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# Ergonomic assessment of the da Vinci console in robot-assisted surgery

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**Abstract**

**Background:** Robot-assisted surgery is considered to improve ergonomics over standard endoscopic surgery. Nevertheless, previous research demonstrated ergonomic deficits in the current console set-up.
**Aim:** This study was designed to objectively assess body posture in the da Vinci console during robot-assisted endoscopic surgery.
**Methods:** Multiple sagittal photographs from six physicians were taken during robot-assisted procedures. Trunk, neck, shoulder, elbow, hip, and knee angles were calculated and compared to ergonomic preferable joint angles. A 2D geometric model was developed using individual anthropometrics. Optimal seat height, armrest height, and viewer height were calculated. These results were compared to the findings of the sagittal photographs.
**Results:** Mean joint angles show potentially harmful neck angles for all participants. Trunk angles vary between surgeons, from inadequate to correct. In short and very tall individuals, optimal armrest height is outside the adjustment range of the console.
**Conclusion:** The da Vinci Surgical System console seating position results in a nonergonomic neck and trunk angle. The developed geometric model revealed that armrest height has a limited adjustment range. Adjustments to the console and optimization of preoperative settings are goals to further improve ergonomics in robot-assisted surgery.

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**Keywords:** ergonomics; operating room environment; robot-assisted surgery.

## Introduction

The first robotic systems in surgery were presented almost 30 years ago. An industrial robot arm, the PUMA (Westinghouse Electric, Pittsburgh, PA, USA), was used to manipulate surgical instruments for brain surgery in 1985 [1]. In 1997, Himpens and Cadière performed the first robot-assisted cholecystectomy using the MONA system, a predecessor of the modern da Vinci Surgical System (Intuitive Surgical, Inc., Sunnyvale, CA, USA) [1]. The breakthrough of robot-assisted surgery occurred several years later when urologists began to use the da Vinci Surgical System for radical prostatectomy [2]. Nowadays, robot-assisted surgery has become the surgical golden standard for prostatectomy in many countries around the world [3]. The amount and diversity of surgical procedures wherefore robotic systems are applied are increasing every year. The main focus of robot-assisted surgery is to improve patient outcomes, but as a side effect surgeons report much better ergonomics for themselves compared to standard endoscopic surgery. This is especially the case for procedures in the small pelvis.

Standard endoscopic surgery is associated with major musculoskeletal discomfort [4–8]. Park et al. showed that 87% of 317 laparoscopic surgeons reported physical strain or symptoms of discomfort [8]. The manipulation of endoscopic instruments from a console provides a completely different perspective. The natural working axis is restored and the surgeon can work in a seated position with the arms on an armrest [9–11].

Although robot-assisted surgery is considered to be more comfortable than endoscopic surgery, studies have shown that ergonomic deficits remain. The optimal sitting position of the surgeon when using the da Vinci console is still unknown. The main goal of this study is to explore the body posture of the surgeon during robot-assisted surgery. Body joint angles were analyzed and ergonomics in the da Vinci console were compared to preferable joint angles according to ergonomic guidelines.

# Methods

## Participants

Six physicians of the Meander Medical Centre (Amersfoort, The Netherlands) participated in this study. All participants were members of the hospital staff and were experienced in robot-assisted surgery (>100 procedures each). The group consisted of three general surgeons, two urologists, and a gynecologist.

## Ergonomic evaluation

Multiple sagittal plane photographs of the participants were taken during surgery. Trunk ($\Delta T$), neck ($\Delta N$), shoulder ($\Delta S$), elbow ($\Delta E$), hip ($\Delta H$), and knee ($\Delta K$) angles were calculated. A custom-made Matlab 2013a (The MathWorks, Natick, MA, USA) program was designed for this purpose. The participants' limbs were traced by appointing hip, knee, ankle, shoulder, elbow, and wrist.

$\Delta E$, for example, is calculated between the appointed upper and lower arm segments. The trunk is appointed by tracing the physician's back with multiple points (red dots; Figure 1). A straight line was fitted through these points using a standard least-squares method. $\Delta T$ is then calculated between this linear fit and a vertical line perpendicular to the floor (dotted line; Figure 1). $\Delta N$ is calculated between the linear fit of the trunk and a straight line between the point that represents the shoulder and the participant's ear. All calculated joint angles are presented in Figure 1. Intraobserver variability was explored by analyzing two participants 10 times. Standard deviations of these data were subsequently calculated.

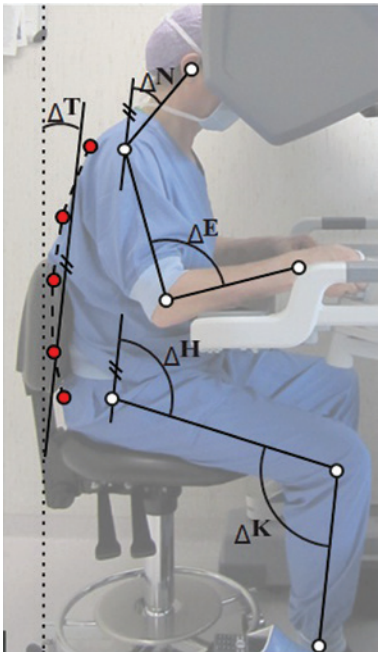



**Figure 1:** Representation of the angles calculated from the sagittal plane photographs: $\Delta T$ (trunk), $\Delta N$ (neck), $\Delta S$ (shoulder), $\Delta E$ (elbow), $\Delta H$ (hip), and $\Delta K$ (knee).

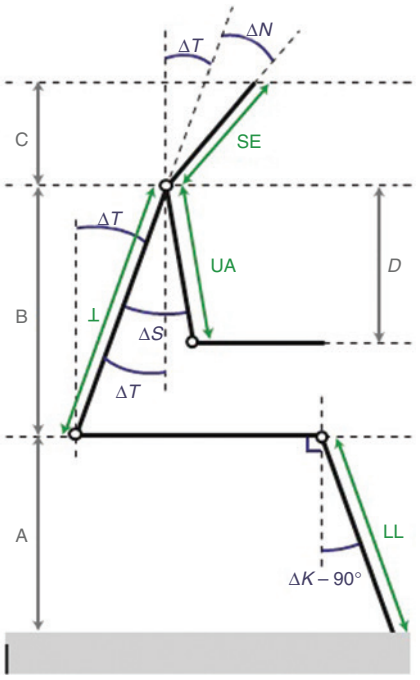



**Figure 2:** Schematic representation of the geometric model. LL, lower leg; T, trunk; SE, shoulder-eye; UA, upper arm.

## Preferable joint angles

The optimal joint angle range was extracted from the Rapid Upper Limb Assessment (RULA) tool [12]. The lowest RULA score (most optimal ergonomic position) is achieved when the joint angles are within the following ranges: $\Delta T = 0–10°$, $\Delta N = 0–10°$, $\Delta S = 0–20°$, and $\Delta E = 60–100°$. The angles $\Delta K$ and $\Delta H$ were defined to be optimal between 90° and 110° and between 90° and 100°, respectively.

## Geometric model

A 2D geometric model was developed to evaluate the console ergonomics. Seat, armrest, and viewer height can be calculated using a person's anthropometry and preferred joint angles. A schematic representation of this geometric model is shown in Figure 2. Seat, armrest, and viewer height are calculated as follows:

Seat height

Seat height can be calculated using Equation (1):

$$A = \cos(\Delta K - 90°) \cdot \mathrm{LL} \quad (1)$$

$\Delta K$, knee angle (°); LL, lower leg (cm).

Armrest height

Optimal armrest height can be calculated by first calculating a person's shoulder height from seat level using Equation (2):

$$B = \cos(\Delta T) \cdot \mathrm{T} \quad (2)$$

$\Delta T$, trunk angle (°); T, trunk (cm).

The difference in height between shoulder and elbow ($D$) is calculated using Equation (3):

$$D = \cos(\Delta S - \Delta T) \cdot \mathrm{UA} \tag{3}$$

$\Delta S$, shoulder angle (°); $\Delta T$, trunk angle (°); UA, upper arm (cm).

The elbow height can be calculated using Equation (4). The elbow height is considered to be the optimal armrest height.

$$\text{Armrest height} = A + B - D \tag{4}$$

Viewer height

Similarly, the viewer optics height can be calculated using Equation (5):

$$\text{Viewer height} = A + B + C \tag{5}$$

where $C$ is the height difference between eyes and shoulder, calculated using Equation (6):

$$C = \cos(\Delta N + \Delta T) \cdot \mathrm{SE} \tag{6}$$

$\Delta N$, neck angle (°); $\Delta T$, trunk angle (°); SE, shoulder to eye (cm).

### Anthropometry

To calculate the optimal settings, the lengths of the upper arm, trunk, and lower leg and the distance between the shoulder and the eye are crucial. For this study, anthropometric characteristics were extracted from the DINED 2004 database (TU Delft, The Netherlands) [13]. To calculate the optimal armrest height, anthropometric proportions were taken into account. For instance, when using an body length of 177 cm in the DINED database, the length of the lower leg length is 48 cm. Dividing the lower leg length (48 cm) by the body length (177 cm), this results in an anthropometric proportion of 0.27. With this number, the lower leg length of a person with a body length of 185 cm can be calculated. After using the equation (0.27×185), the exact lower leg length is determined (50 cm) [13].

### Joint angles

Optimal joint angles used in the geometric model were chosen with the adjustment ranges of the console in mind. The angles $\Delta T$ and $\Delta N$, for example, are both set to 20° because of the viewer angle, which is at least 40°. Furthermore, $\Delta K$ and $\Delta S$ are defined as 110° and 40°, respectively. Although our model is a 2D model, which does not include abduction in legs and arms, a shoulder abduction angle ($S_{abd}$) of 20° is taken into account for the optimal armrest height calculations.

# Results

## Ergonomic evaluation

Data from all participants are shown in Appendix A. The mean joint angles of participants 1 and 2 are plotted in Figure 3A and B, respectively. The green shaded area in Figure 3 represents the preferable joint angles according to ergonomic standards. It can be seen that these participants demonstrate angles that are potentially harmful. Especially, trunk, neck, and shoulder angles are out the "safe" ergonomic zone.

Intraobserver and interobserver variation measurements resulted in standard deviations of less than 2° for all angles in all participants.

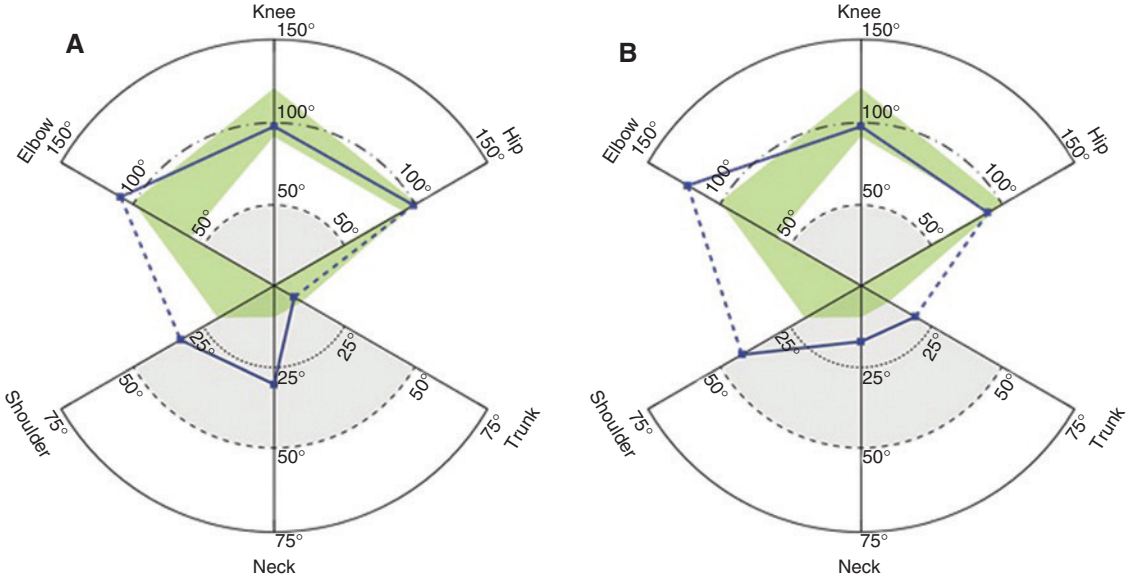



**Figure 3:** (A) and (B) Mean joint angles of participants 1 and 2, respectively.
The green shaded area represents the preferable joint angle range. $\Delta K = 90–110°$, $\Delta H = 90–100°$, $\Delta T = 0–10°$, $\Delta N = 0–10°$, $\Delta S = 0–20°$, and $\Delta H = 90–100°$.

### Limitations of the console

In the current console, the viewer angle can be adjusted between 40° and 60°. The viewer height can be adjusted between 104 and 137 cm. Armrest height can be changed between 74 and 84 cm from the floor to the top surface of the armrest.

The optimal armrest and viewer height for users with a stature between 140 and 200 cm are shown in Figure 4A and B. According to these data, persons smaller than 175 cm are not able to put the armrest at a desirable height. Optics height can vary from 104 to 137 cm. This makes the optics height suitable for persons varying from 155 to 200 cm in length.

## Discussion

Potential harmful neck angles were recorded in all participants (see Appendix A). This is in accordance with previous publications. Bagrodia and Raman compared open, laparoscopic, and robot-assisted prostatectomy ergonomics using survey questions among 106 urologists. Although robot-assisted prostatectomy turned out to be the most ergonomic approach, a proportional amount of 23% of the participants reported physical strain during robot-assisted prostatectomy procedures [10]. Lawson et al. analyzed musculoskeletal discomfort with the body part discomfort (BPD) score and ergonomics with the RULA tool. This study compared endoscopic to robot-assisted gastric bypass procedures. The conclusion of this paper states that robot-assisted gastric bypass surgery results in less musculoskeletal stress to the upper extremities than the conventional endoscopic techniques. However, according to their BPD scores, current robot consoles induce a severe neck strain due to the viewing angle. Furthermore, their RULA scores revealed a less ergonomic position of the surgeons' trunk during robot-assisted surgery [11]. Craven et al. studied robotic gynecologic procedures and concluded that neck strain is an important issue in robotic surgery. Improvements in ergonomics by training and improvements of robotic workstations are suggested [14]. Finally, Lux et al. constructed several guidelines to optimize the ergonomic position of surgeon when using the da Vinci

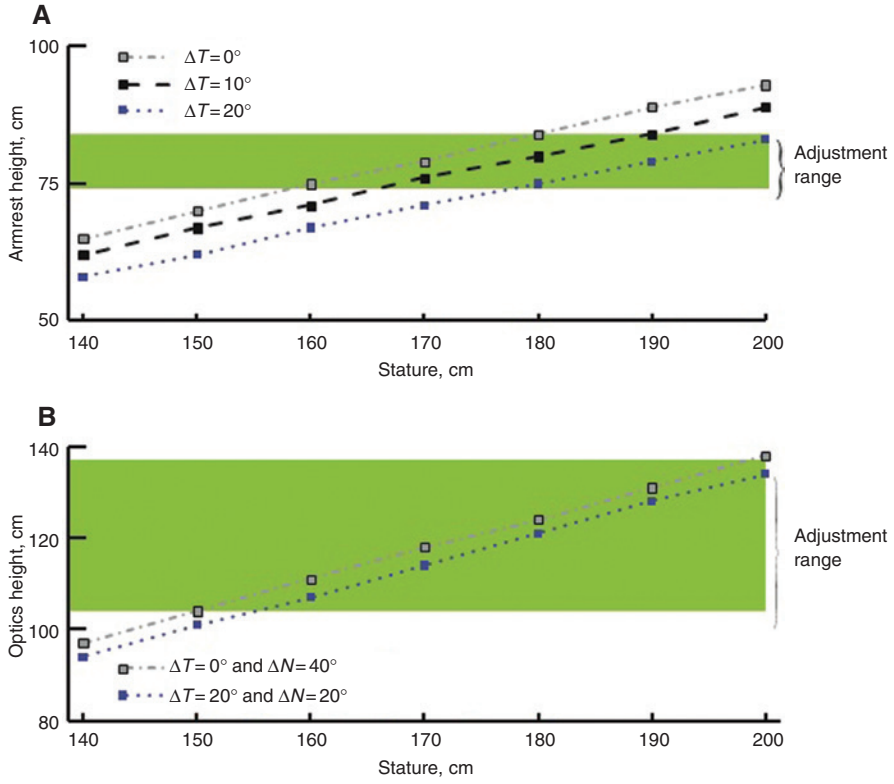



**Figure 4:** (A) and (B) Optimal armrest and optics heights for different statures.
The optimal heights are calculated using the 2D geometric model, anthropometric data from the DINED database. The shaded area represents the adjustment range of the console.

console [15]. When analyzing the data of this research project in more detail, it is noticeable that the neck and trunk angles depend on each other. Participants with reasonable trunk angles suffer from greater neck angles and vice versa. Adding the actual values of the trunk and neck results in a total flexion angle of approximately 40° in all participants. This is caused by the viewer angle of the console, which is at minimum 40°.

Besides the neck and trunk angles, shoulder and elbow angles are also found to be nonergonomic in all participants. Because the da Vinci console has an armrest, which supports the weight of the arm, the nonergonomic angles of the shoulder probably have less impact.

In this study, user-specific optimal ergonomics are calculated with a geometric model. When taking the adjustment range of the console into account, the settings for the armrest height are not sufficient. This is displayed in Figure 4A. Physicians with a length under 175 cm cannot place the armrest height to their optimal height. The adjustment range of the viewer height is much larger and allows acceptable ergonomics for users with a body length between 155 and 200 cm (Figure 4B). Because of the limited adjustment range of the armrest height, it is not possible for the user with a small posture to adjust the console to optimal settings.

An increase of the adjustment range for the armrest height and a decrease of the viewer angle in future consoles would support ergonomic settings in the current console design.

Several limitations of this study should be addressed. First, using photographs from one direction (sideways), only sagittal ergonomic information was calculated. Because the neglected third dimension is considered to be less relevant for neck and trunk angles, the results of this study remain legitimate. The error in angle calculation might be larger for hip, knee, shoulder, and elbow angles. This is caused by the abduction in the upper arm and hip. The geometric model that was applied in this study was corrected for an abduction of 20° in the shoulder. By applying that formula, armrest height calculations were measured accurate.

Another factor is that the identification of anatomical landmarks on photographs comes with a certain level of inaccuracy. To cross-check the reproducibility and


**Figure 5:** (A) Participant 3 photographed on the first day and (B) the same participant during a similar procedure on the next day. It can be seen that the participant did not adjust the chair height. This results in a less ergonomic position.

accuracy of all calculated angles in this study, an intraobserver variability test was performed. This test revealed a standard deviation of less than 2° for all angles. Therefore, the data derived from this study are considered to be reproducible and accurate.

Finally, personal console settings need to be addressed. In this study, there were no ergonomic instructions provided to the surgeons. This might have led to less optimal console statures (Figure 5). With the geometric model described in this study, the optimal user settings for the individual surgeon can be determined. It is now possible to use this algorithm for advise on optimal console settings, chair height, and distance to the console [16].

## Conclusion

Robot-assisted surgery provides better ergonomics compared to standard endoscopic surgery. However, during robot-assisted surgery, several physical complaints are reported. With this study, the surgeon's position in the da Vinci Surgical System console was analyzed. After analyzing the console posture of all study participants, a nonergonomic neck or trunk angle was found. These potential harmful angles are the result of the viewer angle of the console. The viewer of the console does not allow less than 40° downward view; therefore, it forces users to a flexed position of the spine. Furthermore, our geometric model indicates that the armrest height cannot be adjusted sufficiently. Future models of the robot console can take these findings into account. Ergonomic instructions derived from our geometric data can help to optimize the seating position of the surgeon in the future. Our future research projects will also focus on the design of an optimal chair for the robot console.

### Author Statement

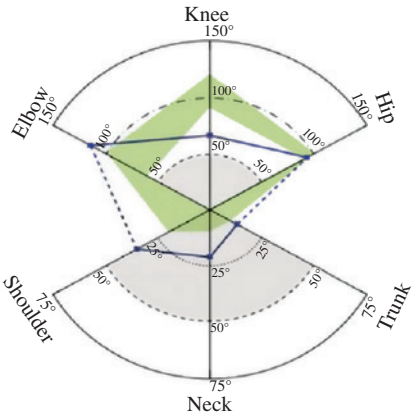
Research funding: Authors state no funding involved. Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals. Ethical approval: The research related to human use complied with all the relevant national regulations and institutional policies and was performed in accordance to the tenets of the Helsinki Declaration and has been approved by the author's institutional review board or equivalent committee.

### Author Contributions

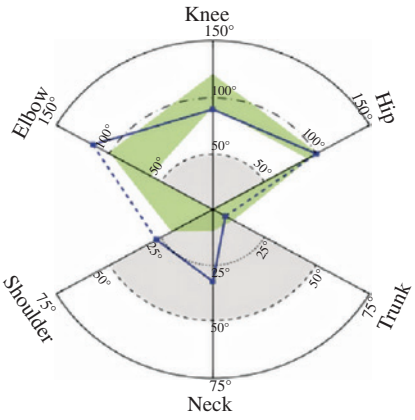
Cas D.P. van't Hullenaar: Data analysis, writing of the manuscript. Ben Hermans: Data analysis. Ivo A.M.J. Broeders: Revision of the manuscript.

# Appendix

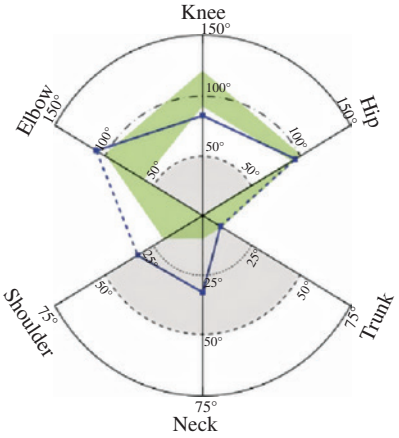
Mean joint angles of participant 1



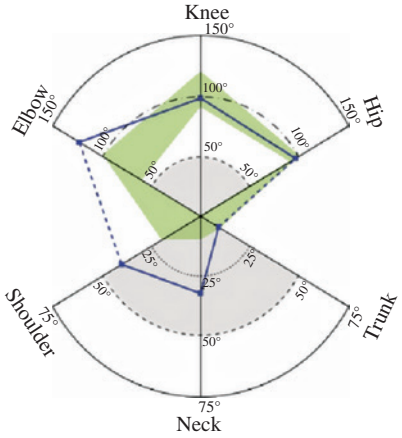

Mean joint angles of participant 2

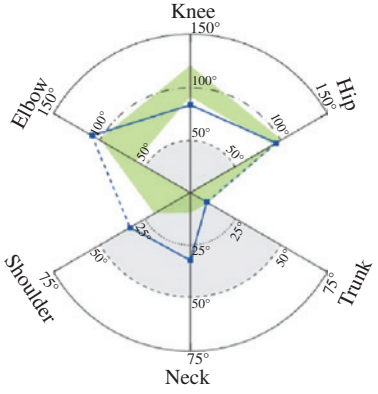



Mean joint angles of participant 3

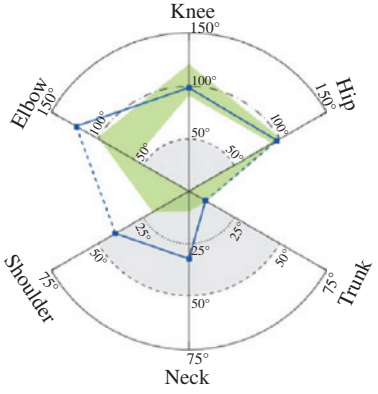



Mean joint angles of participant 4




Mean joint angles of participant 5




Mean joint angles of participant 6

**Appendix A:** Mean joint angles of all participants. The green shaded area represents the safe joint angles range according to the RULA score. $\Delta K = 90–110°$; $\Delta H = 90–100°$; $\Delta T = 0–10°$; $\Delta N = 0–10°$; $\Delta S = 0–20°$; $\Delta H = 90–100°$.

## References

[1] Pugin F, Bucher P, Morel P. History of robotic surgery: from Aesop and Zeus to da Vinci. J Visc Surg 2011;148:e3–e8.
[2] Broeders IA. Robotics: the next step? Best Pract Res Clin Gastroenterol 2014;28:225–232.
[3] Chopra S, Srivastava A, Tewari A. Robotic radical prostatectomy: the new gold standard. Arab J Urol 2012;10:23–31.
[4] Broeders IA, Kalisingh SS. Handboek Endoscopische chirurgie. Houten: Bohn Stafleu Van Loghum, 2009.
[5] Lanfranco AR, Castellanos AE, Desai JP, Meyers WC. Robotic surgery: a current perspective. Ann Surg 2004;239:14–21.
[6] Cavallo F, Pietrabissa A, Megali G, et al. Proficiency assessment of gesture analysis in laparoscopy by means of the surgeon's musculo-skeleton model. Ann Surg 2012;255:394–398.
[7] Miller K, Benden M, Pickens A, Shipp E, Zheng Q. Ergonomics principles associated with laparoscopic surgeon injury/illness. Hum Factors 2012;54:1087–1092.
[8] Park A, Lee G, Seagull FJ, Meenaghan N, Dexter D. Patients benefit while surgeons suffer: an impending epidemic. J Am Coll Surg 2010;210:306–313.
[9] van Veelen MA, Jakimowicz JJ, Kazemier G. Improved physical ergonomics of laparoscopic surgery. Minim Invasive Ther Allied Technol 2004;13:161–166.
[10] Bagrodia A, Raman JD. Ergonomic considerations of radical prostatectomy: physician perspective of open, laparoscopic, and robot-assisted techniques. J Endourol 2009;23:627–633.
[11] Lawson EH, Curet MJ, Sanchez BR, Schuster R, Berguer R. Postural ergonomics during robotic and laparoscopic gastric bypass surgery: a pilot project. J Robot Sur 2007;1:61–67.
[12] McAtamney L, Nigel Corlett E. RULA: a survey method for the investigation of work-related upper limb disorders. Appl Ergon 1993;24:91–9.
[13] Technical University Delft. Dined, 2004. Available at: http://dined.io.tudelft.nl/dined. Accessed 20 Apr 2014.
[14] Craven R, Franasiak J, Mosaly P, Gehrig PA. Ergonomic deficits in robotic gynecologic oncology surgery: a need for intervention. J Minim Invasive Gynecol 2013;20:648–655.
[15] Lux MM, Marshall M, Erturk E, Joseph JV. Ergonomic evaluation and guidelines for use of the daVinci robot system. J Endourol 2010;24:371–375.
[16] Harrison DD, Harrison SO, Croft AC, Harrison DE, Troyanovich SJ. Sitting biomechanics part I: review of the literature. J Manipulative Physiol Ther 1999;22:594–609.

**Supplemental Material:** The article (DOI: 10.1515/iss-2017-0007) offers reviewer assessments as supplementary material.

**Reviewer Assessment** **Open Access**

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## Reviewers' Comments to Original Submission

### Reviewer 1: Brigitte Vollmar

Feb 02, 2017

| | |
|---|---|
| **Reviewer Recommendation Term:** | Accept |
| **Overall Reviewer Manuscript Rating:** | N/A |

| **Custom Review Questions** | **Response** |
|---|---|
| Is the subject area appropriate for you? | 3 |
| Does the title clearly reflect the paper's content? | 5 - High/Yes |
| Does the abstract clearly reflect the paper's content? | 4 |
| Do the keywords clearly reflect the paper's content? | 4 |
| Does the introduction present the problem clearly? | 4 |
| Are the results/conclusions justified? | 4 |
| How comprehensive and up-to-date is the subject matter presented? | 4 |
| How adequate is the data presentation? | 5 - High/Yes |
| Are units and terminology used correctly? | 4 |
| Is the number of cases adequate? | 3 |
| Are the experimental methods/clinical studies adequate? | 5 - High/Yes |
| Is the length appropriate in relation to the content? | 5 - High/Yes |
| Does the reader get new insights from the article? | 5 - High/Yes |
| Please rate the practical significance. | 4 |
| Please rate the accuracy of methods. | 4 |
| Please rate the statistical evaluation and quality control. | 5 - High/Yes |
| Please rate the appropriateness of the figures and tables. | 4 |
| Please rate the appropriateness of the references. | 4 |
| Please evaluate the writing style and use of language. | 5 - High/Yes |
| Please judge the overall scientific quality of the manuscript. | 4 |
| Are you willing to review the revision of this manuscript? | Yes |

**Comments to Authors:**

The present study addresses a clinically relevant problem, i.e. the non-ergonomic body posture during robot-assisted surgery by using the da Vinci console. The major findings are (i) trunk and in particular neck angles are not in the physiological range and potentially harmful. The range of armrest height adjustment is too small to provide optimal conditions for short and very tall individuals, while optics height adjustment range seems to be sufficient. The established 2D geometric model can be applied for further refinement of the da Vinci console. The study is accurately described and well performed. Noteworthy, intraobserver variability was assessed to cross check the reproducibility and accuracy of calculated angles. The authors are aware of the limitations of the study (low number of individuals studied, usage of only sagittal ergonomic information's, etc.) and provide their critical perspectives. Nevertheless, the study is of scientific value and contributes to the improvement of robot-assisted surgery.

## Reviewer 2: Thomas Becker

Feb 09, 2017

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|---|---|
| **Reviewer Recommendation Term:** | Accept |
| **Overall Reviewer Manuscript Rating:** | N/A |

| **Custom Review Questions** | **Response** |
|---|---|
| Is the subject area appropriate for you? | 2 |
| Does the title clearly reflect the paper's content? | 4 |
| Does the abstract clearly reflect the paper's content? | 4 |
| Do the keywords clearly reflect the paper's content? | 4 |
| Does the introduction present the problem clearly? | 4 |
| Are the results/conclusions justified? | 4 |
| How comprehensive and up-to-date is the subject matter presented? | 4 |
| How adequate is the data presentation? | 4 |
| Are units and terminology used correctly? | 4 |
| Is the number of cases adequate? | N/A |
| Are the experimental methods/clinical studies adequate? | 4 |
| Is the length appropriate in relation to the content? | 4 |
| Does the reader get new insights from the article? | 4 |
| Please rate the practical significance. | 3 |
| Please rate the accuracy of methods. | 4 |
| Please rate the statistical evaluation and quality control. | 4 |
| Please rate the appropriateness of the figures and tables. | 4 |
| Please rate the appropriateness of the references. | 4 |
| Please evaluate the writing style and use of language. | 4 |
| Please judge the overall scientific quality of the manuscript. | 3 |
| Are you willing to review the revision of this manuscript? | Yes |

**Comments to Authors:**

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