












Proposal of a Multi-parametric Ergonomic Assessment Protocol Integrating Intra-operative Use of Wearable Technology to Evaluate Musculoskeletal Discomfort for Surgeon During Laryngeal Surgery

Emma Sala¹ , Marco Mazzali², Emilio Paraggio² , Gianluca Rossetto³ ,
Giorgio Cassiolas⁴ , Emilia Scalona² , Francesco Negro⁵,
Giuseppe De Palma^{1,2} , Cesare Piazza² , and Nicola Francesco Lopomo³  

¹ Unit of Occupational Medicine, Hygiene, Toxicology and Occupational Prevention, ASST Spedali Civili di Brescia, Brescia, Italy

² Department of Medical and Surgical Specialties, Radiological Sciences and Public Health, University of Brescia, Brescia, Italy

³ Department of Information Engineering, University of Brescia, Brescia, Italy
nicola.lopomo@unibs.it

⁴ Complex Structure of Surgical Sciences and Technologies, IRCCS Istituto Ortopedico Rizzoli, Bologna, Italy

⁵ Department of Clinical and Experimental Sciences, University of Brescia, Brescia, Italy

Abstract. Musculoskeletal disorders (MSDs) represent a cross-cutting problem among healthcare workers; particular attention should be given to surgeons who are involved in mentally and physically demanding tasks. This work aimed to propose a multi-parametric ergonomic approach able to exploit different wearable devices to estimate cervical discomfort and the muscular fatigue sustained by an otolaryngology (ENT) surgeon during the execution of laryngeal surgeries. The proposed protocol includes the use of both inertial measurement units (IMUs) and surface electromyography (EMG) probes to monitor head movement and muscle activation during the surgical procedures. IMUs were placed on the forehead and at the C7 level, while EMG probes were positioned on relevant bilateral upper body muscles involved in the surgical tasks. Data analysis encompassed the extraction and examination of flexion/extension, bending, and axial rotation joint angles and EMG signals were scrutinized to assess muscle activation and fatigue. The proposed protocol was preliminary validated involving one expert surgeon, who realized 28 surgeries, employing either a conventional microscope or an advanced exoscope; the setup was well-tolerated, with only minor discomfort reported. The protocol effectively captured detailed information regarding head movement and muscle activation patterns throughout the surgeries, revealing notable features in surgical approaches. The ergonomic assessment protocol provides a solid foundation for future investigations and the development of tailored surgical training programs aimed at mitigating the risk of MSDs among surgeons.

Keywords: Ergonomics assessment · risk assessment · otolaryngology surgery · ENT · wearable technologies · inertial measurement units · electromyography

1 Introduction

Musculoskeletal disorders (MSDs) are a cross-cutting problem among healthcare workers, whose prevalence varies depending on the occupation and the departments in which they work [1].

Among these operators, scientific literature clearly reports that surgeons are overall involved in some of the most both mentally and physically demanding tasks [2]. Indeed, all the specialists in surgery could be at high risk of developing MSDs and, the overload they perceive could directly impact also on the overall quality of the surgical performance, the clinical outcomes, and – in extrema ratio – the safety of the patients themselves [2–4]. In fact, among surgeons, the most commonly reported issues mainly involve the upper body, including the neck, lower back, shoulders, and upper back; indeed, the cervical track of the spine appears to be one of the most affected regions [2].

Due to the impact of repetitive tasks and sustained muscular activities while maintain awkward postures, otolaryngology (or ENT – Ear, Nose and Throat) surgeons result to be at high risk of developing MSDs, with a reported prevalence between 47 and 90%, a percentage that is indeed in line with other surgical specialties but much higher with respect to the general population [5–7]. Typical disorders affecting ENT surgeons include musculoskeletal pain, swelling, stiffness, restricted movement, and fatigue; further, typical disease are tendonitis and carpal tunnel syndrome [5]. It is worth underlining that it is fundamental to identify the effective musculoskeletal overload since musculoskeletal disorders can contribute to shortening the length of surgeons' careers [8, 9].

In order to overcome these issues, during the last decades, several improvements have been proposed addressing both the surgical procedure, equipment and supporting tools [10]. In fact, the type of instrumentation used by the surgeons during an ENT procedure affects the posture they assume while performing the task and with repercussions on the engagement of their muscles [11–13]. To counteract some of these issues, the introduction of the exoscope in ENT surgery – for instance – has been representing a very recent innovation; the field of application of this technology is microsurgery for benign and malignant pathologies, in both adult and children's surgeries [14–16]. Indeed, the approach on the neck lesion with exoscope presents the advantage of reducing the iatrogenic risk of injury and improves the correct exeresis of neoformations [14].

Focusing on risk assessment, studies presenting an evaluation of musculoskeletal overload conducted with questionnaires and observational methods are mainly reported in the literature with little information about data validity [17]. In fact, most of the used approach to actually assess risk exposure in this context is related to the use of qualitative tools/scales and surveys, such as the NASA-TLX, which was developed to ascertain a subject's level of cognitive and physical load [18].

For the past few years, improvements in technology have made it possible to use wearable solutions so as to objectify the risk and support a multifactorial quantitative approach [19]; indeed, wearable devices integrate well into the surgeon's activities with minimal impact on her/his/their work, also intra-operatively [2, 10, 18, 20].

In this study, we hypothesized that it was fundamental to integrate information concerning both kinematics and kinetics to assess the overall musculoskeletal risk related ENT surgery. For this reason, this work aimed to propose a multi-parametric ergonomic approach able to exploit different wearable technologies (i.e., inertial measurement units

and surface electromyography probes) so as to estimate the cervical discomfort and the muscular fatigue sustained by an ENT surgeon during the execution of laryngeal surgeries.

2 Materials and Methods

2.1 Participants

The presented preliminary study involved for 12 months one expert surgeon. All the involved patients were specifically diagnosed with pathologies at laryngeal level. The study was conducted at the ASST Spedali Civili, Brescia, Italia, according to the values expressed in the Declaration of Helsinki and the principles of good worker health surveillance.

2.2 Experimental Setup

In order to assess the discomfort of the postures and the muscular fatigue during the surgery, we introduced specific wearable devices that allowed us to track both the kinematic of the head with respect to the trunk and the muscular activation of several muscles of the upper body involved in the realization of the surgical tasks.

In particular, for the kinematic acquisitions, we include two wireless inertial measurement units (IMUs, WaveTrack Inertial System, Cometa System), whereas 8 wireless probes for surface electromyography (EMG, Mini Wave Infinity, Cometa System) were used to acquire muscular electrical activity.

IMUs were placed on the forehead by means of an elastic headband and at C7 level via adhesive tape, respectively; IMUs provide raw data (acceleration, angular rate, magnetic field), fused data (quaternion), and relative joint angles at a sampling rate of 140 Hz; joint angles were available after having realized the static calibration process as suggested by the manufacturer. Position of the IMUs is reported in Fig. 1.

EMG probes were placed on the belly of several bilateral muscles including:

- right/left sternocleidomastoid muscles;
- right/left cervical splenii;
- right/left upper trapezii;
- right/left anterior deltoids.

Before placing the probe, the skin was deeply cleaned with alcohol. All these muscles represented - in our hypothesis after having performed a preliminary analysis - the muscular structures mainly involved during the surgery. In order to compare across different sessions, a maximal voluntary contraction (MVC) task in isometric conditions was included in the protocol at the beginning of each session and specifically performed for each defined muscular group. The MVC tasks were selected in order to estimate the maximal activation of all the investigated muscles; all the EMG signals were then normalized with respect to the MVC so as to obtain a signal included in the range $[-1, 1]$. The 8 probes were recorded and sampled at 2000 Hz according to the specifications of the used hardware. Position of the EMG probes is depicted in Fig. 2.

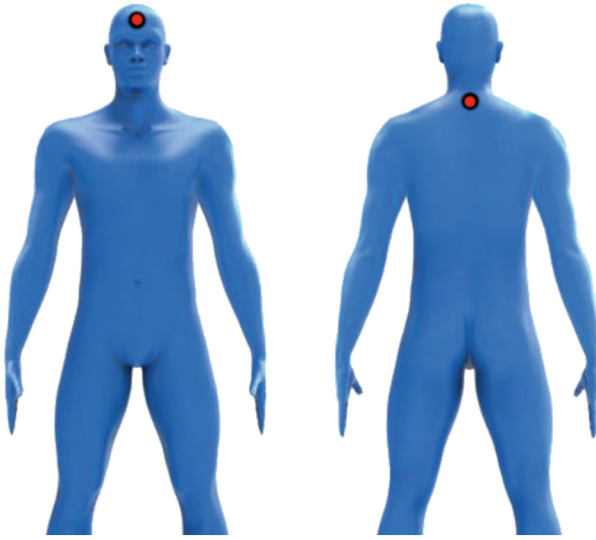


Fig. 1. Experimental setup: position of the wireless inertial measurement units on the head and cervical spine (C7 level) are highlighted in red (Color figure online).

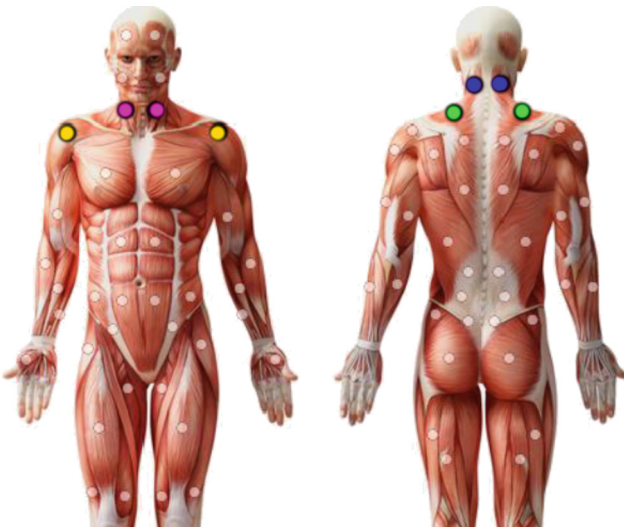


Fig. 2. Experimental setup: position of the wireless probes for the acquisition of surface electromyography signals. Right/left sternocleidomastoid muscles are highlighted in magenta, right/left cervical splenii in blue, right/left upper trapezii in green, and right/left anterior deltoids in yellow (Color figure online).

All the wearable devices were tested before their use within the operating room so as to assess the corresponding risks for the surgeon and the patients in terms of electrical and electromagnetic compatibilities and the overall usability of the approach.

2.3 Data Analysis

Both three-dimensional joint angles and EMG signal for each muscle were extracted from *.c3d files via custom processing and analysis pipeline (Matlab R2022a; MathWorks Inc.).

Joint angles (flexion/extension, bending, and axial rotation) were filtered by using a moving average digital filter (rectangular time window of 250 ms) to get smoother signals; any drift was compensated before extracting the data by identifying the time frame with the head in the neutral position. From the signals we specifically extracted maximum and minimum values, overall range, average value and standard deviation; the latter parameter was defined to estimate the head “stillness” during the surgery.

Before performing any further analysis, all the EMG signals were compensated for DC component, filtered with a notch digital filter ($f = 50$ Hz with harmonics, q-factor = 35), and a band-pass digital system ($f_{\text{high-pass}} = 20$ Hz; $f_{\text{low-pass}} = 250$ Hz; $n = 50$; Hann window-based zero-phase FIR filter). Onset for each muscle was identified using the Taeger-Kaiser energy operator ($k = 5$ and threshold defined on MVC baseline level) [21] and kept into account to recognize the burst with an overall temporal duration of at least 5 s. Within each identified muscular burst, on a time window of 250 ms, we evaluated the median frequency of the corresponding power spectrum, RMS value, and the integral under the signal curve. As an index of fatigue, we estimated also the median frequency percentual drop on the whole burst considering the difference between the average value of the last 3 s with respect to those of the first 2 s; when the drop was higher than 8% we identified the burst with a possible evidence of fatigue [22]. Overall, we analysed the number of recognized bursts and the number of bursts with possible muscular fatigue and normalized them with respect to the temporal length of the intervention.

The whole set of available parameters proposed for the analysis is reported in Table 1 for joint angles and Table 2 for EMG, respectively.

Table 1. Parameters used to analysis head movement with respect to trunk.

<i>Flex/Ext</i>				
<i>Bending</i>				
<i>Ax. Rotation</i>				
<i>Angle Max [deg]</i>	<i>Angle Min [deg]</i>	<i>Angle Range [deg]</i>	<i>Angle Average [deg]</i>	<i>Angle STD [deg]</i>

3 Results and Discussion

In order to validate the approach, the proposed protocol was applied on 12 different whole surgery days on the defined period by involving a single experienced ENT surgeon who performed 28 laryngeal surgeries by means either of a conventional transoral approach via an operating microscope system or a commercial exoscope (Endoskope, Karl Storz).

Table 2. Parameters used to analysis EMG signals.

<i>N. Activation > 5 s</i>		
<i>N. Activation with Possible Fatigue (when Med Freq Drop > -8%)</i>		
<i>% N. Activation with Fatigue/N. Activation [%]</i>		
<i>N. Activation/Surgery Duration [#min]</i>		
<i>N. Activation with Possible Fatigue/Surgery Duration [#min]</i>		
<i>Mean Activation Duration [s]</i>	<i>Overall</i>	Mean
		STD
	<i>Fatigue</i>	Mean
		STD
	<i>No Fatigue</i>	Mean
		STD
<i>Mean RMS</i>	<i>Overall</i>	Mean
		STD
	<i>Fatigue</i>	Mean
		STD
	<i>No Fatigue</i>	Mean
		STD
<i>Mean Median Freq Drop [%]</i>	<i>Overall</i>	Mean
		STD
	<i>Fatigue</i>	Mean
		STD
	<i>No Fatigue</i>	Mean
		STD
<i>Mean Signal Integral</i>	<i>Overall</i>	Mean
		STD
	<i>Fatigue</i>	Mean
		STD
	<i>No Fatigue</i>	Mean
		STD

The setting up lasted on average less than 5 min and the overall setup was quite well tolerated by the surgeon, who reported a slight discomfort due to the headband, but only when the surgeries lasted more than 30 min, overall, with an average time of the surgeries of 29.7 ± 16.2 min.

From the kinematic point of view, the protocol allowed us to estimate the flexion/extension, axial rotation, and bending of the head with respect to the trunk and the

variations in the head posture during the execution of different surgeries. On a few occasions the calibration procedure was sub-optimal, thus reporting angular values with a systematic bias; anyhow, the overall range and the variation can be considered as reliable values. An example of the obtained information is reported in Fig. 3.

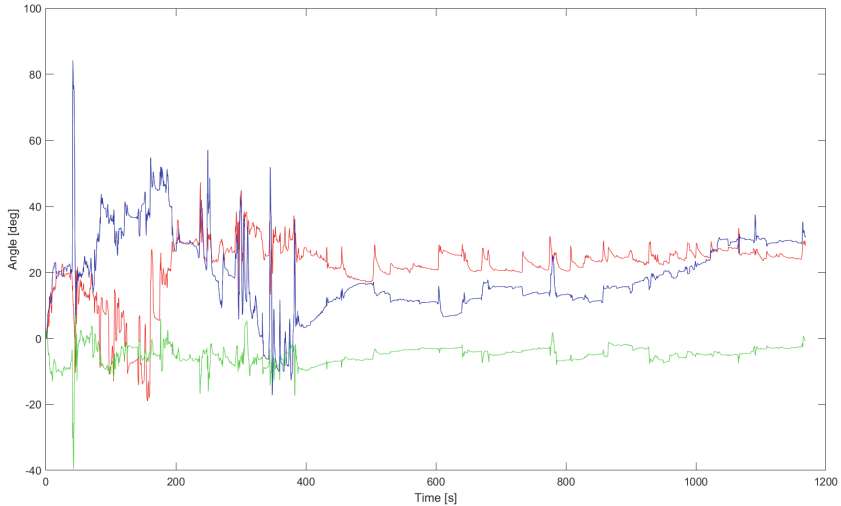


Fig. 3. Example of joint angles obtained for the head movement with respect to the trunk; flex/ext angle is highlighted in red, bending in green and axial rotation in blue (Color figure online).

Furthermore, the protocol allowed us to assess the muscular activation in terms of onsets, number, and duration of the activations, and estimation of muscular fatigue through median frequency analysis. An example of muscular burst identification is reported in Fig. 4 for the right anterior deltoid muscle and Fig. 5 for the left sternocleidomastoid muscle.

As highlighted by the previous figure, the identification of the onset was easier on the “bigger” muscle (i.e., deltoids and trapezii), whereas there were some critical issues for the cervical splenii and sternocleidomastoid muscles due to a lower signal-to-noise ratio.

The preliminary analysis of the data suggested that there are several differences in the performed surgical approaches, which affect the head postures and the development of fatigue of upper limb muscles indeed, despite demonstrating similar patterns in muscle activations.

4 Conclusions

The proposed ergonomic assessment protocol resulted in being easy to set up and well accepted by the surgeon during the realization of the laryngeal surgeries considering both the used procedure, i.e., the conventional operating microscope and exoscope.

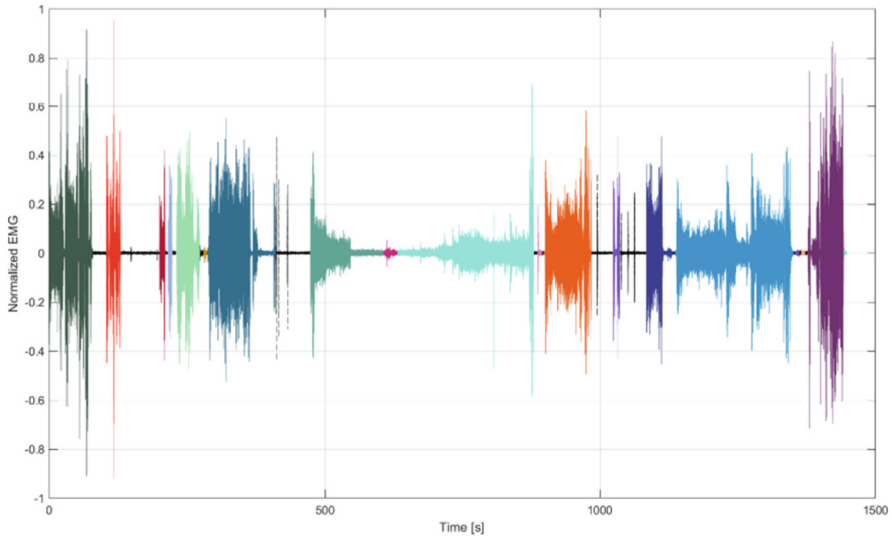


Fig. 4. Example of identification of the muscular burst on right anterior deltoid muscle; every color is a different muscular activation that lasted, continuously, at least 5 s. EMG signal is normalized and reported in the range $[-1, 1]$.

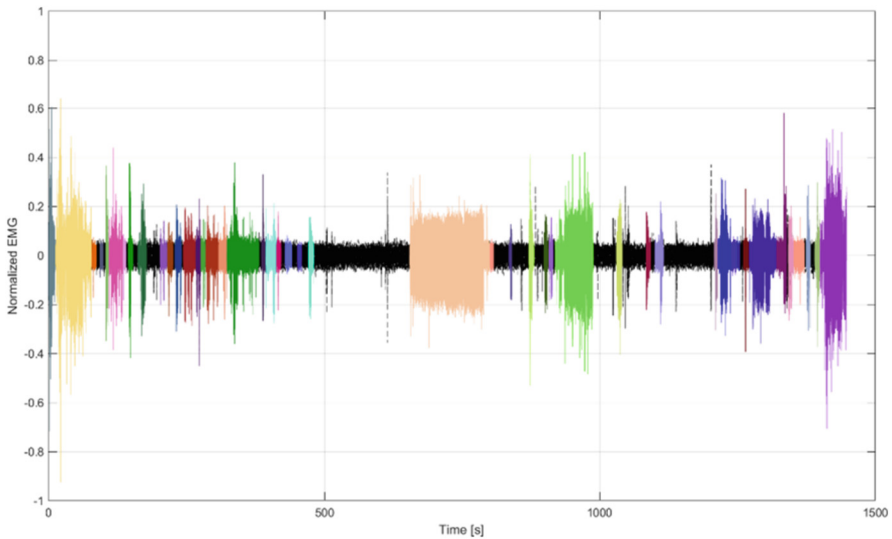


Fig. 5. Example of identification of the muscular burst on left sternocleidomastoid muscle; every color is a different muscular activation that lasted, continuously, at least 5 s. EMG signal is normalized and reported in the range $[-1, 1]$.

The main findings of this study represent a first basis for further ergonomic studies, including standard assessments, and the acquired information can be used to develop

specific surgical training programs so as to minimize the overall risk of developing MSDs.

References

1. Epstein, S., et al.: Prevalence of work-related musculoskeletal disorders among surgeons and interventionalists. *JAMA Surg.* **153**, e174947 (2018). <https://doi.org/10.1001/jamasurg.2017.4947>
2. Yang, L., Wang, T., Weidner, T.K., Madura, J.A., Morrow, M.M., Hallbeck, M.S.: Intraoperative musculoskeletal discomfort and risk for surgeons during open and laparoscopic surgery. *Surg. Endosc.* **35**, 6335–6343 (2021). <https://doi.org/10.1007/s00464-020-08085-3>
3. Abbruzzese, K., et al.: Physical and mental demand during total hip arthroplasty. *Orthop. Clin. North Am.* **53**, 413–419 (2022). <https://doi.org/10.1016/j.ocl.2022.06.005>
4. Galaiya, R., Kinross, J., Arulampalam, T.: Factors associated with burnout syndrome in surgeons: a systematic review. *Ann. R. Coll. Surg. England* **102**, 401–407 (2020). <https://doi.org/10.1308/rcsann.2020.0040>
5. Storey, B., Verkerk, M., Hashtroudi, A., Golding-Wood, D.: A systematic review of interventions to prevent work-related musculoskeletal disorders in ENT surgeons. *J. Laryngol. Otol.* **136**, 622–627 (2022)
6. Szeto, G.P.Y., Ho, P., Ting, A.C.W., Poon, J.T.C., Cheng, S.W.K., Tsang, R.C.C.: Work-related musculoskeletal symptoms in surgeons. *J. Occup. Rehabil.* **19**, 175–184 (2009). <https://doi.org/10.1007/s10926-009-9176-1>
7. Bolduc-Bégin, J., Prince, F., Christopoulos, A., Ayad, T.: Work-related musculoskeletal symptoms amongst otolaryngologists and head and neck surgeons in Canada. *Eur. Arch. Otorhinolaryngol.* **275**, 261–267 (2018). <https://doi.org/10.1007/s00405-017-4787-1>
8. Giagio, S., Volpe, G., Pillastrini, P., Gasparre, G., Frizziero, A., Squizzato, F.: A preventive program for work-related musculoskeletal disorders among surgeons. *Ann. Surg.* **270**, 969–975 (2019). <https://doi.org/10.1097/SLA.0000000000003199>
9. Dianat, I., Bazazan, A., Souraki Azad, M.A., Salimi, S.S.: Work-related physical, psychosocial and individual factors associated with musculoskeletal symptoms among surgeons: implications for ergonomic interventions. *Appl. Ergon.* **67**, 115–124 (2018). <https://doi.org/10.1016/j.apergo.2017.09.011>
10. Choi, H.S., In, H.: The effects of operating height and the passage of time on the end-point performance of fine manipulative tasks that require high accuracy. *Front. Physiol.* **13**, 944866 (2022). <https://doi.org/10.3389/fphys.2022.944866>
11. Chen, T., Dailey, S.H., Naze, S.A., Jiang, J.J.: The head-mounted microscope. *Laryngoscope* **122**, 781–784 (2012). <https://doi.org/10.1002/lary.21877>
12. Statham, M.M., Sukits, A.L., Redfern, M.S., Smith, L.J., Sok, J.C., Rosen, C.A.: Ergonomic analysis of microlaryngoscopy. *Laryngoscope* **120**, 297–305 (2010). <https://doi.org/10.1002/lary.20686>
13. Maxner, A., Gray, H., Vijendren, A.: A Systematic review of biomechanical risk factors for the development of work-related musculoskeletal disorders in surgeons of the head and neck. *Work* **69**, 247–263 (2021). <https://doi.org/10.3233/WOR-213474>
14. Ferlito, S., et al.: High definition three-dimensional exoscope (VITOM 3D) in E.N.T. surgery: a systematic review of current experience. *J. Clin. Med.* **11**, 3639 (2022). <https://doi.org/10.3390/jcm11133639>
15. Carlucci, C., Fasanella, L., Maccarini, A.R.: Exolaryngoscopy: a new technique for laryngeal surgery. *Acta Otorhinolaryngol. Ital.* **32**, 326–328 (2012)

16. Chebib, E., Benoit, C., Bois, E., Teissier, N., Van Den Abbeele, T.: New surgical frontiers for 4k 3D-exoscope in paediatric head and neck surgery. *Eur. Arch. Otorhinolaryngol.* **280**, 2033–2041 (2023). <https://doi.org/10.1007/s00405-022-07785-x>
17. Hansson, G.-Å., et al.: Questionnaire versus direct technical measurements in assessing postures and movements of the head, upper back, arms and hands. *Scand. J. Work Environ. Health* **27**, 30–40 (2001). <https://doi.org/10.5271/sjweh.584>
18. Arrighi-Allisan, A.E., et al.: Ergonomic analysis of functional endoscopic sinus surgery using novel inertial sensors. *Laryngoscope* **132**, 1153–1159 (2022). <https://doi.org/10.1002/lary.29796>
19. Meltzer, A.J., et al.: Measuring ergonomic risk in operating surgeons by using wearable technology. *JAMA Surg.* **155**, 444 (2020). <https://doi.org/10.1001/jamasurg.2019.6384>
20. Thurston, T., et al.: Assessment of muscle activity and fatigue during laparoscopic surgery. *Surg. Endosc.* **36**, 6672–6678 (2022). <https://doi.org/10.1007/s00464-021-08937-6>
21. Solnik, S., De Vita, P., Rider, P., Long, B., Hortobágyi, T.: Teager-Kaiser operator improves the accuracy of EMG onset detection independent of signal-to-noise ratio. *Acta Bioeng. Biomech.* **10**, 65–68 (2008)
22. Whittaker, R.L., La Delfa, N.J., Dickerson, C.R.: Algorithmically detectable directional changes in upper extremity motion indicate substantial myoelectric shoulder muscle fatigue during a repetitive manual task. *Ergonomics* **62**, 431–443 (2019). <https://doi.org/10.1080/00140139.2018.1536808>