

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

David Lobo, PhD¹ , Pedro Anuarbe, BEng² , José Miguel López-Higuera, PhD^{2,3,4} ,
Jaime Viera, MD¹, Nathalia Castillo, MD¹ and Roberto Megía, MD¹

Background: The purpose of this study was 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 were collected with the help of Kinect and a .NET WPF (Windows Presentation Foundation) software application to record images of the surgical procedures, and then 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 surgeons obtained a high RULA score, meaning that urgent changes are required in the task. © 2019 ARS-AAOA, LLC.

Key Words:

ergonomics; endoscopic surgery; otolaryngologists; musculoskeletal; RULA; motion tracking

How to Cite this Article:

Lobo D, Anuarbe P, López-Higuera JM, Viera J, Castillo N, Megía R. Estimation of surgeons' ergonomic dynamics with a structured light system during endoscopic surgery. *Int Forum Allergy Rhinol.* 2019;9:857–864.

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 patients (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 patients describe 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. RULA 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.

¹Hospital Universitario Marqués de Valdecilla, Santander, Spain;

²Universidad de Cantabria, Santander, Spain; ³Centro de Investigación Biomédica en Red (CIBER) de Bioingeniería, Biomateriales y Nanomedicina, Madrid, Spain; ⁴Innovation Support Program "InnVal" of the Marques de Valdecilla Research Institute, Santander, Spain

Correspondence to: David Lobo, PhD, Hospital Universitario Marqués de Valdecilla, Av de Valdecilla 25, 39008, Santander, Cantabria, Spain; e-mail: dlobo28@gmail.com

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Funding sources for the study: Innovation Support Program (InnVal) of the Marques de Valdecilla Research Institute.

Received: 20 December 2018; Revised: 29 March 2019; Accepted: 28 April 2019

DOI: 10.1002/alr.22353

View this article online at wileyonlinelibrary.com.

Subjects 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 sinus surgery variables were recorded, including: Trendelenburg tilt of the operating table; angle of the endoscope to the horizontal plane; angle of the head of the operating table to the horizontal plane; height of the operating table with respect to the floor; distance from the handle of the endoscope to the surgeon's anterior superior iliac spine; height of the monitor relative to the surgeon's eyes; and the visual angle. Together these conformed to 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 without 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, and frontal sinusotomy, and advanced procedures such as Draf III frontal sinusotomy, skull base approaches, an 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 6 surgeons, all of them right-handed (4 practicing otolaryngologists who regularly perform endoscopic sinus surgery and 2 residents: 1 Postgraduate (PG)-2 resident and 1 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 PM to 6:30 PM, with a 30-minute break at 11:00 AM and a 1-hour break at 2:00 PM.

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 version 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 these data to calculate the angles needed by the RULA method see supplementary video.

We used the application to record the work of 6 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 1.15 meters. 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 are 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 musculoskeletal disorder (MSD) risk.⁹

The acquired images were used to construct a histogram that represents the frequency and variability of the postural angles during the intervention (Fig. 2). A temporal analysis of the recorded data was also performed to identify repetitive postures because 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 1-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.

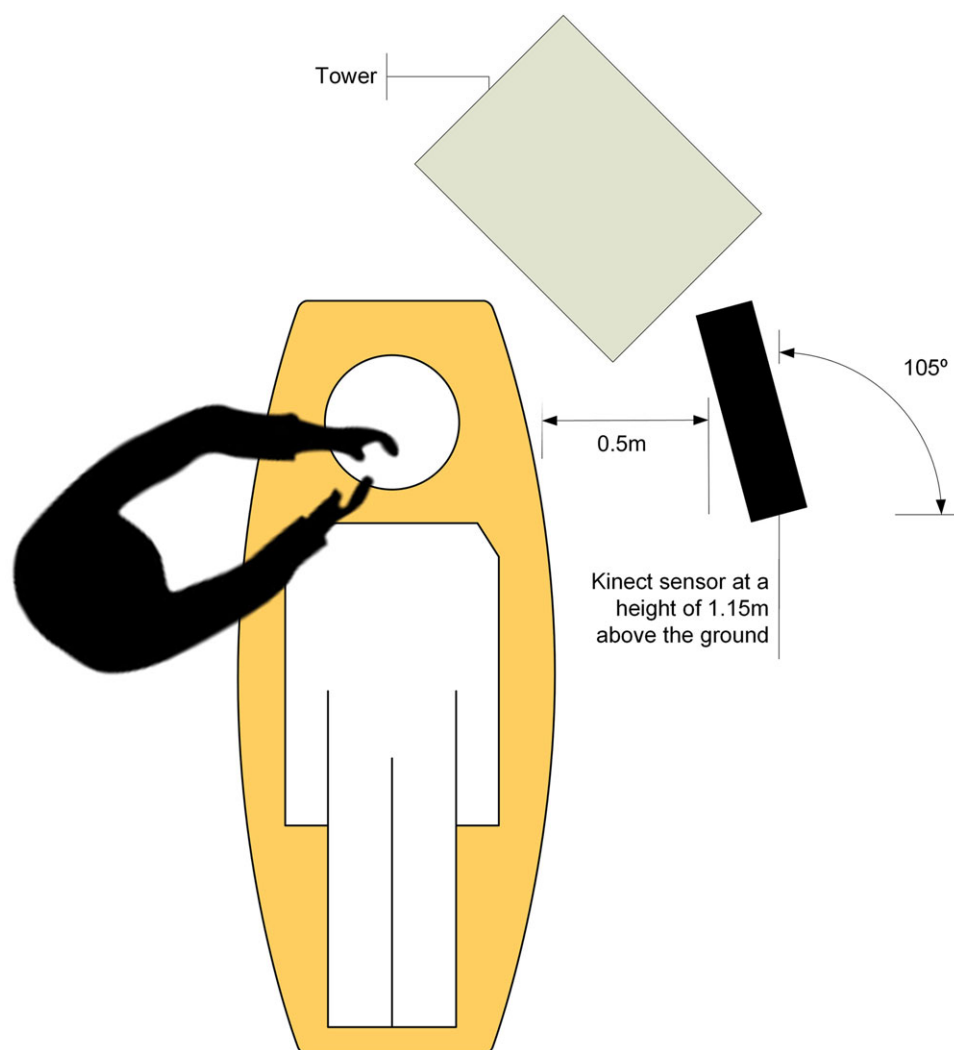


FIGURE 1. Specific setup for motion capture during the surgical procedures.

Results

Sex and anthropometric measures

Bilateral endoscopic sinus surgery was performed in 5 cadaver heads by 2 female residents, and 4 male practicing rhinologists. Table 1 shows the demographic data and other details of personal background and work activity.

Endoscopic sinus surgery variables

Surgical variables conformed what was considered objectively to be the most comfortable position for each surgeon to perform the operation. The values obtained by the sitting and standing group are shown in what follows (median and range are used where appropriate): Trendelenburg tilt of the operating table (0° ; 0°); angle of the endoscope to the horizontal plane (45° - 70° ; 55° - 100°); angle of the head of the operating table to the horizontal plane (5° ; 10° , 5° - 15°); height of the operating table with respect to the floor (80 cm; 80 cm); distance from the handle of the endoscope to the surgeon's anterior superior iliac spine (55 cm; 40 cm,

37-42 cm); height of the monitor relative to the surgeon's eyes (+25 cm; +15 cm, -3 to +25 cm); and visual angle ($+11.8^\circ$; $+6.8^\circ$, -1.4° to $+14^\circ$).

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 $>45^\circ$ were observed, except occasionally during the act of picking up an instrument. Flexions of $<60^\circ$ for 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 flexion $>20^\circ$ was very common. Rotation or tilting of the head was also common. Most of the time, the trunk was bent forward $<20^\circ$ during the surgical procedure, except for extremely rare situations or in cases of measurement error. The most typical degree**

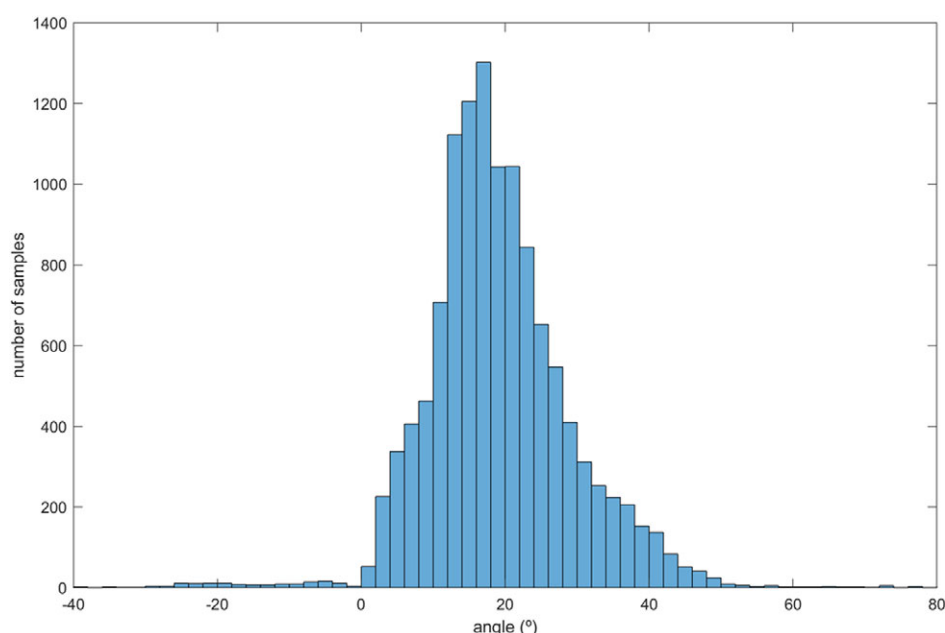


FIGURE 2. Histogram representation of surgeon 1's neck flexion angles during the surgical procedure.

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 | SBH&NO ^a | RSBS ^b | | | | |
| Number of ESSs per year | 50-75 | 75-100 | 50-75 | | | > 100 |

ESS = endoscopic sinus surgery; F = female; M = male; SBH&NO = skull base and head and neck oncology fellowship RSBS = rhinology and skull base surgery fellowship.

of trunk flexion was $<5^\circ$. 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 to those described for the practicing otolaryngologists. The overall score was 6.8 (relative frequencies: 80% scored 7; 20% scored 6). A score of 7 indicates that urgent changes were required in the task.

An independent analysis of the data for each upper limb still resulted in a score of 7 for the left side (5/5), and 6.6 (relative frequencies: 60% scored 7; 40% scored 6) for the right arm. A score of 6 indicates 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. Flexion between 60° and 100° of the forearm was very frequent, although flexion $<60^\circ$ was 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 was 6, indicating a need to redesign the task (Table 2).

Although more experienced surgeons obtained a slightly lower RULA score, there was no significant association between years in practice and RULA score.

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

TABLE 2. RULA results by surgeon

| | S1 R/L | S2 R/L | S3 R/L | S4 R/L | S3 R/L | S6 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 |

L = left; R = right; RULA = Rapid Upper Limb Assessment; S = surgeon.

Physical discomfort assessment

All 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 >1 month, but not consecutively. Surgeon 3 also reported occasional discomfort of 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 >1 year.

Surgeon 6 reported discomfort in both lower extremities, mostly in both knees in the last 12 months. In fact, he had experienced 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 demonstrated a worsening at previously affected sites after the surgical procedures, and she also



FIGURE 3. Surgeon 1' skeleton tracking.



FIGURE 4. Surgeon 2' skeleton tracking.

reported muscular discomfort in the shoulders, hip, thighs, ankles, and feet. She attributed the discomfort 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 pathology processes. 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 increased number of publications on this issue in recent years. 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



FIGURE 5. Surgeon 4' skeleton tracking (PG-2 resident). PG = Post-graduate.



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. RULA = Rapid Upper Limb Assessment.

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 non-invasive surface electromyography to evaluate 4 muscle

groups objectively 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 Notably, they found that the sitting position was objectively much more favorable for the left hamstring muscle group than the standing position. In contrast, the sitting position was less favorable for the right and left medial deltoids, as there was a decrease in mean power frequency compared with the standing position. **One of the limitations of their study is that the dissections were performed by only 1 surgeon.** 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 may be responsible for muscular fatigue and on which we must act ergonomically. In this sense, our study complements their results by offering additional information that can help when reformulating the surgical environment.

The RULA method identifies those positions that involve greater postural load because of their duration or frequency or because of the greater deviation with respect to the neutral position.

RULA has been employed for ergonomic analyses of microlaryngoscopy and recommends lower risk surgeon positioning be utilized during microlaryngeal surgery.⁷

In this study we have gathered information through the Kinect system and processed it to obtain a RULA score in a simulated laboratory environment. Using this approach we were able to reproduce 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. RULA was designed for easy use without the need for advanced training in ergonomics or expensive equipment. In principle, it is designed to be applied manually in the field; however, perception errors and interrater reliability can affect the accuracy of the estimated joint angles. In addition, because surgical activity normally implies awkward or repetitive postures to be held for long periods, observation of posture can be labor-intensive. The histograms utilized allowed us to summarize comprehensively a large quantity of basic descriptive statistical information. Because the RULA method can evaluate a wide range of angles and the histograms can reveal the most frequently repeated values and trends, we were able to estimate the RULA score. The RULA method evaluates 4 risk factors (number of movements, static muscle requirement, strength, and postures), but it 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 these other relevant factors, thereby providing further information in addition to that collected for calculation of RULA score. Further, the information obtained could potentially be used for strain

index or revised strain index (RSI) calculations while taking duty cycle into account.

The primary issue of concern in our study is the small sample size, especially in the sitting group. In most cases, only 1 surgeon adopted the sitting position during sinus surgery. Bodily strain levels experienced by the surgeons cannot be compared if the operative conditions are not matched with regard to their preferences and comfort levels. Admittedly, this is a difficult issue to address given the unique individual variations among subjects.

Multiple basic and advanced procedures were performed over the course of 1 day. Ultimately, **this may not reflect the true musculoskeletal strain or load that endoscopic surgeons face while performing actual surgery, where the number of procedures may be more limited and longer breaks may be instituted.** To account for this, shifts were established so that there was a rotation among the different surgeons (ie, the time spent by each surgeon in each procedure such as total ethmoidectomy or Draf IIb frontal sinusotomy was not the same, but at the end of the 3 days the workload was similar among the surgeons).

The RULA scores were not analyzed separately for basic and advanced procedures. However, it would be of interest to ascertain whether 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 were analyzed independently for each upper limb is that the score for the left arm was higher than for the right arm, both in the standing and sitting positions. In the latter case, this result can be explained by the fact that both shoulders were raised and abducted and the left forearm extended. In the standing position, it is generally believed that the left arm is exposed to an increased risk of musculoskeletal problems 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}

These findings correlate with muscular discomfort levels reported by subjects on the physical discomfort questionnaires. In this regard, it is important to point out that, in spite of his previous lower limb problems, the surgeon who operated in the seated position reported discomfort in the upper extremity after the dissection, which coincides with previous study data.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 ear-nose-throat resident. Muscle tension, which in turn causes fatigue, can start as early as the first years of training in ear-nose-throat surgery, and our findings are in line with earlier survey studies.^{13,14}

The subjectivity of comfort for surgeons is a major limitation of our study due to small number of surgeons analyzed. We believe that our ergonomic study would not be complete without collecting the aforementioned data.

It is also important to highlight that 4 of the surgeons assessed are experienced rhinologists with a deep knowledge of ergonomics, yet they showed similar scores to those of residents.

It is crucial to follow the recommendations proposed by Ayad et al and Ramakrishnan and Montero for endoscopic sinus and skull base surgery. Their indications 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 may not be enough, because, as we have shown, basic and advanced endoscopic surgery requires maintaining non-neutral positions of the neck, arms, trunk, and legs that expose the surgeon to musculoskeletal complications.

Matern and Konecny evaluated the workplace conditions of the operating room (OR) and identified elementary ergonomic deficiencies within the spatial and architectural setting of ORs and with regard to devices and equipment. They concluded that OR optimization should be a priority and ergonomic standards should be implemented in all hospital ORs.¹⁵ As Seagull noted, ergonomists have been decrying the lack of sound ergonomic practices in ORs since at least 1914.¹⁶

We share the view that new technical development and innovations in the daily routine of the OR must take ergonomics into account and that improving surgeon knowledge of sound, basic ergonomic principles be encouraged. Moreover, we must take advantage of the knowledge and experience of rehabilitation doctors and physiotherapists

who can advise on the adoption of proper postures at work along with other ergonomic aspects and exercises appropriate to the workload.

Our study has shown the value and general potential of the technology available for use in future research, and the aforementioned points can be applied in further study. The software used was adapted ad hoc for this investigation and not prepared for public use; however, the team is currently working on an improved version of the software (based on Kinect version 2) that will be available to the public.

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 the associated skeleton tracking were recorded and duly processed in accordance with the RULA method. Significant musculoskeletal symptoms were reported after endoscopic operation by both residents and practicing otolaryngologists. Moreover, all surgeons obtained a high RULA score, which indicated the urgent need to implement changes in the task. 🌐

Acknowledgements

The authors are thankful to the staff of the Valdecilla Virtual Hospital (HvV). The cadaveric surgical procedures were performed in the simulated laboratory environment of the HvV.

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