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Analysis of selected ergonomic problems in the use of surgical laparoscopic tools

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Abstract

The article demonstrates the important problematic areas associated to the ergonomics of surgical instruments during their usage. For this purpose, an analysis of cholecystectomy surgery with the use of laparoscopic instruments was conducted. There was identified the individual operations performed by surgeon, as well as the particular laparoscopic instruments.

The prepared in this way study material, allowed for evaluation of design features of tools used in laparoscopic surgery from functional and ergonomic point of view and developing special research procedure for ergonomic assessment. Particularly, the critical states within the selected body postures in the system were identified: an operator (surgeon) and a surgical tool, as well as the areas of ergonomics corrective intervention in the process of using laparoscopic instruments.

Introduction

Laparoscopic surgery is one of the rapidly developing fields of minimally invasive surgery and is now used in all areas of a general surgery [1].

The idea of laparoscopic surgery was born in the early twentieth century. The most dynamic growth occurred during the 90^{th} years of last century. Fischer, Reddick and Olsen published then the study, in which they had compared the results of laparoscopic cholecystectomy with the results of open surgery. The study undoubtedly showed that laparoscopy is safer and cheaper, and its use is associated with less severe postoperative pain, shorter hospitalization and shorter inability to work [2].

In Poland, the first laparoscopic surgery was performed on May 15, 1991. The French surgeon Jacques Domerque assisted by Dr. Przemysław Pydy has removed the gallbladder. Then a month later, professor Marek Krawczyk performed the first laparoscopic cholecystectomy with polish team. In the 90s of the twentieth century, many Polish surgeons were going to foreign centers, mainly to France, for the trainings in laparoscopic techniques. Thanks to expanding their knowledge of minimally invasive surgery the number of operations performed with using laparoscopic tools was increasing in Poland as well as the spread of this method.

At first there were serious financial limitations to perform laparoscopic procedures in Poland. Only a few centers could afford to buy very expensive laparoscopic equipment. In 1991 there were performed 219 surgeries in four Polish centers. Within the following year the number of operation increased to 2703 and the number of hospitals using laparoscopic tools was 31. In 1996, 85 centers possessed laparoscopic equipment and the surgery of cutting gallbladder was performed with more than 14 thousand patients.

Today, only a few patients are operated by the open method and laparoscopic cholecystectomy is the most frequently performed laparoscopic surgery in Poland. The development of laparoscopic surgery in Poland is supported by Association of Polish Surgeons and the Section of Videosurgery which was created in 1995 [3].

The genesis of research

The history of laparoscopy is closely related to the development of surgical instruments. The improved handling techniques enforce designing the new and more complex surgical instruments aiming to achieve the effect “a lot of tools in one”. These multifunctional tools have particular importance in laparoscopic procedures. Their using reduces in fact the number of activities related to changing tools during the procedure, and thus inserting and removing them from the abdominal cavity of patients. On the one hand such tendency significantly limits the risk to patients in the area of infection, on the other hand, however, requires from the surgeon high manual skills and knowledge of the proper techniques for handling of tool with complex configuration of applications. Following of the technical development of surgical instruments, the development in the area of improving the functionality, comfort and simplicity of using them by future users should take place. Science, which defines rules for selection of constructional and operational features of the technical artifacts in terms of their adaptation to the natural properties of the humans, is ergonomics [4]. In many cases, ergonomic improvement is the process of achieving a compromise between ease of use, safety for the user and a patient [5], the objective function, the economy and the current legal and formal guidelines on the selection of material properties [6].

The source of knowledge about the ergonomic needs of the tools features, identified on the background of other dimensions in above mentioned process of finding the compromise, is a detailed analysis of work activities, based inter alia on a participatory approach, it means with participation of users of these tools.

The literature provides a few descriptions of the results of research in the field of ergonomics of laparoscopic instruments. However, they clearly indicate the problems in this area [7, 8, 9, 10, 11, 12, 13].

In addition, the need to improve the laparoscopic instruments in terms of ergonomic criteria is revealed within the preliminary results of the survey conducted under the project “Online Vocational Training course on laparoscopy’s ergonomics for surgeons and laparoscopic instruments’ designers of the Lifelong Learning Programme: Leonardo da Vinci Multilaternal Projects for Development of Innovation, Agreement number: 2012-3649/001-001, financed by National Agency for Lifelong Learning Programme Organismo Autónomo Programas Educativos Europeos (OAPEE), where Silesian University of Technology is a partner. In particular, the survey aimed to identify training needs in the field of education of ergonomic competence of surgeons performing laparoscopic surgeries. One of the issues in the survey was the identification of factors which can cause a physical discomfort and fatigue during laparoscopic procedures. According to 52 polish doctors participating in the survey the most common factors are: 1) longer operation times, 2) awkward postures, 3) the instrument handle design. In addition using laparoscopic tools is the cause of numbness in the fingers and loss of sensitivity, as well as the forming the calluses.

The objective and object of the study

Taking into account the above considerations the following research objective was formulated: identification and analysis of critical states within the use of laparoscopic instruments including ergonomic criteria for the selected laparoscopic surgery. The critical states are defined here as the somatic relations in the system: operator – a surgical tool, which can cause discomfort or fatigue of the arms, back and neck.

The specific objectives are:

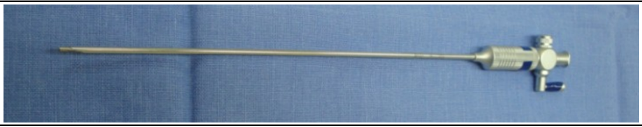
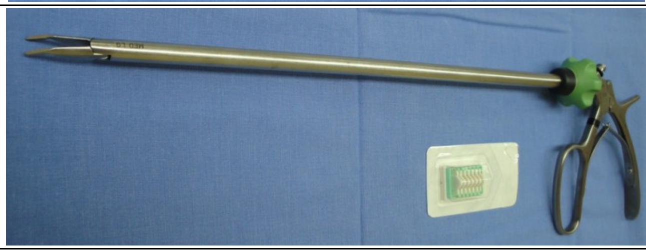
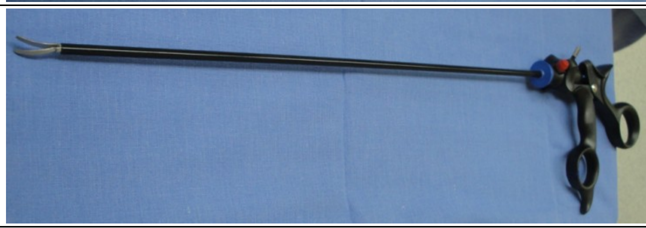
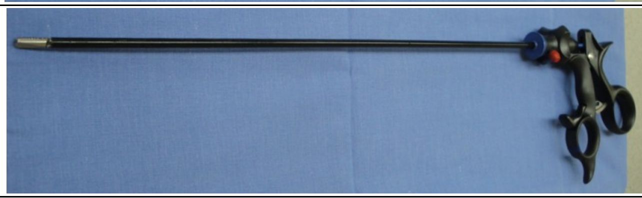
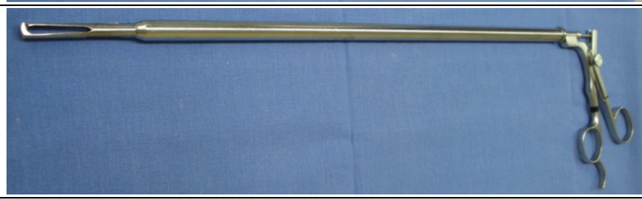
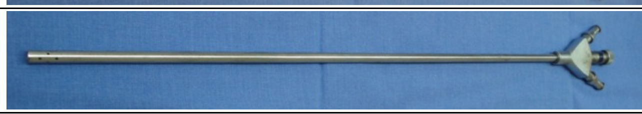
- Developing a procedure of recording laparoscopic surgeries.
- Elaboration of criteria for the identification of critical states.
- Developing procedures for ergonomic analysis.
- Identifying the areas of ergonomics corrective intervention in the process of using laparoscopic instruments.

The subject of the research is a cholecystectomy surgery with particular emphasis on the way of using laparoscopic surgical instruments. Cholecystectomy is the surgery of removal of the gallbladder. The procedure of laparoscopic cholecystectomy can be divided into four basic stages. The first one covers the preparatory steps involving washing of the operating field, the skin incision near the navel through which an optical telescope connected to fiber optic cable and video camera is introduced and then inserting the Varess needle so as to insufflate carbon dioxide gas (CO_2) into abdominal cavity and to obtain pneumoperitoneum. As a result of the fulfillment the abdominal of CO_2 is the raising of the abdominal walls which allows the surgeon to look more closely at the internal organs. The next step performed by the surgeon is introducing into abdominal cavity the trocars through the small skin incisions. The second stage is to identify the cystic duct and cystic artery and dissection of gallblader by using laparoscopic tools (grasper, scissors).

After dissection, the control of homeostasis is conducted. The third step is the removal of gallblader from the abdominal and the fourth step consists of establishing drain into the abdominal cavity, the removal of CO_2, the control of adominal cavity and the stitching layered incisions.

In the table 1 the set of laparoscopic tools using during cholecystectomy is presented.

Table 1. The set of laparoscopic tools using during cholecystectomy [own study]

The type of instrument	Photos
Veress Needle is used to insufflate carbon dioxide gas (CO_2) into abdominal cavity.	
Trocars with the diameter of 10 mm and 5 mm are used to introduce ports in the abdomen. Through trocar there are entered other laparoscopic tools.	
Clip applier is used to apply titanium clips.	
Laparoscopic scissor with diathermy system is used to cut and coagulate.	
Grasper is used to prepare gallbladder.	
Hook probe serves to dissecting the gallbladder from the liver.	
Extractor is used to removal of gallbladder from abdominal cavity.	
Flushing and suction tool is used to flush the abdominal cavity and suction of space of abdominal cavity.	

Material and methodology

The study was conducted based on video recording of activities performed with using laparoscopic instruments during cholecystectomy surgery with the three skin incisions.

The research methodology included three basic stages:

E1. The stage of preparation for the study;
E2. The stage of video recording of surgery procedures;
E3. The stage of evaluation of activities with the use of laparoscopic instruments according to the dedicated research procedure.

The stage of preparation for the study E1 included following tasks:

E1.1. Performing photographic documentation of the operating room, and all of the tools used to the planned laparoscopic cholecystectomy (Table 1).

E1.2. Preliminary organoleptic identification of the design and utility features of the tools.

E1.3. Conducting an interview on the application and the way of usage of tools with the scrub nurse and the surgeon realizing laparoscopic procedure.

E1.4. Performing the scheme of the deployment of the camera operator and the secondary person performing the photos during surgery.

The video recording of surgery procedures E2 contained all the manual activities of using laparoscopic tools. The camera operator was located opposite to the surgeon conducting the procedure and behind the patient's head on the other side to the operating table. This location is possible when the area of anesthesiologist activities is not separated from the area of surgical operations by a special screen.

The stage of the evaluation of activities with use of laparoscopic instruments E3 was carried out with using a dedicated study procedure. This procedure comprises in particular the following phases:

E3.1. Developing a procedure for identifying the somatic relations which will the basis for further analysis. This stage aims to separation of momentary positions of the body segments, saved in the form of photoshots that can be a potential source of static discomfort and fatigue for surgeons. There was adopted here a subjective quality assessment based on the procedure for evaluation of static discomfort described in [14], where the evaluation depends inter alia on the index of the degree of exhaustion of movables in the joints. Based on the mentioned index, there was selected such body positions of the surgeons which present the maximum angles in the joints.

E3.2. Elaboration of the criteria for the identification of critical states of the extracted body position in frames of the E3.1. The basis for the selection of the body position is the procedure for static load assessment according to the REBA method. [15]. The REBA method puts a special emphasis on the assessment of the load of the upper body, including the hands and wrists, and takes into account the quality of a tool grip. The operation principle of the REBA method is based on encoding of the body posture, where the higher number in the code is noted the body position differs more from neutral one and, therefore, the risk of static load in skeletal system increases. There was adopted, as a criterion for the selection of critical code, the occurrence in the same time at least code 2 for the forearm and wrist, and code 3 for arms (or code 2 when there are additional factors, such as abduction or raised shoulders). For such criteria system, while maintaining the neutral position of the other segments of the body, the static load assessment reaches level 3 (the maximal score is 15), which means that the improvement of work environment may be needed in the future. However, it should be noted that any additional deviation from neutral somatic relations increases the risk level. The degree of deviation from the neutral position in the REBA method is identified on the basis of the angle value between a body segment and the reference plane (sagittal, frontal and lateral). The angle values are specified in the 3DSSPP [16], which enables the modeling of anthropometric features of human body and somatic relations based on photographic registration. Defining the position of the model of anthropometric features is performing by adjusting the position of individual segments of the model to the body position of recorded employee. The finished model of anthropometric features in the 3DSSPP software is a source of information about above mentioned angle values, acting an input material for analysis with using the REBA method. In the figure 1 an example of application of the 3DSSPP for modeling and identification the angle values of sample body segment is presented.

E3.3. Performing the ergonomic analysis with use of REBA method and an interview with the tools operator.

The comparison of the angles indicating the position of the individual segments computer model of anthropometric features in the 3DSSPP with the angles included in the REBA method allows for classifying the recorded somatic relations to critical states. Accordingly, the further analysis is carried

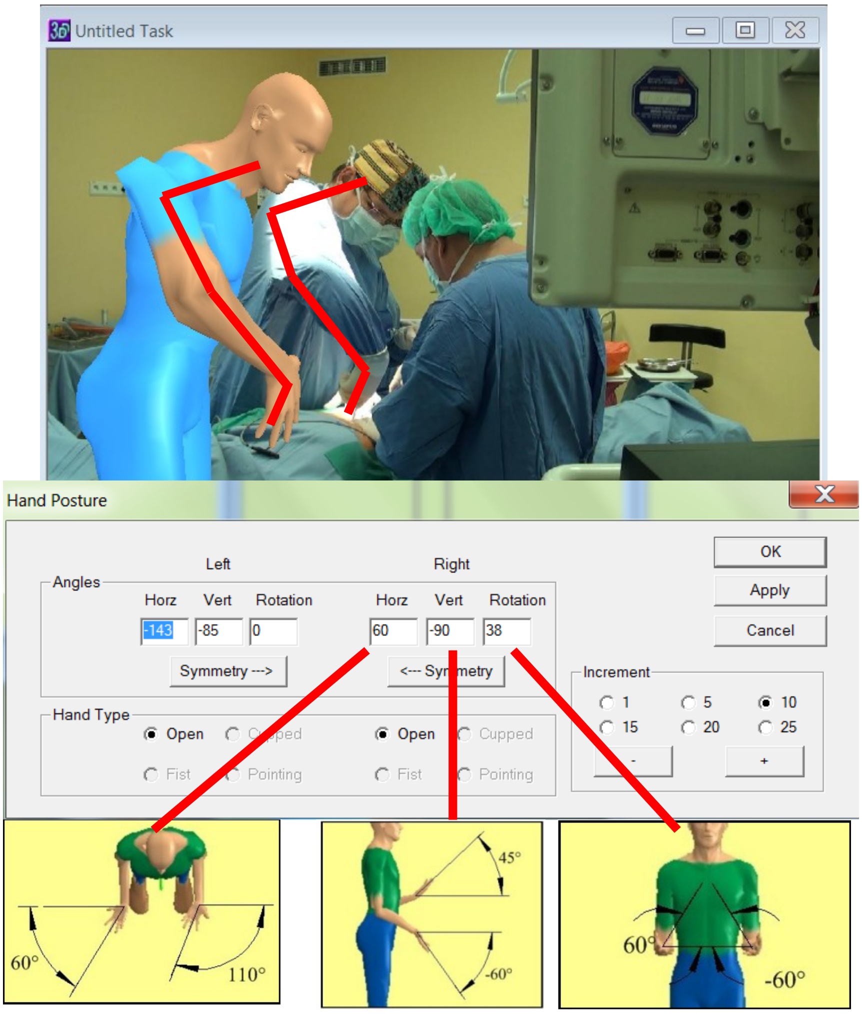


Fig. 1. The mode of identification of body segment angles on the example of hands (own study with using the illustrations available in [16])

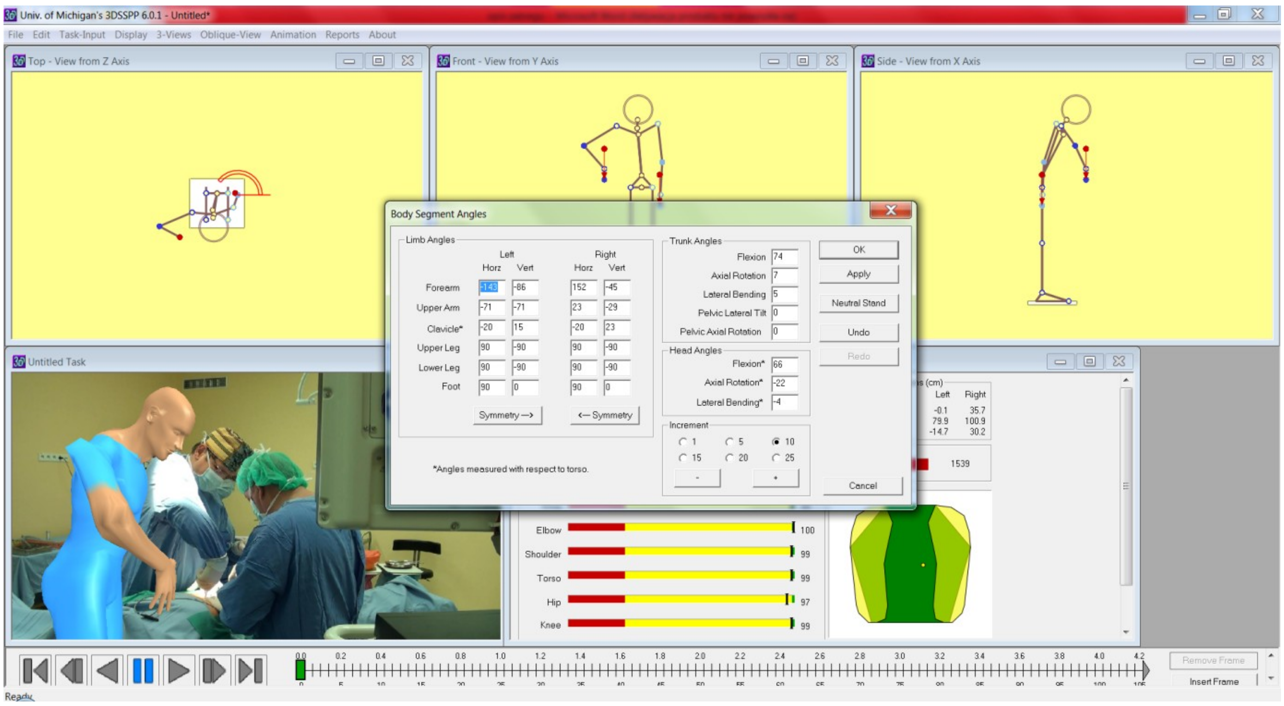


Fig. 2. Information about position of the model of antropometric features based on body segment angles [own study]

out in standard way basing on REBA method and taking into account the values of angles for the position of other body segments, such as back, head, legs, the quality of grip, the frequency of operation, duration of keeping one position for specific parts of the body.

Figure 2 shows the body angles for the other segments in the model of anthropometric features based on the 3DSSPP method.

As a result of the analysis, the risk level 6 (medium) was determined. It means that the further detailed ergonomic analysis and changes improving workplace in the near-term are needed.

Presentation of the study results and discussion

Based on the analysis of video footage with the recording of surgery there were selected photoshots showing momentary and differentiated body positions, which may be a potential source of fatigue and musculoskeletal stress (por. E3.1). The number of photoshots was $n = 34$. After identification of the angles in the musculoskeletal system (see E3.2) there were recommended for further analysis $n = 16$ body position.

Table 2 presents the results of an ergonomic assessment taking into account the REBA method. The first column contains information about the type of instrument and the number of analyzed positions n with use of the certain instrument, the second column summarizes the results of an ergonomic assessment, where:

– Score 4 to 7 means medium risk, further investigation and that changes are needed soon;
– Score 8 to 10 means high risk, quick investigation and implementation of changes.

The analysis of the body position of the surgeon during surgical procedures using laparoscopic instruments is compatible with the opinions of the respondents (see point *The genesis of research*), who pointed out the problems of fatigue of upper body including the hands and arms. However, by using the study procedure it is possible to identify the critical states which particularly should be further examined and become an inspiration for the improvement of the working methods of the surgeon.

Table 2. The results of the ergonomic evaluation with using REBA method [own study]

Type of tool	Risk level
Veress Needle $n = 0$	–
Trocars $n = 2$	Score 4 for $n = 1$ Score 5 for $n = 1$
Fiber optic cable and video camera $n = 4$	Score 4 for $n = 1$ Score 5 for $n = 2$ Score 6 for $n = 1$
Laparoscopic scissors $p = 2$	Score 5 for $n = 1$ Score 6 for $n = 1$
Grasper $n = 5$	Score 5 for $n = 1$ Score 7 for $n = 2$ Score 8 for $n = 2$
Clip applier $n = 1$	Score 7 for $n = 1$
Hook probe $n = 1$	Score 6 for $n = 1$
Extractor $n = 1$	Score 7 for $n = 1$

The lowest classified risk is level 4 for the activities for the tasks of introducing trocars into the abdominal cavity and the task of abdominal control using the video camera. However, level 4 is characterized by medium risk, which point out the improving actions. It can be concluded that the risk is present within operations of almost all of laparoscopic instruments. The only tool where there was no possibility for a risk during surgery was Veress needle.

In turn, a tool which determines the highest level of risk (score 8) for the musculoskeletal system during the procedure is Grasper. The posture factors creating such risk level in figure 3 is presented.

Table 3 shows the sources of body postural risk while operating by grasper taking into account the five elements indicated in figure 3.

The results of ergonomic assessment of other instruments indicate the similar sources of postural risk. Additional factors contributing to problems with using laparoscopic tools are: required high of squeeze strength in such tools like extractor and clip applier, jamming of tools outside and inside the abdomen. Summarizing the sources of risk factors, they are varied and are related not only to the design of tools, but also to the position of the patient or the monitor location. An ergonomic intervention

Table 3. The sources of body postural risk [own study]

Item	Posture factors	The source of postural risk/potential ergonomic intervention
1	Neck is twisted and side bending	Interaction between the operator, stationery position of the patient and stationery position of the monitor
2	Shoulder is raised	The high length of instrument, position of the patient, the long horizontal distance of the hands from the patient
3	Upper arm is raised more than 90 degrees and abducted	
4	Wrist is bent more than 15 degrees down and twisted	The stationery position of the patient, the instrument grip design
5	Handle is fair	Difficulties with opening and closing blockade, the same size of handles, the need of permanent turning the knob, the distance of the grip and the knob

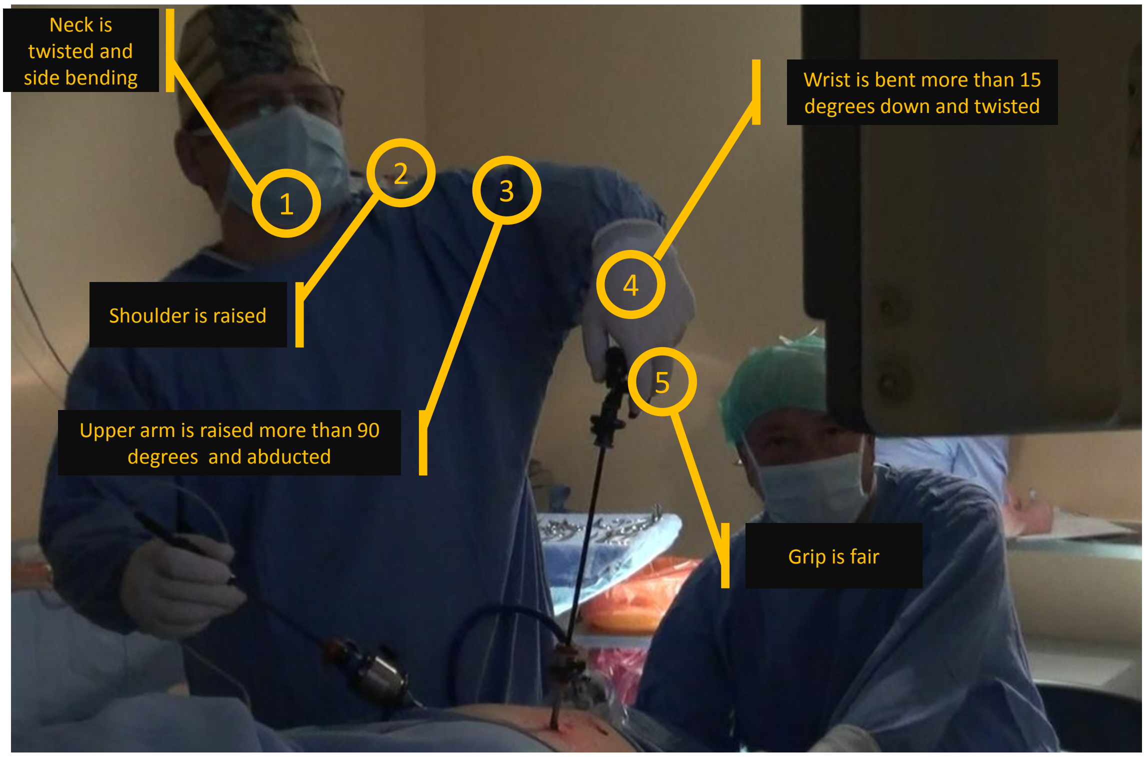


Fig. 3. Posture factors in REBA methods [own study]

concerning the laparoscopic procedures should therefore be carried out in a comprehensive manner with the participation of surgeons.

The study did not include legs position due to the space restrictions and barriers in operating room. However, taking into account the opinions of surgeons expressed in the survey research (see point *The genesis of research*) there is possible to indicate additional factors impacting negatively on the level of risk, such as non-symmetrical support for the feet or using of pedals for controlling diathermy systems.

Conclusions

The proposed method is useful for the analysis of difficult working conditions in terms of the data collection. An example of these are undoubtedly conditions in an operating room. High sanitary rigor and dim prevailed during surgery significantly impedes the use of modern data storage techniques, such as motion capture techniques. The research procedure of ergonomic analysis does not interfere in the work processes of medical personnel, which is its advantage. It should be borne in mind that this type of procedure is time-consuming and the analysis of factual material must be conducted by an experienced researcher.

However, there is pointed out the important problem areas associated with ergonomics of surgical laparoscopic tools confirmed by the interview with laparoscopic surgeon, which is the basis for looking for improvement of the working condition in operating rooms.

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References

1. NGUYEN N.T., HO H.S., SMITH W.D., PHILIPPS C., LEWIS C., DE VERA R.M., BERGUER R.: An ergonomic evaluation of surgeons' axial skeletal and upper extremity movements during laparoscopic and open surgery. The American Journal of Surgery 182, 2001, 720–724.

2. FISHER K.S., REDDICK E.J., OLSEN D.O.: Laparoscopic cholecystectomy: cost analysis. Surg Laparosc Endosc. 1, 1991, 77–81.
3. STANEK A., KOSTEWICZ W.: Rys historyczny chirurgii laparoskopowej w Polsce. In: Kostewicz W. (Ed.) Chirurgia laparoskopowa. PZWL, 2002.
4. HANCOCK P.A.: Human Factors / Ergonomics. Encyclopedia of Human Behavior, 2012, 358–363.
5. XUEFANG WU, GARETH THOMSON, BENJIE TANG: An investigation into the impact of safety features on the ergonomics of surgical scalpels. Applied Ergonomics 40, 2009, 424–432.
6. Dz.U. 2010 nr 107 poz. 679, Ustawa z dnia 20 maja 2010 r. o wyrobach medycznych.
7. BERGUER R.: Surgical technology and the ergonomics of laparoscopic instruments. Surgical Endoscopy 12, 1998, 458–462.
8. MATERN U., EICHENLAUB M., WALLER P., RUCKAUER K.: MIS instruments. An experimental comparison of various ergonomic handles and their design. Surgical Endoscopy 13, 1999, 756–762.
9. TREJO A.E., DONÉ K.N., DIMARTINO A.A., OLEYNIKOV D., HALLBECK M.S.: Articulating vs. conventional laparoscopic grasping tools – surgeons' opinions. International Journal of Industrial Ergonomics 36 (1), 2006, 25–35.
10. TREJO A.E., JUNG M.-CH., OLEYNIKOV D., HALLBECK M.S.: Effect of handle design and target location on insertion and aim with a laparoscopic surgical tool. Applied Ergonomics 38, 2007, 745–753.
11. VAN VEELEN M., NEDERLOF E., GOOSSENS R., SCHOT C., JAKIMOWICZ J.: Ergonomic problems encountered by the medical team related to products used for minimally invasive surgery. Surg Endosc. 17, 2003, 1077–1081.
12. AVINASH N. SUPE, GAURAV V. KULKARNI, PRADNYA A. SUPE: Ergonomics in laparoscopic surgery. Journal of Minimal Access Surgery 6(2), Apr-Jun 2010, 31–36.
13. MARVIK R. et al.: Ergonomic design criteria for a novel laparoscopic tool handle with tactile feedback. Minerva Chir. 61(5), Oct 2006, 435–444.
14. ANTHROPOS – ErgoMax: User Guide, Version 3.0, 1999, IST GmbH, Keiserslauter.
15. HIGNETT S., MCATAMNEY L.: Rapid Entire Body Assessment (REBA). In: Applied Ergonomics 31, 2000, 201–205.
16. 3D Static Strength Prediction Program. User Manual, The University of Michigan Center for Ergonomics, 2012.