Ergonomic Assessment and Analysis of Postural Load of Surgeons Performing Laparoscopic Surgeries in Cuenca, Ecuador

Mónica Ordóñez-Ríos[1(✉)], Oswaldo Jara-Díaz[2], Juan C. Salamea[3], and Vladimir Robles-Bykbaev[4]

[1] Consorcio Ecuatoriano para el Desarrollo del Internet Avanzado (CEDIA), Cuenca, Ecuador
moni.carol19897@gmail.com
[2] Universidad Internacional SEK, Cuenca, Ecuador
oswaldojara@outlook.com
[3] Universidad del Azuay, Cuenca, Ecuador
jsalamea@gmail.com
[4] GI-IATa, Universidad Politécnica Salesiana, Cuenca, Ecuador
vrobles@ups.edu.ec

Abstract. Despite current progress made in the design and development of surgical instruments, nowadays surgeons report ergonomics risks related to open, laparoscopic, and robotic procedures. A recent study carried out by Stanford University Medical Center (SUMC) claims that nearly 61% of surgeons have reported ergonomic symptoms, and of this population, 55.4% attributed the symptoms to laparoscopic surgery, 36.3% to open surgery, and 8.3% to robotic surgery. The most of studies performed in ergonomics and surgical procedures analyze the following elements: (a) disposition of different elements used during laparoscopic procedures, (b) musculoskeletal symptoms, or (c) ergonomic assessment of postural load. However, it is important to mention that in South America, and specifically in Ecuador, few studies exist that solely analyze in a general way the ergonomic risk due to postural load. On those grounds, in this paper we present a study that is aimed on determining the risks experienced by surgeons in laparoscopic surgeries due to problems related with ergonomic factors, in Cuenca, Ecuador. To analyze the risks factors, we have used an approach that combines the anthropometric characteristics of surgeons and the evaluation of the operating room design.

Keywords: Ergonomics · Laparoscopic surgery · Anthropometric characteristics · Postural risk level · Musculoskeletal symptoms

1 Introduction

Nowadays, the technological advances in the medical area allow doctors conduct surgeries with the support of advanced surgical instruments, despite the low adaptation level of these instruments to surgeons' requirements. In the same way, it is important to

V. Duffy and N. Lightner (eds.), *Advances in Human Factors and Ergonomics in Healthcare and Medical Devices*, Advances in Intelligent Systems and Computing 590, DOI 10.1007/978-3-319-60483-1_44

bear in mind that a laparoscopic surgery is an operation that requires a high level of precision on the surgeon´s side, and can lead surgeons to adopt forced positions during the surgery. In this line, the ergonomics' objective is to improve working conditions, trying to avoid health problems due to postural load as well as contributing to improve the employees comfort and their work efficiency. However, in the medical area (especially in Ecuador), there is currently a lack of ergonomics principles application in several areas.

The surgeons are professionals considered in the group that present a high risk of suffering musculoskeletal diseases due to working activities (whose symptoms are closely related with physical efforts) [1].

According to the VI National Survey about Working Conditions, in Spain 74.2% of workers feel some musculoskeletal discomfort in the lower back and neck due to working postures and efforts [2].

In the same line, according to research presented by Adams et al. in 2013, more than 70% of surgeons have presented musculoskeletal discomfort during laparoscopic surgeries. Likewise, this study claims that it is important to relate surgical activity and neck pain (43%) and wrists (31%) [3].

Similarly, Perez et al. claim in their study that surgeons present static neck and trunk postures, situation which produces inadequate movements of superior limbs. Likewise, according to the authors a surgeon maintains a vertical posture without mobility and a lower balance and weight distribution along his/her body (in comparison with open surgeries) [4].

Despite the several advantages of laparoscopic surgery, it commonly reduces the freedom of movements and forces surgeons to adopt difficult body postures during relatively long periods. This situation reduces the surgeons' performance as well as their precision during the surgeries.

For these reasons, in this paper we present a complete study that is aimed on determining the risks experienced by surgeons in laparoscopic surgeries due to problems related with ergonomic factors, in Cuenca, Ecuador. With the aim of performing an appropriate analysis of risk factors, we have used an approach that combines the anthropometric characteristics of surgeons and the evaluation of the operating room design.

The rest of the paper is organized as follows. Some relevant researches related with laparoscopic surgery and ergonomics are presented in Sect. 2. The study that we have carried out in Cuenca, Ecuador is depicted in Sect. 3. Section 4 describes the main findings and results of our research. Finally, Sect. 5 presents some ideas for discussion and future work.

2 Laparoscopic Surgery and Ergonomics: A Brief Overview

Nowadays, the laparoscopic surgery, also called Minimally Invasive Surgery (MIS), has been adopted by several medical-surgical specialties. However, despite the advantages that MIS presents for patients, the surgeon commonly suffers from mental fatigue as well as musculoskeletal disorders. Therefore, it is of great interest in analyzing the surgery environment/conditions and conducting a complete study in terms of ergonomics.

Miller et al. have carried out a study about ergonomics and fatigue levels experienced by 61 surgeons during their activities in the operation room. The results show that 100% of participants have suffered at least one musculoskeletal disorder due to laparoscopic surgeries, being neck and back the most affected areas [5]. Commonly, the management of laparoscopic instruments is performed by the principal surgeon with his eyes fixed on the video monitor (in a static position), standing, with limited working space, with a high concentration level and with abducted arms.

Therefore, some studies indicate that there is a relationship between the time required to perform the surgical activity and the pain experienced in the neck and hands [6].

During laparoscopic surgery, the surgeons adopt static positions (in comparison to open surgery). This situation occurs due to: (a) the requirement of using bidimensional vision to perform the operation, (b) the available instrument is less effective, and (c) the visual-motor coordination causes mental fatigue [7].

The musculoskeletal disorders suffered by surgeons are due to difficulty to remain in a neutral position during the laparoscopic surgery. This circumstance occurs because the workstation design does not consider an appropriate relation between the surgeon, his/her needs, and the following elements: design of surgical instrumental, video monitor position, foot pedals (to control diathermy), operating table height, and static postures adopted by staff [8].

The neck pain is one of the most common problems registered after the arrival of laparoscopic surgeries [9]. Given that the surgeons must be in a standing position during long periods, they require performing a major muscle effort that can produce disorders in low back as well as tension in the shoulders. In long periods, the static postures are more harmful than dynamic postures, given that they produce lactic acid and toxin accumulation in the muscles and tendons [10].

Other studies claim that 73% of surgeons report physical inconveniences during MIS in areas than involve neck, low back, shoulders and thumbs. This situation is due to three factors: incorrect setting of the height of the operating table, incorrect location of video monitor, and inadequate design of the equipment (instrumental) [11]. Likewise, Gutierrez et al. used the Rapid Entire Body Assessment (REBA) in a study with 33 principal surgeons to confirm that 91% of them present medium risk level, hence action and investigation is needed [1].

With the above mentioned, an approach to improve forced postures that generate low risk mainly depends on an ergonomics principle: the anthropometry. This principle is related with the workstation design, and its aim is to adjust the MIS to the surgeon skills and limitations, not otherwise. This principle defines the guidelines that allow improving the quality of surgeon's working environment, avoiding forced postures and reducing surgery time, since it is possible to count with appropriate instrumental and equipment. However, the surgeons are not aware about ergonomics guidelines as well as how to put them in practice [7].

3 Ergonomics and Laparoscopy: A First Approximation to Ecuadorian Reality

The study that we have carried out in this research is observational and descriptive cross-sectional, and was carried out in a tertiary referral hospital. We have analyzed seven principal surgeons during laparoscopic cholecystectomy, because the historical data of the hospital shows that this kind of MIS corresponds to 65% of total surgeries performed per year.

Below we will describe the different methodologies applied in this study, considering surgeons and operating room.

3.1 Musculoskeletal Symptomatology Analysis Procedure

With the aim of determining the data referring to musculoskeletal symptoms, we have used the Nordic Musculoskeletal Questionnaire [12, 15]. Each questionnaire was directly applied to each surgeon through an interview. To carry out this process, we asked doctors to sign the informed consent form, and all personal data was removed to keep people's anonymity. With the aim of performing a statistical analysis, in the following stage we collected data about pain, fatigue or discomfort in several surgeons' body areas related with MIS.

3.2 Postural Load Analysis Procedure

After performing the musculoskeletal symptomatology analysis, we have proceeded to analyze the postural load of each surgeon through REBA method [13]. For this target, we have carried out the following tasks:

- In order to analyze the surgeons' postural load we have made a real-time video recording, considering the visual field (during the entire recording). Our goal was to observe the different movements performed by surgeons on both upper extremities (left and right sides).
- Each video recorded allowed us to make a detailed analysis of each posture adopted by each surgeon during the MIS. On this basis, we have selected the most relevant observations of the higher postural loads (those that can produce or exacerbate musculoskeletal disorders in surgeons).
- After selecting the risk postures for each surgeon, we have determined the angles that were formed through the following body segments: Group A (trunk, neck and legs) and Group B (arm, forearm and wrists). These groups are considered for the different postures of the body (to later obtain the level of risk by postural load).

3.3 Procedure for the Analysis of the Workstation Design (Operating Room)

In this procedure, direct observations of the operating room and their components (video monitor, operating table, instrumental and foot pedal) have been made (Fig. 1). Below we describe the main analysis performed by our team:

- The adaptability and adjustment of each element (according to its design) to surgeon's needs were determined. To achieve this goal, we have analyzed the elements' sizes (width, height and depth as well as the maximum and minimum height on which can set).
- The operating room in which were performed the different studies. As it can be seen, this figure describes the main characteristics of the elements that belong in the operation room as well as medical team location.
- The disposition and position of the elements that are part of the operating room are closely related with the cholecystectomy and were analyzed with the target of determining whether the position is adjustable or can be modified according to surgeon's needs.

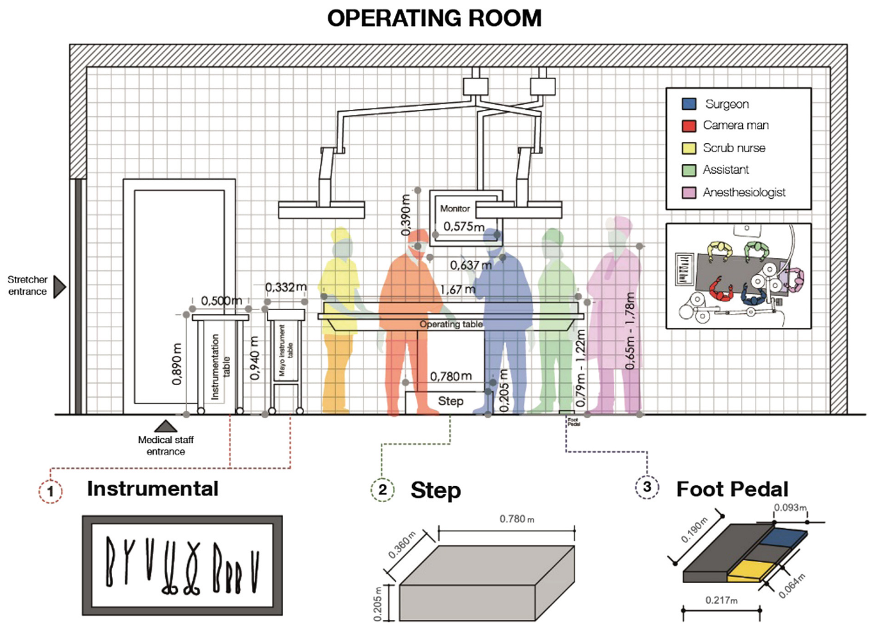


Fig. 1. The operating room in which were performed the different studies. As it can be seen, in this figure are described the main characteristics of elements that belong to operating room as well as medical team location.

3.4 Procedure for Taking Anthropometric Measurements

With the objective of suggesting an appropriate workstation design for the surgeons, we have taken anthropometric measurements of each analyzed surgeon. The anthropometric variables considered in the analysis are the following: acromial-radial, radial-styloid, shoulder-to-floor height (stand position), height of eyes to floor (stand position), height of elbows of floor, knuckle height (to floor) with clenched fist, width and length of hand, width and length of foot, maximum and minimum horizontal reach with grip and wingspan.

The anthropometric measures were collected through an anthropometric proform taking into account three measurements of each anthropometric variable. From the three measures analyzed, the median was taken as the final measure for calculating percentiles (P5, P50 and P95), using STATA (Data Analysis and Statistical Software) [14].

4 Results

In this section the main findings of our research are described, considering the following: symptomatology presented by surgeons, and the different elements that constitute the operating room (operating table, surgical instrumental, video monitor, foot pedals), postural load, and anthropometric measurements.

4.1 Symptomatology

We have analyzed seven surgeons, which have the following characteristics:

- They average age is 43 ± 9 years (43% corresponds to ages between 31–38 years) and the average weight is 68 ± 9 kg
- The dominant hand is the right (in the 100% of cases)
- Most of the surgeons are men (86%)
- The experience of surgeons is between 5 and 20 years

The prevalence of symptoms of musculoskeletal disorders related with laparoscopic surgery is 100%. After the performing the analysis, we have determined that the body area that presents more pain and discomfort is the neck (in all cases). Likewise, the lower back is another area with high level of prevalence of pain, with 71%, followed by shoulders and wrists with 57% (Fig. 2).

4.2 Workstation Design (Operating Room)

Below we describe analysis about the different elements that are part of operation room:

- *Operating table*: is located on the center of operating room and has a device controlled remotely to adjust its height from 79 to 122 cm. At this height, it is important to consider that patient's thorax thickness is between 30 and 45 cm. The working area of the operating table is 167 cm × 53 cm.
- *Surgical instrumental*: Surgical instrumental (grasper, scissors, needle holder, cautery hook, stapler) used during surgery have a two-finger ring clamp mechanism with scissor-type handle and clamp-type (pinch grip) for the cautery hook. This grip is poor (possible but not acceptable) because of this type of grip, there is compression at the points of contact and visible in the phalangeal metacarpal joint of the index finger, compromising the fine musculature. These instruments are characterized by being large with respect to its length, which goes on an average of 34 cm–37 cm and weighing less than 5 kg. The instruments are placed on the instrumentation and mayo tables and have a height of 0.89 m and 0.94 m, respectively. The instruments are located at the foot of the operating table to the right of the scrub nurse.

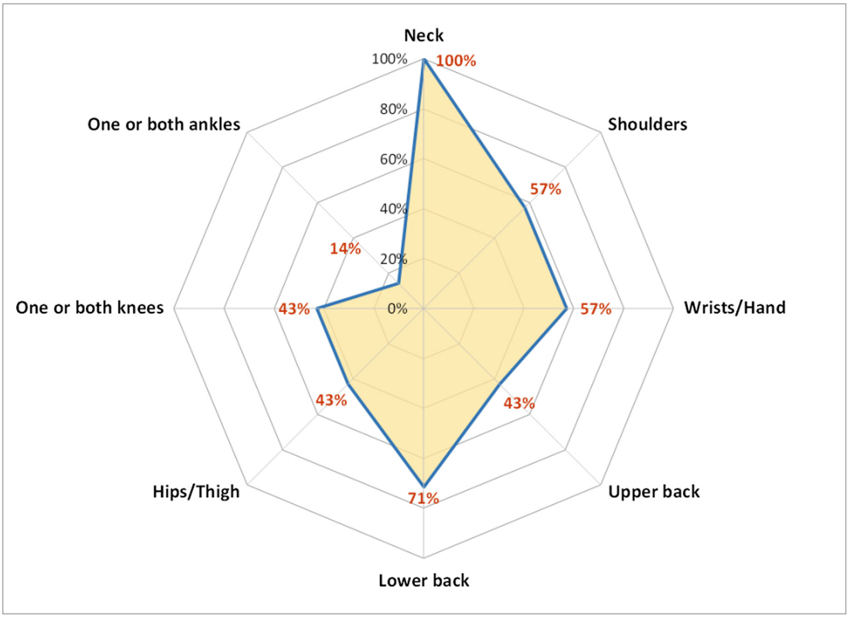


Fig. 2. The different parts of the body and the level of discomfort that is present in each one of them.

- *Video monitor*: has a dimension of 0.64 m by 0.39 m and is located on the laparoscopic tower. The image projected in the video monitor is in two dimensions (high definition) and has the possibility of adjusting the height and has three degrees of freedom (axis x, y, z). The height of video monitor is adjustable from 0.65 m to 1.78 m.
- *Pedals for the diathermy system:* the pedal to control diathermy system is located at the right side of principal surgeon (above ground level) and does not have anti-slip material. The dimensions of pedal are 0.093 m by 0.064 m.

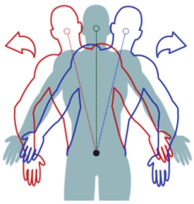
After monitoring the four main elements that are involved in the cholecystectomy, we have noticed some surgeons have used a step due to their short height. This step has the following dimensions: 0.78 m by 0.36 m by 0.205 m.

In the same way, we have noticed that the working area of the principal surgeon it is not adequate due to the closeness of the camera-man to him/her. This situation reduces the freedom of movement of surgeon given that the arm of the assistant is below the surgeon's arm.

4.3 Postural Load

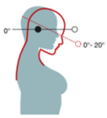
In our study we analyzed 70 postures for each body side during the dissection phase of the cholecystectomy process with an average time of 58 ± 13 min and an interval of 40–75 min (without taking into account preparation or closure times).

The different postures have considered in two groups (for left and right sides): Group A (trunk, neck and legs) and Group B (arm, forearm and wrists). As it can be seen in Fig. 3, Group A presents the following results: the neck is between 0° and 20° of flexion in 66% of the cases, the neck shows torsion fit in 99% of the postures, the trunk is between 0° and 20° of flexion in 99% of cases, the trunk has torsion adjustment in 97% of total postures with bilateral support of legs (in 100% of the cases).

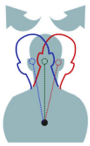


Trunk twisting or side flexed	
Frequency (70 postures)	Percentage
68	97%

Trunk flexion 0° - 20°	
Frequency (70 postures)	Percentage
69	99%



Neck flexion 0° - 20°	
Frequency (70 postures)	Percentage
46	66%



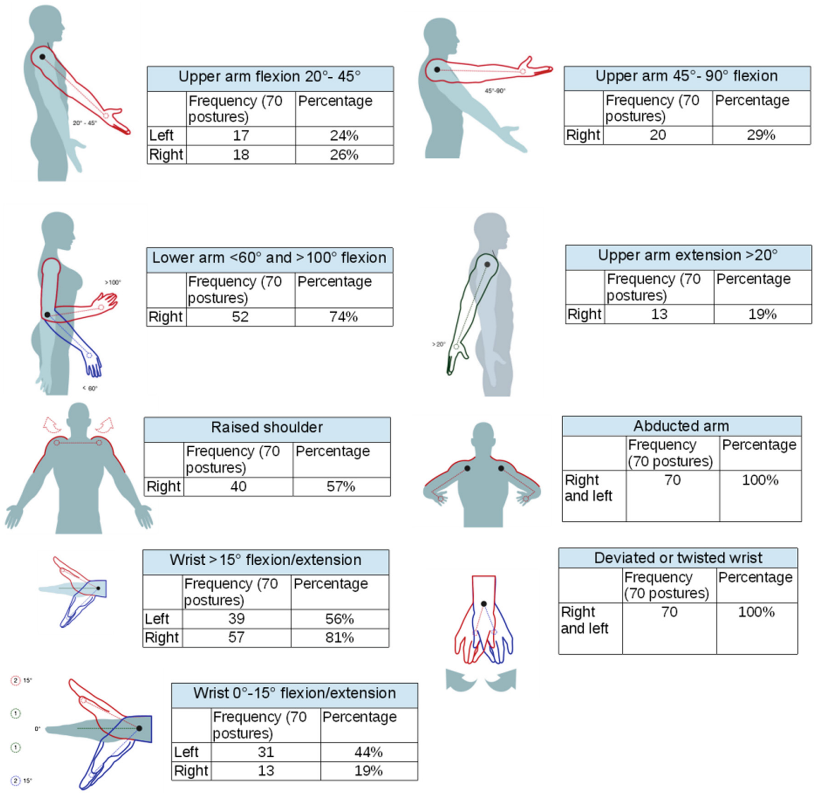
Neck twisting or side flexed	
Frequency (70 postures)	Percentage
69	99%

Fig. 3. Postural evaluation of the different parts of the body, Group A.

The Group B is the most affected due the following results (Figs. 4 and 5): 29% of postures have the right arm flexed between 45° and 90° and 26% between 20° and 45° whereas for the 66% of postures the left arm is flexed between 0° and 20°. Likewise, it can be seen that in all postures the task is performed with the arms abducted in both the left and right limbs as well as the shoulder is elevated in 57% of the total surgeons. In the 74% of postures, the right forearm it is flexed in an angle less than 60° or greater than 100° whereas in the 66% of cases the left limb is flexed between 60° and 100°. Moreover, the wrist is flexed in an angle greater than 15° in 81% of cases for the right arm, as long as for the left arm is in 56% and the lateralization of the wrist in all positions analyzed. In this evaluation, it was possible to determine that the grip is poor, possible but not acceptable, because of the used instrumental at workstation (this situation produces an adjustment in the final score).

Finally, it is important to remark the following conclusions that we have reached after carrying out the postural analysis:

- There is a trend in which it can be observed that the body segments of Group A mostly remain static because the surgical process requires it.
- The level of risk is in the range of 5 to 10, which is considered between medium and high (for the right limb is high in all cases).
- For the left limb, the risk level is considered medium for the 64% of cases.
- In both cases, left and right limbs, it is required an investigation and implement changes in postural conditions and ergonomics



Upper arm flexion 20°- 45°	Frequency (70 postures)	Percentage
Left	17	24%
Right	18	26%

Upper arm 45°- 90° flexion	Frequency (70 postures)	Percentage
Right	20	29%

Lower arm <60° and >100° flexion	Frequency (70 postures)	Percentage
Right	52	74%

Upper arm extension >20°	Frequency (70 postures)	Percentage
Right	13	19%

Raised shoulder	Frequency (70 postures)	Percentage
Right	40	57%

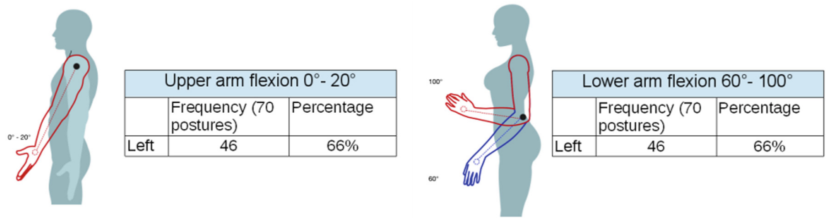
Abducted arm	Frequency (70 postures)	Percentage
Right and left	70	100%

Wrist > 15° flexion/extension	Frequency (70 postures)	Percentage
Left	39	56%
Right	57	81%

Deviated or twisted wrist	Frequency (70 postures)	Percentage
Right and left	70	100%

Wrist 0°-15° flexion/extension	Frequency (70 postures)	Percentage
Left	31	44%
Right	13	19%

Fig. 4. Postural evaluation of the different parts of the body, Group B.



Upper arm flexion 0°- 20°	Frequency (70 postures)	Percentage
Left	46	66%

Lower arm flexion 60°- 100°	Frequency (70 postures)	Percentage
Left	46	66%

Fig. 5. Postural evaluation of the different parts of the body, Group B.

4.4 Anthropometric Measures

The measures of the elements that are part of the analyzed operating room and the adjustment ranges with respect to the determined percentiles that must be taken into account for the design of the work place (operating room) are shown in Table 1.

Table 1. Measures of the operating room elements and its relation with the percentiles for an adequate adjustment range.

Operating room element	Measure (cm)	Anthropometric variable	Percentile	Adjustment range (cm)
Height of the video monitor to the top edge	104–217	Eyes-floor distance	P5-P95	141.03–166
Height of the operating table plus the thickness of the patient's thorax.	79–122 + 30–45	Elbows-floor distance	P5-P95	93.10–113.95
Surgical instruments	Poor grip	Hand width	P95	8,94
		Hand length		19,22
Width and deep of diathermy pedal	9.3 × 6.4	Foot width	P95	9,72
		Foot length		26,16
Width and depth of the working plane (operating table)	53 × 167	Maximum horizontal reach with grip.	P5	75,45
		Minimum horizontal reach with grip.		28,05
		Wingspan		128,34

5 Discussion

In this paper, we have presented a study of postural risks presented by principal surgeon during the practice of cholecystectomy surgeries. This analysis was carried out considering the operating room design as well as the musculoskeletal symptomatology present in each doctor.

In the same way, it is important to mention that our study follows the general guidelines proposed by other experts and establishes the support to develop future research process related with laparoscopic surgeries. Currently, the MIS are highly requested due to the advantages that they present against traditional surgeries. Therefore, applying ergonomics criteria in the area of MIS allows to obtain important improvements as to reduction of postural risk, efficiency during surgery, and mitigation of musculoskeletal conditions.

Although in several researches, guidelines have been proposed about ergonomics and medical area, currently in several countries (especially in developing ones) the surgeons do not apply properly these guidelines and recommendations. Likewise, several surgeons continue adopting wrong postures or bad positioning surgical instruments, even though the surgical equipment can be easily adapted to the surgeon.

Therefore, it is very important adjusting the operating room elements according to ergonomics guidelines, e.g., using steps or platforms with the aim of adjusting the operating table according floor elbow height.

It is key to remark that the correct positioning of the monitor, height of the surgery table, design of the surgical instruments and position of the pedal play a very important role in the performance of the surgeon's work and are directly related to the postures that he or she adopts.

Acknowledgments. This work has been funded by the Consorcio Ecuatoriano para el Desarrollo del Internet Avanzado (CEDIA).

References

1. Gutiérrez, M.C., et al.: Valoración postural y síntomas musculo esqueléticos en el alumnado de un centro de simulación en cirugía mínimamente invasiva guiada por la imagen. J. Sociedad Española de Medicina y Seguridad en el Trabajo **7**, 121–173 (2012)
2. Arenas-Ortiz, L., Cantú-Gómez, Ó.: Factores de riesgo de trastornos músculo-esqueléticos crónicos laborales. J. Medicina Interna de México **29**, 370–379 (2013)
3. Adams, S.R., Hacker, M.R., McKinney, J.L., Elkadry, E.A., Rosenblatt, P.L.: Musculoskeletal pain in gynecologic surgeons. J. Minim. Invasive Gynecol. **20**, 656–660 (2013)
4. Pérez-Duarte, F.J., Sánchez-Margallo, F.M., Díaz-Güemes, M.P.I., Sánchez-Hurtado, M.Á., Lucas-Hernandez, M., Usón, G.J.: Ergonomics in laparoscopic surgery and its importance in surgical training. J. Cir. Esp. **90**, 284–291 (2012)
5. Miller, K., Benden, M., Pickens, A., Shipp, E., Zheng, Q.: Ergonomics principles associated with laparoscopic surgeon injury/illness. Hum. Factors **54**, 1087–1092 (2012)
6. Díez, M.C.G., Herrera, R.S., González, M.A.B., Palazuelos, J.C.M., Figuero, C.R., González, M.A.G., Barragán, R.A.C.: Valoración postural y síntomas musculoesqueléticos en el alumnado de un centro de simulación en cirugía mínimamente invasiva guiada por la imagen. Revista de la Sociedad Española de Medicina y Seguridad del Trabajo **7**, 125–136 (2012)
7. Modi, Y.S., Kuswaha, M.R., Dave, S.P.: Awareness of ergonomic guidelines regarding laparoscopic surgeries, its practice among surgeons and comfort level during and after surgery. Med. J. **68**, 31–34 (2013)
8. Berguer, R., Rab, G.T., Abu-Ghaida, H., Alarcon, A., Chung, J.: A comparison of surgeons' posture during laparoscopic and open surgical procedures. Surg. Endosc. **11**, 139–142 (1997)
9. Nguyen, N.T., Ho, H.S., Smith, W.D., Philipps, C., Lewis, C., De Vera, R.M., Berguer, R.: An ergonomic evaluation of surgeons' axial skeletal and upper extremity movements during laparoscopic and open surgery. Am. J. Surg. **182**, 720–724 (2001)
10. Supe, A.N., Kulkarni, G.V., Supe, P.A.: Ergonomics in laparoscopic surgery. J. Minim. Access Surg. **6**, 31 (2010)
11. Sari, V., Nieboer, T.E., Vierhout, M.E., Stegeman, D.F., Kluivers, K.B.: The operation room as a hostile environment for surgeons: physical complaints during and after laparoscopy. Minim. Invasive Ther. Allied Technol. **19**, 105–109 (2010)
12. Aghilinejad, M., Ehsani, A.A., Talebi, A., Koohpayehzadeh, J., Dehghan, N.: Ergonomic risk factors and musculoskeletal symptoms in surgeons with three types of surgery: open, laparoscopic, and microsurgery. Med. J. Islam. Repub. Iran (MJIRI) **30**, 1232–1237 (2016)
13. Norhidayah, M.S., Mohamed, N.M.Z.N., Mansor, M.A., Ismail, A.R.: A study of postural loading in Malaysian mining industry using rapid entire body assessment. In: MATEC Web of Conferences, vol. 74, p. 14 (2016)
14. StataCorp, L.P.: Stata data analysis and statistical software. Spec. Ed. Release **10**, 733 (2007)
15. Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sørensen, F., Andersson, G., Jørgensen, K.: Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl. Ergon. **18**, 233–237 (1987)