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ORIGINAL ARTICLE

Ergonomic assessment of the first assistant during robot-assisted surgery

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Abstract

The use of the da Vinci robot in minimal invasive surgery comes with numerous advantages. Recent papers describe improvements in the ergonomic environment and benefits for the surgeon's posture in the console. Ergonomics for first assistants or scrub nurses at the OR table during robot-assisted procedures, however, have gained minor attention. The aim of this study, therefore, is to analyse the ergonomic environment specifically for first assistants during robot-assisted surgery. Three techniques were used to evaluate body posture and ergonomics during three discriminated actions. First of all, a questionnaire was conducted. Second, sagittal and dorsal photographs of all first assistants were shot. From these photographs, joint angles of the trunk, neck, shoulder, elbow, pelvic girdle and spine were calculated and rapid upper limb assessment (RULA) scores were determined. In addition, intra-observer variability was assessed to determine the robustness of the results. Lastly, the number of obstructions during the surgery was registered by an observer present at the operation theatre. The questionnaires displayed that 73% of the first assistants were in uncomfortable working positions for longer periods of time. Twenty percent of the participants even report pain or visible bruising due to hinderance of the robot arm. Furthermore, an average of 2.8 obstructions per surgical procedure was registered, mainly affecting the lower arm (60%). The photographs demonstrated that all joint angles, except for the elbow joint, are potentially harmful when assisting during robot-assisted surgery. RULA scores revealed high-risk ergonomic risk scores for all measured actions. Tissue traction was recognized as the action with the highest physical workload. During robot-assisted surgery, first assistants experience non-ergonomic trunk, neck and shoulder angles. These recordings are supported by posture analysis. Tissue traction is reported as the most intensive action by the nurses. Tacking, however, can lead to the most unfavourable RULA score. The surgeon's awareness of the position of the robot arms could reduce the number of obstructive moments for the first assistant. Lowering the number of instrument replacements is plausible to lead to better ergonomic postures for first assistant.

Keywords Robot-assisted surgery · Ergonomics · Operation room work environment

Introduction

The number of robot-assisted surgical procedures is increasing by more than 15% every year. In 2017, approximately 877.000 procedures were performed worldwide with the da Vinci systems [1]. Improvement of the ergonomic environment and reduction of physical strain for the surgeon during minimal invasive surgical procedures is a particular advantage of working with de da Vinci system [2–4]. Several studies demonstrated ergonomic discomfort for surgeons while performing laparoscopic procedures [5–10]. This can lead to musculoskeletal symptoms such as pain, fatigue and stiffness. The da Vinci robot systems tackle numerous ergonomic disadvantages. Sitting in a console with an armrest leads to more comfort and using the instrument clutch feature, large movements in the shoulder, elbow and wrists can be avoided [11]. Although most research focusses on ergonomic advantages for the surgeon, the da Vinci system might negatively influence body posture of first assistants. Considering first assistants play a crucial role in all robot-assisted procedures, their ergonomic situation is

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of major importance. When performing surgery from the console, the surgeon is not always aware of the position of the robot arms. This can lead to unfavourable ergonomics and potential hazardous situations for the first assistant. Additionally, the robot arms cause discomfort when a change of instruments or assistance during a procedure is warranted. Therefore, the goal of this study is to analyse ergonomics for the first assistant during robot-assisted procedures.

Methods

Participants and questionnaires

Eleven first assistants of the Meander Medical Center (Amersfoort, the Netherlands) participated in this study. All participants were experienced nurses; all assisted in more than 30 robot-assisted cases. All first assistants filled out a 5-min questionnaire with questions regarding the ergonomic environment. Subjective ergonomics were assessed with this questionnaire. Additionally, the validated Dutch Musculoskeletal Questionnaire, which analyses musculoskeletal symptoms due to the workload, was also filled out by all participants [12].

Ergonomic evaluation

Joint angles

To evaluate the ergonomic posture of the first assistant during robot-assisted surgery, multiple sagittal and dorsal plane photographs were taken during three common actions: (1) tissue traction, (2) tissue tacking and (3) instrument replacement. Anatomical landmarks were used to calculate the angles from the neck (Δ*N*), trunk (Δ*T*), shoulder (Δ*S*) and elbow (Δ*E*) in the sagittal plane during these actions. Angles of the neck (Δ*N*), trunk (Δ*T*), shoulder girdle (Δd*S*), pelvic belt (Δd*P*) and torsion of the spine (ΔdTS) were analysed in the dorsal plane photographs.

Optimal joint angles were determined based on the RULA score. This includes angles of 10° for the neck (Δ*N*) and the trunk (Δ*T*). Shoulder angles (Δ*S*) are ergonomic up to 20° anteflexion or abduction (Δd*S*). For elbow angles (Δ*E*) this range is between 60° and 100° flexion [11, 13]. For the remaining angles, dorsal photographs were used. An angle higher than 5° outside the range was considered potentially harmful to the optimal ergonomic situation.

All joint angles are calculated using Matlab 2013b (The MathWorks, Natick, MA, USA), as visualized in Fig. 1. The trunk angle was calculated by comparing a vertical line with a straight line through the marked points. This 'backfit' was measured using the standard least squares method. The angle

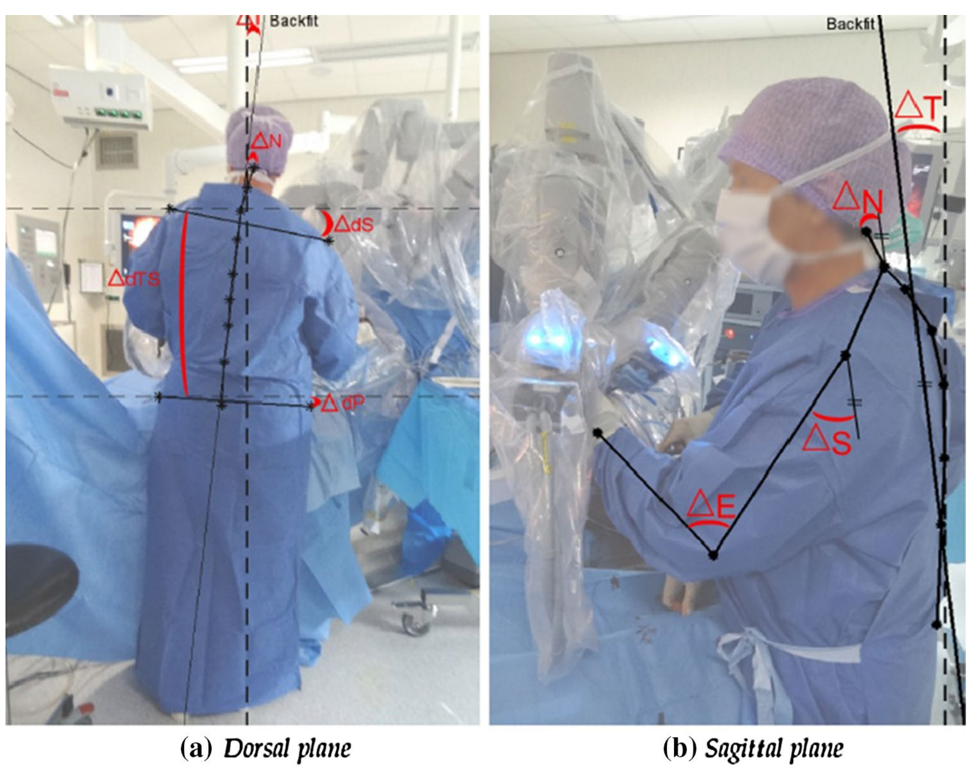

Fig. 1 Representation of the angles calculated from the different planes. *ΔN* neck; *ΔT* trunk; *ΔS* shoulder; *ΔE* elbow; *Δ*d*S* shoulder girdle; *Δ*d*P* pelvic belt; *Δ*dTS torsion of the spine angles

between this ‘backfit’ line and the line between vertebrae C1 and C7 represents the neck angle. The shoulder angle was calculated by drawing a line between the olecranon and the acromion. Torsion of the spine was measured by $\Delta TS = \frac{\Delta S}{\Delta P}$.

Intra-subject variability was determined by analysing two participants ten consecutive times and calculating the standard deviation from these results.

Rapid upper limb assessment

The rapid upper limb assessment (RULA) is a validated and reliable tool to evaluate work-related upper limb ergonomics [13]. This RULA score, ranging from 1 to 7, determines the severity of the ergonomic exceedances. A low score means optimal ergonomics, a high score represents a serious health threat. Due to the often invisible wrist position on the photographs caused by the arms of the robot, it was not possible to determine a separate wrist score. Assuming the wrist joint is often more than 15° bended results in a RULA score of three. The mean RULA score per participant in every action category was determined by calculating the mean angle in all photographs of that participant.

Time frames

To validate the outcome parameters of the questionnaire, time frames of each activity of the first assistant were timed in a score sheet. During tacking, the time frame was defined as the time between the first and the last tacking session. It is important to realize that the length of time frames influences the RULA score. Subsequently, the number of obstructions caused by the robot arms was registered with a score sheet. Obstructions were defined as unintentional contact of the robot arms with the arms, trunk or head of the first assistant.

Results

In total, 13 procedures with 11 first assistants were analysed. Three specialties were included this research project: Urology, Gynaecology and General surgery. An overview of all procedures is displayed in Table 1. Also, the various RULA scores with standard deviations of the different tasks are displayed here.

Questionnaires

The mean exposure of the participants with robot-assisted procedures was 14 h weekly. The mean work experience with robot-assisted surgery is 3.0 years (range 2.0–4.0 years).

Seventy-three percent of the first assistants reported working in a bended, stooped or twisted posture for longer periods as common practice. This can lead to musculoskeletal

Table 1 RULA scores of all procedures (mean ± standard deviation)

No.	Surgery	Specialism	Scrub nurse	RULA scores		
				Tissue traction	Tissue tacking	Instrument replacement
1	Redo fundoplication	General surgery	MB	3.0	NA	NA
2	Redo fundoplication	General surgery	PD	3.5 ± 0.7	NA	NA
3	Abdominoperineal resection	General surgery	MM	5.3 ± 0.5	3.0	5.7 ± 1.5
4	Prostatectomy	Urology	NM	3.7 ± 0.6	NA	NA
5	Sacropolcopexy	Gynaecology	NM	4.0 ± 1.4	NA	NA
6	Rectovaginopexy + sacrocolporectopexy	General surgery + Gynaecology	MV	5.3 ± 1.0	4.5 ± 2.1	NA
7	Rectovaginopexy	General surgery	PD	3.7 ± 1.2	4.0	5.0
8	Pyeloplasty	Urology	MV	5.0 ± 1.4	6.0	NA
9	Redo fundoplication	General surgery	RS	3.3 ± 0.6	6.0	NA
10	Prostatectomy	Urology	EvD	3.3 ± 0.5	3.5 ± 0.7	7.0
11	Sacropolcopexy	Gynaecology	EvZ	6.0 ± 1.0	5.0 ± 1.4	7.0
12	Sacropolcopexy	Gynaecology	RD	5.0 ± 1.0	5.5 ± 0.7	5.0 ± 1.7
13	Sacropolcopexy	Gynaecology	AK	6.0 ± 0.0	3.8 ± 1.0	6.5 ± 0.7
14	Rectopexy	General surgery	RS	3.5 ± 0.7	5.0	4.5 ± 0.7

If only one photograph of a certain action is available, there is no standard deviation mentioned

NA not applicable

strain on trunk, neck and wrist. Short repetitive movements are common for the neck (82%), the trunk (73%) and the wrist (73%). In addition, participants mentioned several work-related activities with their arms above shoulder level. Uncomfortable postures, such as reaching out for the robot arm and working in the same position for a longer period of time, were reported by all participants. Moreover, a limited work-space was noticed due to the robot arms. This can result in static postures, obstruction and hindrance. The questionnaires revealed that 20% of the participants reports pain or visible bruising due to interference with the robot arm. Obstructions, reported when accidental contact of the robot arm with the first assistants was recorded, occurred on average 2.8 times (range 0–8) per surgical procedure. This was mainly affecting the lower arm (60%). Position of the monitor plays a vital role in minimal invasive ergonomics. However, monitor position preferences display a wide variation. The monitor was mostly positioned on the same side as the first assistants, between the patient and the instrument table (45%).

Ergonomic evaluation

Joint angles

The mean joint angles of all participants for each defined action are displayed in Fig. 2. The green-shaded area represents the preferable joint angles defined by RULA. As can be seen, all joint angles—except for the elbow joint—are potentially harmful. In addition, the neck joint is on the edge of the danger zone during tissue tacking and traction. In both planes (dorsal and sagittal), instrument replacement was determined as the most harmful action, followed by tacking and tissue traction. This was recorded in all joints, except the elbow joint. The intra-subject variability in both planes is below 5° for the neck angles and below 2° for the other joint angles.

RULA

The mean time frames of the actions are summarized in Table 2. This influences the RULA score. For tissue traction and tissue tacking, an additional point in the RULA score is calculated for static posture, because these actions take longer than 60 s.

The mean RULA score per first assistant is illustrated in Table 1. The average RULA scores of subspecialties are summarized in Table 3.

These tables demonstrate that the highest RULA score was found during tacking. Gynaecology can be seen as the specialism with the most uncomfortable ergonomic body postures for the first assistant.

Discussion

To date, no previous study was published describing the ergonomic environment for the first assistant during robot-assisted surgery. This issue was recognized as a serious point

Table 2 Mean time frames of the duration of tasks, each displayed in seconds

Specialism	Tissue traction	Tacking	Instrument replacement
General surgery	177	142	38
Gynaecology	234	81	58
Urology	212	134	65
Overall	207	119	54

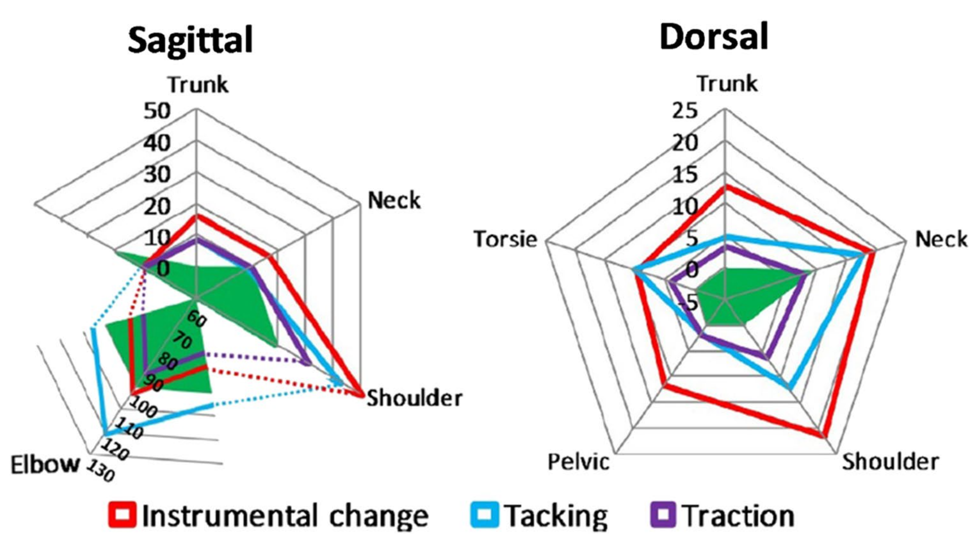

Fig. 2 Spider plot of the mean angles of the measured joints in the dorsal and sagittal plane, where the green area is defined as not harmful

Table 3 RULA scores (mean and standard deviation) of all scrub nurses during specific tasks in all fourteen surgical procedures, specified in different specialisms

Specialism	Tissue traction	Tissue tacking	Instrument replacement	Overall
General	4.3 ± 1.1	5.8 ± 1.0	4.6 ± 1.0	4.9
General surgery	3.7 ± 0.8	5.1 ± 0.6	4.5 ± 1.3	4.4
Gynaecology	5.3 ± 0.8	6.2 ± 1.0	4.7 ± 0.7	5.4
Urology	4.0 ± 0.9	7.0 ± 0.0	4.8 ± 1.8	5.3
Overall	4.3	6.0	4.7	

of concern at the European Association of Endoscopic Surgery (EAES) consensus meeting on robot-assisted surgery [14].

Three techniques to evaluate ergonomics were applied in this study: a questionnaire, photographs in the operation room and application of a RULA score sheet.

When only taking into account the joint angles derived from the photographs, instrument replacement is defined as the least ergonomic action. The RULA score, however, determines tacking as the least ergonomic action. This discrepancy is caused by factors such as static postures and repetitive movement that are being included in the RULA score, but cannot be measured in the photographs. Moreover, tackers are placed deep in the pelvic space and this can also result in more physical strain and uncomfortable joint angles. The fact that Gynaecology is the specialism where most ergonomic uncomfortable positions are recorded is probably caused by extensive tissue traction and frequent instrument replacements, as well as manipulation of the uterus simultaneously with other tasks.

In the questionnaires, tissue traction was addressed as the action with the highest physical intensity level. This is caused by the static posture that is essential during tissue traction. Although joint angles are often not extreme during tissue traction, the intensity of the action is caused by the time needed to perform it. In contrast, tacking and instrumental replacement are brief actions. Thereby such actions require the full attention and concentration of the first assistant; awareness for non-ergonomic joint angles might be lower at such moments.

The joint angles during instrument replacement display extreme values. This is based on the fact that replacement of the instruments of the third robot arm (the furthest arm) demands extensive bending and reaching out from the first assistant. This causes extreme joint angles. Less often replacing instruments of the third arm could, therefore, result in a reduction of physical strain for the first assistant. Another solution for the first assistant could be to change position. For instance, when standing on the other side of the patient, instrument replacements at the third robot arm can be less stressful and harmful.

To overcome work-related musculoskeletal disorders, optimal hardware settings are required. Monitor position is vital to reduce rotation and twisting of the neck and back [15, 16]. Due to the robotic chart in the operation area, an optimal monitor position (monitor in line with the viewer) cannot always be achieved. Results from the questionnaire show wide inter- and intra-subject variability in the use of monitor location. The preferred monitor position is dependent on the specialism, the type of surgery and the type of action. Perioperative placement of more monitors at optimal view angles might lead to more ergonomic body postures.

Operation and instrument tables are adjustable in height. However, the operation table is limited in its movement during robot-assisted surgery. The table cannot always be put at an optimum height and several factors disturb an optimal operation table height. For instance, the condition of the patient can limit the amount of (reversed) Trendelenburg position. The preferences of the surgeon and the process of docking of the da Vinci patient-side cart also determine the final height of the operation table. The first assistant, therefore, frequently has to compensate a suboptimal table position by working with a larger elbow angle. It is of clear importance that evaluating table height during every procedure can reduce serious strain during surgical procedures.

The da Vinci Si Surgical System operates with three or four robot arms that pass trocar portals. At the start of the procedure, additional trocar portals are placed. Such a remaining trocar port is used by first assistants to assist during procedures. When this trocar port is positioned too close to the trocar portals used by the robot arms, this will result in a limited and narrow working space for the first assistant. With regard to the elbow and wrist, this means major twisting and bending. Combined with the continuous movements of the robot arms navigated by the surgeon, serious hinderance and discomfort are experienced by the first assistant. Good communication between the surgeon and first assistant is likely to reduce this discomfort.

Our questionnaire recorded a mean hindrance of at least one incident per surgical procedure. However, our objective score sheet measurement determined an average obstruction number of three times per surgery. This difference can be explained by the fact that some level of hindrance is 'accepted' by the first assistants and is not even addressed in a questionnaire.

This study is based on photographs of the first assistant. According to our intra-observer variability, this study method is reproductive and reliable. However, sometimes it can be difficult to locate all anatomical landmarks when the nurse is wearing a sterile jacket. This might influence accuracy of the measurements.

Conclusion and points of advice

During robot-assisted surgery, the first assistant experiences non-ergonomic trunk, neck, shoulder and wrist angles. Tissue traction is reported as the most intensive action by the participants. The highest RULA score was found during tacking. The outcome of these RULA scores display that all actions need further ergonomic investigation.

To reduce discomfort and optimize ergonomics, several points of advice can be formulated. First of all, the first assistant needs to be aware of optimal monitor and table settings. They have to take care of a comfortable position, with an acceptable reach distance to instruments and trocar portals.

Second, to prevent extreme joint angles for the first assistant, the most remote trocar portal must be used as little as possible, especially for instrument replacements. In conjunction, to reduce the strain for the nurse, the surgeon can place an instrument at this portal just before entering the console.

Awareness of the trocar portal positions is vital to optimize ergonomics. Careful consideration of placement of the assistant trocar portals will result in more freedom of movement for the first assistant. A distance of 8 cm (> 3 inches) at minimum is advised between trocar portals. Surgeons need to be aware of the fulcrum effect: large external movements of the robot arms can be reduced by placing trocars further from the target organ. A smaller range of motion outside the body is generated by placing a larger part of the instrument inside the body.

Besides that, surgeons need to be aware of the relation between the external movements of the robot arms. Calm and smooth movements in the console lead to slower movements of the robot arms. This can reduce hindrance for the first assistant because there is more time to anticipate.

Intensive communication between the surgeon and first assistant is essential. The team has to take care that visual contact between the surgeon and the operation team is possible from the console. Verbal communication can be optimized by correct speaker settings. Clear instructions regarding an expected large range of motion, a sudden change in camera position or placement of instruments outside the optical field are crucial. Lastly, when briefing for a procedure, explicit communication with your team on ergonomics is a key part of robot-assisted surgery. Check the patient position, check the hardware and software settings and make your team aware of the movement of the robot arms.

Compliance with ethical standards

Conflict of interest Author CDP van't Hullenaar, Author Paula Bos and Author Ivo Broeders declare that they have no conflict of interest.

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