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Identification of musculoskeletal hazards for laparoscopic surgeons

Identyfikacja zagrożeń dla układu mięśniowo-szkieletowego u chirurgów wykonujących zabiegi laparoskopowe

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Słowa kluczowe

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S u m m a r y

Introduction. This article is dedicated to the problematic of hazards that accompany surgeons during laparoscopic procedures, and may affected in excessive loads of certain segments of musculoskeletal system.

Aim. The work focuses on new, in relation to the literature, methods for identifying hazards based on cross-sectional ergonomic analysis with the use of video recording and measurements of body position surgeon during the real surgical procedures.

Material and methods. Research included three phases: diagnostic, simulation and fundamental. The aim of the diagnostic study was to determine the main problems in the field of body position ergonomics and the associated risks for the musculoskeletal system. Simulation study aimed at identifying the constraints and determining the conditions that are necessary in terms of making video recordings of real surgical procedures as well as real-time acquisition of measurement data defining postures surgeon. The aim of the fundamental study was to acquire basic knowledge about how to identify hazards for musculoskeletal of surgeons based on video recordings in real operational conditions, and to investigate the possibility of creating hazard maps in the field of musculoskeletal disorders.

Results. There was identified relationships between the certain stressed body postures of surgeons and particular stage of the procedure as well as the type of surgical instruments.

Conclusions. The synchronization of both video recordings of surgery and quantitative data identifying critical positions of the musculoskeletal system makes it possible to create hazard maps for surgeons and enables identification of the weak and strong points of the entire surgical procedure. This methodology may also reveal new knowledge in the work organization, workflow and ergonomics in surgery.

S t r e s z c z e n i e

Wstęp. Niniejszy artykuł poświęcony jest tematyce zagrożeń, jakie towarzyszą chirurgom podczas wykonywania zabiegów laparoskopowych i mogą ujawnić się nadmiernym obciążeniem określonych segmentów układu narządu ruchu.

Cel pracy. W pracy skoncentrowano się na nowej, w stosunku do przeanalizowanych doniesień literaturowych, metodyce identyfikacji zagrożeń, opartej na przekrojowych analizach ergonomicznych, których podstawą jest zapis wideo i pomiary pozycji ciała chirurga podczas rzeczywistych zabiegów chirurgicznych.

Materiał i metody. Badania naukowe obejmowały trzy fazy: diagnostyczną, symulacyjną i zasadniczą. Celem badań diagnostycznych było określenie głównych problemów w zakresie ergonomii pozycji ciała i związanych z nimi zagrożeń dla układu mięśniowo-szkieletowego. Badania symulacyjne miały na celu zidentyfikowanie ograniczeń i określenie warunków koniecznych w zakresie dokonywania rejestracji wideo rzeczywistych zabiegów chirurgicznych oraz akwizycji w czasie rzeczywistym danych pomiarowych określających pozycje ciała chirurga. Celem badań zasadniczych było pozyskanie wiedzy na temat możliwości identyfikacji zagrożeń dla układu narządu ruchu u chirurgów na podstawie zarejestrowanych w warunkach rzeczywistych czynności operacyjnych, a ponadto określenie możliwości tworzenia map ryzyka wystąpienia zagrożenia dla układu mięśniowo-szkieletowego w zależności od warunków realizacji procedury chirurgicznej.

Wyniki. Dokonano identyfikacji zależności pomiędzy przyjmowaniem przez chirurgów uciążliwych pozycji przy pracy a określonym etapem zabiegu i rodzajem narzędzi chirurgicznych.

Wnioski. Synchronizacja zapisu wideo zabiegu chirurgicznego z danymi ilościowymi identyfikującymi pozycje krytyczne układu narządu ruchu umożliwia tworzenie map zagrożeń dla chirurgów oraz określenie słabych i mocnych punktów całego procesu przebiegu zabiegu, a ponadto może ujawnić nową wiedzę w zakresie organizacji i ergonomii pracy w chirurgii.

INTRODUCTION

Laparoscopic surgery is a more common alternative to open surgery, *inter alia* because of such advantages for patient as reduction of post-operative pain, shorter hospitalization, decreased loss of blood, reduced risk of infection or surgical complications (1, 2).

The positive, in relation to the patient, aspects of using laparoscopic techniques unfortunately does not go hand in hand with the comfort of laparoscopic surgeon. The literature sources regarding ergonomics of laparoscopic procedures clearly indicate a problem with the static burden by surgeons.

This problem applies to non-physiological position of the body during surgery which is more upright with fewer moves of back and a smaller range of motion than among surgeons performing open operations (3). Characteristic factors are also uncomfortable, repetitive movements of the upper limbs as well as long-lasting static posture of the head (2).

In most cases, when performing laparoscopic procedures, the surgeons adopt the standing position which entails the risk of loss of stability. In fact surgeons have limited ability to move their body weight. They must quite often do precise movements by hands while standing only on one leg and use their foot to operate the pedals of laparoscopic devices (3-6).

I addition, the design of laparoscopic instruments and the way of using them determines the untypical positions of the arms, hands and fingers (7).

These all factors which define the laparoscopic surgeon body positions can take the form of health hazards, especially in relations to the musculoskeletal system. Particularly they include awkward and uncomfortable positions for long period of time as well as the repeatability of operations. The literature review draws attention to the consequences of such risks like overload of the musculoskeletal system (8-11), neuromusculoskeletal dysfunctions (12), discomfort and arms paresthesia and formation within them injuries and nerve irritation (7, 13) as well as a great physical fatigue (14).

The literature report shows that dominant research methods applied to the ergonomic diagnosis among surgeons were:

- surveys, such as a questionnaire or interview (9, 10, 15-18),
- direct observation with video recording of surgical procedures (11),
- simulation studies (18).

In turn, the material gathered on the basis of that research was used mainly for identifying general trends of the hazards for musculoskeletal system indicating rather the need for further, more detailed studies in this area. According to the authors the detailing refers to:

- hazards assessment for specific segments of the musculoskeletal system,
- strict connection between certain type of hazards and specific activities performed by surgeon during surgery,
- identification of the differences and commonalities in terms of hazards, depending on the type of surgery,
- identification of relationships and dependencies existing between various factors influencing working conditions.

Taking into account the results and ways of performing previous studies, the authors of this article have adopted a different way of conducting research. An essential part of this procedure are in fact research doing in a real work environment, in particular with regard to measurements based on wireless capturing body position of surgeon during the whole surgery. Such procedure allows to perform the detailed studies, enabling formulation of cross-sectional conclusions giving a complete picture of the ergonomics in relation to the performance of laparoscopic procedures.

AIM

The aim of the article is to present the methodology for identification of hazards of laparoscopic surgeons basing on cross-sectional ergonomic research. The main assumption of the research is a synchronization of graphical data which is video material of performing surgery and ergonomic data which are surgeon's body positions acquired by wireless sensors: goniometer and torsiometer.

MATERIAL AND METHODS

The research was divided into three main phases:

1. The phase of diagnostic studies based on: a) survey with participation of surgeons performing laparoscopic procedures; b) participant observation of surgeries.
2. The phase of simulation studies based on: a) observational study; b) video recording; c) measurements of body position during the simulated operations.
3. The phase of fundamental research based on: a) measurements of body position during the real surgical laparoscopic procedures with the use of Captiv system (20); b) video recording; c) ergonomic analysis.

The aim of diagnostic studies was to diagnose of major problems in terms of body position ergonomics, and associated risks for musculoskeletal disorders and to identify possible causes and consequences of the postural loads of surgeons. The main research technique applied in this part of the study was a questionnaire. In addition, the interview method was used free interview and participant observation.

The results of preliminary tests allowed the delineation of specific research directions, including the formulation of basic research and definition of appropriate testing procedure. A preparatory element for their implementation was, in turn, the simulation study and in particular identification of constraints and designation of necessary conditions in terms of making a video recording of surgical procedures and real-time acquisition of measurement data defining the surgeon body positions that he adopts during surgery.

The aim of the basic research was to acquire knowledge about the possibilities of hazards identification for musculoskeletal system of surgeons based on recorded operational activities in real conditions and to investigate the possibility of creating risk maps of hazards for certain segments of the musculoskeletal system depending on the type of surgical procedure. These maps was called "health hazard maps". In particular, the basic research was based on the methodology that integrates three components:

a) video-registration of surgical procedures,
b) measurement data describing the surgeons' body positions during surgeries,
c) safety zone ranges of motion of individual body segments.

The environment in which the mentioned integration has been done is software environment of CAPTIV. In this environment the measurement data indicating the angular data of surgeons' body position during surgery are collected and synchronization of these data with video recording is performed. In the same software environment the body positions to certain security zones is assigned. This action is done by defining the appropriate mathematical models. Thus, it is possible to identify critical positions, i.e. those which can be a potential source of risks for musculoskeletal system.

Safety zones, included in the studies, have been defined on the basis of biomechanical models developed at the Center for Ergonomics, University of Michigan under the direction of Don B. Chaffin (19). There are highlighted four zones: two zones preferred, i.e. the zone 0 and zone 1, which indicate the minimum the postural stress for muscles and joints, and in addition zone 2, which indicates increased postural stress and zone 3 indicating the extreme positions for muscles and joints, wherein they should be avoided during operation and which represent a risks of musculoskeletal disorders.

The assumption was taken in the studies, that all the body positions from zone 3 are critical and should be placed on the hazard maps. In turn, the assigning positions from zone 2 to the map is dependent on additional factors affecting postural load, i.e. the length of maintaining a given position, the maintained external weight, the value of the forces required to perform the activity and the factor of repeatability activities.

Table 1 presents an aggregated information on source materials gathered in the phase of diagnostic and basic research.

Table 1. Specification of research material.

Research method	Quantitative data
Questionnaire	The number of surgeons participating in the survey n = 56
Free inteview	The number of surgeons participating in the survey n = 4
Observations participating and/or video-recordings of surgeries	The number of operators surgeons participating in the study n = 4
	The number of observed/recorded surgical procedures n = 196 including: Cholecystectomy n = 82 Inguinal Hernia Surgery n = 20 Sleeve Gastrectomy n = 46 Gastric bypass n = 20 Colectomy n = 28

Source all tables: own elaboration

RESULTS

Survey results

The survey were divided into two stages. The first step was to conduct a survey in which was used questionnaire drawn up by the project LapForm (527985-LLP-1-2012-ES-LEONARDO-LMP), whose realization took place in 2012-2014 with financial support from the European Commission under the "Lifelong Learning Programme". The second stage was consisted of free interviews to clarify or complement certain issues discussed in the questionnaire. The questionnaire was divided into six main areas:

1. Personal data.
2. Experience in laparoscopic surgery.
3. Course features.
4. Level of knowledge.
5. Problems of ergonomics.
6. Training needs.

Taking into account the purpose of the present study, in the article there was omitted a discussion of the third area: *Course features*.

Personal data

The average work experience in performing laparoscopic procedure of respondents was 12.3 years, which means that the answers are reliable and crucial for achieving the study. The vast majority of laparoscopic surgeons are men, i.e. 75 percent of respondents.

When analyzing the age of the respondents it can be concluded that a clear majority are people over 36 years of age. The doctors at the age of 25-35 years represent less than 30 percent of respondents. The age of respondents are linked to a certain extent to the job position. Table 2 presents the employment structure of respondents due to the workplace.

Table 2. The structure of respondents by work position.

Position	Number of persons	Percentage
Resident	8	14.29%
Medical specialist	27	48.21%
Medical assistant	8	14.29%
Head of department	7	12.50%
n/d	6	10.71%
Total	56	100%

The experience in performing laparoscopic procedures

On average, during the working day, surgeons spend from 1 hour to 2 hours in performing laparoscopic procedures. The most commonly performed laparoscopic procedures among surveyed surgeons are procedures in the abdominal area, including the removal of gallbladder (cholecystectomy) and inguinal hernia (TAPP hernioplasty).

The level of knowledge in the field of laparoscopic and ergonomics

The survey revealed a limited awareness of the respondents in terms of ergonomics during laparoscopic procedures. The reason of that is the lack of training in this field both at the stage of education, higher education, specialization, as well as professional practice. Only 18 percent of respondents have participated in ergonomics training.

Ergonomic problems

According to the majority of respondents performing laparoscopic activities result overloading the back muscles, shoulders and neck. Among other the mentioned negative consequences are: numbness and loss of feeling in the fingers, calluses on the fingers, pain in musculoskeletal system, general physical and mental fatigue (tab. 3).

The musculoskeletal disorders and overloading are mainly caused by position at work. According to the respondents the main contributors to take a specific position of the body during surgery are (tab. 4):

- patient positioning,
- the adjustment ranges of the table,
- type of laparoscopic surgery,
- monitor position,
- the use of pedal for controlling diathermy systems.

It should be noted that the indicated factors, except the type of laparoscopic procedure, there are ergonomic factors and, therefore, can be shaped and improved. In turn, according to respondents the main factors that influence the musculoskeletal system burden are following (tab. 5):

- longer operation times,
- awkward postures,
- the position of the monitor,
- the instruments grip design.

Table 3. The types of disorders that occur most often during or shortly after the laparoscopic surgeries.

Type of disorders	Number of persons	Percent
Tired legs and feet	12	21.43%
Fatigue in the muscles of the back, shoulders and neck	35	62.50%
Paresthesias	6	10.71%
Muscle fatigue	8	14.29%
Numbness in the fingers and loss of sensitivity	16	28.57%
Musculoskeletal stress	12	21.43%
Mental fatigue	8	14.29%
Loss of orientation	0	0.00%
Poor coordination	0	0.00%
Overload hamstrings	3	5.36%
Legs go to stiff	3	5.36%
Others	0	0.00%

Table 4. Factors affecting the body position during laparoscopic procedures.

Factor	Number of persons	Percent
Patient position	29	51.79%
The adjustment ranges of the table	27	48.21%
Design of surgical tools	8	14.29%
Type of laparoscopic surgery	27	48.21%
Monitor position	22	39.29%
The use of pedal for controlling diathermy systems	20	35.71%
Others	0	0.00%

Interview

As part of the free interviews the detailing of substantive and organizational aspects of the course of selected types of laparoscopic procedures in the context of the causes and consequences of health risks from surgeons was done.

The survey results were used to make diagnosis of common problematic areas related to ergonomics, in which the risks for musculoskeletal disorders of surgeons may be revealed.

The results of observational studies – a case study in the field of bariatric procedures

There is presented the results of observations and video recordings of surgical procedures involving both the phase of simulation tests and the phase of basic research. To simplify the discussion, we present the case of identification of health risks within the operator's right wrist performing the sleeve gastrectomy procedure.

Table 5. The factors contributing the formation of discomfort musculoskeletal.

Factor	Number of persons	Percent
Longer operation times	38	67.86%
Tendency to maintain a more upright posture	8	14.29%
Static body posture	24	42.86%
Low back mobility	17	30.36%
Little weight distribution, a single suport (foot)	11	19.64%
Awkward postures	35	62.50%
Repetitive movements	3	5.36%
Having to stand	15	26.79%
The inadequate height of surgical table	3	5.36%
The instruments grip design	16	28.57%
The lack of sizes for laparoscopic surgical instruments	10	17.86%
Other aspects of instrument design: stoffness, shape, length, etc.	8	14.29%
The position of monitor	16	28.57%
The use of pedals for controlling diathermy systems	15	26.79%

Figure 1 shows the selected recordings made during simulation tests: how to install measuring equipment on surgeon's right hand (fig. 1a) and examples of activities that simulate bariatric surgery (fig. 1b).

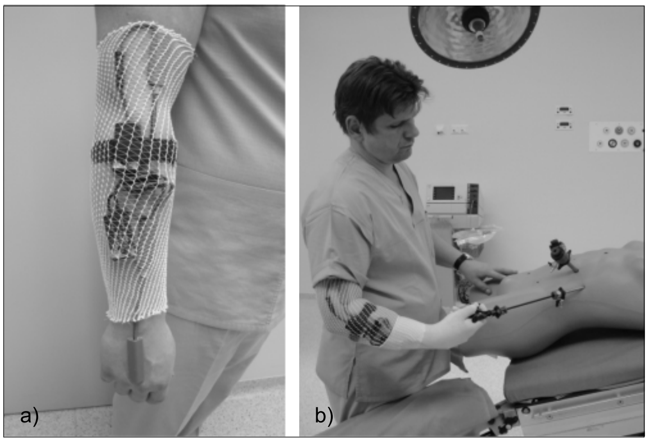

Fig. 1. Simulation of bariatric surgery a) the way of install measurement equipment, b) activities simulating bariatric surgery.
Source all figures: own elaboration

In particular, the aim of the simulations was to determine the conditions for real-time acquisition of measurement data defining surgeon's body positions that occur during surgeries.

The analysis of simulation of selected surgical procedures enabled the preparation for video recording of surgeries in real conditions. One of the components of such preparation was to define the settings of the surgical team members and camera operator what is showed in figure 2.

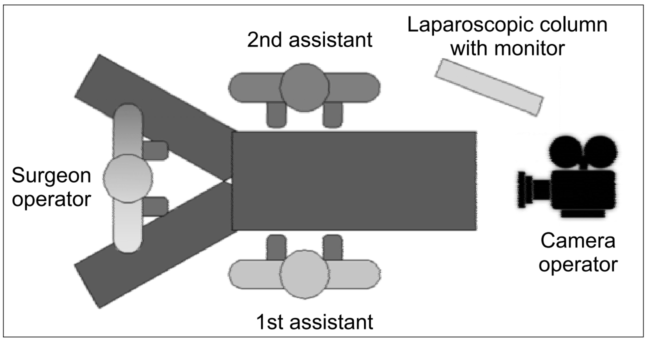

Fig. 2. Placement of the surgical team members and the camera operator during video recording of bariatric surgery.

The recording of sleeve gastrectomy operation procedure was made with the acquisition of body position of the surgeon. The duration of surgery was 1 h 8 min. Based on the factual material the statistical analysis indexing total time of using various surgical tools by the surgeon was performed (fig. 3) as well as a division of surgery at various stages along with the timing of the various phases (fig. 4).

For tools used in the recorded surgery following designations are indicated: NH – knife harmonic, GJ – safe Grasper Johann, ED – endostapler, KS – forceps, KP – clip applier, KJ – disposable clip applier, IL – laparoscopic vice.

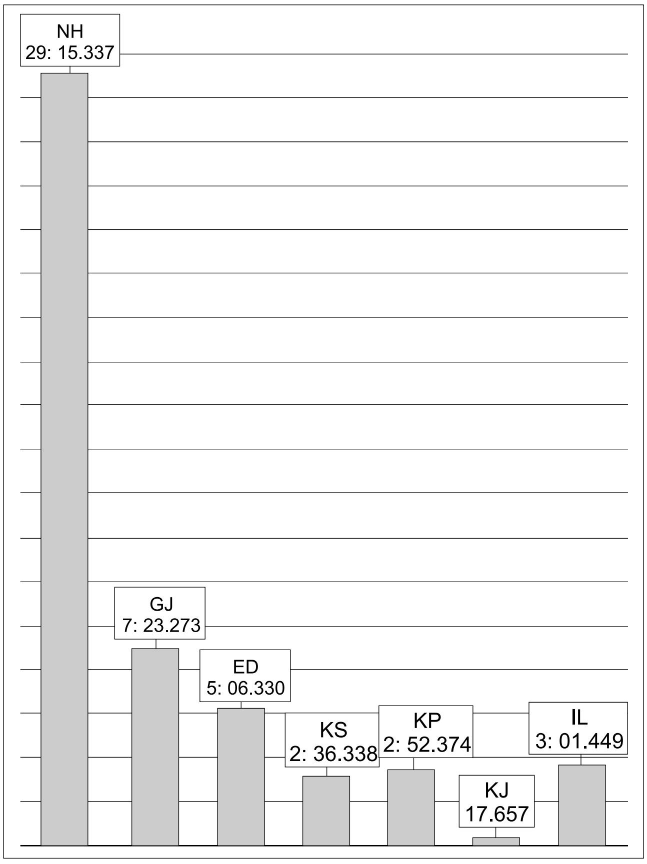

Fig. 3. The duration of using various tools in the analyzed laparoscopic surgery.

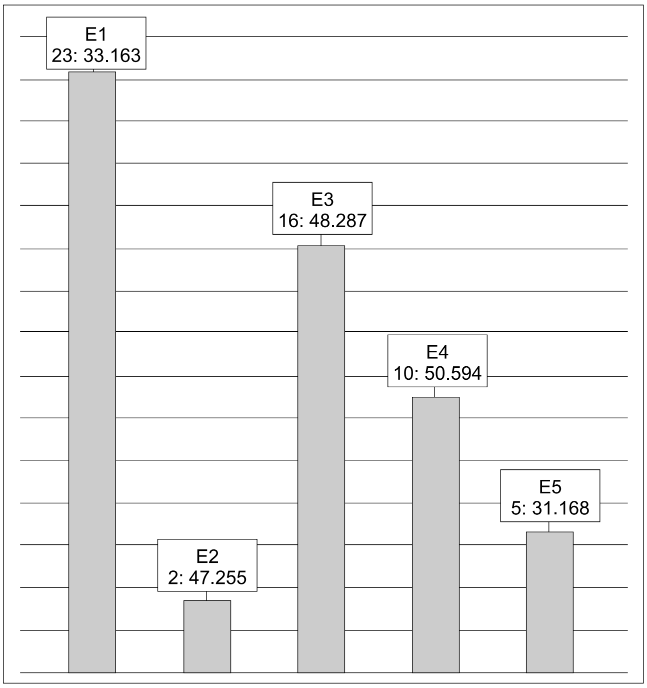

Fig. 4. The duration of the various stages of surgery.

Adequately for specified stages of surgery the assigned designations were assigned: E1 – the release of the greater curvature of the stomach; E2 – preparation of gastric for resection; E3 – staplers gastrectomy; E4 – gastric anastomotic leak test; E5 – extraction of the sleeve part of the stomach and leak test.

The next step was to appoint safety zones covering angular ranges for wrist in the sagittal plane. They are respectively:

- zone 0: flexion: 0°-10°, extension 0°-9°,
- zone 1: flexion: 11°-25°, extension 10°-23°,
- zone 2: flexion: 26°-50°, extension 24°-45°,
- zone 3: flexion: 51°+, extension 46°+.

Then, the number of positions with the division of the various zones were identified:

- zone 0: 2231 body positions,
- zone 1: 2091 body positions,
- zone 2: 1048 body positions,
- zone 3: 126 body positions.

According to the study assumptions, to further research proceeding the body positions from zones 2 and 3 were included. Figures 5 and 6 show a maps of the course of surgery with regard to: a chart mapping the angular bend of the wrist (fig. 5a and 6a), stages of surgery (fig. 5b and 6b), maintenance of various surgical instruments (fig. 5c and 6c), and also visualization in the form of vertical lines for both zone 2 and zone 3.

When it comes to identified positions in zone 2 there was done an assessment including:

- duration of maintaining a given positions: maximum duration of maintaining a given positions was 28 sek,
- the maintained external weight: the maximum weight was 1 kg,
- repeatability of activities: none.

Regarding the feature of force value required to perform a given activity there is a lack of data. However, based on information obtained during free interview with operation surgeon, it can be assumed that the force required to perform operational activities is negligible and rather not influence on evaluation outcome of the postural load. For this reason, further analysis was focus on the activities assigned to the zone 3. This analysis takes into account, among others, correlations between the type of surgical tools and critical positions of the wrist, correlations between specific activity and critical positions

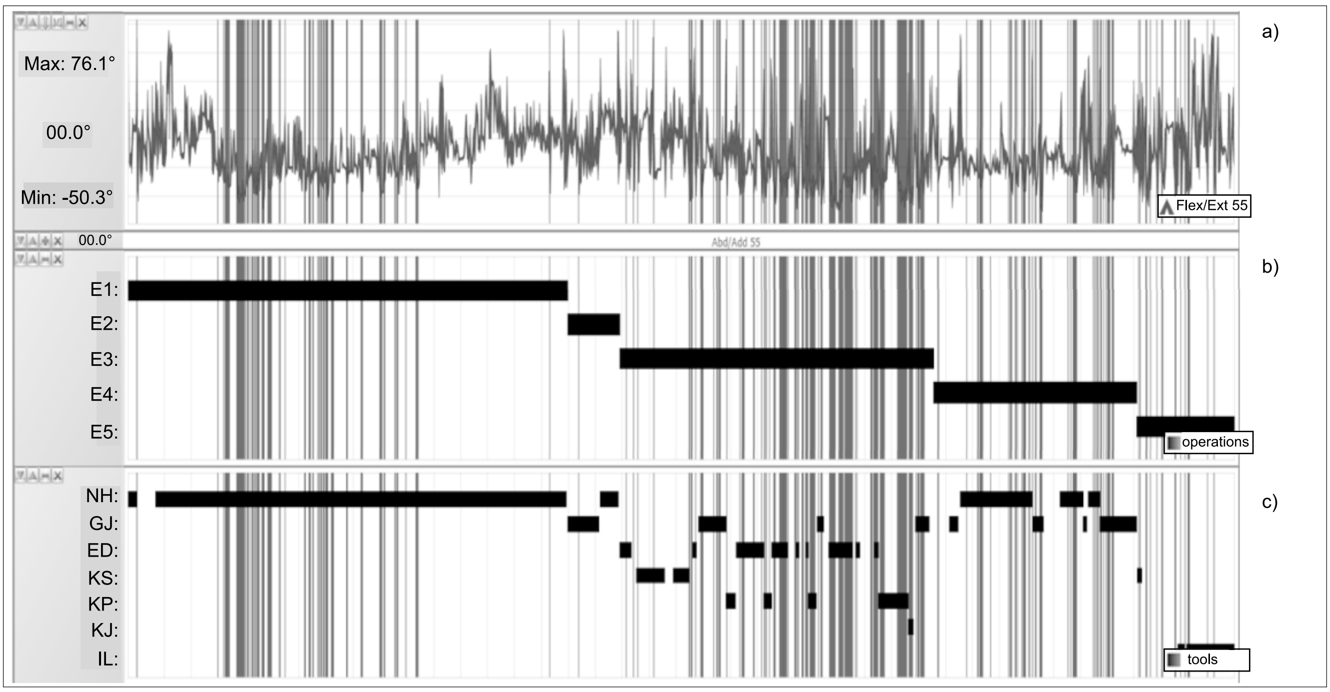

Fig. 5. Map of the course surgery with regard to areas of zone 2.

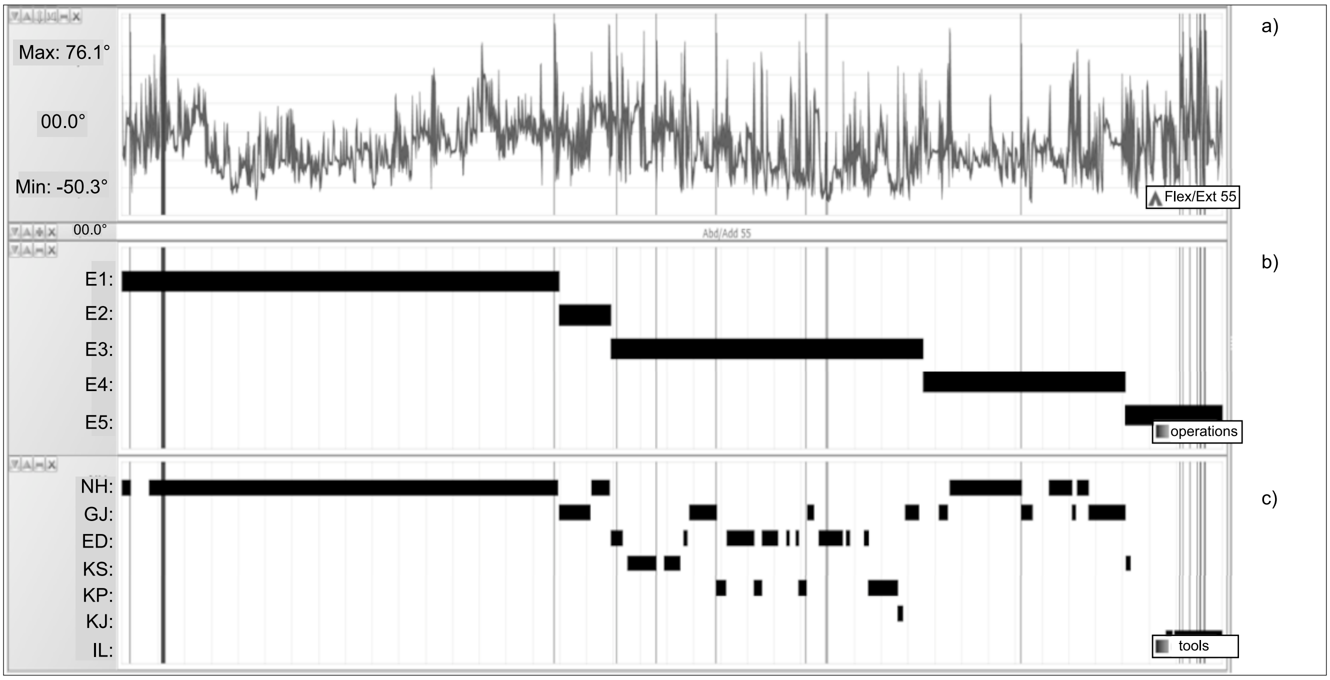

Fig. 6. Map of the course surgery with regard to areas of zone 3.

of the wrist and characteristics of somatic relationships in the operator's hand – a surgical tool system.

Table 6 shows the list of surgical instruments, including the number of identified critical positions and the number of positions per work minute with the use of tool.

Table 6. The number of critical positions in terms of used surgical instrument.

Surgical tool	Number of critical positions	Number of critical position per minute
Knife harmonic (NH)	30	1.03
Safe Grasper Johann (GJ)	13	1.76
Endostapler (ED)	52	10.20
Forceps (KS)	2	0.77
Clip applier (KP)	0	0.00
Disposable clip applier (KJ)	0	0.00
Laparoscopic vice (IL)	16	5.30

The analysis outcome shows that the most critical positions for the wrist were observed when handling endostapler. This result is all the more surprising that the operator was using the tool only for about 5 min (which gives on average more than 10 critical positions per minute), while the harmonic knife was used for total almost half an hour, and 30 critical positions were recorded (an average score is one critical position per minute). A relatively large number of critical positions took to operations with vice laparoscopic tool which was used only 3 minutes (more than 5 critical positions per minute).

A similar analysis was performed in relation to particular activities (tab. 7).

Table 7. The number of critical positions calculated on surgery stages.

Surgical tool	Number of critical positions	Number of critical position per minute
E1: the release of the greater curvature of the stomach	21	0.89
E2: preparation of gastric for resection	4	1.44
E3: staplers gastrectomy	65	3.87
E4: gastric anastomotic leak test	14	1.29
E5: extraction of the sleeve art of the stomach and leak test	17	3.08

The analysis of all identified critical positions revealed certain regularity. For example, positions with the highest deviation of flexion relate to perioperative operations, such as insertion or removal of tools to/from the trocars, or receiving and placing tools (fig. 7). Meanwhile, the positions characterized by the highest deviations of extension are assigned mainly to operations with the tools placed inside trocars, including first and foremost endostapler (fig. 8). This type of activities is characterized by a longer maintaining the same position, which enhances the feeling of postural stress.

Summing up the results of the analysis it can be concluded that there is a risk to the musculoskeletal system during bariatric surgery. This risk is variable depending on the type of tool being used and actions performed during the surgical procedure.

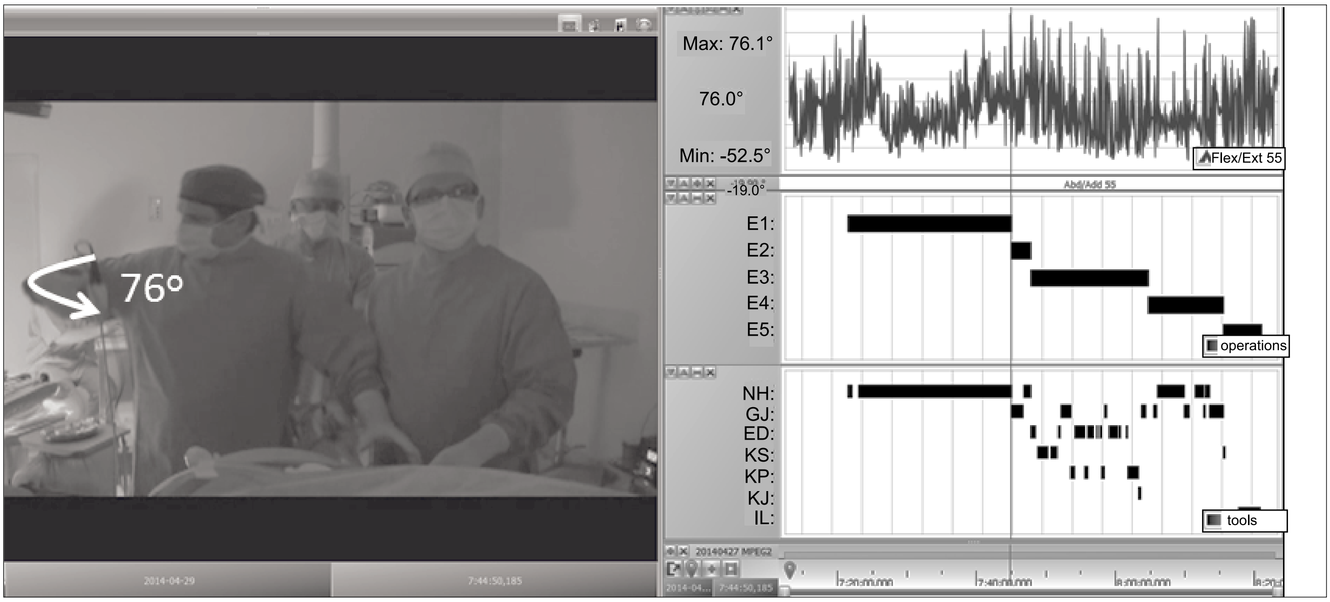

Fig. 7. Critical wrist position while placing the harmonic knife.

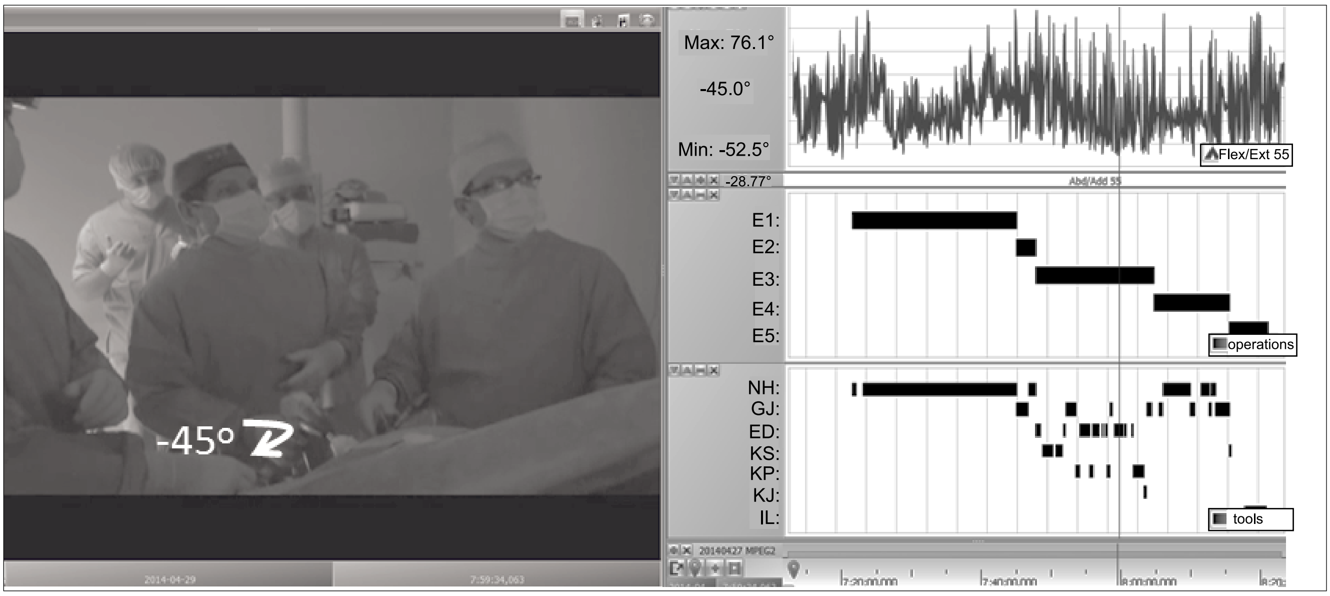

Fig. 8. Critical wrist position when operating endostapler.

DISCUSSION

Insufficient knowledge in the area of ergonomics certainly contributes to perform forced and overloading musculoskeletal system body positions. However, it seems that this is not the main factor influencing this state of affairs.

Operator surgeons intuitively try to organize surgical team work in such a way that the surgeon's body position was the most physiological. Therefore, the problem remains to lack of adjustment of the technical aspects of operations, such as: non-ergonomic surgical instruments, the lack of additional and/or mobile monitors, lack of auxiliary equipment such as ergonomic chairs or platforms supporting selected body segments of surgeon (21, 22). Moreover, an attempt of adjusting the working environment factors for leading surgeon has an impact on how to perform auxiliary activities by assisting doctors who are characterized by a high degree of awkward body position, and thus a high degree of static load of the body.

It should have on mind that the mode of surgeons' action, including the adoption of a specific body position, way of moving, communication is formed and perpetuated over many years of work. There is therefore a high probability that the change in technology, e.g. the ability to adjust the height of the operating table to the patient, mobility devices will not lead to changing the way of performing the procedure, which after many years has become a routine for the experienced surgeon. So it is reasonable to train doctors in the field of ergonomics and how to form working conditions already in medical school and from the beginning of surgical practice. In case of experienced surgeons it should attempt to change their habits in the direction of ergonomic practices e.g. by using auxiliary equipment enforcing ergonomic rules of operation.

It could be concluded from the observations of laparoscopic procedures and from interviews with laparoscopic surgeons that the way of adopting body position depends mainly on where the surgeon is located in relation to the patient. Body position of surgeon will be different when the surgeon stands on the left, right side of the patient, or between his legs. In addition, an important aspect influencing the way how to operate the upper limbs is the location of laparoscopic incisions for surgery. If the incisions are too close, the laparoscopic tools are parallel to each other, and thus the movements of the limbs have a smaller range causing more static burden and performance of the procedure is more difficult. However, if the incisions are dismissed, it causes more easily and free movements of the upper limbs, reducing static loads and facilitating work in the operating field of the abdominal cavity.

Considering the results of the analysis carried out in the CAPTIV environment it is desirable to accept the thesis that there is a possibility of mapping the hazard risk to certain segments of the musculoskeletal system depending on the method for performing the surgical procedure. Thus, it is reasonable to search for optimal solutions in terms of working methods and the selection of surgical equipment.

CONCLUSIONS

The cross-sectional analysis including the varied elements of ergonomic assessment and factors affecting working conditions can reveal new knowledge in the organization and ergonomics in surgery. Additionally, graphical data synchronization of video material of surgery course and quantitative data identifying critical positions of musculoskeletal system, enables to create hazard maps for surgeons and to identify strengths and weaknesses of the entire process-flow of the surgery.

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