organization, technology, environment, and people showing similarities with those reported in the first study. However, this reality is not only Peruvian but also evidenced in other LMIC hospitals. For example, in Ecuador, Ordóñez-Ríos et al.(2019) conducted a baseline study on ergonomics in laparoscopic surgery, finding a mismatch between equipment and surgeon characteristics that increased the rate of WRMSD.

Likewise, countries in Africa and Mongolia with extreme poverty levels showed deficiencies in implementing optimal laparoscopic operating rooms (Bendinelli et al., 2002; Teerawattananon & Mugford, 2005), which were similar to the thesis findings. For example, among the main limitations were lack of adequate equipment, reuse of surgical equipment, lack of training of surgeons, operating rooms not prepared for laparoscopy, and limited budgets to cover the population's health in urban and rural areas. Similarly, the findings of study one revealed that surgeons were reusing surgical tools due to a lack of availability to acquire suitable surgical equipment, lack of medical education, and operating rooms were deficient in terms of space, among other factors. However, in the Peruvian case, the root of the problem lies in the inequity of healthcare services, the lack of investment in healthcare, and, unlike countries of the region, the healthcare system fragmentation (Aceves-González et al., 2021; WHO, 2020).

Only to give the reader an idea of the disparity in the regions of Peru, the most representative hospitals and clinics in the country are located in Lima, and many of them are already implementing modern laparoscopic surgery stations and even thinking in the medium term in robotic laparoscopic surgery (Cornejo et al., 2019; Gobierno del Peru, 2017; INEN, 2019). Therefore, the country's external environment plays a crucial role in understanding the dynamics of the factors evident in the laparoscopic work system.

The external environment incorporates the macro level, which includes social, economic, ecological, and political factors that in some way impact globally on the work system (Holden et al., 2013). Thus, the problem from the SEIPS model would start from the external environment and not internal to the work system.

Despite the external contextual deficiencies, this does not mean that it is impossible to intervene at the micro or meso level of ergonomics; on the contrary, it is mandatory to make internal changes. However, in order to propose solutions, it is necessary to take into account the context and the real environment in which they are developed, balancing the positive and resilient aspects of the system to compensate for deficiencies by achieving a harmonious balance between the several factors of the system (Carayon et al., 2006; Smith-Jackson et al., 2013). Thereby, the thesis provides a comprehensive framework of analysis based on the SEIPS model to understand the dynamics of the real working system of laparoscopic surgery and provides specific recommendations to address the problem of working heights, taking into account the working context of Peruvian surgeons. In addition, it offers a range of possibilities for other researchers to consider the various factors evidenced and find solutions to reduce the musculoskeletal overload of surgeons and thus safeguard the safety of patients.

Finally, although the thesis findings are about the Peruvian context, this does not limit the possibility of extending many of these issues to other LMICs that share similar socio-cultural and socio-economic levels as those of the Latin American region. Hence, many of the findings and recommendations as a result of the thesis could be helpful in other regional countries.

10.3.2. Transfer technology process

The transfer of technology to LMICs requires rationally selecting technology based on the destination, adapting the technology to the destination's socio-economic context, providing training to use the technology, and preparing the environment for the changes precipitated by the new technology (Shahnavaz, 2009). Many equipment, instruments, clinical guidelines, and surgical procedures are acquired from HICs without a responsible technology transfer process (Scott, 2009). Thus, technology transfer issues can increase the mismatching of the user population with the technologies and may increase the amount of biomechanical stress on joints and muscles, contributing to an increased risk of WRMSD (Dianat et al., 2018; Kushwaha & Kane, 2016). Several examples were cited across the studies, such as restriction of operating table height adjustment, lack of screens, and use of unsuitable equipment in surgery.

However, the development of technology transfer processes in Peru is still incipient, and the conditions to develop it are limited (CCL, 2019; CONCYTEC, 2016). Peru currently has technology transfer policies regulated by law (INS, 2010) but not fully applied to all processes due to the extensive logistics and deployment required for their application. This problem is relevant to Peru because almost 98% of its medical equipment is imported, of which 68% is practically obsolete or deficient in healthcare centres (CCL, 2019). These deficiencies and mismatch issues were confirmed in studies one and four, where much of the medical equipment was inadequate, had faults and wear and tear that often had to be adapted, and even the design of many tools was not prepared for surgeons' characteristics.

Thus, in order to achieve an efficient technology transfer process, it is necessary for medical equipment design and manufacturing companies to have sufficient information about the different contexts to create technology and processes that are appropriate to the reality of each context (Shahnavaz, 2009; Smith-Jackson et al., 2013).

Despite the differences, many of the studies developed in HICs may serve as key references to optimize the systems in Peru, based on an experiential learning approach adapting them to Peruvian needs and the available resources (Alfa-Wali & Osaghae, 2017; Chinelli & Rodriguez, 2018; Scott, 2009). By, sharing mutual experiences facilitates the exchange of knowledge in such a way that designers and manufacturers of medical technology in HICs could adapt their products to local needs and ensure safe technology transfer processes (Shahnavaz, 2009). However, the technology transfer process should not be limited to relying only on foreign manufacturers to transform the actual work but also on the strength of each locality based on its context.

In Peru, numerous isolated proposals developed through national manufacturers have innovative projects based on the country's reality, many related to laparoscopic surgery. Surgeons in study one stated that these initiatives are growing in Peru but are limited and still not widely accepted by the medical community. For example, small companies develop low-cost simulators for laparoscopic techniques based on local research and international experience. Similarly, non-governmental organizations in Peru, such as CEPCEA, make medical education in laparoscopic surgery accessible to Peruvian physicians without participating in expensive international training (CEPCEA, 2021).

Another technological initiative from a Peruvian university proposes the development of robotic laparoscopic surgery with local resources in the medium term (Universidad de ingeniería y Tecnología [UTEC], 2020). Therefore, working with local universities and institutions could facilitate the development of technology and local knowledge relevant to Peru's needs and meet the immediate needs of the healthcare sector. However, one issue to be faced is the articulation between local knowledge of reality and the context in which they are developed.

At this point, ergonomics is fundamental because it facilitates the articulation process between science, technology, users, and context. Hence, the thesis findings could be beneficial for future studies focusing on developing technologies, improving techniques, and proposing solutions to the problem of laparoscopic surgery in Peru and LMICs.

10.3.3. Coping strategies and adaptative behaviours in laparoscopic surgery: regulating the activity

In the context of patient safety, coping strategies are defined as deliberate acts committed by patients and healthcare professionals that deviate from or break conventional rules and standards for coping (Santos et al., 2016). From the perspective of the SEIPS model, coping strategies or adaptative behaviours are reactive and usually short-lived responses that are represented as feedback in the work system (Carayon, 2016; Holden et al., 2013). Reactive adaptations have limitations because they usually occur at the activity level per se (work process) and depend only on the surgeons and not the work system itself. If the activity produces excessive fatigue, discomfort, or a painful posture, the operator will adapt his activity to reduce the effort with consequences on himself and the task.

On the other hand, if the activity is stimulating or seems achievable, it will have positive effects that can transform the activity appropriately (Leplat, 2006). These practical solutions are adopted to deal with problems effectively and promptly, often increasing surgeons' physical and mental burden by adopting movement patterns and problem-solving behaviours that increase the overuse of musculoskeletal structures and risk behaviours (Santos et al., 2016).

Through the thesis, several coping strategies adopted by the surgeons to cope with the system's deficiencies were evidenced, which in some way had outcomes that generated fatigue, pain, numbness, and limitation, as well as consequences in the technique used during surgery.For example, the adaptation of the surgeons' posture to reach the working height due to the high operating table heights.

Among the main coping strategies reported was the use of surgical stools to be insufficient to reach the working heights, especially in surgeries with obese patients. Nevertheless, due to this interaction, surgeons also sought new ways of positioning themselves for surgical work by adopting new postures that could reduce the risk of WRMSD. For instance, one surgeon (chapter four) changed from a standing position for cholecystectomy to a sitting position between the patient's legs, also known as the French position (Youssef et al., 2011). This adaptation in the working position occurred due to the surgeon's diagnosis of ankle pain.

However, although it reduced the risk of foot overload, it increased the load on the upper limbs. To reduce this, the surgeon tilted the operating table and rested his arms on the patient's legs to reduce the discomfort. This is an example of how surgeons, in their day-to-day work, must implement strategies to reduce physical overload due to system deficiencies. However, many of these strategies must be devised and validated with patient safety in mind.

For this reason, solutions or improvement plans should be focused primarily on intervening in the work system and in a complementary way to the work process to have sustainable and long-lasting solutions (Holden et al., 2013).

Finally, coping strategies are closely related to the level of training of the surgeons (Santos et al., 2016). On many occasions, the learning curve is inadequate, and strategies can endanger the patient and increase the physical and mental load of the surgical team (Carayon, 2006). Achieving these levels of resolution is not easy, especially when coping strategies have not been successful and generate adverse patient events, constituting a physical and mental burden for health personnel (Mira, 2015; Rinaldi et al., 2016). Thus, the need for adequate training of surgeons to cope safely and efficiently with the demands of the laparoscopic working system becomes relevant.

10.3.4. Camera assistants needs specific training

This thesis found that residents or surgeons trained in laparoscopy do not have specific training in camera conduction techniques, which increases inefficient movements and fatigue, directly impacting the success of the surgery. This is consistent with Alam et al. (2017), who stated that laparoscopic camera assistants do not receive formal training. These limitations could significantly affect the team's dynamics to the detriment of the patient. In study two (chapter five), surgeons reported that the lack of collaboration with the team (34%) and inexperienced residents (44%) were factors that affected surgical performance.

These discrepancies affected team dynamics and may increase the possibility of errors and adverse events due to poor interaction and coordination of the surgical team (Carayon, 2012; Catchpole et al., 2008).The assistant's lack of experience can lead to communication failures with the surgeons limiting the positioning of the camera in the demanded view, making the surgery more physically and mentally challenging for the surgeons (Gilbert, 2009). A surgeon coach explained in study one that in Peru, the training of the assistants is almost non-existent, underestimating, in many cases, the use of the camera constraining the horizon of the surgical field.

One of the main issues in the training of the camera assistant was the conduction of endoscopes with angles from 0 to 45° due to the complex visuospatial challenges demanded, especially in untrained personnel. Poor performance in the conduction in the camera angulation is associated with errors in the horizon, collisions of the instrument, smudges, and failures to achieve a viewing angle (Ganai et al., 2007). This is consistent with the findings found in study one, where errors were evident by poor conduction of the endoscopes, showing a list of errors committed during regular surgeries. In Peruvian hospitals, endoscopes with viewing angles are limited, so assistants must adapt.

The use of 30 to 45° endoscopes facilitates greater visual field and less movement; however, many Peruvian hospitals only had laparoscopes of 0°, which have more limitations to improving the surgical field for surgeons (Alam et al., 2017; Zihni et al., 2016). Hence, the assistant camera plays a role as necessary as the surgeon and is also at risk of WRMSD. The inclusion of ergonomic recommendations for the assistant is necessary for future guidelines in laparoscopic surgery and training in-camera guidance using different types of endoscopes.

10.3.5. WRMSD, surgery culture and patient safety in laparoscopic surgery

Stucky et al.(2018) stated that the surgical culture has historically been self-sacrifice, with surgeons aware of the risks within the operating room and assuming them as part of their regular work. The thesis reported a high prevalence of WRMSD , but very little about reported complications or injuries resulting from poor surgical environments (Davis et al., 2014; Hignett et al., 2017; Sari et al., 2010). Hallbeck et al. (2017) stated that when performing laparoscopic surgeries, surgeons put everything (including pain) out of their minds to complete the surgery to benefit the patient. This is consistent with findings from study one, where only two surgeons reported that they were diagnosed and received formal treatment, whilst other surgeons reported episodes of discomfort and some self-medicated.

The lack of a culture of WRMS injury reporting among the medical personnel makes the identification even more invisible. An accurate registry would help determine the number of surgeons injured and allow for appropriate intervention to alleviate overload in the healthcare system. However, the culture of recording work-related injuries or illnesses, especially WRMSD, in Peru is deficient due to the ambiguity that this entails regarding recording terms and state policies (Jhonston et al., 2018). Other studies recently conducted in Peru confirm many reports of WRMSD exceeding 50% of the population sampled in different occupational risk groups, including healthcare professionals (Cáceres-Muñoz et al., 2017; García-Salirrosas & Sánchez-Poma, 2020; Marsh Rehder, 2019; Villalobos-Tupia & Escobar-Galindo, 2021).

However, in the official data of the Peruvian Ministry of Labor, only two cases were reported in 2020, one of cervicalgia and the other of diseases caused by forced postures and repeated movements at work in the whole country. These results evidenced the underestimation of the real data (Ministerio de Trabajo y Promocion del Empleo, 2020). Despite the problems related to underreporting, they are also accompanied by a lack of awareness of relevant ergonomic issues since many surgeons were unaware of the importance and application of ergonomics in the operating room.

Finally, among the main findings, surgeons were aware that WRMSDs could affect patients' tasks and safety. This was evidenced through the different testimonies and observations made in study one that established the possibility of an impact on patients. For example, one camera assistant had to work with her arms raised, and her trunk bent for almost three hours during the surgery, causing fatigue which made it difficult to focus the camera losing per moments the field of vision to operate. Another surgeon pointed out that the appearance of hand tremors was quite frequent, especially in long surgeries. It was challenging to manipulate laparoscopic tools, especially when performing laparoscopic intracorporeal suturing. These findings are consistent with those of Adams et al.(2013); Esposito et al. (2013), and Ruitenburg et al. (2013), concluding that WRMSDs have a potential impact on tasks and patients.

10.3.6. Operating tables height: issues and challenges

Study four results indicated that practically 0% of Peruvian surgeons could accommodate the typical heights of the tables, mainly when operating on obese patients. The measures found were 49 cm to 71 cm to be acceptable for 90% of the surgical population. Also, the analysis in study five confirmed that no surgeon would accept the preferred measures recommended in the standards suggesting new measures based on the surgeon´s preferences.

Despite the differences, one would have expected preferences for working heights lower than the current ones due to the demands of the laparoscopic tasks, the size of the patients, and the short stature of the Peruvians. However, surgeons preferred to work at relatively higher work heights, which may be related to their level of training, the learning curve of laparoscopic surgery, and risk ergonomics awareness related to posture and strain in surgical work. This is consistent with studies indicating that surgeons generally tend to minimise discomfort to cope with surgery so that their level of effort tolerance may be higher to overcome the risks of surgeries (Dianat et al., 2018; Hallbeck et al., 2017). Therefore, their discomfort tolerance levels may be higher, preferring higher working heights. This could explain why the maximum acceptable operating table height in the study was 71 cm for camera conduction and peg transfer tasks when operating a thin patient, matching the minimum height of some models of operating tables in Peruvian operating rooms. However, the height for operating on average and obese patients demand a lower height that does not fit with any model.

The criteria established in the literature for the design of working heights date back more than 20 years and are currently valid by several authors despite various limitations (Supe et al., 2010; Zachariou, 2019).

The first limitation is that the recommendations were based on anthropometric criteria, which may have a measurement bias due to the secular trend growth of the population (Pheasant & Haslegrave, 2006b). Different studies on HICs, showed positive growth changes, especially in measures associated with height over the last 20 years (Lipoldová et al., 2020; Myburgh et al., 2017). In the case of South America, the population is also growing over the last 20 years. However, it remains lower than the European and North American populations, with Peru being one of the lowest (study four). Thereby, recommendations for measures may not be the same today.

A second limitation is that during the last 20 years, the participation of women in surgery has increased and nowadays reaches up to 32% in the USA, which means an increase of more than 20% during the last 12 years (Association of American Medical Colleges, 2008, 2020). This increase in Peru is not as drastic as in HICs but is significant compared to the current reality. Twenty years ago, the presence of women in the operating room was minimal; today, it reaches 12% in general surgery specialities and 26% in gynaecology (Quispe-Arminta & Shu-Yip, 2021). The increase of women in operating rooms has generated anthropometric normality curves related to working heights widened in terms of standard deviation due to the smaller height of the female population, which could increase the possible ranges of adjustment (Pheasant & Haslegrave, 2006c). This finding was evidenced in study four, where the Peruvian population has a higher standard deviation in their anthropometric measurements of height and is shorter than the population of HICs.

Finally, a third limitation is that they do not contemplate a systems approach in their analysis, which, unlike the other studies, the present thesis took into account. Dul et al. (2012) established as a principle of ergonomics to consider work as an integrated system of interconnected factors. Therefore, the results of study five allowed a better approximation of the ranges of adjustments considering the limitations of the system and the surgeons' preferences as a basis for establishing adequate working heights.

10.3.7. Considerations for the redesign of operating tables

As explained in chapter two, operating tables have tilt and lateralisation adjustment systems that permit positioning patients depending on the type of surgery. Suppose the surgeon needs to tilt the patient in Trendelenburg to 20° as is usual in cholecystectomies (Sandoval-Jimenez et al., 2009). In that case, the side of the table that tilts towards the floor will likely be about 38 cm from touching the floor if the table were to maintain the standard minimum height of 70 cm. Nevertheless, if the minimum height recommended in study five were to be followed, then the missing height would be 17 cm, close to touching the floor.

If the tilt angle is 30°, as in inguinal hernia repair surgery (Adorno et al., 2017), and the minimum height recommended is 49 cm, then the lowest height end of the table would be 1.5 cm above the floor. Thus it would be practically in contact with the floor, putting the table's sterilisation at risk (Matern et al., 2001; Mullaney, 2008). In addition, the surgery would be more challenging for surgeons due to the tilt restriction of the operating table.

Therefore reducing the table height to the recommended height might be unfeasible, considering the height and tilt dynamics in the operating table.

On the other hand, the patient's size should also be considered in the possible design. The higher the patient's abdomen height, the greater the challenge for the surgeon because the working height will be greater and demand a lower working surface height (study four). Therefore, the table would require a lower working height that, added to the need to tilt the table due to the nature of the task, would increase the risk of operating table contamination. However, maintaining current working heights with obese patients increases the risk of WRMSD in surgeons with possible consequences of patient harm (Hignett et al., 2017; Sers et al., 2021). This is consistent with the findings in the different studies of the thesis, which revealed a higher risk of WRMSD (studies one, two, and three) and a lower need for working height (studies four and five).

Finally, in economic terms, an operating table is quite expensive, reaching approximately £30,000 or $40,000 with an average life of 10 years (MEDITEK, 2009).

The estimated maintenance and repair cost, including the technician's professional fees, would be approximately £31,628.96 (NHS, 2009; *NHS employers*, 2009). These data are relevant since if it is decided to redesign the operating tables and adjust new heights or add special systems to the operating tables; it will imply that the hospitals would assume new costs within the surgical systems. In addition, the tables would have to be functional to operate in the various specialities and not only apply laparoscopic surgery. Therefore, this solution would be complicated to be applied in Perú and LMICs, mainly due to the deficiencies of the healthcare system's environmental, economic, social, and cultural context (Aceves-González et al., 2021).

10.3.8. Surgical stools and redesign of working heights

Numerous stools are designed for operating rooms with specific characteristics that vary in design, size, height, adjustability, support capacity, and cost. However, most were designed to be used in open surgery and not necessarily in laparoscopy. The size of the most common surgical stool has, on average, 30 x 35 cm (1050 cm^2) of surface and 12 to 23 cm of fixed height, while the stools specially designed for bariatric surgery have ranges of 36 cm x 54 cm (1944 cm2) with a height of 16 to 20 cm, so they are more rectangular.

The size of the support base of a young adult standing person is 961 cm2 (25.2 x 38.1), while that of an older person is 987 cm2 (25.2 x 39.2), taking into account the length of the foot of a p95 male person (Castellucci et al., 2019; Tomita et al., 2021). Thus, the support space of the first stool would be very restrictive and limited, while the second alternative would be more feasible in size. Both stools would be limited if the foot pedal had to be added to the surface, which would be restrictive, losing the ideal support base to work with. This forces surgeons to work without the stool when activating the foot pedals or placing them on the surface, reducing the space to work on the stools. This lack of space causes instability and altered posture, generating a more significant overload on the upper segments and trunk (Tomita et al., 2021). This was evidenced by the surgeons' testimonies and observations in studies one and three.

The literature reports several attempts to design possible stools for laparoscopic surgery that facilitate surgeons to reach acceptable heights. Hu et al. (2013) developed a prototype of an adjustable platform based on the problem of the working heights in laparoscopic surgery. This platform had a 45 x 55 cm space, an adjustment system from 20 to 50 cm, and external space to place surgeons' foot pedals. However, the minimum height of the device was 20 cm and cannot be reduced due to the regulation system used. In addition, the authors refer to oil contamination issues in operating rooms. Finally, the weight of the stool is relatively high, making it difficult to store or move it inside the operating rooms, especially in Peru, where operating rooms are regularly small.

Another stool design was proposed by (Lee et al., 2017) in Korea, which consisted of a height-adjustable stool using a lateral screw adjustment system and snap-joint systems to place foot pedals. However, it is still developing, so a physical prototype is not yet simulated.

Further studies could include the development of low-cost, functional prototypes of surgical stools that follow the recommendations made in the study and facilitate the work with the camera assistant and surgical team.

10.3.9. Reflections about Remote fitting trial as a valid research method

Compared to traditional experiments in which participants had to attend laboratories to complete the tests, online psychophysical experiments have started to be developed and offered through different platforms that allow recruiting a large number of participants with specific criteria (Li et al., 2018; Reinecke & Gajos, 2015). The results of these experiments are highly reliable and comparable with the results of psychophysical experiments done in the laboratory, being the most developed in the field of behavioural experiments and reaction times (Barnhoorn et al., 2015; Germine et al., 2012; Li et al., 2020; Simcox & Fiez, 2014). Although the reported studies were not about working heights, such as those developed in study five, they kept the essence of fitting trials. This essence is grounded in the possibility of participants making judgments based on their experience and perception by repeatedly adjusting the stimulus to find the preferred measure (Fox et al., 2017; Pheasant & Haslegrave, 2006c; Sharples & Cobb, 2015). Thus, remote self-reports are useful since participants can choose the best working height based on their experience as laparoscopic surgeons, maintaining the essence of fitting trials and adequate levels of reliability.

Remote self-reports have also been widely used in anthropometric data collection for ergonomics. Several studies use self-reporting techniques to meet the demand for relevant anthropometric information from populations and groups, especially when difficult to access. The main key to successful anthropometric collection is establishing a methodology containing clear and accurate information so that participants understand the objectives (Gyi et al., 2019). For this reason, study five outlined a protocol and a detailed guide so that participants could perform the tests in a simple and user-friendly way by presenting the information step by step without overloading them. Due to the limited time surgeons had to participate in the trials, the trials did not have to be very long, so time proved to be an essential variable.

Although the results of the remote fitting trial conducted in chapter nine were different from the recommendations of other studies, they were consistent with those of study four and other studies in the literature on HICs that concluded the need for lower working heights than the current ones (Berquer et al., 2002; Van Veelen et al., 2002). In addition, the lowest working height in the remote fitting trial was obtained when simulating intracorporeal suturing tasks in obese patients, similar to Matern's results (Matern et al., 2001). Therefore, the remote fitting trial results show a level of external validity that could be generalisable to the surgical population.

10.4. Recommendations

The recommendations were divided according to the categories of the SEIPS model by setting out general strategies for work improvement in each element of the system.

Person

- ✓ Develop specific medical surveillance programs for surgeons to identify potential musculoskeletal injuries requiring medical treatment. Specific strategies should be developed for surgeons and assistants to report WRMSDs on a recurrent basis and follow up so they can be treated promptly.

Technology

- ✓ Design a low-cost system accessible to optimize working height adjustment for surgeons and assistants. The main characteristics would be:
  - A height system to adjust the working height between 10 cm and 30 cm. If surgeons require a lower height than 10 cm, the height of the operating table will be adjusted to the desired height. It is suggested not to increase the working height of the stool by more than 30 cm as this could lead to instability and a risk of falling, as stated in the study.
  - The minimum surface area would be 987 cm2 (25.2 x 39.2 cm), taking into account the length and width of the foot of an adult male in the 95th percentile. It must include a surface for the foot pedal that should be at least 25 x 15 cm. Another recommendation is to include an automatic adjustment or stacking system to facilitate storage when not in use.

Task

- ✓ Include the possibility of microbreaks in the surgical work to reduce the prolonged exposure of surgeons, especially in complex and long-lasting surgeries. The literature states that surgeons could take two-minute microbreaks at 20-40 minute intervals (Hallbeck et al., 2017). However, this option should be given depending on the complexity and duration of the surgery.

Organization

- ✓ Develop local training programs in laparoscopic surgery using simulations and deconstructive learning to acquire the necessary skills embedding ergonomics as formal training. It must include camera training.
- ✓ To develop practical guidelines on ergonomics in laparoscopic surgery based on local needs.

Internal Environment

- ✓ Organize the working environment to avoid confined spaces or obstacles that make it difficult for surgeons to move and position themselves in operating rooms. This should include space not only for the surgeon but also for the surgical team. Checklists can be included to establish whether the equipment is correctly distributed and spaces are sufficiently free to operate.

10.5. Limitations

In qualitative study one (chapter four), snowball sampling was used to select participants who may have reduced the diversity of the sample. However, this was compensated for by purposive sampling to select the most representative Peruvian hospitals, including one of the regions. In addition, this study may have had some bias during participant observation in the operating rooms due to the Hawthorne effect (Bridger, 2018b), which could have changed the behavioural pattern of the surgeons. However, the researcher reduced this possibility by avoiding interrupting surgeries, not bringing complex equipment into the operating room that could have caused surgeons to lose their attention, and reducing their participation to a minimum.

The questionnaire-based survey in study two (chapter five) was addressed to the surgeons, not the assistants conducting endoscopes. Although part of the survey addressed teamwork issues, the use of an endoscope was not mentioned among the factors. Therefore, the possibility of including specific questionnaires for assistants should be considered for future studies considering that assistants usually are not necessarily surgeons. They can be residents, medical students or physicians.

On the other hand, although in a self-reported questionnaire, participants have time to think about their answers and submit them at a given time, there is a risk that they may not reflect reality and therefore have the possibility of bias (Robson & Mc Cartan, 2016c). However, several studies have pointed out that self-reported surveys have similar results to expert examinations regarding the presence of WRMSD (Perreault et al., 2008; Takekawa et al., 2015). In addition, chapter seven states that the questionnaire results are consistent with the testimonies and observations addressed in studies one and three.

In chapter six, the RULA method could not consider specific working environment factors such as slippery floors, which could increase postural instability when operating. In addition, the lack of space or poorly arranged equipment in several operating rooms made it challenging to position the cameras and tripods, limiting postural observation and thus reducing frames. This could have limited the observation of relevant postures.

The main limitation of study four (chapter eight) was the use of static protocols using the method of limits to make recommendations. In order to reduce the possibility of error in the final recommendation, it was decided to complement the results with the following study involving fitting trials.

The protocol developed to implement the fitting trial in chapter nine was changed to a remote protocol due to the covid 19 pandemic. Despite being a limitation, this limitation represented an opportunity to experiment using technological resources and to test the possibility of applying psychophysical experiments on working heights remotely.

10.6. Future research opportunities

The thesis opened up various possibilities for investigating the problems in Peruvian laparoscopic surgical systems.

Chapter four lists the 15 factors contributing to the development of WRMSD and how they interact with surgeons. Although the height of the operating tables was the main problem, other relevant factors, such as the lack of surgical equipment and the height of the screens, were also mentioned. Likewise, microbreaks during surgeries are accepted strategies with the possibility of implementation in the short term; however, it is necessary to establish precise frequencies and procedures. Future studies could focus on how these factors interact and may influence surgeons and patient safety and what redesign proposals could be made considering the Peruvian systems' external factors.

On the other hand, the thesis did not explore the problem of healthcare administrators and logistic managers who are ultimately responsible for acquiring medical and logistic equipment in operating rooms. Future studies should focus on analysing how the system works from the administrators' perspective to understand how the surgeons' needs can be articulated with those of the system.

Chapter eight results provide the first background on anthropometric studies in the medical population by showing a set of practical measures for the design of heights, spaces, and working ranges. Future research may be focused on developing anthropometric studies for Peruvian healthcare workers divided into occupational groups. For instance, medical hand tools (hand measurements), clearance and reach measures in different positions (seated and bipedal), and even for developing clothing and personal protective equipment such as scrubs. It will also facilitate the development of technical norms or standards specific to the population without relying only on international standards, which are unsuitable for the specific population in many situations.

Although the thesis provided recommendations for regulating working heights (chapter nine) and discussed available devices and their possible impact on surgeons, developing prototypes is undoubtedly necessary to solve this problem. Future studies may include the development of low-cost prototypes adaptable to the Peruvian reality to regulate the working heights of surgeons and assistants. This study suggests possible recommendations to develop a surgical stool for laparoscopic surgery

Future studies could also complement the results with a multi-system analysis based on the "patient's journey" through the different work systems to allow a patient-centred perspective throughout the surgical process. For instance, work systems can be analysed from the patient's surgery preparation until discharge. This will facilitate a comprehensive perspective of the problem and perfectly complement the system analysis developed through the different chapters of the thesis.

Finally, future studies may be focused on demonstrating the impact of ergonomics and laparoscopic surgical training in improving the learning curve of surgeons and camera assistants. There is very little evidence on the importance of surgical training using simulation and deconstructive methods in Latin American countries, so it is imperative to create a need to establish specialised surgical training centres for surgeons and assistants.

10.7. Conclusion

The thesis explored the working system of laparoscopic surgeons and identified the main factors that contributed to the development of WRMSD and impacted patient safety. The prevalence of WRMSD among surgeons practising laparoscopy is high and similar to that of industrial workers and was associated with elements of the work system that impact patients. This system forces surgeons to adopt postures that increase the overload of their musculoskeletal system, increasing the risk of WRMSD and the impact on patient safety. Raised operating table heights and factors specific to surgery demands (complexity, duration, and patients' characteristics) were the main factors affecting surgeons, assistants, and patients. Therefore, improving working heights considering the system's elements, including the Peruvian context of surgeries, can reduce WRMSD and improve patient safety. The findings of the thesis suggest that heights should have a minimum setting of 49 cm, which differs from current operating tables, with higher settings increasing the risk of WRMSD. Future studies can build on these findings by considering an ergonomics systems model.

11. References

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12. APPENDICES

12.1. Appendix 1 . Study 1:

Reference formats for semi-structured interviews and participant observation (used only as reference)

INTERVIEWS

What factors do you think contribute to your physical fatigue?

Do you think it affects your surgical technical skills?

Have you been diagnosed with WRMSD or received treatment?

TASKS

What surgical procedures do you think are more challenging to perform?

What activities during surgery is the more challenging? Do you want to explain more about

What are the postures that you usually adopt to operate? What factors do you think may affect your posture?

What about patients? Is there any type of patient more challenging to operate than others? Did you feel pain, fatigue or musculoskeletal disorders when you operated on any patient in particular?

INSTRUMENTS

Tell me please about the equipment. What do you think about the equipment provided by the hospitals?

Did you have problems manipulating the handle to operate? Did you feel fatigue , pain or musculoskeletal discomfort when you use it?

Do you prefer any type of equipment to use when working? Why?

Are available the basic equipment necessary to operate?

The operating table can be adjusted? Do you usually adjust to your height? Do you think it is a problem to be considered?

What about the laparoscope? Do you feel fatigue or pain when use the laparoscope? Do you have issues manipulating it?

WORK SYSTEM

How many cases do you operate in one day? How many of them are laparoscopic surgery? Do you have issues booking surgeries?

Tell me more about teamwork. What about communication and coordination?

Have you received formal training in laparoscopic surgery and ergonomics? Tell me more about your training . Have you heard about ergonomics?

ENVIRONMENT

What do you think about the operating room space in your hospital to perform laparoscopic surgery ? Is that correct? What about the lightning and noise in the OR ? Is that ok?

The limitation in the space have affected your posture or contribute to pain and WRMSD

PERSON

Do you have WRMSD symptoms (ache , pain , discomfort in segments) ? Could you tell me what segments? What activities in the surgery increase your MSD discomfort?

Tell me about the errors and events adverse that occurred in surgeries. What type of errors is most common? Are these errors related to fatigue, pain or musculoskeletal discomfort? Some errors had severe complications for patients?

Do you have some restrictions to operate?

12.2. Appendix 2. Study 1: Participant observation format

OBSERVATIONS IN THE OPERATING ROOM

Observation N° : …………………………………… **Date:** ……………………………….

Hospital : ……………………………………………….. **Surgery:** ……………………………………..

Number of participants: …………………………………… **Surgeon code:** …………………………….

Time: ………………………….

Guide of observations (just as a reference)

The environment of work :

Organization and layout :

Instruments used for surgery :

What instruments demand more effort? Is that common or frequent?

Task complexity: what tasks are complex

Is the operating table regulated? Working well?

Monitor display location

Foot pedal, where is located? Hand switch

Electrical instruments state

Use of instruments in the task

Description of tasks

Duration of the tasks

Postures adopted and position of surgeons

Teamwork

Use of gloves (glove size used). How many gloves?

Temperature and air quality of the place

Noise and lightning

12.3. Appendix 3. Study 1 and 3: Consent Form

Consent form

Participant ID:

My name is Manuel Escobar, a PhD student in Human Factors at the University of Nottingham. I am carrying out a study aiming to identify work-related risk factors in the operating that can affect your performance and physical health. This study will not interrupt your regular activities, you will be free to work without pressure of any kind, and you are free to withdraw from the study at any time

Please tick to confirm the following:

- ☐ I have read and understood the participant information sheet
- ☐ I have had the opportunity to ask questions
- ☐ I agree that the proceedings may be filmed for the envisaged investigation.
- ☐ I understand that my participation is voluntary
- ☐ I understand that I am free to withdraw from the study at any time
- ☐ I understand that anonymous data will be stored for seven years and will be used in academic dissemination materials such as journal articles and conference presentations, which may be publicly available
- ☐ I agree to participate in this study

Signed: ……………………………………………………………

Name: ……………………………………………………………

Date: ……………………………………………………………

If you have any questions, please contact to my email: manuel.escobar@nottingham.ac.uk or PhD supervisor Dr Sarah Atkinson (sarah.atkinson@nottingham.ac.uk) from the Human Factors Research Group, Faculty of Engineering.

12.4. Appendix 4 . Study 1 and 3: Participant information sheet

Participant Information Sheet – Sugery observations

My name is Carlos Manuel Escobar Galindo and I am PhD. Student at The University of Nottingham.

As part of my PhD, I would like to invite you to participate in this study. Before you start, you must understand why the research is being done and what will be involved. Please take some time to read through this information sheet carefully and ask questions if anything is unclear or if you would like more information.

Purpose of the study

This study aims to identify ergonomic risk factors in the operating room that increase the physical workload and affect the surgical technical skills of laparoscopic surgeons in Public Hospitals in Peru. The methodology includes observing the whole surgery from the beginning to taking notes about the different factors evidenced during the surgery that can be included according to the aim of the study. A video camera will be used to film the surgery and register all the factors or events that could not be evidenced during the observation. The video will be processed only for the researcher and will not be shared through any media. Your names and faces will be protected. The main focus of the research will be the surgeons' activities and possible factors affecting their work. Data of patients will not be required

What will happen if I decide to take part?

If you agree to participate, I will give you full instructions. You will also be given the opportunity to ask any questions. You may ask questions at any time if you do not understand anything.

What will happen to my information?

All information provided will be kept stored on a password-protected computer.

It will be deleted seven years after any work publication, per the university data storage policy. Your name (i.e. signature on the consent form) will be kept separate from the observations made during the surgery. Consent forms will be stored in a locked filing cabinet for the duration mentioned above. A code will be assigned for each participant, just for analysis purposes, in the event that the information is stolen, lost, etc.; the code assigned will prevent anyone who views the data from determining the participant

The information that I collect during this project will be used to inform my design. Your name will not be used in association with the data. At the end of the study, the data will be stored for up to 7 years, after that will be deleted

What will happen if I don't want to carry on with the study?

You can withdraw from the study at any time without providing a reason. If you withdraw, any information you have collected will be destroyed and will not be included in the study. You also do not have to answer any particular question.

Will my taking part in this study be kept confidential?

Yes, you confidentiality will be protected in this study

Who is organising and funding the research?

This research is being conducted as a PhD student project at The University of Nottingham.

Who has reviewed the study?

This study has been approved by one University of Nottingham Faculty of Engineering Ethics committee.

Whom do I contact if I have questions or require further information?

If you have any questions or concerns about the study, please contact:

CARLOS MANUEL ESCOBAR GALINDO
Human Factors Research Group
Faculty of Engineering
University of Nottingham
NG7 2RD
Email: manuel.escobar@nottingham.ac.uk
Telephone number : 994391336

Supervisor (s)
Dr. Sarah Atkinson
Human Factors Research Group
Faculty of Engineering
University of Nottingham
NG7 2RD
Email: sarah.atkinson@nottingham.ac.uk

UNITED KINGDOM · CHINA · MALAYSIA

Participant Information Sheet- Semistructured interviews

My name is Carlos Manuel Escobar Galindo and I am PhD. Student at The University of Nottingham.

As part of my PhD research , I would like to invite you to take part in this study. Before you start it is important for you to understand why the research is being done and what will be involved. Please take some time to read through this information sheet carefully and ask questions if anything is unclear or if you would like more information.

Purpose of the study

The aim of this study is to identify the ergonomic risk factors in the operating room in Public Hospitals of Peru. The work methodology involves undertaking a semi-structured interview with laparoscopic surgeons. Questions are related to your experience in surgery and the possible ergonomic risk factors present. The entire interview will be audio recorded and later transcribed for the purpose of analysis.

What will happen if I decide to take part?

If you agree to take part, I will provide you with full instructions. You will also be given the opportunity to ask any questions. You may ask questions at any time if you do not understand anything.

What will happen to my information?

All information provided will be transcripted and keep it stored on a password protected computer. It will be destroyed seven years after any publication arising from the work, in accordance with the university data storage policy. Your name (i.e. signature on consent form) will be kept separate from the observations made during the surgery . Consent forms will be stored in a locked filing cabinet for the duration mentioned above.

What will happen if I don't want to carry on with the study?

You can withdraw from the study at any time without having to provide a reason. If you do withdraw, any information that you have collected will be destroyed and will not be included in the study. You also do not have to answer any particular question.

Will my taking part in this study be kept confidential?

Yes, you confidentiality will be protected in this study

Who is organising and funding the research?

This research is being conducted as a PhD student project at The University of Nottingham.

Who has reviewed the study?

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12.5. Appendix 5. Study 1 : General and detailed factors in the laparoscopic work system

SEIPS category (elements)	Subcategory (factors)	N°	Detailed factors (barriers)	Examples
People	***1. Clinicians´ characteristics***: physical and mental characteristics of surgeons and assistants that could impede their work	1	Different statures of surgeons and assistants	"The size influences a lot, and just a few (surgeons) realize of that"(I-13); ... "if he were of 1.80m tall, that would be another story, but we have to be realistic." (I-16)
		2	Surgeons and assistants are overweight	"The stature influences a lot, and few realize it." (I-13)
		3	Advanced age of surgeons and assistants	
		4	Sensorial issues, including poor vision and the use of bifocal glasses	“Surgeons wear bifocal glasses and keep an extension posture of the neck for a long time ….”. “screen is placed far from the surgeons stimulating to take the neck and trunk forward.” (S-15)
	2. The surgical team have inadequate or insufficient knowledge of LAPS: inadequate or insufficient skills and knowledge of laparoscopic techniques due to issues related to poor training	5	Inadequate and/or insufficient training in LAPS and ergonomics	"There is no surgeon who does not know how to tie a knot, in LAPS, it is the last thing we learn to do, and there is much that they never learned intracorporeally, that is, in the belly, so in Peru LAP surgery is being taught in the patient's belly and very little in the laboratory when it should be 95% in the laboratory and 5% in patients ... "(I-13)
		6	Surgical staff´s lack of experience and skills	

	3. Teamwork issues: difficulties in the collaboration, communication, coordination, interaction and resolution of conflict among team members	7	Poor communication among surgical team members	During the surgery: "The surgeon again asked the nurse for tools and anticoagulants, and she told him that they were not available because she forgot to ask to the logistic area. The surgeon said, " these are the problems when you do not work as a team ".... After that incident the communication was minimal .... "(S-05).
		8	Coordination before and during surgery is not assertive, and support among members is limited	"The scrub nurse did not have enough space to assist the main surgeon, and she had to lean the trunk in a limited space between the resident and the support table. The space was not well delimited for lack of coordination since the beginning."(S-05)
	4. Patients' characteristics: physical features of patients that may change the task's demands and increase the surgeons' and assistants' burden	9	Shape and size of patients (obese, adult or child)	"...When we have super obese patients even though the table is down to the floor, the patient has an abdomen like this (makes the gesture of an obese person) then piña (an expression to refer there is no option) we have to work like this…its harder when the patient is chubby."(I-01)
		10	Anatomical variants that change the normal procedure	
Tasks	***5. Long duration and complexity of surgery:*** prolonged time to complete LAPS, usually longer than two hours, and related to complex surgery, acute or specialized treatment	11	The complexity of LAPS depends on the patient's status and job demands	"... when we stand for a long time, I felt discomfort on my feet. In the morning I have been since 8 am to 1:30 pm stood, standing one hour, standing two hours, standing 3 hours...it fatigued and hurt.."(I-14)
		12	The operation may last longer than planned due to surgical complexity and other systemic factors	
	6. Laparoscopic surgery demands and workload: the effects of the demands of direct and indirect laparoscopic tasks on the surgeon's and assistants' workloads as a result of the interactions between	13	Highly skilled tasks that demand specific tools, techniques, coordination and perceptual skills that turn complex surgery (such as suturing and knot-tying)	"During the cutting of structures, it produced bleeding which is controlled by cauterizing the surrounding structure and taking time in a task that should have been shorter."(S-05)

	the elements of the Peruvian operating system	14	Unexpected situations during surgery (such as surgical complications and unexpected events)	
		15	Laparoscopic tasks shared with assistants that demand specific skills (such as laparoscopic camera conduction, positioning the camera in the surgical field, the lack of guidelines on the screen and holding the camera still)	“The camera assistant has complications with seeing the screen because his visual field is covered by the assistant with his body (especially the arm). So it is very difficult to see the objective; on several occasions, it implies that you have to lean to be able to aim the camera."(S-10)
		16	The location of LAPS changes the position of surgeons and assistants. French position (between the patient's leg), American (standing patient's side) and others (contralateral, etc.)	"In my case, the French position (between the patient's leg position) is more anatomical. I can see the structures, it seems more familiar to me, but the American style is not comfortable because I look like a bullfighter(torero) working at the side of the patient... Instead, in the French position, you are in the middle of the patient and cover the gallbladder frontally..so I may work with laparoscopic triangulation "(I-10).
Technology and tools	***7. Poor design of tools and surgical equipment:*** issues related to the design and usability of surgical technology that may affect its use and efficiency during tasks	17	Design restriction of surgical tools	A female surgeon: "all these devices are designed for male hands, and I have a small hand, I am six and a half glove size, and for example, my assistant is seven and a half (size), so for him is easier to move the instrument and make the suture... in reality for any man who has a big hand, not for me"... " (I-11)
		18	Mismatch issues between tools and technology (for example, operating tables with poor adjustability to fit surgeons and assistants, different handle sizes and shapes of surgical	

		tools, screens with fixed heights and inadequate positioning)	"As a surgeon, I tell you another factor, everything comes standard, but there are different hands in surgeons, thick hands, thin hands, rough hands ... and graspers (handles) come standard, the women are thin, the graspers are too big you have to do exaggerated movements to be able to manipulate them well ... graspers are not tailor-made so ...there are some(surgeons) that have more facility because they are standard but for those who have fat or wide hands they do not fit and squeeze ... tools do not come to the size."(I-17)
8.Lack of Availability of suitable tools and equipment: lack of available surgical tools and the necessary technology to operate when is required	19	Use of unsuitable equipment in surgery or use of the equipment and/or instruments with features that are not the best suited to a specific task (for example, the use of graspers with a ratchet system instead of a free ratchet system, or the use of instruments to grasp general structures instead of instruments for grasping bowels)	"They should not give us dissectors(organization) with ratchet system, because the ratchet makes you have a greater effort on your fingers… with dissectors you have to open, close.The only tool that should have a ratchet and it is not a requirement either, is the tool that the doctor had because she only grabs structures, not need to move it... Instead, we need to use both hands, not need to be locked." (I-01)
	20	Insufficient surgical tools and technology in the OR (such as an insufficient number of screens for clinicians)	"Assistants and surgeons see the same screen because there is no other one available. Assistants rotate and extend their necks to see the screen." (S-02).
9.Poor state of equipment in operating rooms: equipment and/or surgical instruments stop working in surgery or produce issues during use	21	Damaged systems and equipment that fails during LAPS	"Several times the body of trocars are broken ...., and then the pneumo is lost and delay the surgery. Many times, we delay in the surgery because there was no good retention of co2." (I-05) "Sometimes graspers can also be a little harder, more

		22	Signs of wear and tear on equipment and/or surgical instruments that impede the performance of tasks; instruments require more exertion to be used	rigid, and that makes one exert much pressure with the fingers and adopt a movement of the hand that sometimes remains painful, the thumb, the index, even more, when it is a short-term surgery."(I-06)
Organization	***10. Poor ergonomics and safety culture:*** issues related to the lack of patient safety and ergonomics culture in operating rooms that affect the communication and preventing strategies	23	Hierarchical, top-down system	"Unfortunately, this eh, we depend a lot on a budget but a budget that is not handled by the doctor…. it is handled by an administrator who does not, who sometimes does not understand medicine ... Then he does not understand our requirements, prioritizing other things that are not necessarily a priority."(I-11)
		24	Limited efforts to identify and mitigate ergonomics and patient safety risks	"We have a lot of ergonomic errors, so look, I would say that 95% of surgeons have permanent ergonomic errors from standing, neck position, monitor heights…but hospitals seem not to care to improve this situation."(I-13)
	11. Limited education and training opportunities: lack of adequate training policies in LAPS techniques related to physical laboratories and strategies to improve the surgical team's training	25	Lack of adequate training policies	" There are no trained surgeons(coaches) in LAP surgery ..., it is not only about centres but also about teaching surgeons; to do it, you have to know how to do it. It's not only about to try to do it, I know how to teach, but they are also taught not to commit errors, and they are taught so that everything goes well..."(I-13)
		26	Lack of physical spaces prepared to offer LAPS training with the appropriate teachers	

	12. Poor organization of surgeries: difficulties surgeons experience in controlling the number of patients and complexity of surgeries scheduled in their working day	27	Lack of control over the pace of work; surgeries scheduled without sufficient rest in between	"After three and a half hours to perform bariatric surgery, surgeons and assistants took a 30-minute break and prepared to perform a second bariatric gastric bypass surgery." (S-12)
Internal environment	***13. Deficiencies in environmental system regulation:*** issues related to the mechanisms managing the temperature and lighting systems in ORs	28	Poor heat regulation systems	"Space is poorly illuminated to prepare the meshes for inguinal hernia surgery. The operation is performed with fluorescent lights with a low-intensity sensation." (S-16)
		29	Low illumination levels in the OR and a damaged lighting system	
	14. Distracting noise: noises identified during surgeries that may increase the likelihood of distraction during LAP surgeries include external stimuli, such as slammed doors, conversations, ringing phones and the sound of equipment	30	Distraction due to external stimuli, such as external staff entering the OR	"Another nurse got into the OR and argued with the scrub nurse during the surgery.” (S-11)
		31	Disturbing sounds	
	15. Limited physical workspace: poor distribution of equipment and accessories in the OR that impedes the performance of surgical tasks	32	Poor disposition of equipment in the OR, impeding the performance of tasks	"Behind the surgeon, there are an infinity of cables (from the equipment); they pass close to the patient's arm, even if this space is limited." (S-01)
		33	Small spaces and/or poor layout in the OR that impedes the distribution and transit	

NB. LAPS: laparoscopic surgery

12.6. Appendix 6. Study 2 : Questionnaire-based survey

Ergonomics and Human Factors in Laparoscopic Surgery

Página 1: INTRODUCCION

My name is Manuel Escobar, a Peruvian PhD student at the University of Nottingham in the UK, currently, I am carrying out a research about how risk factors in the workplace might affect the performance and physical health of laparoscopic surgeons, The first step of this research will be to collect information about the possible risk factors in the workplace of laparoscopic surgeons, and some information about physical health.

The research aims to identify ways to improve performance and reduce physical risk factors, this short survey consists of 15 open questions Please, the survey is only directed to surgeons trained in laparoscopic surgery and who are currently working

This survey should take no more than 15 minutes to be completed Be assured that all answers you provide will be kept in the strictest confidentiality

The survey is completely anonymous, names and personal data won't be requested Y

our participation in this study is voluntary and you are free to withdraw at any time. Your participation in this study will finish when the survey has been submitted successfully

This survey will not request photographs or personal information If you refuse to participate, your survey won't be considered without any detriment and the data will be deleted

The information collected from the survey will be processed directly by the researcher and each participant will respond individually without any information crossover.

The survey will no request personal information

Information will be stored on a server and It will be destroyed seven years after any publication arising from the work, in accordance with the university data storage policy.

If you have any inquiry, please do not hesitate to contact me in the next email: manuel.escobar@nottingham.ac.uk

If you agree with participating in this study please respond the next statement and click "next" If you don't please close the windows and the survey will have finished

1. I consent voluntarily to be a participant in this survey ✱ *Necesario*

Página 2: CUESTIONARIO

Porfavor responda las siguientes preguntas

2. What is your gender? (please select)

- Male
- Female

3. How old are you? (please select)

- < 29 years
- 30 a 39 years
- 40 a 49 years
- 50 a 59 years
- > 60 years

4. What is your stature? (please specify in meters)

5. What is your medical specialty? (Please select)

- General surgeon
- Gynecologist
- Urologist

- Traumatologist
- Oncologist
- Other

6. How long have you been performing laparoscopic surgery? (please select)

- < 1 year
- 1- 2 years
- 2-5 years
- > 5 years

7. What is the typical duration of surgical procedures, performed with Laparoscopic surgery? (please select)

Por favor no elija más de 1 respuesta(s) en cada fila.

Por favor elija al menos 3 respuesta(s).

	Never	A case the majority of weeks	Several cases each week
< 1 hours	☐	☐	☐
1 a 2 hours	☐	☐	☐
2 or more hours	☐	☐	☐

8. Currently, Do you perform laparoscopy surgery in rural areas? (please select)

- Yes
- No

9. **Please specify, What department of Peru do you work as a laparoscopic surgeon?**

10. Currently , Where do you perform Laparoscopy surgery

Por favor no elija más de 1 respuesta(s) en cada fila.

	Don't perform	Majority of the cases	Less of the cases
Public Hospital	☐	☐	☐
Private clinic	☐	☐	☐
Policlinic	☐	☐	☐
Own medical center	☐	☐	☐

10.a. **Other (please specify)**

11. **Have you experienced work-related musculoskeletal symptoms (aich , pain, discomfort) in any part of your body? (please select)**

- Yes
- No

11.a. **If your answer is " yes", please indicate the part of the body by ticking boxes for each alternative**

Por favor no elija más de 1 respuesta(s) en cada fila.

Por favor elija al menos 1 respuesta(s).

	No , symptoms	Symptoms appeared during the Last 7 days	Symptoms appeared during the last 12 months
Neck	☐	☐	☐
Shoulders (one or both)	☐	☐	☐
Elbows (one or both)	☐	☐	☐
Wrist/hands (one or both)	☐	☐	☐
Upper back	☐	☐	☐
Lower back	☐	☐	☐
Hips/thighs (one or both)	☐	☐	☐
Knees ((one or both)	☐	☐	☐
Ankles/feet (one or both)	☐	☐	☐

12. **What factors do you think have contributed to your work-related symptoms?**

Por favor no elija más de 1 respuesta(s) en cada fila.

Por favor elija al menos 12 respuesta(s).

	No contributed	Small contributing factor	Major contributing factor
Inadequate operating table height (e.g it can't be adjusted)	☐	☐	☐
Lack of (or ability of) surgical assistant	☐	☐	☐
Duration of the surgery	☐	☐	☐
Position of the monitor display	☐	☐	☐
Complexity of the surgery	☐	☐	☐
Patient shape and size	☐	☐	☐

Use of disposable graspers and/or scissors more than once	☐	☐	☐
Time pressure (cases on list)	☐	☐	☐
Lack of suitable equipment	☐	☐	☐
Lack of illuminance	☐	☐	☐
Foot pedals and/or hand switch	☐	☐	☐
Double glove (or unsuited glove)	☐	☐	☐
Position to work (side of the patient, in front of	☐	☐	☐
the patient, among other)	☐	☐	☐
Lack of microbreak during surgery	☐	☐	☐
Lack of practice	☐	☐	☐
Lack of shoulder support	☐	☐	☐
Poor distribution of shifts (lack of rest)	☐	☐	☐
Poor handle design	☐	☐	☐

12.a. **If there are other(s) or you want to comment more about one, please specify**

13. **Could you explain what are the most challenging Laparoscopic surgeries that you have performed in terms of physical and mental fatigue and how long does it take?**

14. **Have you ever changed your work because of musculoskeletal symptoms? (please select)**

- Yes
- No

14.a. **If yes, how have you changed? (please tick all that apply)**

- [ ] I try not to take on additional operating list
- [ ] I havel had to reduce the number of operative cases
- [ ] I prefer to perform less Laparoscopic surgery
- [ ] I prefer to perform more Laparoscopy surgery
- [ ] I have had to reduce the complexity of surgery that I perform
- [ ] I have had to reduce the number of cases I perform on patients with a high BMI
- [ ] I have had to stop performing emergency surgery

14.a.i. Is there other condition (please specify)

15. Have you experienced any difficulties with your work team (i.e assistants, nurses, others) during Laparoscopic surgery that might affect your performance? (please select)

- Yes
- No

15.a. **If you have responded "yes" Please choose the possible factors by ticking boxes**

Por favor no elija más de 1 respuesta(s) en cada fila.

Por favor elija al menos 1 respuesta(s).

	No	Less of the time	Most of the time

Lack of ability of surgical assistant	☐	☐	☐
lack of collaboration of staff	☐	☐	☐
Lack of organization	☐	☐	☐
Presence of medical residents without experience	☐	☐	☐
Presence of undergraduate medical students	☐	☐	☐
Lack of experience of nurses	☐	☐	☐

16. **Have you received ergonomics training or formal training on optimizing your operative technique?**

- ○ Yes , I do
- ○ No , but i'm interested if its available
- ○ No I'm not interested even if its available

16.a. Other (please specify)

[ ]

17. **Do you want to add any further comment about your work as a Laparoscopic surgeon?**

[ ]

Página 3: FINAL

If you are interested in participating in future researchers related to improving the performance of your job as a laparoscopic surgeon, please click on the link. This link will open a new page to collect your mail in order to avoid information crossover with your responses and preserve your anonymity

To avoid information crossover, a new page will be displayed and you will be able to complete your e-mail , this will let preserve your anonymity

https://nottingham.onlinesurveys.ac.uk/solicitud-de-email-v1-copy

Thank you very much for participating in this survey

Have a nice day

Clave de opciones

1 - I consent voluntarily to be a participant in this survey

Yes , I consent
No, I dont consent

9 - Please specify, What department of Peru do you work as a laparoscopic surgeon?

Amazonas
Ancash
Apurimac
Arequipa
Ayacucho
Cajamarca
Callao
Cuzco
Huancavelica
Huánuco

12.7. Appendix 7. Study 2: Internal consistency analysis

Statistics

	Scale average if the element has been removed	Scale variance if the element has been suppressed	Total correlation of corrected items	Cronbach's alpha if the item has been removed
Neck	20,6000	64,179	,343	,846
Shoulders	20,3333	64,644	,313	,847
Elbow	20,8667	66,464	,097	,851
Hand/wrist	20,5667	65,151	,219	,849
Upper back	20,6333	65,068	,235	,849
Lower Back	20,7000	66,424	,071	,852
Hips	20,9000	66,231	,152	,850
Knees	20,7333	65,030	,261	,848
Ankles/feet	20,7667	64,530	,342	,847
Inadequate table height	19,6667	61,333	,412	,844
Lack of (or ability of) surgical assistant	20,0333	60,447	,419	,844
Duration of the surgery	19,3333	64,920	,201	,850
Position of the monitor display	19,9667	59,757	,603	,837
The complexity of the surgery	19,4000	62,938	,360	,846
Patient shape and size	20,1667	60,351	,433	,844
Use of disposable graspers and/or scissors more than once	19,9667	61,826	,415	,844
Time pressure (cases on the list)	20,6667	64,092	,278	,848
Lack of suitable equipmentt	19,6333	60,723	,491	,841
Lack of illuminance	20,4000	60,041	,597	,837
Foot pedals and/or hand switch	20,3667	61,482	,468	,842
Double glove (or unsuited glove)	20,6333	62,585	,390	,845
Position to work	19,7000	60,355	,533	,840
Lack of microbreak during surgery	20,1333	62,326	,425	,844
Lack of practice	20,0667	62,409	,285	,850
Lack of shoulder support	20,5333	60,602	,633	,837
Poor distribution of shifts (lack of rest)	20,0333	59,275	,535	,839
Poor handle design	20,0667	59,168	,559	,838

Cronbach's alpha	N elements
,850	27

12.8. Appendix 8. Study 3: Inter-rate reliability study

	Final RULA action levels		
Postures	Researcher	Expert 1	Expert 2
Posture 1	4,00	4,00	4,00
Posture 2	4,00	4,00	4,00
Posture 3	3,00	3,00	3,00
Posture 4	4,00	4,00	4,00
Posture 5	4,00	4,00	4,00
Posture 6	4,00	4,00	4,00
Posture 7	4,00	4,00	4,00
Posture 8	4,00	4,00	4,00
Posture 9	3,00	3,00	3,00
Posture 10	3,00	3,00	3,00
Posture 11	4,00	4,00	4,00
Posture 12	4,00	4,00	4,00
Posture 13	4,00	4,00	4,00
Posture 14	4,00	4,00	4,00
Posture 15	3,00	3,00	3,00
Posture 16	4,00	4,00	4,00
Posture 17	4,00	4,00	4,00
Posture 18	3,00	3,00	3,00
Posture 19	4,00	4,00	4,00
Posture 20	3,00	3,00	3,00
Posture 21	4,00	4,00	4,00
Posture 22	4,00	4,00	4,00
Posture 23	3,00	3,00	3,00
Posture 24	3,00	3,00	4,00
Posture 25	3,00	3,00	3,00
Posture 26	4,00	4,00	4,00
Posture 27	3,00	4,00	3,00
Posture 28	4,00	4,00	4,00
Posture 29	4,00	4,00	4,00
Posture 30	4,00	4,00	3,00
Posture 31	4,00	4,00	4,00
Posture 32	4,00	4,00	4,00
Posture 33	3,00	3,00	3,00
Posture 34	3,00	3,00	3,00
Posture 35	4,00	4,00	4,00
Posture 36	4,00	4,00	4,00
Posture 37	4,00	4,00	4,00
Posture 38	2,00	2,00	2,00
Posture 39	2,00	2,00	2,00
Posture 40	3,00	3,00	3,00
Posture 41	3,00	3,00	3,00

Posture 46	3,00	3,00	3,00
Posture 47	4,00	4,00	4,00
Posture 48	4,00	4,00	4,00
Posture 49	4,00	4,00	4,00
Posture 50	4,00	4,00	4,00
Posture 51	4,00	4,00	4,00
Posture 52	4,00	4,00	4,00
Posture 53	4,00	4,00	4,00
Posture 54	4,00	4,00	4,00
Posture 55	4,00	4,00	3,00
Posture 56	4,00	3,00	4,00
Posture 57	4,00	4,00	4,00
Posture 58	4,00	4,00	4,00
Posture 59	4,00	3,00	4,00
Posture 60	4,00	4,00	4,00
Posture 61	3,00	3,00	3,00
Posture 62	4,00	4,00	4,00
Posture 63	4,00	4,00	4,00
Posture 64	3,00	3,00	3,00
Posture 65	3,00	3,00	3,00
Posture 66	4,00	4,00	4,00
Posture 67	3,00	4,00	4,00
Posture 68	4,00	3,00	4,00
Posture 69	4,00	3,00	4,00
Posture 70	3,00	3,00	4,00
Posture 71	4,00	4,00	4,00
Posture 72	4,00	4,00	4,00
Posture 73	4,00	3,00	4,00
Posture 74	4,00	4,00	4,00
Posture 75	4,00	4,00	4,00
Posture 76	4,00	4,00	4,00
Posture 77	2,00	2,00	2,00
Posture 78	2,00	3,00	3,00

Action category reliability	**agreement (%)**	***Kappa***
inter-rater measure (1)	90	0.79
inter-rater measure (2)	91	0.81

12.9. Appendix 9. Study 3: Example of surgeon 1 results – RULA scores and body region

				DERECHA		IZQUIERDA		HOMBRO				codo	muñeca			
Codigo	Tiempo	N°	Task	RULA	ACCION	RULA	ACCION	flx-ex	abd	eleva	rot	flx-ex	flx-ex	cub	rad	giro
1	00:00:00	1	1	4	2	4	2	1	0	0	0	1	1	1	0	1
901	00:00:30	1	1	4	2	4	2	1	0	0	0	1	1	1	0	1
1801	00:01:00	1	1	4	2	4	2	1	0	0	0	1	1	1	0	1
2701	00:01:30	1	1	4	2	4	2	1	0	0	0	1	1	1	0	1
3601	00:02:00	1	1	4	2	4	2	1	0	0	0	1	1	1	0	1
4501	00:02:30	1	1	4	2	4	2	1	0	0	0	1	1	1	0	1
5401	00:03:00	1	1	6	3	6	3	1	0	1	0	1	2	1	0	1
6301	00:03:30	1	1	6	3	6	3	1	0	1	0	1	2	1	0	1
7201	00:04:00	1	1	6	3	6	3	1	0	1	0	1	2	1	0	1
8101	00:04:30	1	1	6	3	6	3	1	0	1	0	1	2	1	0	1
9001	00:05:00	1	1	6	3	6	3	1	0	1	0	1	2	1	0	1
9901	00:05:30	1	1	6	3	6	3	1	0	1	0	1	2	1	0	1
10801	00:06:00	1	1	6	3	6	3	1	0	1	0	1	2	1	0	1
11701	00:06:30	1	1	6	3	6	3	1	0	1	0	1	2	1	0	1
12601	00:07:00	1	1	6	3	6	3	1	0	1	0	1	2	1	0	1
13501	00:07:30	1	1	6	3	6	3	1	0	1	0	1	2	1	0	1
14401	00:08:00	1	1	6	3	6	3	1	0	1	0	1	2	1	0	1
15301	00:08:30	1	1	6	3	6	3	1	0	1	0	1	2	1	0	1
16201	00:09:00	1	1	6	3	6	3	1	0	1	0	1	2	1	0	1
17101	00:09:30	1	1	6	3	6	3	1	0	1	0	1	2	1	0	1
18001	00:10:00	1	1	6	3	6	3	1	0	1	0	1	2	1	0	1
18901	00:10:30	1	1	6	3	6	3	1	0	1	0	1	2	1	0	1
19801	00:11:00	1	1	7	4	6	3	2	0	1	0	1	2	1	0	1
20701	00:11:30	1	1	6	3	7	4	2	0	1	0	1	1	0	0	1
21601	00:12:00	1	1	6	3	6	3	1	0	1	0	1	1	0	0	1
22501	00:12:30	1	1	6	3	6	3	1	0	1	0	1	1	0	0	1
23401	00:13:00	2	2	7	4	7	4	2	0	1	0	1	2	0	0	1
24301	00:13:30	2	2	7	4	7	4	2	0	1	0	1	2	0	0	1
25201	00:14:00	2	2	7	4	7	4	2	0	1	0	1	2	0	0	1
26101	00:14:30	2	2	7	4	7	4	2	0	1	0	1	2	0	0	1
27001	00:15:00	2	2	7	4	7	4	2	0	1	0	1	2	0	0	1
27901	00:15:30	3	3	6	3	6	3	1	0	1	0	1	2	0	0	1
28801	00:16:00	3	3	6	3	6	3	1	0	1	0	1	2	0	0	1
29701	00:16:30	3	3	6	3	6	3	1	0	1	0	1	2	0	0	1
30601	00:17:00	3	3	6	3	6	3	1	0	1	0	1	2	0	0	1
31501	00:17:30	3	3	7	4	7	4	3	0	1	1	1	2	1	0	1
32401	00:18:00	3	3	7	4	7	4	3	0	1	1	1	2	1	0	1
33301	00:18:30	3	3	7	4	7	4	2	0	1	0	2	2	0	0	1
34201	00:19:00	3	3	7	4	7	4	2	0	1	0	2	2	0	0	1
35101	00:19:30	3	3	7	4	7	4	2	0	1	0	1	2	0	0	1
36001	00:20:00	3	3	7	4	7	4	3	0	1	0	1	2	1	0	1
36901	00:20:30	3	3	6	3	6	3	1	0	1	0	1	2	0	0	1
37801	00:21:00	3	3	6	3	6	3	1	0	1	0	1	2	0	0	1
38701	00:21:30	3	3	6	3	6	3	1	0	1	0	1	2	0	0	1
39601	00:22:00	3	3	6	3	6	3	1	0	1	0	1	2	0	0	1
40501	00:22:30	3	3	6	3	6	3	1	0	1	0	1	2	0	0	1
41401	00:23:00	3	3	7	4	7	4	3	0	1	0	2	2	1	0	1
42301	00:23:30	3	3	7	4	7	4	3	0	1	0	2	2	1	0	1
43201	00:24:00	3	3	7	4	7	4	3	0	1	0	2	2	1	0	1
44101	00:24:30	3	3	7	4	7	4	3	0	1	0	2	2	1	0	1
45001	00:25:00	3	3	6	3	6	3	2	0	1	1	1	2	0	0	1
45901	00:25:30	4	4	7	4	7	4	2	0	1	1	1	2	0	0	1
46801	00:26:00	4	4	6	3	6	3	1	0	1	1	1	2	0	0	1
47701	00:26:30	4	4	7	4	7	4	3	0	1	1	1	2	1	0	1
48601	00:27:00	4	4	7	4	7	4	2	0	1	0	2	2	1	0	1
49501	00:27:30	4	4	7	4	7	4	3	0	1	1	2	2	1	0	1
50401	00:28:00	4	4	6	3	6	3	1	0	1	1	1	2	1	0	1
51301	00:28:30	4	4	6	3	7	4	1	0	1	1	2	2	1	0	1
52201	00:29:00	4	4	6	3	6	3	2	0	1	1	1	2	1	0	1
53101	00:29:30	4	4	6	3	6	3	2	0	1	1	1	2	1	0	1
54001	00:30:00	4	4	6	3	6	3	2	0	1	1	1	2	1	0	1
54901	00:30:30	4	4	6	3	6	3	2	0	1	1	1	2	1	0	1
55801	00:31:00	4	4	6	3	6	3	2	0	1	1	1	2	1	0	1
56701	00:31:30	4	4	6	3	6	3	2	0	1	1	1	2	1	0	1
57601	00:32:00	4	4	6	3	6	3	2	0	1	1	1	2	1	0	1
58501	00:32:30	4	4	5	3	5	3	1	0	1	1	1	2	1	0	1
59401	00:33:00	4	4	5	3	5	3	1	0	1	1	1	2	1	0	1
60301	00:33:30	4	5	7	4	7	4	1	0	1	1	2	2	1	0	1
61201	00:34:00	4	5	7	4	7	4	1	0	1	1	2	2	1	0	1
62101	00:34:30	4	5	4	2	4	2	1	0	1	1	1	2	1	0	1
63001	00:35:00	4	5	7	4	7	4	3	0	1	1	1	2	1	0	1
63901	00:35:30	4	5	7	4	7	4	3	0	1	1	1	2	1	0	1
64801	00:36:00	4	5	6	3	6	3	1	0	1	1	1	2	1	0	1
65701	00:36:30	4	5	6	3	6	3	1	0	1	1	1	2	1	0	1
66601	00:37:00	5	6	3	2	3	2	1	0	1	1	1	1	1	0	1
67501	00:37:30	5	6	3	2	3	2	1	0	1	1	1	1	1	0	1
68401	00:38:00	5	6	3	2	3	2	1	0	1	1	1	1	1	0	1
69301	00:38:30	5	6	3	2	3	2	1	0	1	1	1	1	1	0	1
70201	00:39:00	5	6	3	2	3	2	1	0	1	1	1	1	1	0	1
71101	00:39:30	5	6	3	2	3	2	1	0	1	1	1	1	1	0	1
72001	00:40:00	6	7	6	3	6	3	3	0	1	1	2	2	1	0	1
72901	00:40:30	6	7	7	4	7	4	1	0	1	1	2	2	0	0	2
73801	00:41:00	6	7	7	4	7	4	2	0	1	1	1	2	0	0	1
74701	00:41:30	6	7	7	4	7	4	2	0	1	1	1	2	0	0	1
75601	00:42:00	6	7	7	4	7	4	2	0	1	1	1	2	0	0	1
76501	00:42:30	6	7	7	4	7	4	2	0	1	1	1	2	0	0	1
77401	00:43:00	6	7	7	4	7	4	2	0	1	1	2	2	0	0	1
78301	00:43:30	6	7	7	4	7	4	2	0	1	1	2	2	0	0	1
79201	00:44:00	6	7	6	3	6	3	2	0	1	1	2	2	0	0	2
80101	00:44:30	6	7	6	3	6	3	2	0	1	1	2	2	0	0	2
81001	00:45:00	6	7	6	3	6	3	2	0	1	1	2	2	0	0	2
81901	00:45:30	6	7	7	4	7	4	3	0	1	1	2	2	0	0	2
82801	00:46:00	6	7	7	4	7	4	2	0	1	1	2	2	0	0	2
83701	00:46:30	6	7	7	4	7	4	2	0	1	1	2	2	0	0	2
84601	00:47:00	6	7	7	4	7	4	2	0	1	1	2	2	0	0	2
85501	00:47:30	6	7	7	4	7	4	2	0	1	1	2	2	0	0	2
86401	00:48:00	6	7	7	4	7	4	2	0	1	1	2	2	0	0	2
87301	00:48:30	6	7	7	4	7	4	2	0	1	1	2	2	0	0	2
88201	00:49:00	6	7	7	4	7	4	3	1	1	1	2	2	0	0	2
89101	00:49:30	6	7	7	4	7	4	2	0	1	1	2	2	0	0	2
90001	00:50:00	6	7	7	4	7	4	2	0	1	1	2	2	0	0	2
90901	00:50:30	6	7	5	3	5	3	2	0	1	0	1	2	0	0	2
91801	00:51:00	6	8	7	4	7	4	3	0	1	1	1	2	0	0	2
92701	00:51:30	6	8	7	4	7	4	2	0	1	1	2	2	0	0	2
93601	00:52:00	6	8	7	4	7	4	2	0	1	1	2	2	0	0	2
94501	00:52:30	6	8	7	4	7	4	2	0	1	1	2	2	0	0	2
95401	00:53:00	6	8	7	4	7	4	2	0	1	1	2	2	0	0	2
96301	00:53:30	6	8	7	4	7	4	2	0	1	1	2	2	0	0	2
97201	00:54:00	6	8	7	4	7	4	2	0	1	1	2	2	0	0	2
98101	00:54:30	6	8	6	3	6	3	3	0	1	1	2	2	0	0	2
99001	00:55:00	7	9	7	4	7	4	2	0	1	1	1	2	0	0	2
99901	00:55:30	7	9	6	3	6	3	2	0	1	1	1	2	0	0	2
100801	00:56:00	7	9	7	4	7	4	3	0	1	1	2	2	1	0	1
101701	00:56:30	8	10	7	4	7	4	2	0	1	1	2	2	1	0	1
102601	00:57:00	8	10	6	3	6	3	2	0	1	1	1	2	0	0	1
103501	00:57:30	8	10	6	3	6	3	2	0	1	1	1	2	0	0	1
104401	00:58:00	8	10	6	3	6	3	2	0	1	1	1	2	0	0	1
105301	00:58:30	8	10	6	3	6	3	2	0	1	1	1	2	0	0	1
106201	00:59:00	8	10	6	3	6	3	2	0	1	1	1	2	0	0	1
107101	00:59:30	8	10	6	3	6	3	2	0	1	1	1	2	0	0	1
108001	01:00:00	8	10	6	3	6	3	2	0	1	1	1	2	0	0	1
108901	01:00:30	8	10	6	3	6	3	2	0	1	1	1	2	0	0	1
109801	01:01:00	8	10	6	3	6	3	2	0	1	1	1	2	0	0	1
110701	01:01:30	8	10	6	3	6	3	2	0	1	1	1	2	0	0	1
111601	01:02:00	8	10	6	3	6	3	2	0	1	1	1	2	0	0	1
112501	01:02:30	8	10	6	3	6	3	2	0	1	1	1	2	0	0	1
113401	01:03:00	8	10	6	3	6	3	2	0	1	1	1	2	0	0	1
114301	01:03:30	8	10	6	3	6	3	2	0	1	1	1	2	0	0	1
115201	01:04:00	x		7	4	7	4	4	0	1	1	2	3	1	0	1
116101	01:04:30	x		7	4	7	4	4	0	1	1	2	3	1	0	1
117001	01:05:00	x		4	2	4	2	1	0	0	0	1	1	0	0	1
117901	01:05:30	x		7	4	7	4	3	0	1	1	2	3	1	0	1
118801	01:06:00	x		7	4	7	4	3	0	1	1	2	3	1	0	1
119701	01:06:30	x		7	4	7	4	2	0	1	1	1	2	1	0	1
120601	01:07:00	x		7	4	7	4	2	0	1	1	1	2	1	0	1
121501	01:07:30	x		7	4	7	4	2	0	1	1	2	2	0	0	1

Final Scores (grupo A)						Total A		Final scores (group B)			Total B
Shoulder (R)	Shoulder (L)	Elbow(R)	Elbow (L)	Wrist (R)	Wrist (L)	Right	Left	Trunk	Neck	Legs	Right
1	1	1	2	2	2	2	2	1	2	1	2
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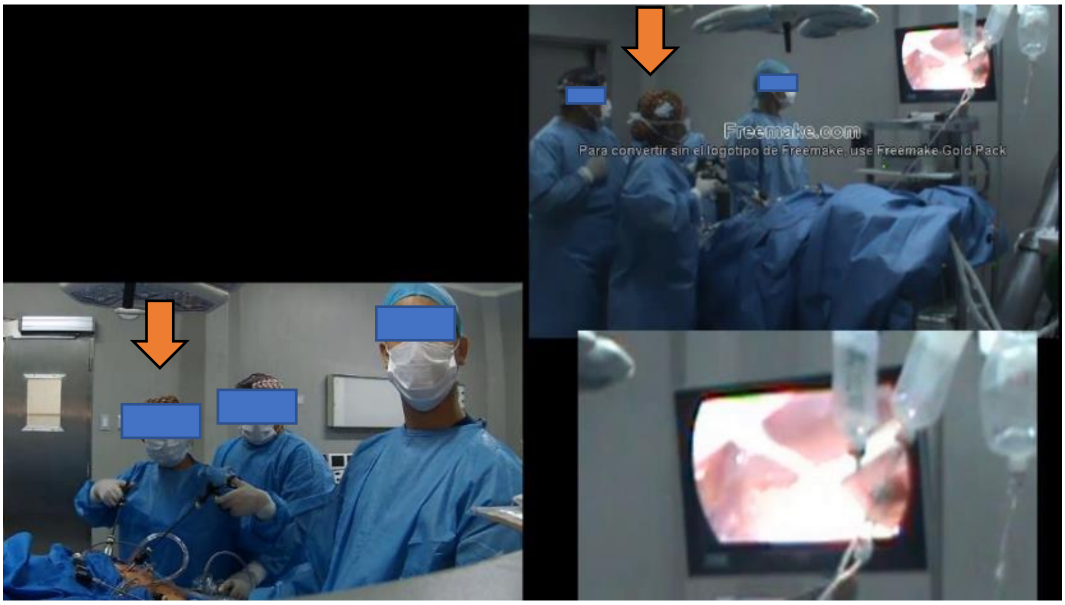
12.10. Appendix 10. Study 3 : Examples of RULA method in surgeries



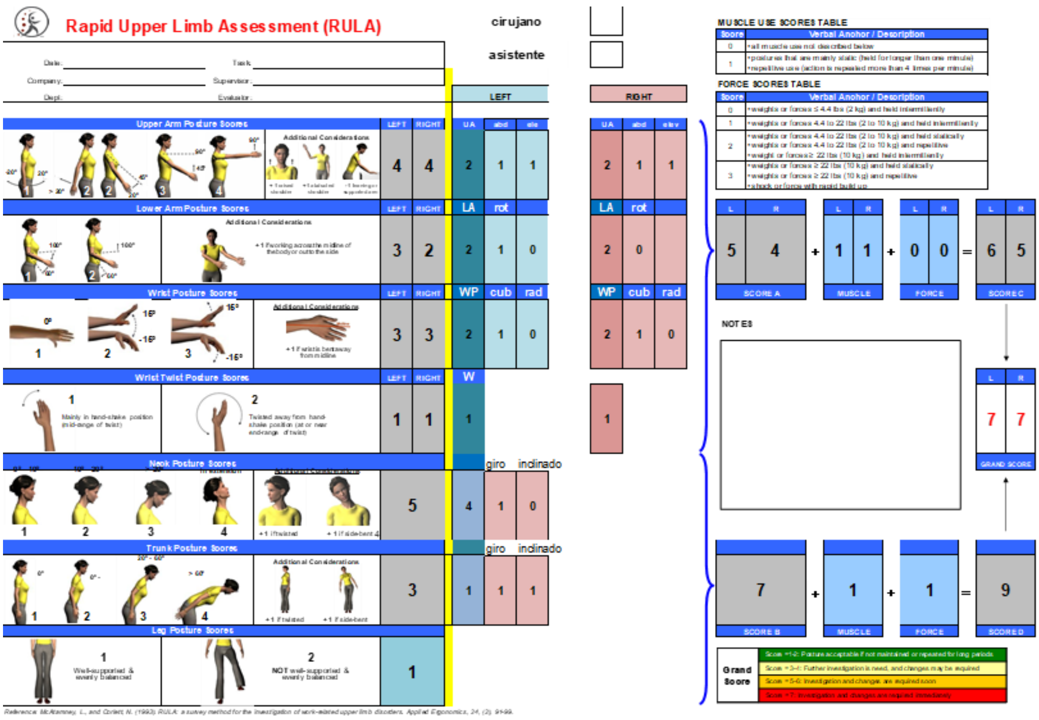
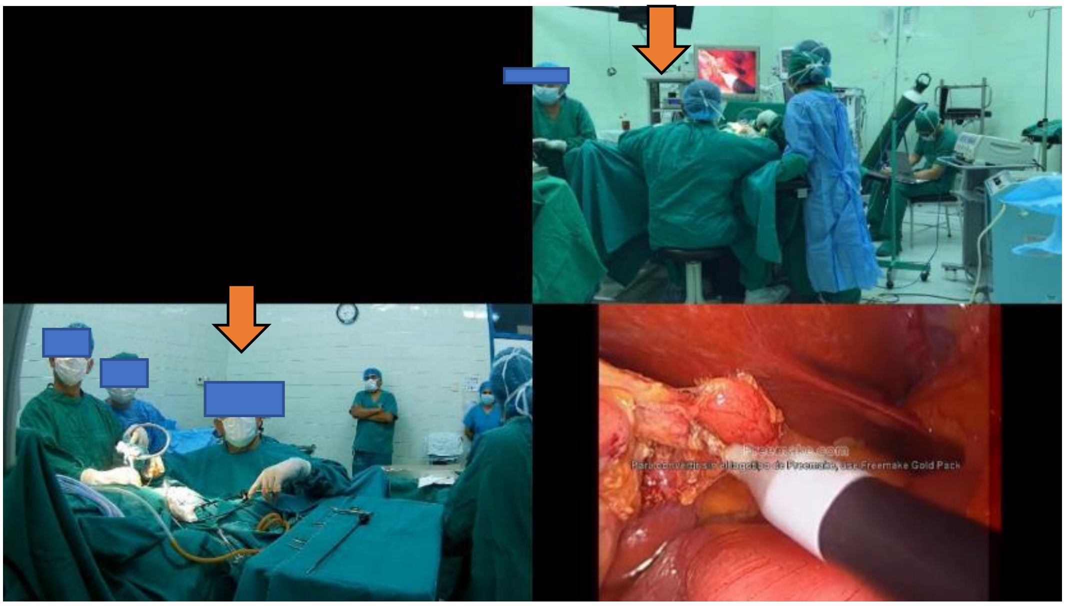


Figure. Method RULA applied to a surgeon in surgery 12- Cholecystectomy with complications. Image code: 188101



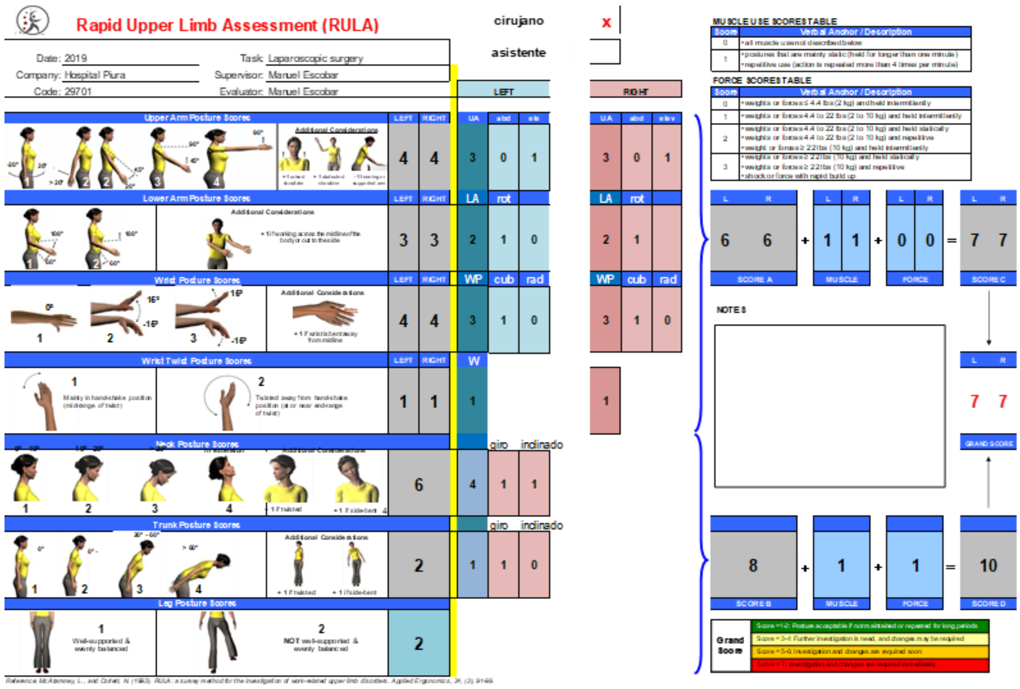
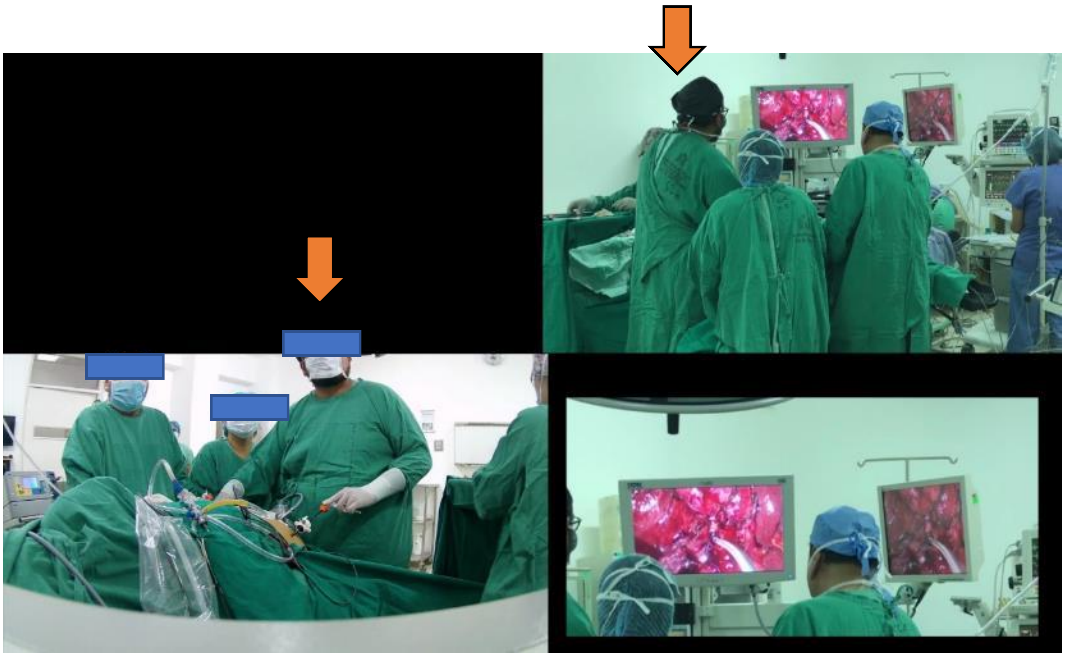


Figure. Method RULA applied to a surgeon in surgery 18- Cholecystectomy. Image code: 29701



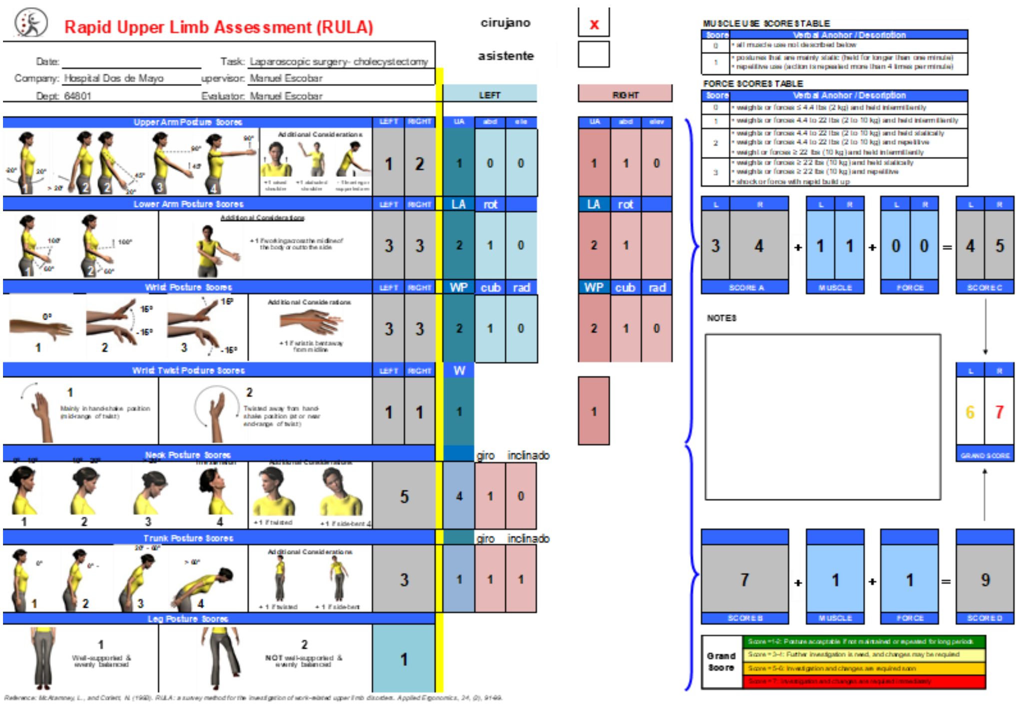
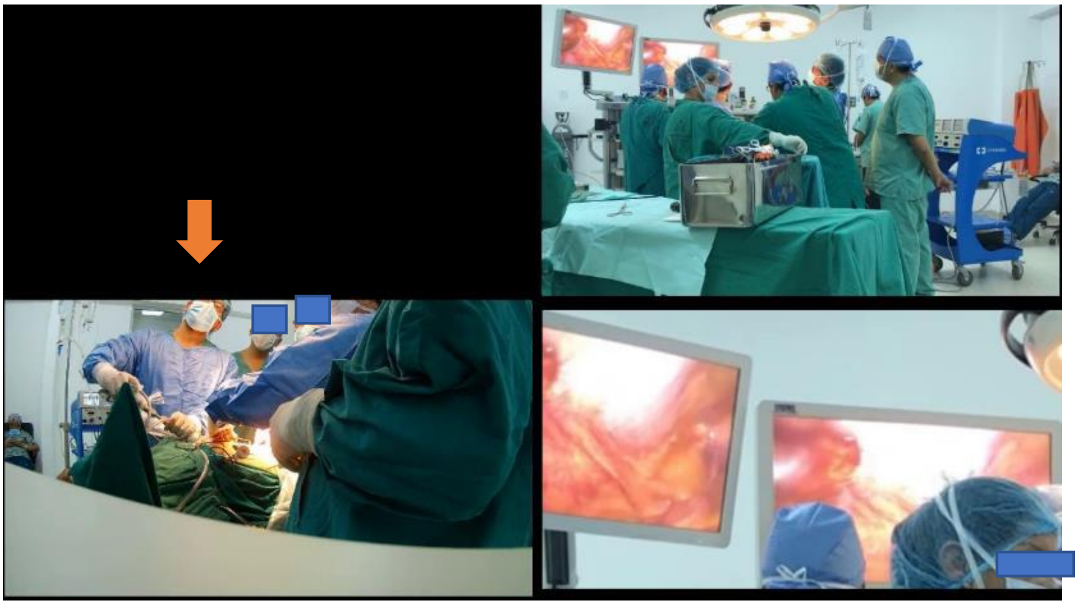


Figure. Method RULA applied to a surgeon in surgery 13- Cholecystectomy. Image code: 64801



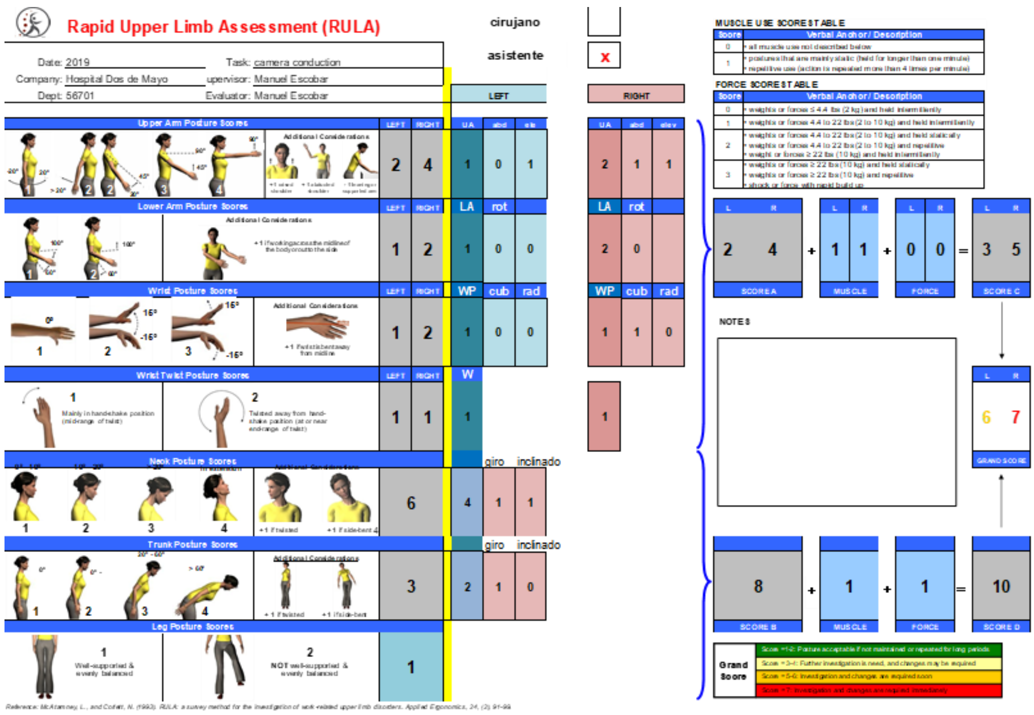
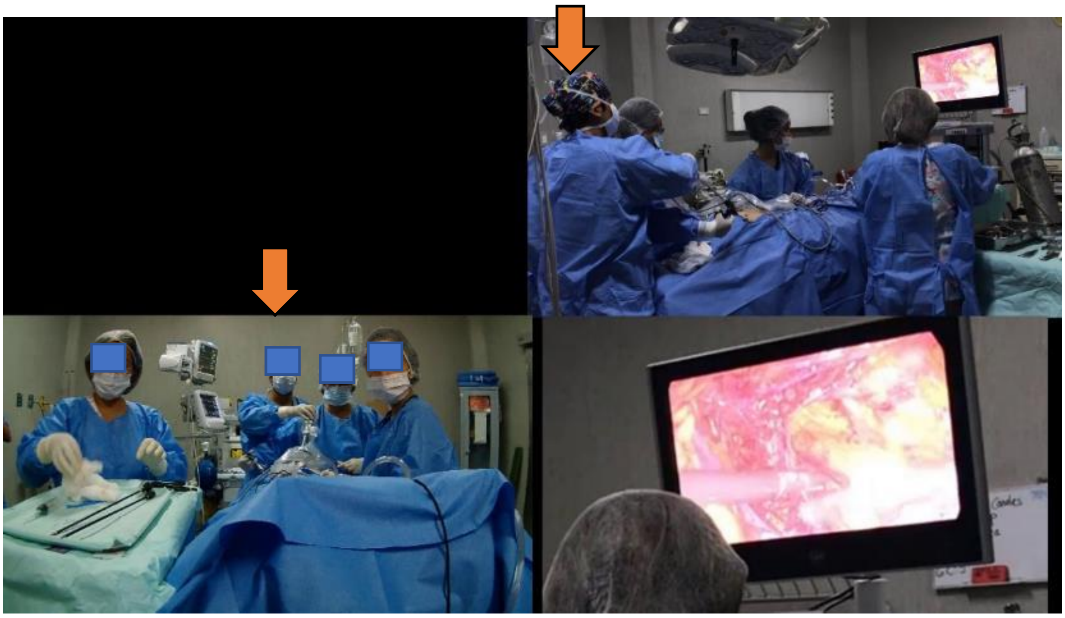


Figure. Method RULA applied to a camera assistant in surgery 15-cholecystectomy. Image code: 56701



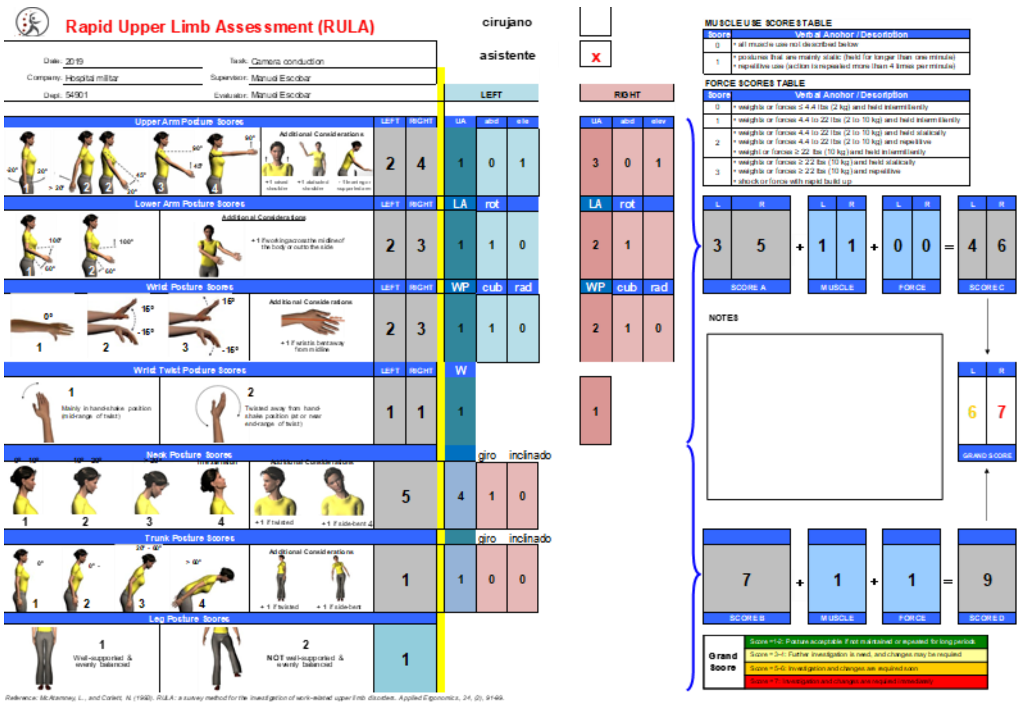


Figure. Method RULA applied to a camera assistant in surgery 16- Inguinal repair hernia. Image code: 54901

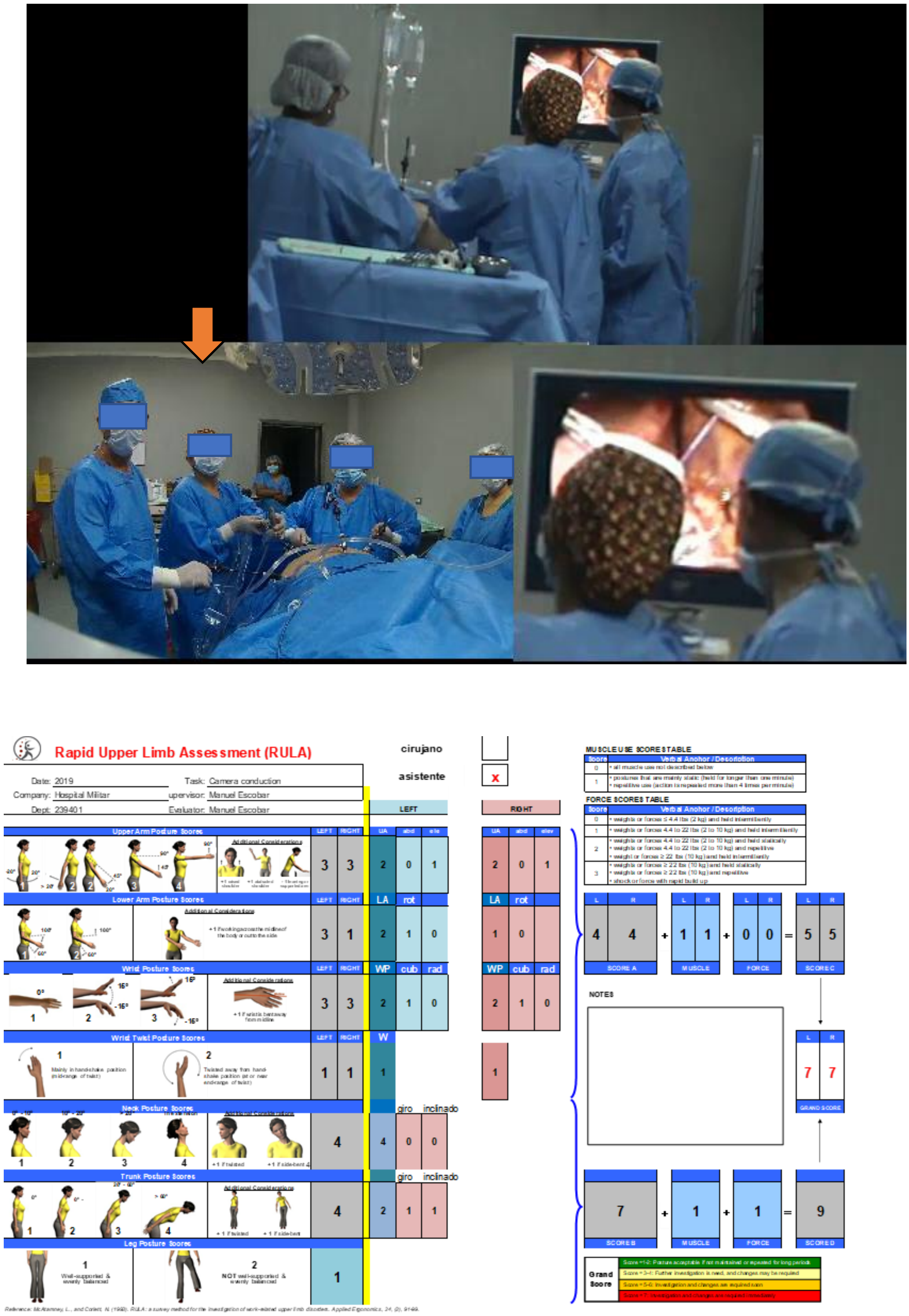
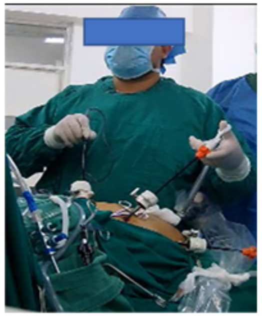


Figure. Method RULA applied to a camera assistant in surgery 10- Bypass gastric surgery. Image code: 234901

12.11. Appendix 11. Study 3 : Main body postures of surgeons and assistants during laparoscopic surgeries

Surgeon



Assistant

Group A		Surgeon n	(%)	Assistant n	(%)	X2 (df)
Upper arm	0-20° fx -ext	1853	(38.5%)	2103	(43.5%)	
	20-45° fx and >20° fx	**2313**	**(48.1%)**	**2306**	**(47.7%)**	
	45-90° fx	425	(8.8%)	205	(4.3%)	
	>90° fx	219	(4.6%)	218	(4.5%)	
	Elevation	**3814**	**(79.3%)**	**3937**	**(81.5%)**	
	Rotation	3163	(65.8%)	3128	(64.8%)	
Final score Upper arm	1 (lower risk)	810	(16.8%)	803	(16.6%)	0.09(1)
	>1 (higher risk)	4000	(83.2%)	4029	(83.4%)	
Lower arm	60-100 fx	1341	(27.8%)	1706	(35.3%)	
	<60° and >100°	**3471**	**(72.2%)**	**3126**	**(64.7%)**	
Final score Lower arm	1 (lower risk)	1048	(21.8%)	1137	(23.5%)	3.77(1)
	>1 (higher risk)	3762	78.2%	3695	(76.5%)	
Wrist	0°	932	(19.4%)	1450	(30.0%)	
	0-15 ° fx and ext	**3033**	**(63.1%)**	**2924**	**(60.5%)**	
	>15° fx and ext	845	(17.6%)	458	(9.5%)	
	Deviation	3533	(73.5%)	3256	(67.4%)	
Final score Wrist	1 (lower risk)	495	(10.3%)	736	(15.2%)	**54.57(1)****
	>1 (higher risk)	**4315**	**(89.7%)**	4096	(84.8%)	

Group B		Surgeon n	(%)	Assistant n	(%)	X2 (df)
Trunk	0°	**2408**	**(50.1%)**	**2400**	**(49.7%)**	
	0-20° fx	2095	(43.6%)	**2370**	**(49.0%)**	
	>20° and <=60°	68	(1.4%)	22	(0.5%)	
	>60°	239	(5.0%)	40	(0.8%)	
	twisted	3112	(64.7%)	2916	(60.3%)	
Final score trunk	1 (lower risk)	608	(12.6%)	950	19.6%)	**88.9(1)****
	>1 (higher risk)	**4202**	**(87.4%)**	3884	(80.4%)	
Neck	0-10°	374	(7.8%)	338	(7.0%)	
	10-20°	228	(4.7%)	122	(2.5%)	
	>20°	1102	(22.9%)	928	(19.2%)	
	extend	**3106**	**(64.6%)**	**3444**	**(71.3%)**	
	twisted	1944	(40.4%)	2606	(53.9%)	
Final score Neck	1 (lower risk)	282	(5.8%)	130	(2.7%)	**57.17(1)****
	>1 (higher risk)	**4528**	**(94.2%)**	**4702**	**(97.3%)**	
Leg	Support	**4266**	**(88.7%)**	**4802**	**(99.4%)**	**492.02(1)****
	Unssuported	544	(11.3%)	30	(0.6%)	

Note. Note. X2 . Chi square of Pearson (degrees of freedom) , p<0.05* ; p<0.001** ; Bold (>1.96) , adjusted standardised residuals ; Medium : AL2; High: AL3+AL4; **Bold and grey box :** greater percentage ; ; n= number of analysis included right and left side

12.12. Appendix 12. Studies integration: Joint displays for integrating studies

Table A. Joint display table for the Tools and Technology category establishing meta inferences from QUAL1 , QUAN2 and QUAN3

Qualitative findings	Quantitative findings	Mixed method meta-inferences
QUAL1 results (n=18 interviews ; n=20 observations) **first top category = 92%** **Work system factors contributing to WRMSD** ✓ **Lack of Availability of suitable tools and equipment (74%)** *"We need platforms you can't operate without a platform(surgical stool). I try to lower the table almost to the floor, but we need platforms; all the places have platforms." (I-14)* *"you start to manipulate a bowel, and it falls out, so sometimes you have to think about it because*	**QUAN2 Results (n=140 surgeons)** **first top category = 87%** **Work system factors contributing to WRMSD** ✓ Inadequate operating table height (75%) ✓ Lack of suitable equipment (67%) ✓ Use of disposable graspers (54%) ✓ Poor handle design (53%) ✓ Lack of shoulder support (46%) **WRMSD prevalence**	**Convergence** ✓ The categories Tools and technologies in QUAL1 and QUAN2 contain the main factors contributing to the development of WRMSD. It is the first category of the SEIPS model with the highest number of reports in QUAL1 and QUAN2. In addition, QUAL1 and QUAN2 converge that problems related to lack of adequate equipment and poor tool design are top priorities for more than 50%. ✓ Inadequate operating table height was the most frequently reported factor associated with WRMDS in QUAN2 ($p<0.05$) and was contained into the factor related to "poor design and usability of the technology" (QUAL1).

you don't know whether to schedule a surgery or not because you don't have the material." (I-04) ✓ **The poor state of equipment in operating rooms (63%)** *"sometimes the trocar diaphragms fail, and then we lose C02, and the visibility drops a little bit having difficulties with the surgery." (-I-05)* *"The main and most frequent thing is that the tables are regulated, but there are tables that are not working properly".(I-01)* *"They do not allow a good grasp, the grasper (disposable reused) is already damaging the tissue, of course, you can't grasp a gall bladder and the intestine." (I-04)*	✓ Neck (51%) ✓ Shoulder (59%) associated with table height ($p<0.05$) ✓ Hand/wrist(41%) associated with table height ($p<0.05$) ✓ Upper back (41%) ✓ No gender differences WRMSD ($p<0.05$)	✓ The WRMSD rates identified in QUAN2 were associated with operating table height issues ($p<0.05$) confirmed in the QUAL1. ✓ The most frequent postures adopted by surgeons (QUAN3) converge with problems related to high working heights and the manipulation of laparoscopic tools (QUAL1 and QUAN2). ✓ QUAL1 and QUAN2 agreed that poor tool design was the third and fourth most frequent factor related to technology. QUAN1 and QUAN3 converged that reusing disposable tools was a significant contributor to WRMSD. ✓ QUAN2 and QUAN3 converged that shoulders, neck and hand/wrist were the most affected body segments.
	QUAN3 results (n=19 surgeries)	**Divergence**
✓ **Poor design and usability: (47%)** *"This is an obese, large patient; the table will not go any lower because it is limited"(I-07)* *"But I mean, sometimes it happens that you ask the anesthesiologist to lower the table and sometimes it is the maximum, it is a bit difficult, sometimes we*	**Surgeon's posture** Overall RULA = High risk (AL3 and AL4) ✓ Raised Shoulder :79.3% ✓ Upper arm (20-45°) :48.1% ✓ Lower arm (<60° or >100°):72.2% ✓ Wrist (0-15° fx and ext):63.1%	✓ No evidence was found in QUAL1 for the need to use armrests in surgery. **Expansion** ✓ QUAL1 expanded knowledge of the operating table issue by including factors related to the lack of suitable

have had to ask for support to reach the height of chubby patients." (I-02) *"There is no grasper specifically for our hand because they are designed for male surgeons. In other countries, they are taller, so you just accept them." (I-01)*	✓ Wrist deviation :89.7%	equipment and the poor state of equipment in operating rooms identified as the most contributing factors. Some tables had broken height regulation systems as well as malfunctioning controls. In addition, the lack of surgical stools (lack of suitable tools) did not make it easy for the surgeon to reach the desired heights, linking the problem directly to the high operating table heights. The few surgical stools available had features that created instability and did not reach a suitable working height. ✓ The women's short stature impacted the working height and the size of their tools, which were designed for large hands. ✓ QUAN3 expanded the understanding of the postures due to the raised table height by describing the awkward postures adopted mainly in upper limbs ✓ QUAL1 expanded the understanding of how the reuse of disposable tools hinders the performance of surgery and puts patient safety at risk.

Table B. Joint display table for the task category establishing meta inferences from QUAL1 , QUAN2 and QUAN3

Qualitative findings	Quantitative findings	Mixed method meta-inferences
QUAL1 results (n=18 interviews ; n=20 observations) **Second top category = 74%** **Work system factors contributing to WRMSD** ✓ **Laparoscopic surgery demands (53%)** *"Basically, the same laparoscopic surgery sometimes forces you to put yourself in an antalgic posture that is typical of the surgery."(I-03)* *"The camera assistant has a face that shows her tiredness because the posture she has to hold is quite uncomfortable, especially when following the horizon for the surgeon to complete the suture, ... she has to keep her shoulders elevated." (S-10)* ✓**Long duration and complexity of LAPS (42%)** *"yes... after two or three hours a lumbar pain starts, not so much in the back, but the lumbar region bothers me".(I-05)*	**QUAN2 Results (n=140 surgeons)** **Second top category = 86%** **Work system factors contributing to WRMSD** ✓Duration of the surgery (81%) ✓The complexity of the surgery (73%) ✓Position of the surgeon in LAPS (64%) ✓Patient shape and size (50%) Durantion and complexity associated to WRMSD ($p<0.05$) ✓ Neck (51%) ✓ Shoulder (59%) ✓ Hand/wrist(41%) ✓ Upper back (41%) ✓ Lower back (36%)	**Convergence** ✓ The QUAN2 and QUAN3 studies converged that factors related to the duration and complexity of surgery were a priority and contributed significantly to WRMSD. ✓ QUAL1 identified that camera conducting tasks had a high physical load for assistants, which was confirmed in QUAN3, showing a high postural risk of WRMSD. ✓ Patient shape and size were the least frequent factors in QUAL1 and QUAN2. ✓ QUAN3 identified the priority laparoscopic tasks that increase WRMSD risk (dissecting, cutting, intracorporeal suturing and camera conduction).QUAL1 confirmed this finding. ✓ QUAN2 WRMSD were highly associated with the duration and complexity of surgeries. It converged with testimonies and observations of QUAL1 and results of QUAN3 **Divergence** ✓ The QUAN2 study reported that the complexity of surgery and duration were the most frequent factors

"only sutures and knots need a long time, that is the most difficult and the most stressful ... and sometimes you have to suture or make an anastomosis, making anastomosis is the most difficult."(I-18) *"It is a shoulder up position, that's horrible it hurts your shoulders, after 3 hours of surgery that's why we had to help her, she was in this position (shows her shoulders up), the clothes also made me tired." (I-11)* ✓ **Patient's characteristics (21%)** *"When we have super obese patients even though the table is at ground level, the patient has an abdomen like this (he makes the gesture of an obese person), then we have to work like this (shows working with arms above shoulder)". (I-01)* *"Of course, you realise that there is much fat on top (patient) which makes us lose a lot of time, the trocars were failing, only one failed, sometimes two fail, but this time one failed us" (I*	**QUAN3 results (n=19 surgeries)** WRMSD risk by the complexity ✓ Cholecystectomy=89% ✓ Hernia inguinal repair=94% ✓ complex surgery (>90min)=95% ($p<0.005$) WRMSD risk in Laparoscopic tasks ✓ dissecting, cutting and intracorporeal suturing and camera conduction ($p<0.001$) **WRMSD risk by position** ✓ Side standing position has a higher WRMSD risk ($p<0.001$) WRMSD risk by role	contributing to WRMSD. However, for QUAL1, it was the second most frequent factor. ✓ Patient characteristics were the least frequent factor in QUAL1. However, it was a factor that surgeons associated with operating table height, which was the most frequent factor in QUAN2. Also, the patient´s size in QUAN2 was identified as a relevant contributing factor for 50% (not high-contributing) ✓ The surgeon's position was the third frequent factor in QUAN2, but it was contained in the "laparoscopic surgery demands" factor of QUAL1, which was the most frequent ✓ QUAL1 identified testimony in which lumbar pain is high, but QUAN2 identified that it was significantly lower than the neck, shoulder, hand/wrist and upper back. **Expansion** ✓ QUAL1 allowed for expansion of the results. The problems of complexity and duration were not only centred on the surgery itself but also on the techniques needed to operate. For example, intracorporeal suturing in complex surgeries require anastomosis tasks, making the surgery complex. QUAN3 expanded on this point by indicating that the

	✓ Both, surgeons and camera asistants had similar postural high-rik (p>0.05)	complexity of surgery is a significant risk factor for WRMSD in both surgeons and assistants. ✓ QUAL1 expanded knowledge about laparoscopic tasks describing how challenging they are for surgeons (camera conduction, intracorporeal suturing). ✓ QUAL1 also expanded on the problems of camera assistants who, in many surgeries, they expressed physical discomfort and fatigue, especially in the upper limbs when performing long surgeries. ✓ QUAL1 has also broadened the understanding of the problem of patient size, which has a more significant impact when surgeons and assistants have short stature. This is due to the increased table height. Surgeons also pointed out that obese patients can break the tools because of the amount of fat mass in the abdomen.

Table C. Joint display table for the category Person establishing meta inferences from QUAL1 , QUAN2 and QUAN3

Qualitative findings	Quantitative findings	Mixed method meta-inferences
QUAL1 results (n=18 interviews ; n=20 observations) **Third top category = 68%** ✓ **Stature mean = 167.9 cm** **WRMSD risk rate** ✓WRMSD rate = 66% ✓two diagnoses of WRMS injuries ✓ **Clinician's characteristics (49%)** *"The height influences a lot, and little do they realise that(a short female surgeon)"(I-13)* *",,,, joint pains (due to old age), tremors ... one has to make a self-assessment as to when one should or should not continue to operate."(I-18)* ***The surgical team have inadequate or insufficient knowledge of LAPS (28%)**	**QUAN2 Results (n=140 surgeons)** **Third top category = 78%** ✓ Stature mean: 166.9 cm **WRMSD risk rate** ✓WRMSD rate = 89% ✓no diagnoses of WRMS injuries ✓Lack of training of practice in LAPS (57%) ✓Poor abilities of surgical assistants (54%) ✓Teamwork issues (41%) ✓ Lack of training was associated with a higher rate of WRMSD (p<0.05). ✓ (79%) indicated that surgeons did not receive formal training in	**Convergence** ✓ The QUAL1 and QUAN2 studies converged in the Person category as the third most frequent. ✓ The mean stature of participants in QUAL1, QUAN2 and QUAN3 was similar (p<0.005), below the international population average and relatively higher than the Peruvian average. ✓ QUAN3 established that women surgeons had higher risk postures than men. QUAN1 also pointed out that anthropometric differences were a factor related to the characteristics of the clinicians and that women may have problems operating on patients since short anthropometry ✓ Factors related to lack of skills and training in laparoscopic surgery and surgical work team issues converged in QUAL1 and QUAN2 as the second and third most frequent factors. ✓ QUAL1 and QUAN2 converged that lack of training increase WRMSD **Divergence** ✓ QUAN2 established that there is no difference in reports of WRMSD in males and females surgeons. However, QUAN3

"I think the main thing is that the staff is not trained in ergonomics, right? Here in the room, I have to ask for the monitor to align with the patient in my axis of action (front of him)."(I-14) *"We are full of ergonomic errors, so look, I would say that 95% of surgeons have permanent ergonomic errors .... not only for positioning but also the position of the hands, we train a lot and twist the hand to open the armpits (arm abduction) and the elbows in the air to handle the graspers... For that have pain" (I-13).* *"The bleeding persists and must be controlled by cleaning the surrounding area, but the resident does not position himself well and is not aware of the surrounding spots that must be taken into account when cleaning."(S-9)* ✓**Surgical teamwork issues (33%)** *"The doctor asked the nurse for "a reduction forceps" when she is given it, the doctor said, "you don't know how to do it"? Evidencing the discomfort due to the nurse's lack of skill in*	Laparoscopic surgery and ergonomics but would be interested in being trained ✓ 4% said they would not be interested ✓ Agre group not associated with WRMSD (p>0.05) ✓ No gender differences WRMSD (p<0.05) **QUAN3 results (n=19 surgeries)** **Surgeons posture** ✓ Overall RULA = High risk (AL3 and AL4) ✓ Female surgeons had significantly more risk than male surgeons (p<0.001) ✓ Camera assistants had significantly more risk than female assistants (p<0.001)	established a higher risk of WRMSD due to postural overload in females than in males surgeons and assistants. ✓ Although the prevalence rate was high in QUAL1 and QUAN2, QUAN2 had a WRMSD rate of almost 90% of surgeons while QUAL1 had 66%. ✓ There were no reports of WRMS injuries in QUAN2, while in QUAL1, two surgeons indicated that they had injuries but were not officially reported. ✓ Age was a risk factor for WRMSD in QUAL1, while in QUAN2, it was not associated with WRMSD. **Expansion** ✓ QUAL1 expands on the results of QUAN3 and QUAN2 by pointing out the problems that shorter surgeons have in surgeries, especially when working in teams with taller surgeons because they have to adjust the heights of the taller surgeons. ✓ QUAL1 expanded on the work team issues and their relationship with the camera assistants, where interaction problems that restricted the assistant's movement were observed. In addition, communication issues with other team members jeopardised patient safety. ✓ QUAN 2 pointed out that more than half of surgeons surveyed had no training in laparoscopic surgery and ergonomics and had the willingness to be trained. QUAL1 gave different examples of how the lack of ergonomics

preparing the material. It increased the duration of surgery"(S-05) *"I have a guy (medical resident) I in my floor (hospital), young and who had kidney problems, as he is the shortest of the whole group when you put him o with a tall surgeon, wow... The one who suffers is the short one in the table, and he has to do this (raise the shoulders)."(I-17)* *"The suture is performed in a rather awkward position, the surgeon is positioned in the same way with the wrist flexed, and the resident's arm with the camera crossed. It did not facilitate the free movement (of the surgeon) at that point of the work."(S-16)*		training impacts the surgeons' posture and expanded on the possible harm to the patient. ✓ QUAL1 expanded the knowledge on the impact of age and sensory restrictions in laparoscopic surgery.

Table D. Joint display table for the Internal Environment category establishing meta inferences from QUAL1 , QUAN2 and QUAN3

Qualitative findings	Quantitative findings	Mixed method meta-inferences
QUAL1 results (n=18 interviews; n=20 observations) **fourth top category = 68%** **Work system factors contributing to WRMSD** **Limited physical workplace (49%)** *"Due to the space we have to move the electrocautery pedal that we usually activate it with the right foot, makes all our weight rests on the left side, causing heel problems and spinal problems."(I-13)* *"The surgeon operates together with the resident at the patient's side in close proximity to the entrance and exit door. This layout is due to the fact that the table does not allow for more space."(S-10)*	**QUAN2 Results (n=140 surgeons)** **fourth top category = 68%** **Work system factors contributing to WRMSD** ✓ Position of monitor display (64%) ✓ Foot pedals and/or hand switch position (50%) ✓ Lack of illuminance (49%) **QUAN3 results (n=19 surgeries)**	**Convergence** ✓ The two studies QUAL1 and QUAN2 converged in that "internal environment" was the fourth most frequent category. ✓ The factors related to screen display position and foot pedals identified in QUAN2 were contained in the "limited physical workplace" factor of QUAL1, the most frequent factor in the internal environment category. ✓ QUAL1 and QUAN 2 converged that factors related to limited physical workplace (including foot pedals and monitor display position) were the most frequent factors. ✓ The monitor position increased the neck extension of the surgeons and assistants, which was confirmed in QUAN3, identifying that neck postures exceeded 60%, being one of the most critical working postures.QUAl 1 and QUAN 2 converged as a recurrent factor the monitor display position
	Surgeons posture	**Divergence**

"You have to organize yourself in such a way that the tubes and cables don't bother you, I-11) ***"for example, our monitor is set high and you have to be in this position (extended neck) and it hurts." (I-07)*** **Distractor sounds and noise (46%)** *"It is difficult to hear the surgeons' words on the audio due to the high volume of the radio. "(S-03)* *"All surgeons operate with music, almost all of them, music relaxes you." (I-11)* **Deficiencies of environmental system regulation (18%)** *"The nurse indicates that the air conditioning does not work, and it is quite hot inside the room (the observation was made in summer, Peru)."(S-08)* *"It's an issue when you can't see ... that it is opaque or poorly illuminated,... sometimes you*	✓ Overall RULA = High risk (AL3 and AL4) ✓ Neck extended (64.6%) surgeons and 71.3% (assistants) ✓ Leg: unssuported (11.3%) surgeons and (0.6%) assistants	✓ There were no reports in QUAN2 on other environmental factors such as noise. In QUAL1 it was identified that noise was frequent in operating rooms. ✓ There were no major reports in QUAN2 on the lack of physical space in operating rooms as a factor for WRMSD. While QUAL1 describes lack of space as a risk factor. ✓ Although foot pedals contributed to WRMSD in QUAN2 , QUAN3 reported that only 11.3% had poor foot support. **Expansion** ✓ QUAL1 expanded on the problem of foot pedals by pointing out that the lack of space on surgical stools makes it difficult for surgeons to position themselves. QUAN2 confirmed this finding with the association between foot pedals and WRMSD in feet and other body regions. ✓ QUAL 1 extended information about the screen positioning identified in QUAN2. Positioning issues were centred on the inability to lower the screen's height, damaged screen adjustment systems (bendable arms) and the lack of additional screens for assistants. The assistants had severe difficulties in reaching adequate screen heights. ✓ The lack of illumination was an issue that was broadened in QUAL1, showing situations in which the

can't get it and we have to keep operating that way." (I-06)	lack of light in operating rooms forced the surgical team to stop the surgery and, in other cases, to continue operating, increasing the visual effort. In both cases, the risk for the patient increased. ✓ QUAL1 allowed to expand on the problems related to limited space within the operating room, especially in small rooms. These conditions forced surgeons to operate, adopting awkward postures and restricting their movements. It also impacted the nurses and assistants, blocking the screen view constraining surgeons' fields. Besides, other factors could endanger patients and surgeons, such as slippery floors or loose cables throughout the operating room. ✓ While noise and distractions were reported as negative factors, music was a factor that surgeons indicated as relaxing for work (QUAL1).

Table E. Joint display table for the organizational category establishing meta inferences from QUAL1 , QUAN2 and QUAN3

Qualitative findings	Quantitative findings	Mixed method meta-inferences
QUAL1 results (n=18 interviews ; n=20 observations) **Fifht top category = 46%** **Work system factors contributing to WRMSD** ✓**Poor organization of LAPS (26%)** *"Sometimes it (laparoscopic surgeries)can be booked all morning, but usually it is two surgeries sometimes" (I-11)* *"You are already tired, it's a long surgery, and then you have to do that, you have no other choice, sometimes the shifts are not well organized, and it's bad for us."(I-11)* ✓ **Limited education and training opportunities (18%)**	**QUAN2 Results (n=140 surgeons)** **Third top category = 70%** **Work system factors contributing to WRMSD** ✓ Lack of microbreak during surgery (59%) ✓ Poor distribution of shifts (53%) ✓ Time pressure (36%) ✓ Lack of training was associated with a higher rate of WRMSD ($p<0.05$). Surgeons' training ✓ 79% indicated that surgeons did not receive formal training in Laparoscopic surgery and	**Convergence** ✓ The two studies QUAL1 and QUAN2 converged in that "Organization" was the fifth most frequent category. ✓ QUAL1 and QUAN2 converge that the poor distribution of laparoscopic surgeries represented a considerable risk for surgeons as one of the priority factors in this category. ✓ Lack of microbreaks during surgery was reported by almost 60% of surgeons in QUAN2, which QUAN3 and QUAL1 confirmed. During participant observations, there was no evidence of any microbreak during surgeries. **Divergence** ✓ Although QUAL1 and QUAN2 identified the factors in the organizational category as being of lower frequency, QUAN2 accounted for responses from

"Unfortunately, learning is on the patient. There are training centres, but attendance is very low, and training is very limited."(I-13) *"There are many (surgeons) who have never learnt intracorporeal surgery, so in Peru, surgery is being taught in the tummy of the patient and very little in the laboratory, when it should be 95% in the laboratory and 5% in patients."(I-13)*	ergonomics but would be interested in being trained ✓ 4% said they would not be interested	over two-thirds of surgeons, very close to the Internal Environment category. ✓ QUAL1 indicated that surgeons are not knowledgeable about ergonomics, but they are not interested in further training. On the other hand, QUAN2 indicates that although more than 70% of surgeons have no formal training, they are willing to receive it. ✓ Surgeons did not express time pressure problems in QUAL1. However, in QUAN2, it was reported as a less frequent factor.
	QUAN3 results (n=19 surgeries)	
✓ **Poor ergonomics and safety culture (16%)** *"last night I passed the invitation to everyone, nobody was interested, they don't even know what ergonomics is, they don't know what they are missing, what they are gaining either."(I-13)*	There were no microbreaks during surgeries.	**Expansion** ✓ QUAL 1 expanded the problem of surgeon training, with no formal training places accessible for the Peruvian surgical community. This undoubtedly relates to the lack of training observed in the person category, so the organizational component is directly related to the person category. Education is mainly on the patient and not through formal simulator training (e.g. box trainers). ✓ QUAL 1 broadened the problems related to poor shift distribution. Surgeons indicated that shifts are sometimes poorly organized, forcing them to

	operate two complex surgeries, increasing fatigue and the risk of WRMSD. This can also have consequences for patients. ✓ QUAL1 evidenced that only five surgeons indicated they knew about ergonomics in surgery and guidelines about laparoscopic and ergonomics but considered it challenging to apply in their realities. Only two surgeons were aware of ergonomics' importance

12.13. Appendix 13. Study 4: Description of anthropometrical measures

		Description	Instrument
Standing measurement			
1	Stature (H)	The vertical distance from the floor to the vertex	Anthropometer
2	Eye height (EH)	The vertical distance from the floor to the inner canthus(corner)	Anthropometer
3	Shoulder height (SH)	The vertical distance from the floor to the acromion	Anthropometer
4	Elbow height (EH)	The vertical distance from the floor to the radial bony point, the measurement will be taken with the elbow bent to 90°	Anthropometer
5	Umbilicus height (UH)	Vertical distance from the floor to the navel	Anthropometer
6	Knuckle height (KH)	The vertical distance from the floor to the third knuckle	Anthropometer
7	Grip reach; Forward reach (FR)	Distance from the back of the shoulder to the tip of the middle knuckle.	Anthropometer
8	Elbow-grip-length (minimum functional reach)(MFR)	Distance from the back of the elbow to the tip of the middle knuckle.	Anthropometer
9	Abdominal depth (AD)	Maximum horizontal Depth of the chest measured from the vertical reference plane to the front of the abdomen in a standing position	Escalated from the Chilean population

12.14. Appendix 14. Study 4: Anthropometric measures form

Anthropometric measurements form

Name :…………………………………………………… **Day:** …………………………..

Age : ………………………………….. **Birth of placement:**……………………….. **Gender:** M F

Father´s place of birth:……………………… **Mother´s place of birth:** ………………………………….

Occupation: ………………………………………..

Postura de pie

	Anthropometrical measures	Measure 1	Measure 2
P1	Stature		
P2	Eye height		
P3	Shoulder height		
P4	Elbow height		
P5	Umbilicus height		
P6	Knuckle height		
P7	Grip Reach		
P8	Elbow grip reach		

12.15. Appendix 15. Study 4: Participant information sheet

Participant Information Sheet

My name is Carlos Manuel Escobar Galindo and I am PhD. Student at The University of Nottingham.

As part of my PhD , I would like to invite you to take part in this study. Before you start it is important for you to understand why the research is being done and what will be involved. Please take some time to read through this information sheet carefully and ask questions if anything is unclear or if you would like more information.

Purpose of the study

The aim of this study is to determine what are the physical characteristics of surgeons or future surgeons, to do that will be necessary to take different measures to your body in a standing position. All the measures will be collect with different instruments like an anthropometer that is a large ruler and tape measure, do not worry that this only implies no more than 10 minutes of your time. It is a simple quick evaluation and will not cause any kind of pain, fatigue or unnecessary exposure. You will only be asked to remove your jacket or sweater and shoes and dressing only a t-shirt and pants.

What will happen if I decide to take part?

If you agree to take part, I will provide you with full instructions. You will also be given the opportunity to ask any questions. You may ask questions at any time if you do not understand anything.

What will happen to my information?

All information provided will be stored in a protected computer with password. It will be destroyed seven years after any publication arising from work, in accordance with the university data storage policy. Your name (i.e. signature on consent form) will be kept separate from the observations made during the surgery . Consent forms will be stored in a locked filing cabinet for the duration mentioned above.

The information that I collect during this project will be used to inform my design. Your name will not be used in association with the data.

What will happen if I don't want to carry on with the study?

You can withdraw from the study at any time without having to provide a reason. If you do withdraw, any information that you have collected will be destroyed and will not be included in the study. You also do not have to answer any particular question.

Will my taking part in this study be kept confidential?

Yes, you confidentiality will be protected in this study

Who is organising and funding the research?

This research is being conducted as a PhD student project at The University of Nottingham.

Who has reviewed the study?

This study has been approved by one University of Nottingham Faculty of Engineering Ethics committee.

Who do I contact if I have questions or require further information?

If you have any questions or concerns about the study, please contact:

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12.16. Appendix 16. Study 4: Photos of the anthropometric measurement process

Anthropometer GPM Swiss. N°683656

12.17. Appendix 17: Surgeons using surgical stools to offset working heights

12.18. Appendix 18. Study 5: Protocol A

1. MATERIAL AND METHODS

Study design

The study design consist of a fitting trial explained by Pheasant & Haslegrave (2006c) following parameters of classical psychophysical approach explained by Snook and Ciriello to determine the maximum acceptable lifting weight (Ciriello & Snook, 1978; Snook et al., 1995) and the adaptation made by Lin, Catalano, y Dennerlein (2016).

Sample size

A total of 22 adult participants is projected as a minimal sample size with no history of neck or upper extremity musculoskeletal injuries.

In order to be included in the experiment, participants will have to accomplish the following requirements: Participants should be medical residents in the training process to be surgeons and or/ surgeons specialists with experience in laparoscopic surgery and Fundamental Laparoscopic Surgical training tasks. Novice physicians will not be allowed to participate. Participants should be available to participate in the test following the protocol statements. Participants will not have to present any injury or musculoskeletal disorder that may affect their normal performance in the test.

Laparoscopic surgical tasks

Two tasks were chosen due to the level of difficulty and standardization in laparoscopic surgery, and one represents the main surgical assistant task of holding and conducting the camera. Two laparoscopic surgical tasks are based on the Fundamental of Laparoscopic surgery training course (FLS). These tasks were broadly used in other studies emphasising ergonomics (Rodrigues Armijo et al., 2020; Siri et al., 2020 ; Zihni et al., 2014), so it represents the different levels of complexity of laparoscopic surgery (Fried, 2008) . Hence, FLS manual technical skills have high reliability and validity to represent the tasks in laparoscopic surgeries. The selected tasks were those with the highest risk of WRMSD as described in detail in chapter seven.

Peg transfer (PT)

Surgeons grasp (with a surgical instrument) each object (cube) with a non-dominant hand and transfer the object mid-air to the other dominant hand. Once all six objects have been transferred to the opposite side of the board, surgeons have to reverse the process and first grasp each object with the dominant hand, transferring mid-air to the other non-dominant hand, and placing it on the original site of the pegboard.

Instrument: Two Maryland dissectors ring handle

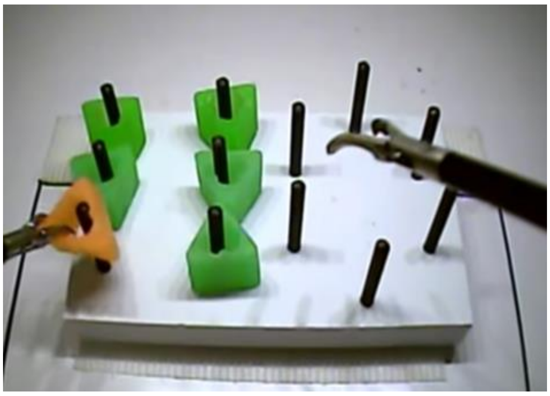

Figure 1. Screenshot of an example of the peg transfer (PT)

Intracorporeal Suturing task (IS)

This suturing task requires placing a suture precisely through two marks on a Penrose drain, that has been slit along its long axis. Surgeons then are required to tie the knot using an intracorporeal knot. They must place at least three throws, including one double throw and two single throws on the suture. Surgeons must also ensure the knots are square and won't slip.

Instrument: Axial handle two needle drivers

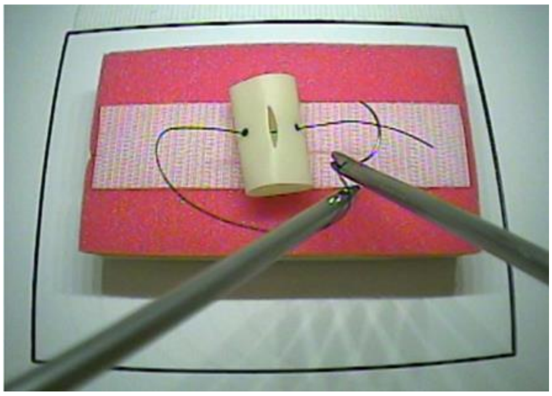

Figure 2. Screenshot of an example of the peg transfer

Camera Driving Task (CT)

A 0° scope will display endoscope images on a standard liquid crystal display (LCD) monitor positioned at eye level at the head of the table. A laparoscope will be introduced into the training box, which also contains four 2-cm circles functioning as targets placed on the rear panel in the following relations to the participant: distal superior, proximal superior, distal inferior, and proximal inferior (target effect). Four additional 2-cm circles approximately 10 cm apart will be marked in a straight line between the superior and inferior targets. A rubber band will be stapled to each of the outermost circles (A, C) for the purpose of retraction to the inner circles (B, D). The camera task for the subject will require holding the camera with the left hand and pointing it at the target. On the screen will there be a transparency sheet with two circles attached to it. The task will be to maintain the target's accuracy constraints by confining it between the boundaries of both circles.

Figure 3. Screenshot of an example of camera task (CT)

Measures to evaluate in fitting trial : Working surface height

Working surface height

The height measured centimetres from the ground up to the top of the pelvis trainer mock-up. Three different measures will be taken into account as acceptable limits: Highest acceptable level, optimum level,Lowest Acceptable level

To compare results with international data, the preferred height measured as a percentage of the participant´s elbow height will be considered.

Anthropometric dimensions

Stature, elbow height, umbilicus height,

Level of experience in Laparoscopic surgery

Determined by the surgeon instructor according to the training level and experience in laparoscopic surgical training with FLS

Place for applicating fitting trial

CEPCEA Training centre- Lima Peru

Figure 4 . CEPCEA training centre. Place where experiment will be carried out

2. EXPERIMENTAL PROCEDURE

Previous to experiment

Participants will be recruited from the training program run by the CEPCEA training centre. Firstly, the researcher will ask potential candidates to determine if they accomplish the study inclusion criteria. Accepted participants will be explained the objectives of the study, letting them the opportunity to ask questions about the study. To complement the information, instructions will be given in a printed version. Once their questions are answered and their doubts clarified, they will be requested to sign the informed consent if they agree to participate. Since the current pandemic, this step would be carried out by virtual connection with participants to keep the distancing measures.

Participants will be advised to wear light and comfortable clothes with shoes that they normally wear in operating rooms. They will be encouraged to wear surgical masks, surgical gloves and scrubs to simulate similar conditions of surgery. In addition, they will be asked that at least two hours before starting the study, they do not perform surgeries or activities where they need to exert a great effort on upper limbs to avoid the rapid onset of high fatigue levels.

Before the experiment, participants will be trained first on the use of regulation systems of the table, so they will have the opportunity to regulate the table to understand its functioning before beginning real trials. Participants will be encouraged to make as many adjustments as necessary to determine the best acceptable range for working as laparoscopic surgeons. Secondly, participants will be given general and short ergonomics training. Only general aspects of the importance of working following ergonomics recommendations in general works will be considered. Training will not comprise specific examples of how to set up a laparoscopic surgery workstation to avoid bias.

Procedure

To familiarize surgeons with tasks, they were allowed 15 minutes of training before the session. The researcher will present the three tasks that the surgeon will have to perform. All surgeons will have experience in tasks presented in the study, so the familiarization period will be relatively short.

The psychophysical protocol (fitting trial) will consist of a 30-min session for each laparoscopic task, alternating among the three tasks assessed. The order of tasks will be chosen randomly. The duration of the session will be 30 min for every task since it would be long enough for participants to develop an early sign of fatigue or discomfort (Ali Keshavarz Panahi & Sohyung Cho, 2016; Lin et al., 2016).

In order to organize the time in the activity and present the stimulus, the 30-minute session will be divided into four equilibrated segments. To the extent to which participants are performing trials, the researcher will interrupt the task every 8 minutes (1 segment) to abruptly reset the table on an extreme condition. It means that table will be adjusted randomly at the highest or lowest level. The participant must correct this condition by adjusting the table at their preferred working height. During resetting the workstation, participants will turn their faces back to avoid viewing the resetting process and bias the test (Figure 2). Participants will have 10 minutes to take a rest to recover energy and reduce the level of fatigue. In normal conditions, the duration of training sessions for the FLS tasks has similarities to the protocol (FLS, 2020). Besides, real surgeries may last more than 2 hours (study 1)

Participants will not be allowed to change the table height during the final 6 minutes segment, so they have to conclude the final segment on the chosen height. At the end of the session, the final height chosen by participants will be considered as optimum height and then they will be asked to indicate the acceptable lowest and highest height in which task may be performed. This is how the data represent a real condition (Snook et al., 1995; S.-P. Wu, 1997). Tasks will be presented once randomly to each participant to avoid bias. Figure 5 represents a basic scheme for one participant. The "X" represents the segment of one sequence task in which participants will not be allowed to change the height.

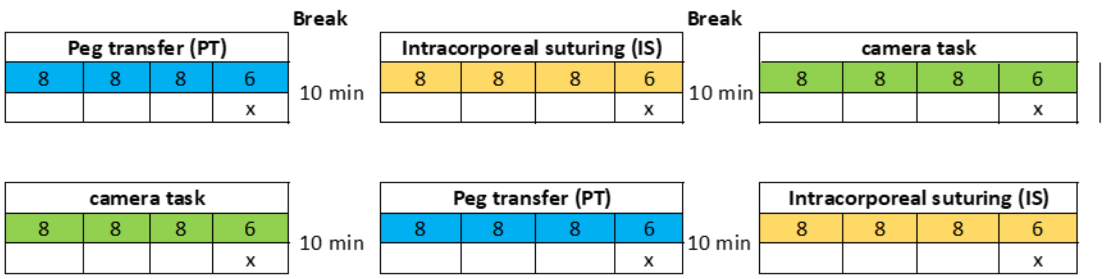

Figure 5. Psychophysical Fitting trial protocol to determine optimum workstation

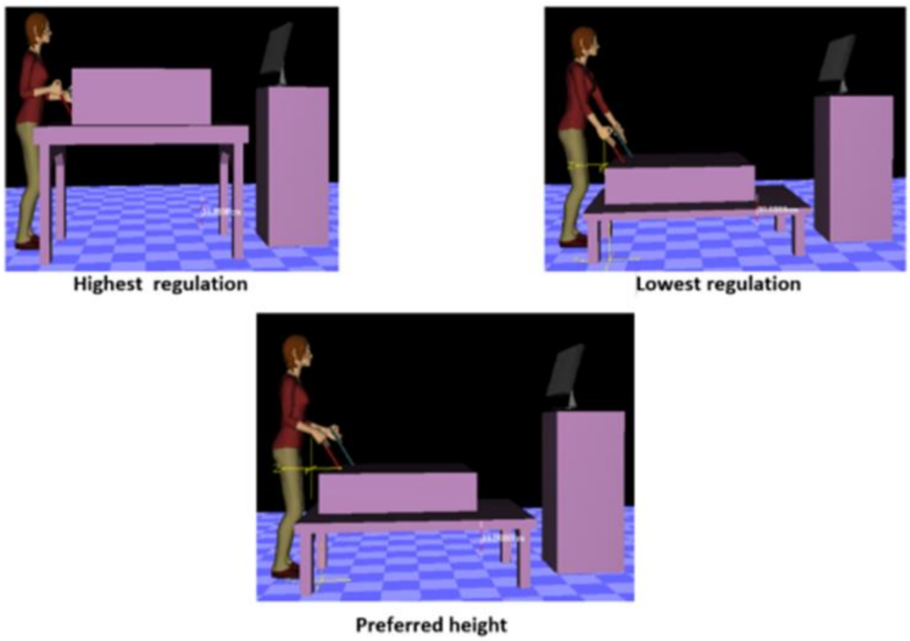

Figure 6. Fitting trial protocol. Resetting the table height

Participants will be correctly instructed to follow the protocol successfully. They will be instructed to set up the best working surface height that they would be able to do for a regular surgery day (Ciriello & Snook, 1978). The instruction to participants will be as follow :

"Adjust the table height to minimize discomfort as if you were to work in this posture for a whole day performing laparoscopic surgeries in the Hospital. You may continue to make as many adjustments as you like, even in the middle of your task whenever you feel like to, and even if you have not made any adjustment for some time. At the end of the trial, you will be asked to set the table to the Lowest and highest heights that you consider acceptable and to your own personal preferred optimum height."

All the instructions will be printed and read to participants at the beginning of the protocol

3. **Special considerations to performing protocol due to current COVID-19 pandemic**

- The distance will be more than 1.5 metres between participants and the instructor. Space will be marked with specific circles drawn on the ground.
- Participants may require to use a mask and other PPE necessary according to the requirement of the training centre and local government requirements.
- The training centre is allocated out of a hospital or any medical centre, so the interaction with possible patients is low.
- The use of latex gloves will be mandatory to manipulate instruments. It will not affect the experiment because latex gloves are used in real surgeries. All the instruments will be disinfected previous to trials among participants.
- The researcher and assistant will wear gloves, mask and PPE and disinfect the mechanism to regulate the table to avoid a source of infection.

12.19. Appendix 19. Study 5: Participant´s guide for remote fitting trial

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PARTICIPANT´S GUIDE

DETERMINING PREFERRED WORKING HEIGHT TO PERFORM LAPAROSCOPIC SURGERY

INTRODUCTION

Thank you very much for participating in the study. Your contribution will be relevant to improve the design of systems that facilitate the work of laparoscopic surgeons.
Surgeons who play an important role in people's health require furniture and equipment that are appropriate to their capabilities, characteristics, as well as their limitations. However, many of the equipment are not adequate and are usually too large such as the current operating tables, increasing physical and mental discomfort of surgeons which sumed to the high mental load that surgery demands, may incur in possible injuries to surgeons and assistants and thus potential risk for the patient.

For this reason, the Doctoral research has developed different studies to analyze this problem, determining that the heights of the working surfaces are an essential element in Operating rooms, especially with laparoscopic surgery. Hence , The present study aimed to determine the most suitable working heights to perform laparoscopic surgery. To achieve the aim it is necessary to test surgeons with experience to ask them about their preferences to work in laparoscopic surgery . Since , restrictions for the current pandemic, the information will be taken remotely taking advantage of the technology , therefore the information is requested as a preliminary study for subsequent future studies. For this reason , the present guide set up directives to follow specific instructions to perform the task in your home with simple materials . We really appreciate your collaboration for the study that will benefit to healthcare community

El siguiente documento es una guía breve que le guiará en el proceso en 5 pasos definidos . Además esta guía estará acompañado de un video instruccional en donde se detallara las tareas a realizar.

RESEARCH TEAM

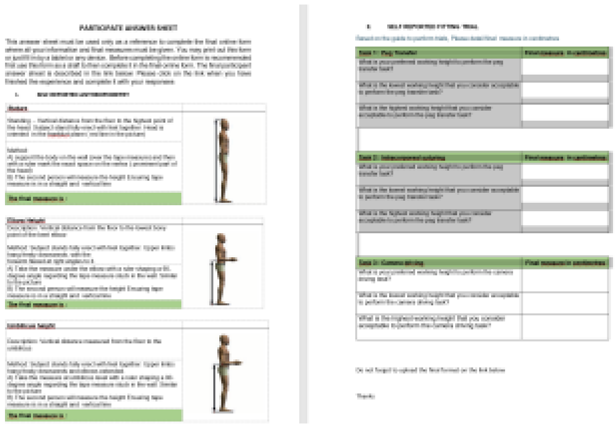
MAIN RESEARCHER	: PhD © Carlos Manuel Escobar Galindo
SUPERVISORS	: Dr . Alexandra Lang ; Dr. Brendan Ryan ; Dr. Sue Cobb
MEDICAL ADVISOR	: Dr. Carlos De Dios (CEPCEA training centre)

STEP 1	Download the participant´s answer sheet
STEP 2	Prepare your materials
STEP 3	Take anthropometric measures
STEP 4	Determine your preferred working heights
STEP 5	Upload your results to the virtual participant´s answer sheet

STEP 1

Download the participant´s answer sheet

- ✓ Download the participant´s answer sheet and print it out or fill it from your tablet or device.
- ✓ If you do not have access to a printer, you can also complete your answers on a blank sheet
- ✓ The answer sheet is available in the folder "Remote fitting trial



✓ ***This is the link direct to "Remote fitting trial file"***

https://uniofnottm-my.sharepoint.com/:f:/g/personal/manuel_escobar_nottingham_ac_uk/ErSsxlhltbRKiZKFxEuRb0MBb0a8y94jT8MZC3EZljl0Tg?e=doeMIH

STEP 2

Prepare your materials

✓ Prepare your materials to complete the experience

Materials :

- ✓ Plastic scissors (2)
- ✓ Ruler of 30 cm (3)
- ✓ Adhesive tape
- ✓ Medium size box (less than 20 cm high approx.)
- ✓ Books, notebooks, packages, boxes, magazine or any material that can be stacked
- ✓ Measure tape (1)
- ✓ Flexible measure tape (plastic

STEP 2a

Build your simulated tools

✓ In this substep, you must follow the instructions to build the ring handle tools.

1. To preprare ring handle tolos , you will need two rulers , two scissors and adhesive tape

2. Position the scissors at an angle of about 45 ° to the outside edge of the ruler. Remember to use the beginning of the numbering and stick them with the adhesive tape

Simulation of Maryland Scissors

2. Place one scissor at an angle of about 90 ° regards to the edge of the ruler. Remember to use the beginning of the numbering. Scissor should be stuck at 5 cm

Simulation of laparoscope with 45°

STEP 2b

Build your stadiometer

✓ In this step you must build your homemade stadiometer

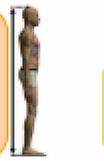
1. You need a plastic tape measure and masking tape. You will need to prepare a wall where the stadiometer will be placed

2. Measure 30 cm vertically from the floor to the edge of the wall and make a mark

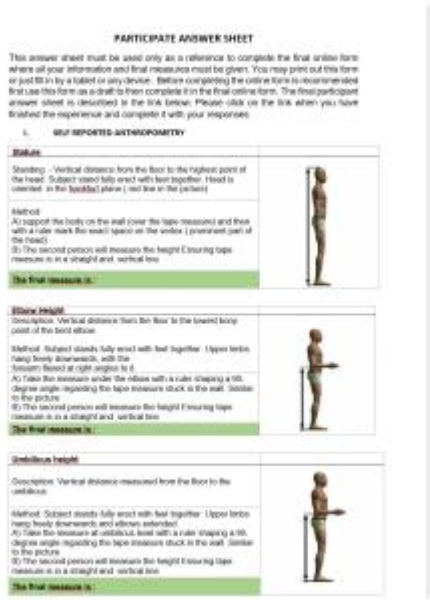
3. Stick the tape measure starting with the initial numbering from the wallmark , extending it along the wall . Stick it with the masking tape

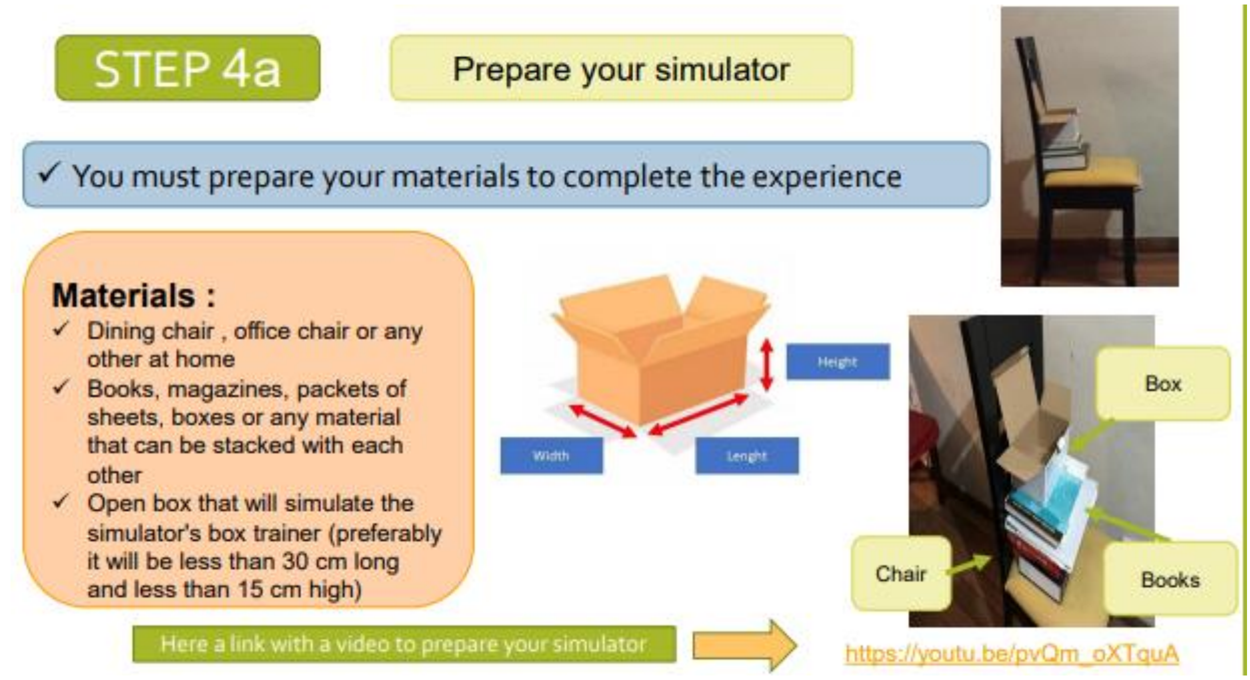
STEP 3

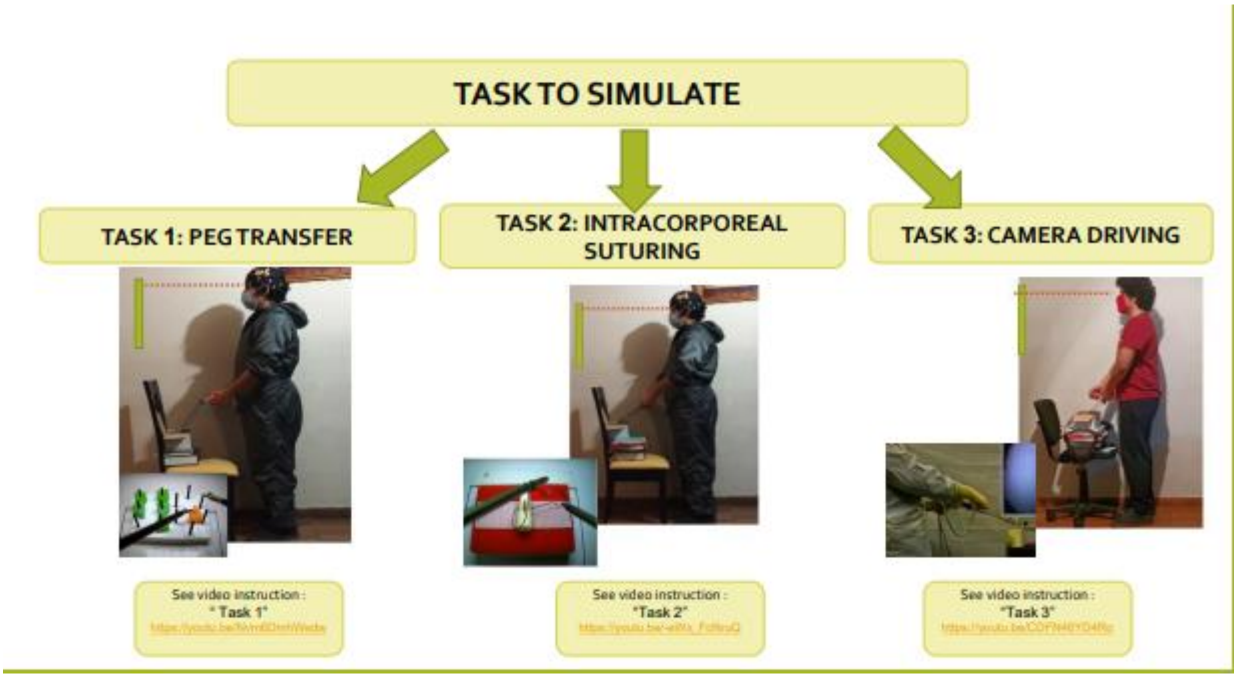
Take anthropometric measures

STATURE	Stand upright facing forward with your back to the wall where the tape measure is attached. Keep your head straight as much as possible so that your eyes are parallel to the ground. Once you are in position, you will place the ruler at the top of your head called the vertex, pointing the edge of the ruler toward the tape measure.		See video instructions:
ELBOW HEIGHT	Stand upright facing forward close to the wall. You will bend the elbow of the dominant limb forming a 90 ° angle keeping the shoulders relaxed and looking forward. Once you adopt the position, you will place the ruler below the bent elbow pointing to the centimeter attached to the wall.		See video instructions:
UMBILICUS HEIGHT	Stand upright facing forward parallel and close to the wall where the tape measure is attached. Keeping your shoulders relaxed and looking forward, you will make a projection with the ruler at the level of the umbilicus in a perpendicular direction towards the wall.		See video instructions:

Annotate the measurements on the participant's answer section : SELF-REPORTED ANTHROPOMETRY




STEP 4a
Prepare your simulator
✓ You must prepare your materials to complete the experience
Materials :
✓ Dining chair , office chair or any other at home
✓ Books, magazines, packets of sheets, boxes or any material that can be stacked with each other
✓ Open box that will simulate the simulator's box trainer (preferably it will be less than 30 cm long and less than 15 cm high)
Height
Width
Lenght
Box
Chair
Books
Here a link with a video to prepare your simulator
https://youtu.be/pvQm_oXTquA

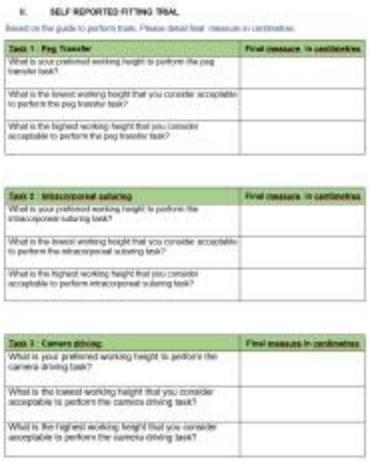

TASK TO SIMULATE
TASK 1: PEG TRANSFER
TASK 2: INTRACORPOREAL SUTURING
TASK 3: CAMERA DRIVING
See video instruction :
" Task 1"
See video instruction :
"Task 2"
See video instruction :
"Task 3"

- ✓ With the help of a tape measure, annotate the height from the ground to the upper edge of the box as shown in the figure. Annotate all measurements on the participant's answer sheet in section " Self Reported Fitting trial"
- ✓ Remember that there are 3 measurements for each task.

Optimal height preferred for work

Highest height for acceptable work

Lowest height for acceptable work



II. SELF REPORTED FITTING TRIAL

Based on the guide to perform trials. Please detail final measure in centimetres.

Task 1 : Peg Transfer	Final measure in centimetres
What is your preferred working height to perform the peg transfer task?	
What is the lowest working height that you consider acceptable to perform the peg transfer task?	
What is the highest working height that you consider acceptable to perform the peg transfer task?	

Task 2 : Intracorporeal suturing	Final measure in centimetres
What is your preferred working height to perform the intracorporeal suturing task?	
What is the lowest working height that you consider acceptable to perform the intracorporeal suturing task?	
What is the highest working height that you consider acceptable to perform intracorporeal suturing task?	

Task 3 : Camera driving	Final measure in centimetres
What is your preferred working height to perform the camera driving task?	
What is the lowest working height that you consider acceptable to perform the camera driving task?	
What is the highest working height that you consider acceptable to perform the camera driving task?	

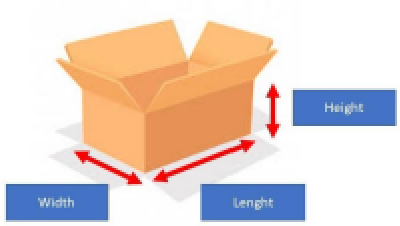
STEP 5

Upload your results to the virtual participant´s answer sheet

✓ ***This is the link direct to "Virtual answer sheet"*** → https://nottingham.onlinesurveys.ac.uk/fitting-trial-answer-sheet-v2

Upload your results to the virtual participant´s answer sheet

Don't forget to add the features of the box !!

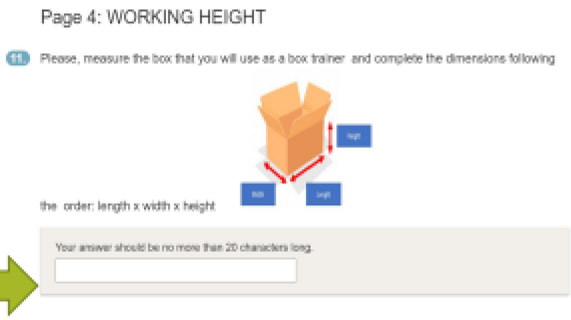


Upload the information of the characteristics of the box that will be used as a boxing training
In the item " WORKING HEIGHT" complete the measurements of the boxes following the order indicated:

lenght x width x height

For example: if the box is 30 cm long, 20 cm wide and 10 cm high then you must complete the format as follows:

30 x 20 x 10



SHARE YOUR EXPERIENCE

Optionally, you can share us photographs of your experience to assist you and validate your information. If you wish, you can put a stamp on the face of the photograph.

To share your images you can use remote applications such as ICLOUD; ONE DRIVE, GOOGLE DRIVE, DROPBOX or any of your preference.

Photo example. Preferably the photograph should be in this plane.
You can use the countdown shooting function of your phone
Place a small caption on the bottom of the photo specifying the task and height

Here are some tutorials to teach you how to share your photos .

25 In case you have photos to share of your experience, you can copy and paste the link from the Drive where you stored them here. Remember to put the name of the task and working height chosen in the photo. This step is optional. In case you have difficulties you can contact me at the email: manuel.escobar@nottingham.ac.uk

Paste here the link with your file

Desde mi celular ANDROID — Google Drive — https://www.youtube.com/watch?v=-yzyKvygvbc&t=102s

Desde mi celular IPHONE — iCloud — https://www.youtube.com/watch?v=UhLnHCmqlBY

Desde mi celular ANDROID — https://youtu.be/hPyChEVlswU

PASO 5a

Upload your results to the virtual participant´s answer sheet

1. Once the data has been completed and filled in in the physical format which was previously printed or on the data sheet, the information will be uploaded to the virtual participant's file

2. To enter the virtual file, click on the attached link

3. A menu will be displayed with a presentation message reiterating your participation in the study

4. Fill in all the information and finally finish the survey. At the end a thank you message will be displayed

Page 4: WORKING HEIGHT

Task 1. On this section, please determine the Lowest, highest and optimum working height that you consider acceptable to perform the peg transfer task described in FLS

For more information about tasks, you may review the protocol format or visit the next link

11 What is your prefered working height to perform the peg transfer task? Please detail measure in centimetres

12 What is the lowest working height that you consider acceptable to perform the peg transfer task? Please detail measure in centimetres

13 What is the highest working height that you consider acceptable to perform the peg transfer

Remember to only put the numbers in the boxes. It is not necessary to put the word centimeters or abbreviations !!

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THANK YOU FOR YOUR PARTICIPATION

12.20. Appendix 20. Study 5 : Remote fitting trial Data collection form and consent form

DATA COLLECTION FORM

Page 1: INTRODUCTION

Hello

My name is Manuel Escobar main researcher. Thank you for accepting to participate in the study. The following document is an answer sheet which you will be used to upload your final measures. All the information given must be completed to successfully upload it.

It is highly recommended to upload the information once you have finished all the experience, so you must first annotate all the information in a blank paper or by printing out the answer sheet attached in the participants´ guide

This document consists of three parts:

Part 1 : General data

General data about you will be asked, please take your time and read carefully each question.

Part 2: Self- Anthropometry

On this section, you will upload all your measures following instructions of self-reported anthropometry given in the participant´s guide

Part 3: Remote fitting trial

On this section, you will upload all the information obtained from the experience to determine working heights. All the protocol is provided in the participants' guide. Remember only provide numbers, it is not necessary to include measures units ore other additional information.

Remember include photos of your experience following recommendations described in the participant´s guide

Do not hesitate to contact me if you need some assistance in the process. My mail is:

Page 2: GENERAL DATA

1. **What is your gender? (Please select one option)**

- Male
- Female

2. **How old are you ?**

3. What is your email ?

4. What is your phone number?

5. **Are you a resident or physician specialist?**

6. **Please tell us what is your medical specialty or resident program**

7. **How long do you perform laparoscopic surgery ?**

8. **Have you ever received formal laparoscopic surgery training?**

- Yes
- No

9. **Have you ever received training in " Fundamentals of laparoscopic surgery" (FLS) course training?**

- Yes
- No

9.a. **In case you received training in FLS , please indicate your level**

- Basic
- Intermediate
- Advanced

10. Do you have laparoscopic training equipment such as box trainer, needle driver, dissectors among others to simulate?

- Yes
- No

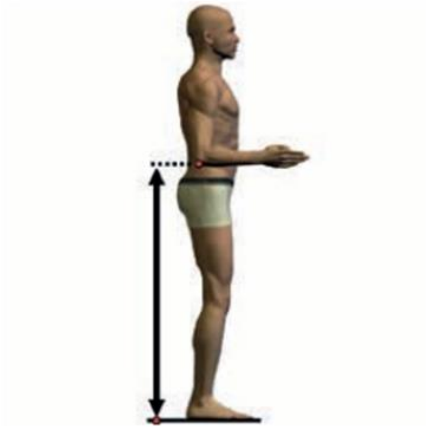
11. For the trial tests you will report, did you use your simulation training kit or build your simulators from the participant's guide with rulers and scissors?

- I used my own simulation kit
- I build my own simulation kit with scissors and ruler

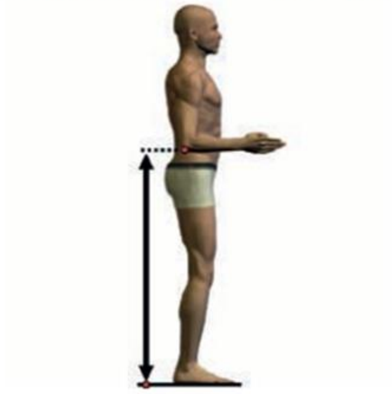
Page 3: ANTHROPOMETRICAL DATA

12. **STATURE** Standing: Vertical distance from the floor to the highest point of the head. Subject stand fully erect with feet together. Head is oriented in the frankfurt plane (eyes parallel to the floor) looking ahead Support the body on the wall (over the tape measure) and then with a ruler mark the exact space on the vertex (prominent part of the head) . Please measures should be taken barefoot. ***The final measure in centimetres is ...***

13. **ELBOW HEIGHT** Description: Vertical distance from the floor to the lowest bony point of the bent elbow. Method: Subject stands fully erect with feet together. Upper arms hang freely downwards, with the forearm flexed at right angles to it. Take the measure under the elbow with a ruler shaping a 90-degree angle regarding the tape measure stuck in the wall. ***The final measure in centimetres is ...***



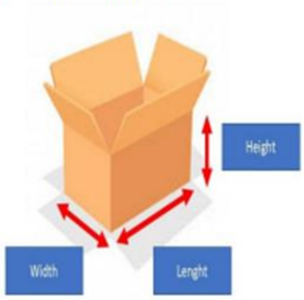
14. **UMBILICUS HEIGHT** Description : Vertical distance measured from the floor to the umbilicus Method: Subject stands fully erect with feet together. Upper arms hang freely downwards and elbows extended. Take the measure at umbilicus level with a ruler shaping a 90-degree angle regarding the tape measure stuck in the wall. See picture.



The final measure in centimetres is

Page 4: WORKING HEIGHT

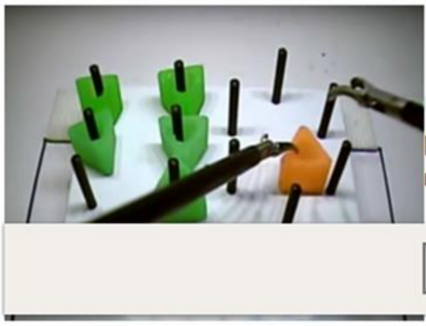
15. Please, measure the box that you will use as a box trainer and complete the dimensions following the order: length x width x height



Your answer should be no more than 20 characters long.

Task 1. On this section, please determine the Lowest, highest and optimum working height that you consider acceptable to perform the peg transfer task described in FLS

For more information about tasks, you may review the protocol format or visit the next link : https://youtu.be/gAQPXHWqdXQ



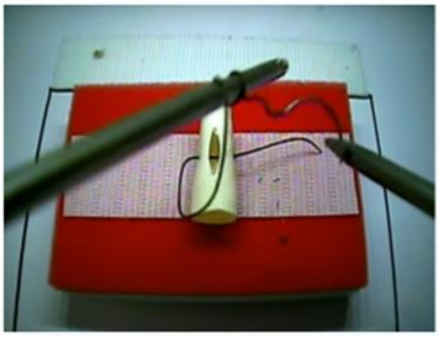
16. **What is your prefered working height to perform the peg transfer task?** Please detail measure in centimetres

17. **What is the lowest working height that you consider acceptable to perform the peg transfer task?** Please detail measure in centimetres

18. **What is the highest working height that you consider acceptable to perform the peg transfer task? Please detail measure in centimetres**

Task 2. On this section, please determine the Lowest, highest and optimum working height that you consider acceptable to perform the Intracorporal suturing task described in FLS

For more information about tasks, you may review the protocol format or visit the next link : https://youtu.be/hAzhqYid5jc



19. What is your prefered working height to perform the Intracorporal suturing task? Please detail measure in centimetres

20. **What is the lowest working height that you consider acceptable to perform the Intracorporeal suturing task?** Please detail measure in centimetres

21. **What is the highest working height that you consider acceptable to perform the intracorporeal suturing task?** Please detail measure in centimetres

Task 3. On this section, please determine the Lowest, highest and optimum working height that you consider acceptable to perform the camera driving task

For more information about tasks, you may review the protocol format or see the next picture

22. **What is your prefered working height to perform the camera driving task?** Please detail measure in centimetres

23. **What is the lowest working height that you consider acceptable to perform the camera driving task?** Please detail measure in centimetres

24. **What is the highest working height that you consider acceptable to perform the camera driving task?** Please detail measure in centimetres

25. In case you have photos to share of your experience, you can copy and paste the link from the Drive where you stored them here. Remember to put the name of the task and working height chosen in the photo. This step is optional. In case you have difficulties you can contact me at the email: manuel.escobar@nottingham.ac.uk

12.21. Appendix 21. Study 5: Virtual Consent form

WORKING HEIGHT FOR LAPAROSCOPIC SURGERY v.2

PRESENTATION

My name is CARLOS MANUEL ESCOBAR GALINDO and I am PhD. Student at The University of Nottingham.

As part of my PhD , I would like to invite you to take part in this study. Before you start it is important for you to understand why the research is being done and what will be involved. Please take some time to read through this information sheet carefully and ask questions if anything is unclear or if you would like more information. My email will be available for your questions.

Since the current pandemic, the social distancing is paramount to avoid possible infection for covid-19 , so the present study takes into account this recommendation and set up a remote study that may be performed at home without exposure of participants. The present study will constitute preliminary data set from which to inform the design of working heights in laparoscopic surgery. This problematic was considered as one of the most common a high contributing factor to physical discomfort in surgeons and assistants in Peru. So, results will be a preliminary for further studies related to this problem and will constitute the first background to analyse the ergonomics of laparoscopic surgery in Peru.

This experiment will not take more than 1 hour of your time and only one day is necessary to perform it. This information will let designers and engineers design devices that may solve issues related to working height in laparoscopic surgery.

Purpose of the study and methodology

The purpose of this study is to investigate the acceptable limits of working surface height of Peruvian laparoscopic surgeons taking into account the complexity of laparoscopic tasks, in order to accommodate at the majority of the population of peruvian surgeons.

The study consists of a fitting trial protocol where you will be asked to adjust the working height while you are performing a simulated laparoscopic task. You will be asked to regulate the working height as if you were to work in this posture for a whole day performing laparoscopic surgeries in the Hospital. You will simulate three different laparoscopic tasks based on the Fundamental of laparoscopic surgery (FLS) training course.

Previous to start trials, you will be asked to complete basic information as gender, age, time as surgeons, experience with FLS task, residence program or medical speciality. Trials will request your basic information but all your data will be stored and your identity will be protected through the use of numerical identifier codes to separate your data from your personal details. Before starting the trials, you will be asked to self report your anthropometric information. It consists of measuring your body segments with a tape measure following specific technique easy to perform. Only three measures will be requested: stature, elbow height and umbilicus height. All the instructions will be explained in detail in the protocol. To perform trials, it is recommended to wear light and comfortable clothes with shoes that you normally wear in their daily hospital activities as a surgeon.

To adjust working surface heights you will construct a system stable enough that permits easily adjust the height. Your participation will no demand extra investment, all the materials necessary are easily found in home without the necessity to buy expensive material or equipment. In case you have equipment for laparoscopic surgery you may use it as part of the trial but it is not mandatory to use it.

A simple dining room chair or an office chair with good stability should be enough to complete the experience. To adjust the height, you will be asked to place books, packages, boxes, phone books, notebooks or any flat material that guarantee good stability. To simulate the laparoscopic training box, you may use a simple cardboard box

At the end of trials, you will be asked to judge the best working height at three levels: (1) your preferred working height to perform the tasks, (2) the lowest working height that you consider acceptable (3) and the highest height that you consider acceptable to perform laparoscopic surgery tasks. To achieve this, you can adjust the height by removing or adding more books until you define the height according to the levels mentioned. The measurements will be recorded on an answer sheet that you can print or view from a tablet or cell phone. Finally, all the information must be uploaded in the virtual answer sheet format that will be available in a link that you can access from your phone, computer or other electronic devices.

In case the researcher requires information from you related to the data uploaded of the study (eg. missing data or some mistakes to complete the answer sheet), he will be able to contact you by using your mail or phone provided keeping the confidentiality and anonymity.

What will happen if I decide to take part?

If you agree to take part, I will provide you with full instructions for the procedures. Easy to follow videos have been developed to support your participation and make it as easy as possible for you to carry out the tasks required. These will be provided if you consent to your involvement. You will also be given the opportunity to ask any questions. You may ask questions at any time if you do not understand anything.

There will not payment of any kind, but if you participate in the study you will receive an online one hour course in ergonomics and laparoscopic surgery technique with the support of CEPCEA training centre and the Human Factors Research Group of University of Nottingham., UK

What will happen to my information?

All information provided will be used only for research purposes. All your data will be codified and your name will be protected. Your Information will keep it stored on a password-protected computer. It will be destroyed seven years after any publication arising from the work, in accordance with the university data storage policy. Your name (i.e. signature on consent form) will be kept in the anonymity. The information that I collect during this project will be used to inform my research. Your name will not be used in association with the data.

Once you accept to participate, a file will be displayed with instructions to download as well also the link to upload the information

What will happen if I don't want to carry on with the study?

You can withdraw from the study at any time without having to provide a reason. If you do withdraw, any information that you have collected will be destroyed and will not be included in the study. You also do not have to answer any particular question.

Will my taking part in this study be kept confidential?

Yes, your confidentiality will be protected in this study

Who is organising and funding the research?

This research is being conducted as a PhD student project at The University of Nottingham.

Researcher: Carlos Manuel Escobar Galindo. Msc Ergonomics , PhD (C) candidate

Supervisors : Dr. Alexandra Lang , Dr. Brendan Ryan and Dr. Sue Cobb

with the medical support of Dr. Carlos De Dios (coach surgeon)

Who has reviewed the study?

This study has been approved by University of Nottingham Faculty of Engineering Ethics committee and main supervisors of the study

Who do I contact if I have questions or require further information?

If you have any questions or concerns about the study, please contact:

manuel.escobar@nottingham.ac.uk

Do you consent to participate in the study?

- ○ Yes
- ○ No

INFORMATION OF PROTOCOL

The next link addresses to a file named " Remote Fitting trial". On this file, you will find all the information to conduct trials and the link that you will use to upload your results. Please, do not hesitate if you need more assistance in the process

https://uniofnottm-
my.sharepoint.com/:f:/g/personal/manuel_escobar_nottingham_ac_uk/ErSsxlhltbRKiZKFxEuRb0MBb0a8y94jT8MZC3EZIjl0Tg'
e=UcuOIe

Please give us your email to resend the link with the FILE and confirmation for your participation

[ ]

12.22. Appendix 22. Study 5. Photos of the experience (remote fitting trials)

12.23. Appendix 23. Study 5: Call for participants

The study is addressed to physicians that perform laparoscopic surgery

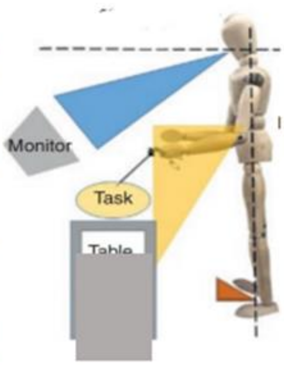
We´re looking for physicians who have experience in laparoscopic surgery in order to investigate what is the best operating table height and operating working height when performing laparoscopic surgery.

Participants will be asked to determine their preferred working height when performing different laparoscopic surgical tasks

ARE YOU ELIGIBLE?

Participants will have to accomplish the following requirements :

- Physicians Physician specialist or residents with experience in laparoscopic surgery and preferably (but not exclusive)with knowledge of fundamentals of laparoscopic surgery training course (FLS)
- Participants will not have to present any injury or musculoskeletal disorder that may affect their normal performance in the test.
- Availability to perform trials since home or working centre only one day for about 1 hour



For your participation, you will receive a one-hour training session about ergonomics tips and laparoscopic surgery techniques with the support of CEPCEA laparoscopic training centre and Human Factors Research Group, University of Nottingham

LOCATION

At home or your training centre

IF YOU´RE UNSURE IF YOU MEET THE REQUIREMENTS CALL OR EMAIL A THE MAIN RESEARCHER

- Msc. Manuel Escobar
- Manuel.escobar@nottingham.ac.uk
- Cel: 994391336

12.24. Appendix 24. Ethics committee reviewer decision (Study 1 , study 3 and study 4)

Ethics Committee Reviewer Decision

This form must be completed by each reviewer. Each application will be reviewed by two members of the ethics committee. Reviews may be completed electronically and sent to the Faculty ethics administrator (Jo Deeley) from a University of Nottingham email address, or may be completed in paper form and delivered to the Faculty of Engineering Research Office.

Applicant full name Carlos Escobar Galindo

Reviewed by:

Name B18

Signature (paper based only) ……………………………………………………………………………………………

Date 06/11/2018

☐ Approval awarded - no changes required

■ **Approval awarded - subject to required changes (see comments below)**

☐ Approval pending - further information & resubmission required (see comments)

☐ Approval declined – reasons given below

Comments:

The consent form for the interviews refers to heart rate sensors and filming and it is not clear that this consent from relates to consent for an interview. I am presuming that these are not used during the interview? Approval for the study is given on the condition that this consent form is revised

Please note:

1. The approval only covers the participants and trials specified on the form and further approval must be requested for any repetition or extension to the investigation.
2. The approval covers the ethical requirements for the techniques and procedures described in the protocol but does not replace a safety or risk assessment.
3. Approval is not intended to convey any judgement on the quality of the research, experimental design or techniques.
4. Normally, all queries raised by reviewers should be addressed. In the case of conflicting or incomplete views, the ethics committee chair will review the comments and relay these to the applicant via email. All email correspondence related to the application must be copied to the Faculty research ethics administrator.

Any problems which arise during the course of the investigation must be reported to the Faculty Research Ethics Committee

12.25. Appendix 25. Ethics committee reviewer decision (study 2)

Ethics Committee Reviewer Decision

This form must be completed by each reviewer. Each application will be reviewed by two members of the ethics committee. Reviews may be completed electronically and sent to the Faculty ethics administrator (Donna Astill-Shipman) from a University of Nottingham email address, or may be completed in paper form and delivered to the APM Hub.

Applicant full name Carlos Manuel Escobar Galindo

Musculoskeletal symptoms and risk factors of Peruvian Laparoscopic surgeons

Reviewed by:

Name David Large

Signature (paper based only) ....

Date ....11.5.18...............

☐ Approval awarded - no changes required

✓ **Approval awarded - subject to required changes (see comments below)**

☐ Approval pending - further information & resubmission required (see comments)

☐ Approval declined – reasons given below

Comments:

Generally, all ok.

Couple of minor points that require attention:

- Ethics form (answer to Q2) doesn't specifically state how participants will be recruited (as requested). While this information is clear elsewhere in the application, please also add it to the form for completeness.
- Collecting email addresses from participants regarding potential contribution to future studies using the same form rather contravenes anonymity. In the past, I have suggested providing a link to a second BOS form that collects only this information. This avoids email addresses being recorded with questionnaire responses (I will discuss this directly with Manuel).
- I am unable to comment on Spanish version of questionnaire, unfortunately.

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Please note:

1. The approval only covers the participants and trials specified on the form and further approval must be requested for any repetition or extension to the investigation.
2. The approval covers the ethical requirements for the techniques and procedures described in the protocol but does not replace a safety or risk assessment.
3. Approval is not intended to convey any judgement on the quality of the research, experimental design or techniques.
4. Normally, all queries raised by reviewers should be addressed. In the case of conflicting or incomplete views, the ethics committee chair will review the comments and relay these to the applicant via email. All email correspondence related to the application must be copied to the Faculty research ethics administrator.

Any problems which arise during the course of the investigation must be reported to the Faculty Research Ethics Committee

12.26. Appendix 26. Ethics committee reviewer decision (Study 5)

Ethics Committee Reviewer Decision

This form must be completed by each reviewer. Each application will be reviewed by two members of the ethics committee. Reviews may be completed electronically and sent to the Faculty ethics administrator from a University of Nottingham email address, or may be completed in paper form and delivered to the Faculty of Engineering Research Office.

Applicant full name Carlos Escobar Galindo

Reviewed by:

Name S11

Signature (paper based only) ....

Date 25/11/2020

- [x] Approval awarded - no changes required
- [ ] Approval awarded - subject to required changes (see comments below)
- [ ] Approval pending - further information & resubmission required (see comments)
- [ ] Approval declined – reasons given below

Comments:

Please note:

1. The approval only covers the participants and trials specified on the form and further approval must be requested for any repetition or extension to the investigation.
2. The approval covers the ethical requirements for the techniques and procedures described in the protocol but does not replace a safety or risk assessment.
3. Approval is not intended to convey any judgement on the quality of the research, experimental design or techniques.
4. Normally, all queries raised by reviewers should be addressed. In the case of conflicting or incomplete views, the ethics committee chair will review the comments and relay these to the applicant via email. All email correspondence related to the application must be copied to the Faculty research ethics administrator.

Any problems which arise during the course of the investigation must be reported to the Faculty Research Ethics Committee