Effect of an upper body exoskeleton for surgeons on postoperative neck, back and shoulder complaints

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Author Contributions

EN and GO had the idea for and designed the study and wrote the first draft of the manuscript; EN and JS collected the data, EN and GO analyzed the data, JT, JS and CK revised the manuscript.

Abstract

Objectives: Surgeons are exposed to high levels of physical stress while working in the operating room. In industry, so-called exoskeletons are used to support the back and shoulder area. The aim of this study was to investigate the feasibility and effects of an upper body exoskeleton on postoperative physical complaints of surgeons.

Methods: Surgeons from a university hospital in the fields of orthopaedics, trauma- and visceral surgery performed two operations of the same type and planned length on two different days. The first operation was performed without an exoskeleton, the second with an exoskeleton. The participants completed questionnaires on shoulder pain (SPADI), neck pain (VAS and NDI) and back pain (VAS and ODI) before and after the procedure.

Results: A total of 25 participants were included and performed 50 surgeries with a mean surgery duration of 144 min without and 138 min with exoskeleton. Without the exoskeleton, the activity of the operation resulted in a significant increase of the VAS neck by 1.0 points (SD 1.2, $p < 0.001$), NDI by 4.8 (SD 8.6; $p = 0.010$), VAS back by 0.7 (SD 1.0, $p = 0.002$), and ODI by 2.7 (SD 4.1, $p = 0.003$). With the exoskeleton the the participants reported about significant less complaints after the surgery (VAS neck: $p = 0.001$, NDI: $p = 0.003$, VAS back: $p = 0.036$, ODI: $p = 0.036$, SPADI: $p = 0.016$)

Conclusion: An upper body exoskeleton can significantly reduce the discomfort in the neck, shoulder and back caused to surgeons by surgery.

Keywords

exoskeleton; musculoskeletal symptoms; preventive care; back pain; shoulder; surgeon

Key Points

What is already known on this topic:

Performing a surgery leads to back, neck and shoulder pain in many surgeons. Work-related pain as a result of unaccustomed postures is one of the most common causes of sick leave and early retirement.

What this study adds:

The use of an exoskeleton during surgery leads to a significant lower increase of pain in surgeons.

How this study might affect research, practice or policy:

The data from this study may help to avoid occupational diseases of surgeons. Long-term studies should be performed to investigate the impact of the use of exoskeletons in surgery on sick leave and early retirement in surgeons.

Introduction

Surgeons are exposed to high physical stress during their work in the operating room. Unaccustomed postures and static muscle strain over a long duration of surgery cause musculoskeletal pain.[1] This includes heavy physical activities in open surgery such as endoprosthetics and the permanent lifting of the shoulder/arm region in arthroscopic and laparoscopic surgery.[2] Sickness-related absence, a reduction in productivity and early retirement can be the consequences.[3]

In the industry, workers are exposed to heavy and monotonous physical stress, also causing sickness-related absences or even incapacity to work resulting in increased costs for employees and employers. [4] So-called exoskeletons have been developed to support the musculo-skeletal holding apparatus during physical work especially in elevated arm positions and are increasingly being used.[5] There are three different classifications of exoskeletons: According to the area of the body region to be supported (whole body vs. upper/lower limbs), according to the mechanical structure (rigid vs. soft materials) and according to the type of drive (active, passive or semi-active).[6] Such an exoskeleton has now also been developed and approved for surgeons (Figure 1). It belongs to the passive exoskeletons and requires no energy. The weight of the raised arms is transferred to the hips via arm shells with the help of a cable pull technique and is thus intended to relieve the muscles and joints in the shoulder area.[7]

The intraoperative postures of surgeons include complex combinations of neck and trunk postures. For this reason, exoskeletons in surgery must allow axial and lateral movements of the trunk in addition to a static support function, so as not to hinder the surgeon in his work.[8,9]

According to the German guidelines on “The use of exoskeletons in an occupational context for prevention of work-related musculoskeletal complaints”, there is no substantiated preventive effect of exoskeletons on work-associated musculoskeletal complaints or disease based on the current state of scientific knowledge.[10]

The aim of this prospective observational study was to investigate the effect of a passive upper body exoskeleton on postoperative physical complaints in surgeons and to evaluate ease of use and comfort.

Methods

The protocol of this prospective interventional study was approved by the Ethics Committee at the Medical Faculty of the University of Leipzig (reference: 369/22-ek).

Participants

Orthopaedic, trauma and general surgeons of a university hospital who had previously given their written informed consent were included in the study. Exclusion criteria were the wearing of a pacemaker or other medical devices that could be potentially disturbed in their function by the exoskeleton's magnets and a known pregnancy or lactation period.

Intervention

The 25 participating surgeons (mean age 39 years, SD 7 years, 20 % female) performed two surgical procedures of the same type (e.g. posterior stabilizations of the spine, pelvic fracture fixations, arthroscopies, laparoscopic hernia repairs etc.) and the same planned duration on two different days. The first operation was performed without, the second with an exoskeleton (intervention). The exoskeleton (Paexo Shoulder, Ottobock SE & Co KGaA, Duderstadt, Germany) weighs 1.99 kg and is worn like a rucksack (Figure 1). It works without electricity according to a biomechanical principle: it redirects the forces in the body, stores them temporarily via a spring mechanism and releases them again as soon as they are needed. In this way, the exoskeleton relieves the strain on the arms and shoulder girdle when working overhead. Before being used on patients, each surgeon was trained in detail on the exoskeleton by the study team and carried out simulation exercises with the exoskeleton outside the operating theater

Assessment of neck, back and shoulder complaints

Before and after each surgical procedure (with and without exoskeleton), the participants completed questionnaires on shoulder pain including a modified version of the Shoulder Pain and Disability Index, (SPADI)[11], a Visual Analogue Scale (VAS) for neck pain, a modified version of the Neck Disability Index, (NDI)[12], a VAS for back pain, and a modified version of the Oswestry Disability Index (ODI)[13]. The level of pain was rated using a 10-point rating scale (VAS) ranging from 0 (no pain) to 10 (extremely painful). The modified SPADI consisted only of the pain scale of the SPADI. The modified NDI consisted only of questions on pain intensity, lifting, reading, headache and concentration of the NDI. The modified ODI consisted only of questions on pain intensity, lifting, walking, sitting and standing of the ODI.

Assessment of the exoskeleton's user friendliness

In addition, a score questionnaire on user friendliness (User Experience Questionnaire) [14] was answered by the participants. The scales of the questionnaire cover a comprehensive impression of user experience. Both classical usability aspects (efficiency, perspicuity, dependability) and user experience aspects (originality, stimulation) are measured.

Statistical analysis

Statistical analyses were performed using SPSS 29.0 (SPSS Inc., Chicago, IL, USA). Data were summarized as mean with standard deviation (SD). Where applicable, nominal variables crosstabs were associated using Chi-Square or Fisher's Exact tests. Student's t-test was used to detect differences in means of normally distributed continuous data. Paired tests were used for comparison of the two procedures among the same participant. To account for interindividual base levels of neck and back pain, comparisons were made between intraindividual changes of the scores. The level of significance was defined as $p < 0.05$.

Results

In total, 25 participants (mean age 39 years, SD 7 years, 20 % female) performed 50 surgical procedures with a mean duration of 144 min (SD 87, range, 45 to 409 min) without and 138 min (SD 82, range, 30 to 309 min) with an exoskeleton (p = 0.522). Six (24 %) of the participants were residents and 19 (76 %) were board certified surgeons of whom 15 were consultants or senior consultants.

Of the 50 procedures, 20 were posterior spine surgeries (each 10 with and without exoskeleton), 26 surgical interventions about the extremities (each 13 with and without exoskeleton) and 4 laparoscopic interventions (each 2 with and without exoskeleton).

The surgeons performed the procedure in standing position in 46 cases (each 23 with and without exoskeleton) and sitting in 4 cases (each 2 with and without exoskeleton).

The type of surgery and the position were the same for each of the two procedures performed by one participant.

Neck, back and shoulder complaints

The surgeon's activity during surgical procedures without an exoskeleton resulted in a mean increase of the VAS neck by 1.0 (SD 1.2, p < 0.001) points, of the NDI by 4.8 (SD 8.6; p = 0.010), of the VAS back by 0.7 (SD 1.0, p = 0.002), of the ODI by 2.7 (SD 4.1, p = 0.003), and no significant change of the SPADI 6.0 (SD 11.3, p = 0.746).

Surgical procedures with an exoskeleton resulted in no relevant increase or decrease of the VAS neck (0.0, SD 1.2 points, p = 0.873), the VAS back (0.1, SD 0.9 points, p = 0.664), the NDI (-2.6, SD 10.1, p = 0.215), the ODI (-0.5, SD 7.1, p = 0.737), and the SPADI (0.6, SD 6.1, p = 0.746).

When comparing intraindividual changes of the complaints for each participant, the use of an exoskeleton led to significantly less complaints caused by performing the surgery (VAS neck: p = 0.001, NDI: p = 0.003, VAS back: p = 0.036, ODI: p = 0.036, SPADI: p = 0.016, Table 1).

Assessment of the exoskeleton’s user friendliness

As per the User Experience Questionnaire, the participants rated most dimensions of the exoskeletons user friendliness above average (Figure 2). Only the dimensions “efficiency” (*Can users solve their tasks without unnecessary effort? Does it react fast?*) and dependability (*Does the user feel in control of the interaction? Is it secure and predictable?*) were rated below average.

When asked how the exoskeleton affected physical exertion during surgery or makes it easier to operate in unusual postures the general feedback was positive (Figure 3). Furthermore, the majority of the surgeons agreed that the exoskeleton can be used without any problems and would be helpful during physically strenuous operations.

Asked for potential improvements, 10/25 participants (40%) suggested an improvement of the arm holders/shells, as these either slipped or were too tight and uncomfortable. Furthermore, a reduction in the size of the back sections was recommended, as these did not fit under the surgical gown and therefore increased risk to the sterility of the operating field. In addition, some participants complained about the heat production in combination with the lead protection underneath the exoskeleton. On the other hand, nine out of 25 participants (36%) praised the good support of the arms in the horizontal plane. If provided for free, only 8% of the participating surgeons would never use an exoskeleton, 48% would use it rarely, and 44% would use it frequently.

Discussion

The aim of this prospective observational study was to investigate the effect of a passive upper body exoskeleton on postoperative physical complaints in surgeons and to evaluate ease of use and comfort. In our study, we found that surgeons complained of an increase in pain in the neck, shoulder and back after the procedures. The use of the exoskeleton led to a significantly lower increase in complaints in the shoulder area and to a reduction in neck and back pain.

Surgeons are already exposed to a high occupational risk from exposure to radiation, noise pollution and at high risk for infection. [15] They are also subject to a high level of physical strain. This high physical strain in combination with the adoption of non-ergonomic positions over long periods of surgery leads to increased musculoskeletal pain.[16] In particular, pain in the neck and shoulder region as well as in the lower back is described as a result of the surgical activity; this applies to both endoscopic and open surgical techniques. [17] [8]

Various measures are being discussed to reduce musculoskeletal complaints. On the one hand, training towards an ergonomic posture can be provided [18] [19], on the other hand, aids such as compression stockings, steps or floor mats are used.[20] All participants performed a surgical procedure first without exoskeleton and then with an exoskeleton. Even though each surgeon performed the surgery with and without exoskeleton on two different days, the results may be biased by the order effects of the experiment. The support force of the exoskeleton can be adjusted to different degrees. This can have an influence on the workflow and pain. For example, if the support force is too weak, the user can move their arms easily, but will experience more pain than without sufficient support. On the other hand, if the support force were too strong, the user would hardly be able to move their arms but would not experience any pain. In the present study, the same support force was used for all surgeons. Future studies need to address the effect of different support forces and of different sequences.

In industry, exoskeletons are used as a possible solution in order to relieve the holding musculature and support an ergonomic body position.[7] [21] Exoskeletons are now also being used in surgery.[22] Under simulated conditions, the use of exoskeletons was shown measurably reduce the strain on neck, shoulder and trunk muscles.[23] [24] This is consistent with the results of our study in which wearing the exoskeleton did not increase shoulder pain during the operation. Furthermore, we were able to show that the pain in the neck, shoulder and back area was even significantly reduced by using the exoskeleton. Most participants were able to use the exoskeleton without any problems; only 3 of the 25 study participants (12%) were not satisfied with the user-friendliness. That participants rated efficiency and dependability below average indicates that wearing the device in the context of an operating room is an additional burden that does not come with corresponding benefits for everyone.The acceptance and willingness to use new technologies is a key factor when implementing these.[25] The majority of the participants of the present study was willing to use the exoskeleton in everyday surgery if provided for free. As the exoskeleton was originally developed for industrial applications, the need for a sterile drape in the operating theater creates problems with the large back section, which can have a negative impact on the surgical procedure and the surgeon.

Even though without an exoskeleton, the increase in NDI was 55%, the increase in ODI was 40% and the increase in SPADI was 113% while there was no such increase when surgons were using the exoskeleton, the absolute changes were rather small. Although we were able to show in our study the feasibility of wearing an exoskeleton during operations even in combination with lead gown and that wearing the exoskeleton led to a significant improvement in pain, our study does not allow us to draw any conclusions about a long-term effect on musculoskeletal pain, as it was only worn once by each participant. In order to be able to make a statement about the long-term effect, it would be necessary to wear the brace more frequently over a longer period of time and to compare it to a control group. It is also not possible to say in which surgical area the exoskeleton has the greatest effect (endoscopic versus open surgery) or in which body position the support is best. The authors impression was that the exoskeleton mainly helps in procedures with elevated arm positions providing support to the deltoid and trapezoid muscles. This would require a larger number of participants and a comparison between these groups. This is also reflected in the current guideline for the use of exoskeletons in an occupational context in Germany, which does not make a clear recommendation for their use due to a lack of long-term studies[10].

In conclusion, an upper body exoskeleton can be worn during operations and significantly reduce the discomfort in the neck, shoulder and back caused to surgeons by prolonged surgery. The promising results of our study should be taken as an opportunity to investigate the long-term effects of exoskeletons in everyday surgery and thus potentially improve the prevention of musculoskeletal complaints and occupational diseases in surgeons.

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Disclosures

- Ethical approval: The protocol of this prospective interventional study was approved by the Ethics Committee at the Medical Faculty of the University of Leipzig (reference: 369/22-ek).
- Informed consent: Written informed consent was obtained from all participants prior to inclusion.
- Registry and the Registration No. of the study/Trial: The study was registered with the German Clinical Trials Register (DRKS00030851).
- Animal Studies: No animals were involved in this study.
- Conflict of Interest: The authors report no conflicts of interest.
- Data availability: Anonymized data can be retrieved from the corresponding author on request.

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Table 1 Pre- and postoperative neck, back and shoulder complaints with and without exoskeleton

Data summarized as mean and standard deviation (in brackets).

VAS: Visual Analogue Scale, NDI: modified Neck Disability Index, ODI: modified Oswestry Disability Index, SPADI: modified Shoulder Pain Disability Index, pre: preoperatively, post: postoperatively.

Δ^1 = mean intraindividual change between preoperative and postoperative score without exoskeleton

Δ^2 = mean intraindividual change between preoperative and postoperative score with exoskeleton

Δ of Δ^1 and Δ^2 = mean difference between intraindividual changes between preoperative and postoperative scores without and with exoskeleton

p: paired intraindividual comparison for Δ^1, Δ^2 and Δ, respectively

	No exoskeleton				**Exoskeleton**					
	pre	post	Δ^1	p^1	pre	post	Δ^2	p^2	Δ of Δ^1 and Δ^2	p
VAS neck	0.5 (1.0)	1.5 (1.4)	1.0 (1.2)	<0.001	0.8 (1.2)	0.8 (0.9)	0.0 (1.2)	0.873	1.0 (1.4)	0.001
NDI	8.8 (11.1)	13.6 (11.3)	4.8 (8.6)	0.010	10.6 (11.1)	8.0 (6.5)	-2.6 (10.1)	0.215	7.4 (11.1)	0.003
VAS back	0.6 (1.0)	1.3 (1.4)	0.7 (1.0)	0.002	0.4 (0.6)	0.4 (0.7)	0.1 (1.0)	0.664	0.6 (1.4)	0.036
ODI	6.7 (8.5)	9.4 (3.3)	2.7 (4.1)	0.003	6.2 (8.4)	5.8 (5.7)	-0.5 (7.1)	0.737	3.2 (7.2)	0.036
SPADI	5.3 (11.2)	11.3 (15.7)	6.0 (11.3)	0.746	4.0 (6.9)	4.4 (7.1)	0.4 (6.1)	0.746	5.4 (10.5)	0.016

Figure legends

Figure 1 pictures of a passive exoskeleton for the upper body

Figure 2 User Experience Questionnaire

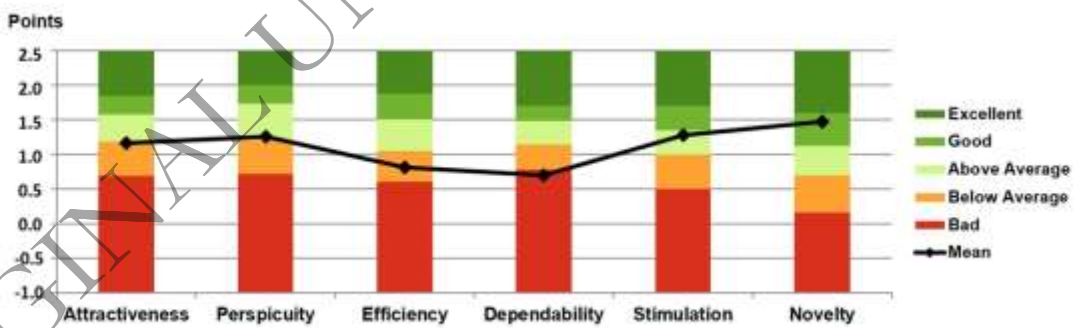

Figure 3 Participants' responses on safety, facilitation of unusual postures, fulfillment of expectations, effort and support associated with wearing the exoskeleton and general user friendliness.