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Application of Lean Methodologies in a Neurosurgery High Dependency Unit

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Abstract

This study aims to apply Lean methodologies at a neurosurgery high dependency unit (NHDU) for increasing safety and quality on the care delivered to acute neuropatients and to reduce time, steps, and distance travelled by nurses accessing life support equipment (LSE). The methodology used in this study is an action research, supported by a longitudinal mixed method approach with a one-group within-subjects pretest-posttest experimental type design. Resulting in a high waste of time, steps, and distance travelled to reach them. After the application of Lean methodologies, distance, steps, and time travelled by Nurses were quite improved. Lean methodologies applied in NHDU contributed to improve the organization, availability, and accessibility of LSE by putting them at the point-of-use. Quality and safety of patient care were also improved by allowing almost immediate life support interventions. Resistance to change was the major limitation. The Lean philosophy empowers health facility managers with tools and methodologies that help them create health gains, implement a culture of continuous improvement of care and working environment, identify and eliminate barriers, and waste that limits the work of staff in providing quality services and saving lives. This chapter highlights the responsibility of health facility managers to properly organize health units to cope with emergency situations, by allowing immediate, efficient, and effective intervention of staff.

Keywords: lean methodologies, critical care nursing, management, work simplification, action research

1. Introduction

Imagine that in a ward or in an acute care unit, a patient develops a sudden and severe laryngeal edema and stops breathing for obstruction of the respiratory tract. Nurse and medical staff starts-up advanced life support (ALS) maneuvers. The primary and emerging interventions are to permeabilize the airway accessing the trachea through an endotracheal tube. Not being possible to access it by the usual routes, the only solution is to perform a tracheotomy or cricothyrotomy, using a tracheotomy surgical tray (TST) or an emergency cricothyrotomy kit (ECK). However, the health team most of the times do not know its existence, location, or has difficulties in accessing it in due time, what could have as consequence the loss of a life.

Portuguese Directorate-General of Health (DGS) points out on the Circular Normative no. 15/DQS/DQCO of 22/06/2010 [1] that “patients who are admitted in hospitals believe that they are being admitted to a safe environment. They feel confident that if their clinical condition gets worse, they are in the best place for a prompt and effective intervention. However, there is some evidence that this does not always happen” (p. 1). This Circular also states, “ALL inpatient areas should have easy and immediate access to equipment, supplies and emergency drugs. They should be organized and stored in a standardized way... throughout the health unit” (p.6). However, compliance with these recommendations depends, above all, on political and management decisions of legislators, regulators, managers, and industry providers, and it is at the health institutions jurisdiction to “adequate resources and create the structures that leads to quality professional practice” [2]. For the Portuguese Republic Government (Governo da República Portuguesa – GRP) is “fundamental, that the available resources are better used, avoiding waste, that is, improving management, transparency, and accountability for the use of money from the citizens” [3]. Corvi [4] draws attention to the “waste epidemic in health care,” as acknowledge by the GRP, and so a great opportunity to improve, being fundamental a spirit of continuous learning as part of “implementing a lean management system” [4].

The Intensive Care Society [5] recommends “all critical care areas should have their own, appropriately stocked and checked difficult airway trolley to deal with airway and tracheostomy emergencies” (p.11). The absence or inaccessibility to this kind of equipment can lead to adverse events with huge impact on the safety and lives of patients, mainly the critical ones. To the matter of the impact of layout configurations in hospital environment, Soriano-Meier et al. [6] points out that “inadequate facility layout negatively affects the performance of the service staff, the quality of care provision and the service temporally over time” (p. 255).

At a particular neurosurgery high dependency unit (NHDU) of a central hospital in Lisbon, problems related to design, layout, architectural barriers, accessibility to life support equipment (LSE) and wastes of time, handling, and transport were identified. Those that may infer greater impact on patients and on the provision of care taken by nurses are as follows: (a) accessibility to LSE, (b) difficulty/inexperience in the use of the resuscitation trolley (RT), and (c) lack of knowledge of ECK and TST existence and location. This chapter summarizes the action research study embarked with the purpose of testing the application of Lean methodologies at NHDU for a quality and safety provision of care to acute neuropatients and to reduce

at least by half, time, steps, and distance travelled by nurses' accessing LSE. Gemba walk, value stream mapping, spaghetti diagrams, 5S, and JIT (just-in-time) were the main Lean methodologies used.

Gemba is the Japanese term used for Shop floor, where products are produced, or where the services are provided [7, 8]. To start an improvement project, it is critical to analyze the current and real situation of an organization or its workplace. Therefore, the gemba should analyze processes, time of setups, physical layout and surroundings with an open mind, to detect where, how, and why clients and staff experience problems [7–9].

The value stream mapping (VSM) is one of the main lean methodologies that engages waste elimination in any organization [10]. VSM will help to identify and analyze, for example, problems experienced by stakeholders, errors in medicine, flow of processes and work, financial analysis, among others. VSM allows checking (visual and graphically) the current state of a particular procedure, its productive time (value-added), and the non-productive time (non-value-added) [11].

Jackson [12] argues that 5S is the foundation of the Toyota production system (TPS). What this methodology tries to ensure is an orderly organized workspace for an efficient and safe work environment [10], increased productivity, fewer errors, and less waste [8]. 5S represents the five levels of this methodology starting with the letter "S". In Japanese vocabulary: SEIRI (sort), SEITON (set in order), SEISO (shine), SEIKETSU (standardize), and SHITSUKE (sustain). Smart [13] summarizes this methodology with the expression "a place for everything and everything in its place" (p. 62).

JIT is a production process that targets the optimization of the process as a whole in a continuous flow improvement and tries to answer to the organization or service needs. Briefly, it means producing no sooner, no later, neither more or less, only and just the necessary [8, 10].

Another Lean methodology is the spaghetti diagram. This diagram consists on a graphic reproduction of the architectural floor plan of a structure, where you draw lines from one space to another, representing the path taken by employees, customers, and objects along a particular process (round trip) [12, 14]. It allows documenting and visualizing the physical flow, in order to identify waste motion or transportation, architectural barriers, and improvement opportunities to expedite process flow [15].

This chapter is organized as follows: Following the introduction, a literature review on Lean philosophy is performed, then the methodology used in the research, and the results of the action research are described. Finally, some discussion and conclusions are drawn.

2. Lean philosophy

It was through Krafcik [16] that the Lean term was released thus referring to the TPS as a lean production system: A system that uses less resources compared to the mass production systems. Less effort, less capital investment, less space, and less time [17]. The Lean philosophy

is essentially focused on waste reduction as a means to increase actual value-added, in order to fulfill customer needs and maintain profitability [17]. The fundamental focuses of Lean are respect for people, teamwork, waste elimination, continuous improvement, value, quality, and safety [8, 16–18]. Several authors have highlighted this and other key principles of Lean philosophy, such as follows: (i) customer relationship [19]; (ii) total quality management (TQM) [20]; (iii) JIT [21, 22]; (iv) pull production/flow [19, 20]; (v) supplier relationships/long-term business relationship [21]; (vi) mistake-proofing [23]; (vii) total productive maintenance (TPM) [22]; and (viii) physical layout [6]. At the operational level, the Lean paradigm is implemented using a number of techniques such as kanban, 5S, visual control, takt-time, poke-yoke, and single minute exchange of die (SMED) [24].

To Imai [8], the importance of applying a Lean philosophy in an organization has at least three components: (1) any activity or process that does not add value is waste, independently of being practiced by people or machines; (2) the reduction or elimination of waste may be the most cost-effective way for improving productivity and reduce operating costs instead of increasing investment in the hope of adding value. Moreover, investing in new equipment is expensive while eliminating waste, in most cases, has no costs. (3) Standardization of processes ensures quality and error prevention. Womack et al. [17] documented the benefits of Lean philosophy compared to the mass production model, arguing that this philosophy would succeed, not only in the automotive industry or aviation, but also in all activities from distribution, retail, and healthcare. Not being the solution to all the problems that health services faces today, the Lean philosophy can bring significant benefits to this sector and in a range of hospital areas [25], contributing to develop the continuous improvement into the organizational culture and improving quality of care, efficiency and effectiveness, while reducing costs, errors, and waste.

In the Portuguese healthcare sector, the implementation of Lean philosophy has been focused on some specific areas such as quality [26, 27] logistics, supply and storage [28–30], agility and continuous process improvement [31–33], workplace reorganization [34], and reducing waiting times [35, 36]. Particularly in services such as community health centers [37], operating room, imaging, ophthalmology, outpatient, ward, pharmacy, and warehouse. Other studies focused on conducting systematic reviews [38, 39]. There is thus a research gap in applying the Lean philosophy to in-hospital medical emergency, especially in inpatient critical care services.

3. Methodology

The methodology used in this study was an action research, supported by a longitudinal mixed method approach with a one-group within-subjects pretest-posttest experimental type design.

Lewin [40] suggests the existence of a cycle in action research. It begins with the diagnosis and identification of the problem(s) with all participants in a democratic way and then follows the proposal, planning interventions, and actions of change. Subsequently, the impact of the changes is monitored, the data collected, analyzed, interpreted, and finally results are reported.

This is a flexible research methodology that integrates an exploratory action in order to investigate and support the implementation of changes according to the diagnosis raised [41]. Action research claims that the researcher participates in the change process since the changes suggested are implemented by himself, that is, he “take action to improve the practice and study ... the effects of the action taken” [42]. Yin [43] considers this methodology as a variant of qualitative research that emphasizes the researcher action role and his active collaboration with the research participants.

3.1. Research design

The research was performed at a level 2 patient care four-bedded NHDU. This unit shares human resources, equipment, and materials with the 44-bedded standard care neurosurgery and neurotraumatology wards. NHDU is a healthcare facility specialized in the care of neuropatients undergoing neurological, hemodynamic, and respiratory instability with the eventual need of non-invasive or invasive ventilatory support by tracheotomy. These patients require critical care nursing and permanent vigilance that, although not requiring intensive care, may potential and quickly evolve to a severe status and thus the need of an immediate intervention. Nurse:patient ratio is 1:4. Located in one of an 802-bedded triple hospital centre at the metropolitan area of Lisbon (Portugal), this centre serves about a million people population. Data available from 2013 institutional performance reports show a surgical movement of 1423 neurosurgeries and a bed occupancy rate of 87.7% and 91.4% at the neurotrauma and neurosurgery wards, respectively.

The research was authorized by the NHDU Medical Director, the NHDU Chief Nurse, and the Ethics for Health Committee of the hospital centre. The unit of analysis is the NHDU with the corresponding nurse team. A convenience sampling was used attending to nurses' availability during the period that took place the visit of the researcher. The two nurses of the management team (chief and coordinator) were excluded from this sample since the purpose was to simulate the performance of the direct care nurses. Thus, from a population of 20 nurses, a sample of 12 nurses (60%) was selected. This is a longitudinal research in which data were collected from two points in time, which allowed studying the changes that have occurred during the period in which it was conducted (November 2014 to January 2015).

The research design follows several phases. The main three phases were (1) pre-intervention, (2) intervention, and (3) post-intervention, in which a simultaneous mixed method approach (qualitative and quantitative) was applied. The pre-intervention phase was further divided into three sub-phases: (i) diagnostic assessment (qualitative approach), (ii) simulation (quantitative approach), and (iii) proposal of changes (qualitative approach). The intervention phase consisted on the application of 5S and JIT lean methodologies. The post-intervention phase was divided into two qualitative approaches: (i) simulation and (ii) unstructured interview.

The pre-intervention diagnostic assessment sub-phase involved the following activities: (a) direct observation of the physical space performed by the participant researcher (PR) which focused mainly on the layout of the NHDU and the location of existing materials and equipment. To support the gemba walk, pictures and paper record with graphical representation of the service plan were used to complement the visual management and spaghetti diagram. The

transition to digital record was made using Microsoft® Office® 2013 software. (b) Personal unstructured interviews performed by the PR to the nurse team, and questionnaires to identify the difficulties and constraints of nurses in their professional daily routines, especially in emergency situations. The questionnaires were anonymous and blind in order to guarantee their confidentiality. The participants returned them in a sealed envelope deposited at a container left in the nursing room. The analysis of questionnaires and interviews was performed using qualitative content analysis, and it was organized according to the research variables, the types of wastes considered by the Lean philosophy and the suggestions of change by the participants.

The pre-intervention simulation sub-phase was accomplished by measuring time, distance, and number of steps (dependent variables) undertaken by nurses in the access to LSE (RT, ECK, TST, and automated infusion systems (AIS)). The simulation context was used because during the research it was not possible to monitor the tasks developed by nurses in a real context. As measuring instruments, the Nokia® 6230 mobile phone chronometer was used to monitor timing performance in seconds, rounded to the unit. Sixty meters' tape Stanley PowerWinder® was used to measure the distance travelled by nurses, with data rounded to the first decimal place. The PR counted the number of steps, and the data were triangulated with the participant itself. The monitoring was performed from the point of departure (nurses' station), arrival to LSE and return to the starting point with the respective LSE.

The third pre-intervention sub-phase was completed by the suggestion of changes presented, as a proposal like determined by Lewin [40], to the Medical Director and Chief Nurse of NHDU.

The intervention phase consisted on the application of lean 5S and JIT methodologies for the reorganization of physical space, equipment location, and NHDU inventory. The tasks performed by the researcher in this phase consisted on the organization of the contents in the NHDU large cabinet, relocation, and availability of TST and AIS. The reorganization of RT, ECK, and NHDU small cabinets was performed with the help of the nurses' management and direct care team. Other human resources such as nurses' aides and the hospital carpentry services were involved to perform small changes and to construct small furniture. Stock boxes abandoned in the hospital storage were recycled and used for better storage and visual management of cabinet contents.

The post-intervention phase was divided into two sub-phases: (i) simulations, using the same methodology and equipments applied in the pre-intervention. (ii) Unstructured interviews, using the same methodology as in the pre-intervention to collect the opinion of nurses regarding the interventions made to the unit, and how this influenced their daily routines and professional practice.

The quantitative results are presented comparing the pre-intervention with the post-intervention phases, allowing a more direct comparison of the data. The IBM SPSS Statistics version 21 and Microsoft® Office® 2013 Excel version 15 software were used for the statistical analysis of data. For the statistical hypothesis tests, the parametric Student's t-test with a significance level of 0.025 (one-sided) was used, such as the nonparametric Wilcoxon W-test with the exact significance of 0.025 (one-sided) for the poorly distributed data situations [44]. Standardized

response mean, calculated through MedCalc Statistical Software version 15.2.2, was used to analyze the effect size (Cohen's d) of the intervention made by the application of Lean methodologies, representing the independent variable. The qualitative results are summarized in tables with transcription of the nurses opinions collected from the interviews and the summary of the answers given by them in the questionnaires. Spaghetti diagrams and photographs are also used for better contextualization.

Attending to the literature review and the pre-intervention phase the following hypotheses are formulated:

H01: The difference of TST time of access between pre- and post-intervention equals zero.

H02: The difference of TST distance of access travelled between pre- and post-intervention equals zero.

H03: The difference of TST number of steps of access between pre- and post-intervention equals zero.

H04: The difference of AIS time of access between pre- and post-intervention equals zero.

H05: The difference of AIS distance of access travelled between pre- and post-intervention equals zero.

H06: The difference of AIS number of steps of access between pre- and post-intervention equals zero.

4. Results of the action research

Throughout Gemba Walk, twelve unstructured interviews were carried out to nurses in order to identify their difficulties in their professional daily routines and what kind of improvements they would like to implement in NHDU (**Table 1**). The collected data focused mainly on the inadequate layout and location of equipment, poor organization of clinical material in NHDU cabinets and units of patients, obstacles, restricted circulation and workspaces, frequent journeys out of NHDU to supply missing materials and equipment, and difficulty in implementing improvements because of a great resistance to change. According to these interviews only 50% of nurses knew the existence and location of TST, and only 33.3% of nurses knew the ECK existence or location. For AIS and RT, all participants were aware of them. After Lean methodologies' intervention and education, 100% of the participants were aware of all life support equipment.

In addition to the interviews, questionnaires were delivered to 12 nurses and eight were returned, representing a 67% response rate. The purpose of the questionnaire was to identify the set of difficulties felt by nurses in their daily professional life in NHDU, mainly in emergencies, monitoring and surveillance of the acute neurosurgical patient. The questionnaire made also possible to study the kind of wastes (according to Lean philosophy) the nurses identify. The collected data from questionnaires are summarized in **Table 2** that includes suggestions provided by the respondents.

-
- A “My greatest difficulty in NHDU is to always have to go out of the unit to look for supplies ...either because we do not have a specific location for them either it was not replaced...
Medication and serums, forget it...”
- B “We should have an adequate level of stocks according to our needs and not have to always go ‘out there’ seek for supplies.”
- C “The NHDU should be independent from all resources of Neurosurgery... Nurses and nurses’ aides should be dedicated to NHDU... Stock, equipment and supplies should be replenished regularly and directly by the supply and pharmacy services.”
- D “The vital signs monitors should be fixed to the wall for not taking up space in patients’ desk . . . and because sometimes they drop of the desk, usually when pulled by confused patients.”
- E “It’s hard to work when there is not enough space to move around the patient bed without going against curtains, literally upon us, against wheelchairs and other patient’s beds.”
- F “There is neither space nor conditions to lift patients to an armchair or wheelchair.”
- G “Patients from one bed can touch and reach things of next patients because everything is so tight and so close to each other... Patients are potentially contaminating each other ... and we ourselves have a hard time for this cross-contamination doesn’t happen, I am sure it does eventually happen. “
- H “We have no space to put a RT next to the patient’s units ... it is impossible to make secure ALS with the available space that we have.”
- I “We usually are trained in basic life support every year, but we should also be trained in the use of RT and ALS... I have some difficulties in perceiving the location of clinical materials in the RT because there is a bad visual perception of it.”
- J “I have little practice in the use of the RT, mainly the defibrillator... We should have training...”
- K “Practices adopted in NHDU goes against scientific evidences ... but it is difficult here to make whatever change we need ... some people do not understand what good practices are.”
- L “The NHDU has a lack of identity and autonomy.”
- M “There is a lack of standards for admittance and clearance of patients... Even the doctors and some nurses do not understand that we only have capacity for 4 patients”
- N “We cannot take any initiative to improve anything, because they fear us to take their place.”
- O “They never listen to us. They do not realize, or understand, the staff who are working with them. We could make a great contribution to the better functioning of the unit.”
- P “There is a huge resistance to change...
There is a fear of loss or prestige transfer.”
-

Table 1. Excerpts from interviews.

Difficulties with location and access to Resuscitation Trolley (RT)	
	.Nothing to declare (8).
.Suggestions:	There ought to be another RT in the ward (1).
Difficulties with the use of RT	
	.Lack of experience (4); Difficulty in quickly locate contents in an intuitively manner (4); Safety seal broken without ALS manoeuvres have been performed (4); Lack of content restocking (3); Difficulty in using RT next to units because of lack of space between beds (2); Manual ventilator is incorrectly mounted (2).
Suggestions:	Enable outer identification of drawers content for optimal access and better perception (2); Training on ALS and RT use (4); Proper RT content replacement and functioning (3).
Difficulties with access and location of the Tracheotomy Surgical Tray (TST)	
	.I do not know where it is (4); I did not know it exist (4); I think it is in the ward treatment room in the medicine car or in one of the cabinets (3); Distant and time-consuming access (4).
Suggestions:	The TST should be on NHUD and/or in the RT (8).
Difficulties with type and number of equipment in patients units	
	.Broken lights (1); Monitors short wires (2); Lack of containers for hazard waste containers (3); Lack of fixation on the wall of vital signs monitors (3); Sometimes what you need is not in the patient unit (2).
Difficulties with layout and access to equipment in patients units	
	.Lack of space and difficulty in moving along the patients units (7); Difficult access (5); Material often falls on the ground, especially the suction probes (2).
Difficulties with type and number of material in NHDU cabinets	
	.Scattered material (3); Lack of material because it is not replaced and/or excess of material by wrong inventory management (7); Insufficient number of manual ventilators comparing to the number of tracheotomized in-patients (3); Lack of stethoscopes (2).
Difficulties with provision and access to the material in NHDU cabinets	
	.Constant lack of several materials (5); Stock boxes not identified (5).
Other barriers or difficulties	
	.Absence of workbench for preparation of medication(3); Poor identification of drugs (2); More critical medication should be available in the cabinets to prevent opening the RT, e.g. amiodarone, aminophylline, hydrocortisone (3); Lack of printer (3); Unnecessary travels in and out of NHDU with long distances (4); A nurse and doctor responsible for NHDU is missing (5).
Wastes identified in the NHDU	
Production and/or procedure	Several doctors requesting the same analysis without patient observation (6); Terminally ill patients on NHDU (4); Printing documents when they are available in digital format (4); Duplicate records on paper and digital databases (3); Unnecessary procedures and bureaucracy (3).
Defect	Lack of verification of the RT (3); Damaged equipment (4); Scarce space between beds (6); Labelling of medicines are alike, sometimes mixed (2); Loss of relevant information (1).
Movement/Transportation	Unnecessary trips to pick up unstocked material (4); Very tall cabinets (2); Bad design of the workspace (2); Patients in isolation without direct access to the corridor (3).
Time	Nurse waiting for having nurse aide available (3); Patients waiting several hours to be admitted or for bed availability (1); Delays in medical procedures and diagnostic tests (3).
Stock	Missing or excess of material on the cabinet shelves (4).
Human potential	There should be a nurse aide responsible for replacing cabinets contents in each shift (5); Unsafe nurse and nurse aide ratios (5); Nurse rehabilitation specialists should be more in touch with patients (3); Lack of training and education for health professionals (3); Absence of effective potential of employees with disability (2); Employees overworked and unmotivated to suggest changes or improvements (2).
Note. Numbers in brackets represents the frequencies of answers.	

Table 2. Data Collected from Questionnaires.

According to the previous results and analysis of the interviews, questionnaires, spaghetti diagrams, value stream mapping (data not shown), and simulations, a set of suggestions were proposed by the PR to the Medical Director and Chief Nurse of NHDU (third pre-intervention sub-phase). This proposal was drawn up from the data collected attending to the Lean philosophy, the recommendations of best practices, and the standards of Portuguese regulatory institutions. The proposal considers several suggestions for amendments procedures, layout updates of the physical space, RT and NHDU cabinets content, and different locations of the clinical material and equipment. Briefly, these suggestions were the following:

1. Place suction probes supports on the wall at each bed side (accepted);
2. Place water bottles supports to ensure suction tubes washing after manipulation (accepted);
3. Place mobile IV pole with AIS mounted at each bed side (accepted);
4. Remove vital signs monitors from patients' desks and fixate them on the wall (accepted);
5. ALS and RT handling workshops for nurse training and education (accepted);
6. RT standardization (accepted);
7. Place TST at NHDU next to nurse station (accepted);
8. Reorganization of NHDU cabinets to improve contents access, variety, and identification (accepted);
9. Place drug vault at NHDU (rejected);
10. Place double air and oxygen pressure regulators at each patient unit (rejected);
11. Place manual ventilator at each unit in the presence of tracheotomized patient (rejected);
12. Organize trolley with clinical material for isolation room (rejected);
13. Eliminate one of the beds to increase circulation space (rejected).

After approval, or disapproval, of each suggestion, Lean methodologies (5S, JIT) were undertaken to ensure a better and safer work environment for patients and staff. The cabinets were reorganized into categories to cover the various patients' needs like breathing, elimination, circulation, and administration, dressings and skin integrity, feeding, individual protection equipment. Sliding frosted glasses were removed from the cabinets, and it was possible to reduce and optimize the occupied space without decreasing the amount of material, but rather increasing its variety and availability, as seen in **Figure 1** that also illustrates the post-intervention TST location. The patients' units were likewise reorganized with the inclusion of supports for suction probes, water bottles, and AIS (in mobile IV poles). Vital signs monitors were placed at a new shelf on each patient's unit and ALS, and RT workshops has been schedule for nurse training and education.



Figure 1. Supplies in NHDU large cabinet before and after Lean intervention.

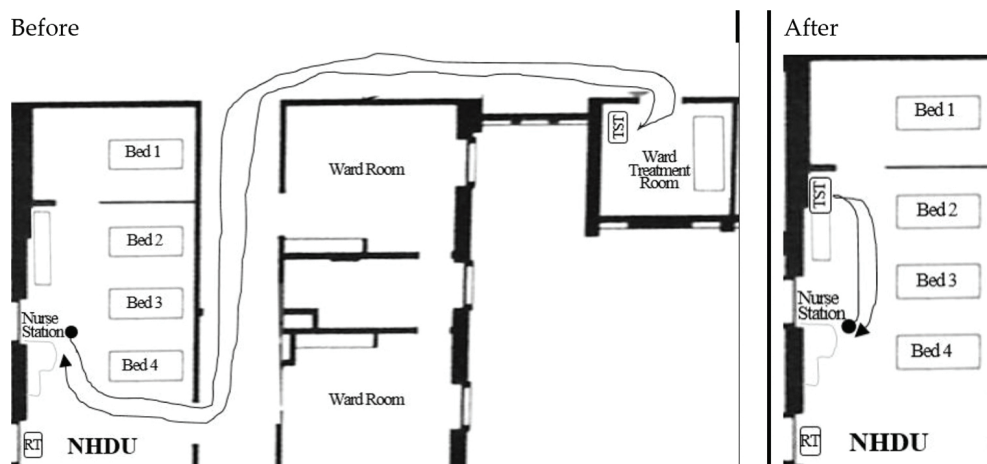


Figure 2. Spaghetti diagram for TST access before and after Lean intervention.

The presence of tracheotomized patients or at risk of being tracheotomized in NHDU is constant; therefore, the availability and accessibility to LSE, particularly ECK and TST, are of extreme importance. In the pre-intervention phase, TST was in the treatment room of neurosurgery, about 63 m (round trip) far from NHDU nurse station. Changing its location into the large cabinet inside NHDU the distance decreased to 6 m (round trip) from the nurse station. **Figure 2** represents the spaghetti diagram made before and after Lean intervention for the TST.

Table 3 shows the quantitative results obtained from the simulations of TST accessibility before and after Lean intervention. Data show the reduction of waste in time (-87.35%), distance (-90.47%), and steps (-87.12%) achieved with the application of Lean methodologies. According to Cohen's *d*, the effect size is large. Shapiro-Wilk normality test (data not shown) rejected the normality of the distance distribution ($p < 0.001$). So, for a one-sided significance level of 0.025, were accepted the alternative hypothesis that time ($p = 0.0017$),

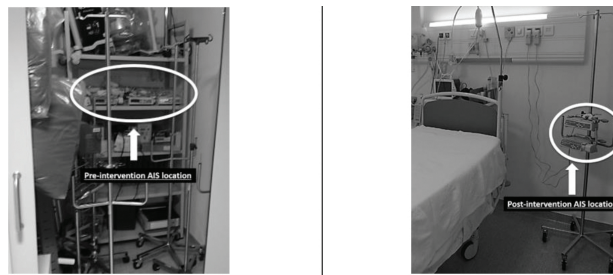


Figure 3. AIS location before and after Lean intervention.

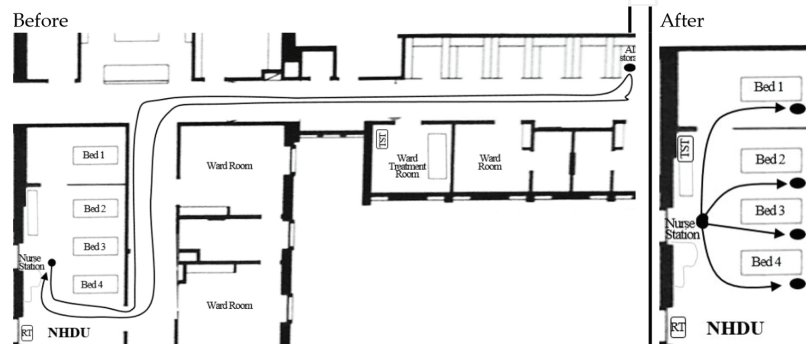


Figure 4. Spaghetti diagram for AIS access before and after Lean intervention.

		Time				Distance				Steps			
		A	B	Δ	Δ%	A	B	Δ	Δ%	A	B	Δ	Δ%
		Collective	Paired			Collective	Paired			Collective	Paired		
Collective and paired data	M	79.5	3	-76.5	-96.27	83.6	3	-80.6	-96.41	107	4.5	-102.5	-95.83
	Mdn	78.5	3	-76	-96.29	83.6	3	-80.6	-96.41	104	4.5	-99	-95.84
	SD	8.13	0.95	7.44	0.91	0	0	0	0	9.72	1.17	8.85	0.85
	Max	92	5	-87	-97.40	83.6	3	-80.6	-96.41	130	6	-124	-97.00
	Min	65	2	-63	-94.57	83.6	3	-80.6	-96.41	97	3	-94	-94.55
	Range	27	3	-24	-2.83	0	0	0	0	33	3	-30	-2.45
t-test	95% CI			[-81.23, -71.77]									
	t (df)			-35.62 (11)									
	p ^a			5.64×10 ⁻¹³									
W ^b -test	Z							-3.46					-3.06
	p ^a							0.00024					0.00024
Effect size	Cohen's d			-10.28				-5×10 ¹⁵					-11.58

A: Pre-intervention (n=6). B: Post-intervention (n=12).

^aOne-sided 0.025 significance.

^bW-test with exact significance.

Table 4. Results from AIS accessibility.

After the intervention and application of Lean methodologies, the AIS mean access was 96.27% in time, 95.83% in steps, and 96.41% in distance lower than in the pre-intervention. The effect size is large (or very large) with $d = -10.28$ for time, $d = -11.58$ to number of steps, and $d = -5 \times 10^{15}$ to distance. For the hypothesis test, the Shapiro-Wilk normality test rejected the normality of steps ($p = 0.039$) and distance (this one constant) distribution. So, for a one-sided significance level of 0.025, were accepted the alternative hypothesis that time ($p = 5.64 \times 10^{-13}$), number of steps ($p = 0.00024$) and distance ($p = 0.00024$) were statistical and significantly lower after Lean methodologies application, as shown in **Table 4**.

The results of quantitative data associated to the hypothesis test, the size effect, and the improvements in accessibility to TST and AIS are summarized in **Table 5**.

Hypotheses	Statistical test	<i>p</i> -value	Size effect	Percentage variation (decrease)	Percentage variation (improvement)
H ₀₁ : The difference of TST time of access between pre and post-intervention equals zero.	Paired samples <i>t</i> -test	0.0017	-2.12	-87.35%	837.22%
H ₀₂ : The difference of TST distance of access travelled between pre and post-intervention equals zero.	Paired samples <i>W</i> -test	0.016	-23.84	-90.47%	950%
H ₀₃ : The difference of TST number of steps of access between pre and post-intervention equals zero.	Paired samples <i>t</i> -test	0.0000151	-5.8	-87.12%	687.46%
H ₀₄ : The difference of AIS time of access between pre and post-intervention equals zero.	Paired samples <i>t</i> -test	5.64×10^{-13}	-10.28	-96.27%	2733.8%
H ₀₅ : The difference of AIS distance of access travelled between pre and post-intervention equals zero.	Paired samples <i>W</i> -test	0.00024	-5×10^{15}	-96.41%	2686.7%
H ₀₆ : The difference of AIS number of steps of access between pre and post-intervention equals zero.	Paired samples <i>W</i> -test	0.00024	-11.58	-95.84%	2310%

^a $\alpha = 0.025$ one-sided.

Table 5. Summary results from quantitative data.

5. Discussion

After all the action research phases performed, it was demonstrated that the application of Lean methodologies contributes for improving the accessibility to equipment and material that are essential to nurses' safe practice. With the application of the Lean methodologies, it is possible to provide optimized care to acute neurosurgical patients, in emergency and life support situations. Lean methodologies such as Gemba walk and spaghetti diagram made possible to identify wastes and difficulties in LSE accessibility, organization, and provision of other clinical equipment and supplies, and security issues such as potential cross-contamina-

tion provoked by exiguous work areas and architectural barriers. 5S and JIT philosophies together with interviews and questionnaires led to the development of a grounded interventional proposal for a functional and organizational harmonization of NHDU. Each suggestion on the proposal was then analyzed by medical and nurse unit managers giving deferral or refusal to certain interventions. The implementation of 5S and JIT methodologies led to the reorganization of NHDU and the allocation of the equipment closer to patients and nurses as well as to the decrease of waste, non-value-added activities and to significant improvements. These same results are argued in Carvalho et al. [45] since they defend that the layout must “reflect the need to reduce the time spent traveling” (p. 291) since “time ‘lost’ in travel between the various services... represents a cost to the organization in question, and that, in most cases, is not noticed or accounted for” (p. 291). For example, a nurse who searches for drugs, supplies, and equipment are doing it to serve the needs of patients, but may not notice that it can result in a waste of time, transport, handling, and human potential. But according to the Institute for Healthcare Improvement [46], if these materials were readily available when, how, and where they are needed (JIT), the time that nurses wasted looking for them would be instantly devoted to other more appropriate and critical tasks.

Through action research and the application of Lean methodologies, nurses of NHDU actually take only 10% of time, 9.37% of the distance travelled and 12.46% of the steps spent accessing TST compared to pre-intervention. The results of the intervention in AIS showed an improvement even more significant since the post-intervention access time is just 3.77% of pre-intervention time, the distance just 3.59%, and the number of steps only 4.21% compared to pre-intervention. To achieve this, nurses were educated about the location of LSE, and the need for training these nurses in ALS and RT handling was identified. Wastes and barriers that conditioned rapid access and action to acute patients were identified, reduced, or removed. Time, steps, and distance travelled accessing LSE were shortened and reduced more than half (-87.12 to -96.41%).

The same results were reached in other researches. Virginia Mason Medical Center (VMMC), in Seattle (USA), is credited to be one of the pioneers in healthcare industry to implement Lean by applying their own Virginia Mason Production System (based on TPS) [47]. Since 2001 VMMC makes efforts with the reorganization of spaces and workflows, minimizing transportation, and handling wastes, where all clinical equipment and supplies essential to care are placed in the point-of-use in UK Hereford Hospital, Lean methodologies led also to reductions of delay in nurses’ response time between 40 and 93% [48]. In Scotland, from a sample of 19 critical care units, nurses available time increased from 35 to 64%, in which 32% of these units reached changes greater than 100%, supported by the program Releasing Time to Care: The Productive Ward, based on Lean and six sigma methodology [49].

In this study, there is a significant and serious lack of nurses’ knowledge on the existence and location of LSE. Intervention through education, awareness, and change of its location resulted in an improvement of 100% to TST and 200% to ECK leading to health benefits for patient’s safety and quality of care. Still on the ECK and the RT, the simulation demonstrated the difficulties experienced by nurses in the use of the RT, particularly in opening it, use of drawers, location, and rapid visualization of contents. It was retrieved from this analysis that the

imperative and urgent need for nurse's professional training and the need for a clearly defined intervention criteria in emergency situations. This is in line with Silich et al. [50] that also highlights that informed and trained professionals provide better care with potential reduction of adverse events, bad practices, and less waste of resources.

Catchpole [51] argues that the undesirable effects of an inadequate working environment can result in fatigue, frustration, reduced performance, and human capacity, increased risk, and adverse events. Hence, the importance that health facility managers have and the impact of their decisions on patients and staff, and "usually, it is the intermediate and elementary level manager, involved in everyday decisions, that affect the care that is actually provided to patients" [52].

6. Conclusion

This research was intended to interfere in the reality studied by solving identified problems in an effective and participatory manner (through action), not only explain it or proposing a problem solution. The impact for practice and health services (quality indicators, safety, and satisfaction) of the Lean interventions carried out by the PR is well grounded by the results. In this research, it was verified that 66.7% of nurses were unaware of the existence or location of ECK and 50% of the TST. The education intervention resulted in an improvement of knowledge of 100% in the TST and 200% in the ECK, leading to potentially high health gains for the patient, because trained professionals provide better care with fewer mistakes. Furthermore, this research identified needs for periodic training and education on ALS and RT practice. Through Lean methodologies such as 5S, JIT, and spaghetti diagrams, it was possible to decrease time, steps, and distance travelled by nurses accessing TST and AIS between 87.12% and 96.41% and to improve this accessibility between 687.46% and 2733.8%.

These results confirm the contribution of this research to address the need of this healthcare unit to improve the care of neurosurgical acute/critically ill patients. The implementation of Lean 5S and just-in-time methodologies led to the reorganization of NHDU environment by allocating LSE closer to patients and nurses station, contributing by this way for improving the security and responsiveness of nurses' team for having more knowledge and quick access to LSE. In addition, it contributes to overcoming emergency, life support situations, and day-to-day professional life action to the needs of patients, freeing up time and availability of nurses for direct care by a work environment with less waste of time, distance, steps, handling, and setup procedures.

Although not focused in this research, for the unit and hospital management, there are potential economic and financial benefits attained from the application of Lean methodologies through the following factors: hand labor and human capital gains by reducing the time required to perform certain tasks (setup time); reduction of the "snowball" effect that leads to the accumulation of everyday work; reprocessing gains from potential reduction of costs in time of hospital internment and patient morbidity.

Besides the advantages reached with the application of the lean methodologies the research findings, however, are tempered by several shortcomings such as the unavailability of participants to collaborate with the research and resistance to change. Financial impact of the intervention was not recorded. Moreover, the results cannot be generalized; other realities can compare them and encounter similar situations that may benefit with the application of Lean methodologies in an attempt to overcome their problems.

It is expected that health professionals, especially their leaders and managers, can take some lessons from the different approaches adopted in this research and may act as a catalyst for future positive changes in all health services.

As a suggestion for future research it would be interesting to study the financial impact (time saved vs. value/hour) of the application of these lean methodologies, the impact on the quality of nurses daily professional life (satisfaction, fatigue, stress, burnout) and on emergency scenarios (LSE accessibility/availability vs. morbidity and mortality).

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