Manuscript Title: Estimation of surgeons' ergonomic dynamics with a structured light system during endoscopic surgery

Authors: David Lobo PhD[1], Pedro Anuarbe BEng[2], José Miguel López-Higuera PhD [2,3,4], Jaime Viera MD[1], Nathalia Castillo MD[1], Roberto Megía MD[1]

Hospital Universitario Marqués de Valdecilla[1]; Universidad de Cantabria[2]; CIBER-BBN[3]; IDIVAL[4], Spain

Corresponding author: David Lobo; Hospital Universitario Marqués de Valdecilla, 39008 Santander (Spain); Email: dlobo28@gmail.com; Telephone: +34 94202520

ORCID: 0000-0002-4322-6638

Short Running Title: Endoscopic sinus surgery ergonomic dynamics

Keywords: Ergonomics; endoscopic surgery; otolaryngologists; musculoskeletal; RULA; motion tracking.

Funding and conflict of interests: This project has been developed thanks to the Innovation Support Program "InnVal" of the Marques de Valdecilla Research Institute (IDIVAL).

ABSTRACT

Background: The purpose of this study is to use motion capture to collect body posture information during simulated endoscopic sinus surgery interventions performed by both specialists and residents in standing and sitting positions and to analyze that information with the validated Rapid Upper Limb Assessment (RULA) tool, which allows calculation of a risk index of musculoskeletal overload.

Methods: Bilateral endoscopic sinus surgery was performed in 5 cadaver heads by 2 residents, and 4 practicing rhinologists. Musculoskeletal symptoms were evaluated before and after the dissection. Full body postural data was collected with the help of Kinect and a .NET WPF (Windows Presentation Foundation) software application to record images of the surgical procedures and analyzed with the RULA tool to calculate a risk score indicative of the exposure of the individual surgeon to ergonomic risk factors associated with upper extremity musculoskeletal disorders.

Results: All subjects reported physical discomfort after nasal endoscopic procedures. An overall similar RULA score was obtained by the residents and the practicing rhinologists. The RULA score was slightly lower for the sitting position than for the standing position, mostly due to a lower score in group B (neck, trunk and leg); however, the RULA score for group A (arm and wrist analysis) was higher, denoting a higher risk for the upper back and arms.

Conclusion: Significant musculoskeletal symptoms were reported after an endoscopic operation by both the resident and the practicing otolaryngologists. All the surgeons obtained a high RULA score, meaning that urgent changes are required in the task.

INTRODUCTION

Scientific evidence has shown that the evolution from open surgery to minimally invasive surgery such as functional endoscopic sinus surgery has brought multiple benefits to the patient (less postoperative pain, reduction of tissue trauma, a lower risk of infections, better aesthetic results, a shorter period of convalescence) and, consequently, considerable benefit to the health system (shorter hospitalization time).[1] However, surgeons frequently report that they suffer musculoskeletal complaints that they attribute to the surgical activity.[2-5] The skills required during the procedures impose strong physical and psychological demands on the surgeon. The tasks can be very complicated, require a high level of attention, and are intellectually and emotionally demanding.[6] Rapid Upper Limb Assessment (RULA) is a validated survey method to assess posture risk in ergonomic investigations in occupational settings. It has recently been used for ergonomic analyses of microlaryngoscopy and for in-office otology procedures, and was able to identify higher-risk postures so that recommendations could be made accordingly.[7-8] To date, no such studies have been carried out for endoscopic sinus surgery.

MATERIAL AND METHODS

Lab setting

Before motion capture, several parameters were obtained for each surgeon: sex and anthropometric measures (weight, height, span of the hand). In addition, multiple endoscopic nasosinusal surgery variables were recorded: Trendelenburg tilt of the operating table, the angle of the endoscope to the horizontal plane, the angle of the head of the operating table to the horizontal plane, the height of the operating table with respect to the floor, the distance from the handle of the endoscope to the surgeon’s anterior superior iliac spine, the height of the monitor relative to the surgeon’s eyes and the visual angle. Together these conformed what was considered subjectively to be the most comfortable position for each surgeon to operate in (although approximately within ergonomic recommended values)[6]. If the surgeon used a surgical chair, this could be adjusted for height and backrest but had no supports for the arms or the forearms.

Cadaveric surgical procedures

Bilateral complete endoscopic sinus surgery was performed on 5 cadaver heads, and included basic procedures such as septoplasty, dacryocystorhinostomy, maxillary antrostomy, total ethmoidectomy, sphenoidotomy, frontal sinusotomy and advanced procedures such as Draf III frontal sinusotomy, skull base approaches, endoscopic approach to the pterygopalatine fossa and extended approaches to the petroclival region, using commonly applied basic and powered instrumentation and techniques. The cadaveric surgeries were performed in 8 separate sessions, by six surgeons, all of them right handed (4 practicing otolaryngologists who regularly perform endoscopic sinus surgery and two residents: one PG-2 resident and one PG-4 resident). One of the practicing otolaryngologists usually adopts the sitting position during sinus surgery and performed all the cadaveric procedures in this position. Surgical procedures were performed over 3 days, from 8:30 to 18:30, with a half-hour break at 11:00 and a 1-hour break at 14:00.

Motion Capture

Motion capture and estimation of the surgeon’s ergonomic dynamics were performed with a structured light system and a custom software application (.NET WPF) developed with the help of Kinect for Windows SDK v.1.8.

The application allowed us to record images of the surgery procedures and associate with each image all skeleton tracking data provided by the sensor. The application uses this data to calculate the angles needed by the RULA method.

We used the application to record the work of six surgeons while performing endoscopic sinus surgery during a period of approximately 20 hours. The sensor was placed in front of the surgeon at a height of approximately 1.15m. Figure 1 shows the specific setup during the procedures.

RULA Risk Assessment

The RULA Assessment Tool was developed to evaluate the exposure of individual workers to ergonomic risk factors associated with upper extremity musculoskeletal demands. The RULA method requires the selection of those postures that represent the greatest risk. Based on the evaluations, scores are entered for each body region in section A for the arm and wrist, and section B for the neck and trunk. After the data for each region is collected and scored, tables on the form are then used to compile the risk factor variables, generating a single score that represents the level of MSD risk[9].

The acquired images were used to construct a histogram that represented the frequency and variability of the postural angles during the intervention (figure 2). A temporal analysis of the recorded data was also performed in order to identify repetitive postures since the RULA method classifies these as representing a greater risk. The abscissa axis represents the angular information of the different limbs under observation and the ordinate axis represents the number of frames in which this particular surgeon maintains the limb in that specified angle. Each frame represents one second time span.

These charts allow us to quickly visualize relevant descriptive statistical information about the postural angles maintained during the totality of the surgical procedure. We can clearly see the time that the surgeon has been in the different RULE zones, so we can select the correct RULE zone for the corresponding limb (the most common or standard postures adopted during endoscopic surgery and not the "extremes").

It was necessary to carry out a visual inspection of the images to discard clearly incorrect measurements and to complement certain data, especially for wrist angles and leg assessment. At the end of the process, we were able to estimate the RULA risk score for this kind of surgical procedure.

Physical discomfort questionnaire.

A physical discomfort questionnaire was completed before and after each dissection. For this purpose, we used the Standardized Nordic Questionnaire for the Analysis of Musculoskeletal Symptoms before the procedure and a physical discomfort questionnaire after the procedure. The value of the Standardized Nordic Questionnaire lies in the fact that it is standardized and one of the most used questionnaires in numerous ergonomic and occupational health studies.[10] It is short and easy to apply, and allows collection of proactive information directly from the worker about pain, fatigue or musculoskeletal discomfort that are most often felt in different work activities.

This study was approved by our institutional review board.

RESULTS

Sex and anthropometric measures.

Bilateral endoscopic sinus surgery was performed in 5 cadaver heads by two female residents, and 4 male practicing rhinologists. Table 1 shows the demographic data and other details of personal background and work activity.

Endoscopic nasosinusal surgery variables

These conformed what was considered objectively to be the most comfortable position for each surgeon to operate in. The values obtained by the sitting and standing group are shown below (median and range are used where appropriate):

Trendelenburg tilt of the operating table (0°; 0°), the angle of the endoscope to the horizontal plane (45°-70º; 55°-100°), the angle of the head of the operating table to the horizontal plane (5°; 10°, 5°-15°), the height of the operating table with respect to the floor (80 cm; 80 cm), the distance from the handle of the endoscope to the surgeon's anterior superior iliac spine (55 cm; 40 cm, 37-42 cm), the height of the monitor relative to the surgeon's eyes (+25 cm; +15 cm, -3-+25 cm), and the visual angle (+11.8°; +6.8°, -1.4°-+14°).

Motion Capture- Kinect and RULA risk assessment

The RULA results by surgeon are shown in table 2.

Standing position (surgeons 1-5): Subject assessment of body posture during standing dissection yielded the following results. In general, flexion values of the arm between 20 and 45° and abduction of the arms were very commonly observed. No extensions greater than 45º were observed except occasionally in the act of picking up an instrument. Flexions less than 60º of the forearm were also very frequent, particularly on the right side. Slight wrist flexions or extensions with pronation were usually observed. Only isolated neck extensions were detected, but a flexion greater than 20º was very common. Rotation or tilting of the head was also common. Most of the time, the trunk was bent forward less than 20º during the surgical procedure except for extremely rare situations or measurement errors. The most typical degree of flexion was less than 5º. Rotation movements of the trunk or lateral tilt were seen less frequently, when the surgeon changed instruments or turned to reach for an object. PG-2 and PG-4 residents (surgeons 4 and 5) flexion values were similar as those described for the practicing otolaryngologists. The overall score is 6.8 (relative frequencies 7:80%; 6 20%). A score of seven indicates that urgent changes are required in the task.

Independent analysis of the data for each upper limb still results in a score of 7 for the left side (5/5), and 6.6 (relative frequencies, 7: 60%; 6: 40%) for the right arm. When the score is 6, it indicates a redesign of the task (table 2).

Sitting position (Surgeon 6): Subject assessment of body posture during sitting dissection yielded the following results. A high degree of arm flexion was observed on both sides, although more pronounced in the right arm. The shoulder was raised and the arms were abducted. Flexions between 60º and 100 º of the forearm were very frequent, although flexions of less than 60º were also commonly observed on both sides. In this case the surgeon performed the procedure in the sitting position so it was necessary to use the sitting mode on the sensor. This mode does not provide neck and trunk values, so a visual inspection was necessary. The final score is 6, which indicates that a redesign of the task is required (table 2).

Figures 3, 4, and 5 show skeleton tracking in the standing position, figure 6 shows skeleton tracking in the sitting position.

Physical discomfort subject assessment

All the subjects reported musculoskeletal symptoms in the 12 months before the study which they attributed to surgical practice. Surgeons 1 and 2 reported discomfort in the right shoulder and neck, and the neck and upper back, respectively. In neither case did the muscular discomfort prevent them from doing their work. The muscular discomfort was described as very mild, mild or moderate (the latter for the upper back) and was present for longer than a month, but not consecutively. Surgeon 3 also reported an occasional discomfort in the right wrist. Surgeons 4 and 5 (PG-2 and PG-4 residents) also reported very mild and mild discomfort in the neck and upper back, respectively, the former for longer than a year.

Surgeon 6 reported discomfort in both lower extremities, mostly in both knees in the last 12 months. As a matter of fact, he had had trouble in the last 20 years, and this had resulted in his adopting the sitting position.

Subject assessment of bodily discomfort revealed a noticeable worsening in previously affected sites in all surgeons. Sitting dissection resulted in increased physical discomfort in both shoulders, which remitted in a short time. The PG-2 resident also experienced a worsening in previously affected sites after the surgical procedures, and she also reported muscular discomfort in the shoulders, hip, thighs, ankles and feet. She attributed it to muscular fatigue, long periods of standing, and lack of stretching.

DISCUSSION

The benefits of functional endoscopic sinus surgery are well known and this is the technique of choice in many pathological processes. There is abundant scientific evidence of the improvement obtained in different quality of life parameters, a shorter hospital stay, fewer complications and even the possibility of performing wider and more complete tumor resections. On the other hand, there is growing concern about musculoskeletal disorders derived from surgical practice in the different surgical specialties, and otolaryngology is no exception, as evidenced by the growing number of publications on this issue in recent years. Different surveys aimed at all ENT professionals or limited to those with a special dedication in a more specific field have shown a really high prevalence of musculoskeletal complaints attributed by the respondents to surgical practice. More specifically, several surveys have been conducted to identify the prevalence of musculoskeletal symptoms, and any associated risk factors relating to endoscopic sinus surgical technique, in rhinologists in Britain, America, Europe and worldwide.[2-5] These cross-sectional studies, with a response rate between 11.2 and 22.2%, have identified musculoskeletal symptoms in 63.5-77% of practicing rhinologists, notably in the back (59.8-71%), neck (46-60.5%), shoulder (45-63%) and wrist (11.7-54%), with 23-35% of rhinologists receiving therapy and 5-7.9% reporting they have had to limit practice due to work related musculoskeletal disorders.

Ramakrishnan and Milan performed an ergonomic analysis of the surgical position in functional endoscopic sinus surgery performed on cadaver heads and used noninvasive surface electromyography to objectively evaluate 4 muscle groups before and after dissection: medial deltoid; upper trapezius; erector spinae; and biceps femoris. They observed a small decrease in mean power frequency across most muscle groups, indicative of muscle fatigue, even after a single 1-hour procedure.[11] There were some findings worth paying attention to: the sitting position was objectively much more favorable for the left hamstring muscle group than the standing position. In contrast to these results, the sitting position was less favorable for the right and left medial deltoids as there was a decrease in mean power frequency in comparison to the standing position. One of the limitations of this study was that the dissections were performed by only one subject. Surface electromyography is considered the best technology to evaluate muscular effort in surgeons; however, it does not provide dynamic information about the positions adopted that could be responsible for this muscular fatigue and on which we must act ergonomically. In this sense, our study complements these results by offering additional information that can help when reformulating the surgical environment.

The RULA method to evaluate postural load requires the selection of those postures that involve a greater postural load because of their duration, because of their frequency or because of a greater deviation with respect to the neutral position.

RULA has been employed for ergonomic analyses of microlaryngoscopy and has identified lower-risk surgeon positioning to be utilized during microlaryngeal surgery.[7]

In this study we gathered data through the Kinect system and processed it to obtain the RULA score in the simulated laboratory environment, which reproduces the characteristics of a real intervention for both basic and advanced sinonasal endoscopic surgery. One concern is that the same information could have been obtained by an assessor simply observing the surgeons perform sinus surgery on a cadaver instead of using motion capture. The RULA was designed for easy use without need for an advance degree in ergonomics or expensive equipment. It is, in principle, designed to be applied manually in the field; however, perception errors and inter-rater reliability can affect the accuracy of the estimated joint angles. In addition, since surgical activity normally implies awkward or repetitive postures held for long periods, posture observation can be labor-intensive. The histograms that we used allowed us to summarize in a graph a great quantity of basic descriptive statistical information. Since the RULA method evaluates wide ranges of angles and the histogram reveals the most repeated values, the trends, our method made it possible to estimate the RULA score. The RULA method evaluates four risk factors (number of movements, static muscle requirement, strength, and postures) but does not consider other relevant ergonomic risk factors such as speed, accuracy of movements, and frequency and duration of breaks. Kinect also proved useful for evaluation of other relevant factors such as speed, accuracy of movements, frequency and duration of breaks, thereby providing extra information to that collected for RULA score calculation.

The presence of a large number of erroneous measurements made it difficult to follow the posture in time; therefore, we used as our main analysis tool a histogram that allowed us to represent the postural tendency when the activity was performed. A previous study of the feasibility of non-contact structured light systems for automatic estimation of surgeons' ergonomics during endoscopic sinus surgery showed a good correlation between the Kinect data and that gathered by a RULA expert for shoulder joint analysis. Wrist joint information was not tracked correctly by the sensor so it was necessary to carry out a visual inspection of the recorded images (unpublished data).

The primary concern of this study is the small sample size, especially in the sitting group. Only one surgeon usually adopts the sitting position during sinus surgery. There is no doubt that the physical strain would be significant if personal preferences and body specifications are not matched. The strain of the surgeons' body cannot be compared if the operating conditions are not matched according to the surgeon's preferences and comfortability. Admittedly, this is a difficult question to address given the unique individual variability with potential subjects.

The RULA scores were not analyzed separately for basic and advanced procedures. However, it would be interesting to understand if ergonomics vary by type of procedure.

Our results are in line with those reported by Ramakrishnan and Milan.[11] Subject 6 obtained a higher score for group A (due to higher shoulder score) and a lower score for group B (due to a lower leg score). Another important finding that emerged when the data was analyzed independently for each upper limb was that the result for the left side scored higher than the right arm, both in the standing position and in the sitting position. In the latter case, this result is explained by the fact that both shoulders are raised and abducted and the left forearm is extended. In the standing position, it is usually considered that the left arm is exposed to an increased risk of musculoskeletal disorders due to the lack of support (which can be counterbalanced by an armrest, which we did not have in the laboratory). It has been shown that, if the surgeon prefers to operate in the seated position, an arm support would also be helpful.[11,12]

It is also important to highlight that four of the subjects were experienced rhinologists with a deep knowledge of ergonomics, yet they obtained a similar score to that of the residents. Although more experienced surgeons obtained a slightly lower RULA score, there was not a significant association between years in practice and RULA score.

It is crucial to follow the recommendations proposed by Ayad et al and Ramakrishnan et al for endoscopic sinus and skull base surgery. These cover aspects of appropriate monitor placement, proper instrument maintenance, adjustable operating tables, correct use of pedals and correct upper body position among others.[6,12] Nevertheless, these ergonomic considerations might not be enough because, as shown in this study, basic and advanced endoscopic surgery requires maintaining non-neutral positions of the neck, arms, trunk and legs that expose the surgeon to musculoskeletal disorders.

These findings correlate with muscular discomfort reported by the subjects in the physical discomfort questionnaires. In this regard, it is important to point out that, in spite of his previous problems in the lower limb, the surgeon who operated in the seated position described discomfort in the upper extremity after the dissection, which coincides with the findings described in previous studies.[11] The dissection performed in the standing position led to increased discomfort in the back and neck. Discomfort in the lower limbs was indeed reported by the PG-2 ENT resident. A high stress level leads to muscle tension, which in turn causes fatigue and an increased risk for work-related musculoskeletal discomfort. This vicious cycle can start as early as the first years of ENT training, and our findings are in line with the results of previous survey studies.[13,14]

Matern and Koneczny evaluated the workplace conditions in the operating room (OR) and identified elementary ergonomic deficiencies within spatial and architectural situation of the OR, OR devices and equipment. They concluded that OR optimization should be given priority and it is necessary to develop ergonomic standards for the OR and implement them in hospitals.[15] As Seagull stated, ergonomists have been decrying the lack of sound ergonomic practices in the OR since at least 1914.[16]

We share the view that new technical development and innovations in the daily routine of the OR have to take ergonomics into account and that improving surgeon knowledge of sound, basic ergonomic principles must be encouraged. Moreover, we must take advantage of the knowledge and experience of rehabilitation doctors and physiotherapists who can advise on the adoption of correct postures at work, other ergonomic aspects and exercises appropriate to the workload.

This study shows the value and general potential in using the presented technology for further investigation; the above mentioned points can be applied in further studies.

CONCLUSION

This study used a structured light system and a custom software application to obtain body posture information during simulated endoscopic sinus surgery interventions. The images and their associated skeleton tracking were recorded and duly processed with the RULA method. Significant musculoskeletal symptoms were reported after an endoscopic operation by both the residents and the practicing otolaryngologists. Moreover, all surgeons obtained a high RULA score, which indicates that there is an urgent need to implement changes in the task.

Acknowledgments: We would like to thank the work of all the staff of the Valdecilla virtual hospital (HvV). The cadaveric surgical procedures where performed in the simulated laboratory environment of the HvV.

References

1. Fokkens WJ, Lund VJ, Mullol J, et al. European Position Paper on Rhinosinusitis and Nasal Polyps 2012. Rhinol 2012; Suppl 23: 1-298.

2. Amin M, Rimmer J, Swift A, White P, Lund VJ. FESS, fingers and other things--you are not alone! Rhinology 2015; 53(2):116-21. 3 Little RM, Deal AM, Zanation AM, McKinney K, Senior BA, Ebert CS. Occupational hazards of endoscopic surgery. Int Forum Allergy Rhinol 2012; 2(3):212-6.

4. Ho TT, Hamill CS, Sykes KJ, Kraft SM. Work-related musculoskeletal symptoms among otolaryngologists by subspecialty: A national survey. Laryngoscope 2018; 128(3):632-640.

5. Rimmer J, Amin M, Fokkens WJ, Lund VJ. Endoscopic sinus surgery and musculoskeletal symptoms. Rhinology 2016; 54(2):105-10.

6. Ramakrishnan VR1, Montero PN. Ergonomic considerations in endoscopic sinus surgery: lessons learned from laparoscopic surgeons. Am J Rhinol Allergy. 2013; 27(3):245-50. doi: 10.2500/ajra.2013.27.3872.

7. Statham MM, Sukits AL, Redfern MS, et al. Ergonomic analysis of microlaryngoscopy. Laryngoscope 2010; 120(2):297-305.

8. Govil N, DeMayo WM, Hirsch BE, McCall AA. Optimizing Positioning for In-Office Otology Procedures. Otolaryngol Head Neck Surg 2017; 156(1):156-160.

9. http://ergo-plus.com/wp-content/uploads/RULA-A-Step-by-Step-Guide1.pdf

10. Kuorinka I, Jonsson B, Kilbom A, et al. Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl Ergon 1987; 18(3):233-7

11. Ramakrishnan VR, Milam BM. Ergonomic analysis of the surgical position in functional endoscopic sinus surgery. Int Forum Allergy Rhinol 2017; 7(6):570-575.

12. Ayad T, Péloquin L, Prince F. Ergonomics in endoscopic sinus surgery: systematic review of the literature. J Otolaryngol 2005; 34(5):333-40.

13. Wong K, Grundfast KM, Levi JR. Assessing work-related musculoskeletal symptoms among otolaryngology residents. Am J Otolaryngol 2017; 38:213-217.

14. Little RM, Deal AM, Zanation AM, et al. Occupational hazards of endoscopic surgery. Int Forum Allergy Rhinol 2012; 2(3):212-6.

15. Matern U, Koneczny S. Safety, hazards and ergonomics in the operating room. Surg Endosc 2007;21:1965-9.

16. Seagull FJ. Disparities between industrial and surgical ergonomics. Work 2012; 41 Suppl 1:4669-72.

Table 1. Demographic data, personal background and work activity

	Surgeon 1	Surgeon 2	Surgeon 3	Surgeon 4	Surgeon 5	Surgeon 6
Gender	M	M	M	F	F	M
Age (y)	41	32	50	28	31	58
Weight (kg)	75	77	70	50	48	72
Height (cm)	180	181	179	158	155	168
Dominant hand	Right	Right	Right	Right	Right	Right
Span of the hand(cm)	23	23	21	14	18.5	20.5
Time practicing (y)	18	8	23	2	4	33
Fellowship	†	‡				
Number of ESS per annum	50-75	75-100	50-75			>100

† Skull base and head & neck oncology fellowship

‡ Rhinology and skull base surgery fellowship

Table 2. RULA results by surgeon.

	S 1	S 2	S3	S4	S3	S6
	R/L	R/L	R/L	R/L	R/L	R/L
Group A						
Upper arm position (1-4)	2/2	2/2	2/2	3/3	3/2	3/3
Shoulder raised or arm rotated (+1)						1/1
Upper arm abducted (+1)	1/1	1/1	1/1	1/1	1/1	1/1
Arm supported (-1)	-1/		-1/			
Lower arm position (1-2)	2/2	2/2	2/2	2/2	2/2	2/1
Arm working across midline or out to side of body						
Wrist position (1-3)	2/2	2/2	2/2	2/2	2/2	2/2
Wrist bent from midline						
Wrist twist (1-2)	1/1	1/1	1/1	1/1	1/1	
Score A	3/4	4/4	3/4	4/4	4/4	4/5
Muscle use score (1)	1/1	1/1	1/1	1/1	1/1	1/1
Force/Load score (0-3)						
Score C	4/5	5/5	4/5	5/5	5/5	5/6
Group B						
Neck position (1-4)	3	3	3	3	3	2
Neck twisted (+1)	1	1	1	1	1	
Neck side bending (+1)						1
Trunk position (1-4)	2	2	2	2	2	1

Trunk twisted (+1)						1
Trunk side bending (+1)						
Legs (1-2)	1	1	1	1	1	1
Score B	5	5	5	5	5	3
Muscle use score (1)	1	1	1	1	1	1
Force/Load score (0-3)						
Score D	6/6	6/6	6/6	6/6	6/6	4
Final score	6/7	7/7	6/7	7/7	7/7	5/6

R: Right; L: Left

Figure Legends

Figure 1. Specific setup for motion capture during the surgical procedures.

Figure 2. Histogram representation of surgeon 1' neck flexion angles during surgical procedure.

Figure 3. Surgeon 1' skeleton tracking.

Figure 4. Surgeon 2' skeleton tracking.

Figure 5. Surgeon 4' skeleton tracking ((PG-2 resident).

Figure 6. Surgeon 6' skeleton tracking. Kinect data for shoulder joint analysis was also very consistent in the sitting position. Kinect accuracy was well within the limits required for RULA analyses.