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Does a robotic surgery approach offer optimal ergonomics to gynecologic surgeons?: a comprehensive ergonomics survey study in gynecologic robotic surgery

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Conflict of Interest
No potential conflict of interest relevant to this article was reported.

ABSTRACT

Objective: To better understand the ergonomics associated with robotic surgery including physical discomfort and symptoms, factors influencing symptom reporting, and robotic surgery systems components recommended to be improved.
Methods: The anonymous survey included 20 questions regarding demographics, systems, ergonomics, and physical symptoms and was completed by experienced robotic surgeons online through American Association of Gynecologic Laparoscopists (AAGL) and Society of Robotic Surgery (SRS).
Results: There were 289 (260 gynecology, 22 gynecology-oncology, and 7 urogynecology) gynecologic surgeon respondents regularly practicing robotic surgery. Statistical data analysis was performed using the t-test, χ^2 test, and logistic regression. One hundred fifty-six surgeons (54.0%) reported experiencing physical symptoms or discomfort. Participants with higher robotic case volume reported significantly lower physical symptom report rates ($p<0.05$). Gynecologists who felt highly confident about managing ergonomic settings not only acknowledged that the adjustments were helpful for better ergonomics but also reported a lower physical symptom rate ($p<0.05$). In minimizing their symptoms, surgeons changed ergonomic settings (32.7%), took a break (33.3%) or simply ignored the problem (34%). Fingers and neck were the most common body parts with symptoms. Eye symptom complaints were significantly decreased with the Si robot ($p<0.05$). The most common robotic system components to be improved for better ergonomics were microphone/speaker, pedal design, and finger clutch.
Conclusion: More than half of participants reported physical symptoms which were found to be primarily associated with confidence in managing ergonomic settings and familiarity with the system depending on the volume of robotic cases. Optimal guidelines and education on managing ergonomic settings should be implemented to maximize the ergonomic benefits of robotic surgery.

Keywords: Robotic Surgical Procedures; Human Engineering; Surveys and Questionnaires; Medically Unexplained Symptoms; Gynecology

Author Contributions
Conceptualization: L.M.R., L.G.I.; Formal analysis: L.M.R., L.G.I.; Investigation: L.M.R., L.G.I.; Methodology: L.M.R., L.G.I.; Project administration: L.M.R., L.G.I.; Resources: L.M.R., L.G.I.; Software: L.M.R., L.G.I.; Supervision: L.M.R., L.G.I.; Validation: L.M.R., L.G.I.; Writing - original draft: L.M.R., L.G.I.; Writing - review & editing: L.M.R., L.G.I.

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INTRODUCTION

The use of robotic surgery is continuously expanding and increasing in various surgical specialties as the da Vinci™ (Intuitive Surgical, Inc., Sunnyvale, CA, USA) robotic surgical systems, which offer several unique features, allow surgeons to perform more precise procedures for patients with complex conditions [1-7]. These unique features include articulating instruments allowing better dexterity, motion scaling function for precise and accurate movements, tremor reduction for instrument stabilization, a high-definition (HD) three-dimensional (3D) vision for clear and stereoscopic scope view, and ergonomic features of surgeon's console. The application of robotic surgery systems to gynecologic surgery was approved by the Food and Drug Administration (FDA) in 2005. Since then, robotic technology has been quickly and widely applied in gynecologic procedures including hysterectomy, sacrocolpopexy, myomectomy, adnexal surgery, and malignancy staging [8-10]. According to recent investor presentation file available from Intuitive Surgical, Inc.'s website, about 40% of worldwide and 48% of the United States robotic surgery cases are gynecologic procedures.

Improved ergonomics for operating surgeons in robotic surgery was commonly assumed a result of surgeons' sitting posture with the various adjustable ergonomic console settings of the viewer's height and tilt, arm rest's height, and the position of the pedal platform. Several studies have shown how the ergonomics associated with robotic surgery is better than manual laparoscopic surgery. Lee et al. [11] found that robotic surgery created improved upper-body posture and a similar level of mental workload for participants when compared with laparoscopic surgery; however, the task performance with robotic surgery was slower. The 2 studies conducted by Stefanidis et al. [12,13] demonstrated that the workloads associated with robotic surgery were lower than with laparoscopic surgery while the task performance depended on participants' existing laparoscopic surgery skill level. Berguer and Smith's study [14] showed that expert surgeons exhibited lower levels of discomfort and difficulty in robotic surgery. The ergonomic advantages of robotic surgery were mostly seen during the performance of more complex tasks. Hubert et al. [15] reported that the physical workload and subjectively reported effort level were significantly lower with robotic surgery, but the mental stress was identical for both surgical approaches.

A cognitive ergonomics study had previously shown that novice medical students exhibited less mental stress with the robotic surgery system [16]. A van der Schatte Olivier et al.'s study [17] included 16 inexperienced subjects performing rope passing, needle capping, and bead dropping by using standard laparoscopy and the robotic surgical system. The results showed that participants exhibited a reduction in cognitive and physical stress with robotic surgery. A recently published study reported the physical and cognitive workloads exhibited by novices and experienced robotic surgeons were significantly lower while experienced laparoscopic surgeons showed similar or higher levels of workloads with robotic surgery performances [18].

While many research studies support the ergonomic benefits of robotic surgery, potential ergonomic challenges in robotic surgery were also discussed in a few research studies. Lawson et al. [19] reported that robotic surgery allowed surgeons to have more ergonomically correct positions; however, increased body part discomfort was reported in the neck and less ergonomically favored body posture was observed in the trunk with robotic surgery. A study conducted by Craven et al. [20] showed that robotic surgery could cause potential posture-related risks that were demonstrated by high Rapid Upper Limb Assessment (RULA) and high strain index (SI). A study conducted by Lee et al. [18] reported higher muscular activation of the thenar compartment of the surgeons' hands, especially during robotic suturing and cutting tasks. Adverse use of the arm rest by novice robotic surgeons caused greater muscular activation at the trapezius muscles during task performance in robotic surgery.

To augment our current knowledge of the ergonomics associated with gynecologic robotic surgery, this ergonomic survey study was planned and conducted to better understand what kinds of physical discomfort or symptoms surgeons might experience, what factors influence surgeons' symptom reporting, and which robotic system components should be improved for better ergonomics.

MATERIALS AND METHODS

The Institutional Review Board at Johns Hopkins University School of Medicine reviewed and approved this survey study protocol. A survey invitation was sent by email to members of the American Association of Gynecologic Laparoscopists (AAGL) and the Society of Robotic Surgery (SRS) between March and December of 2013. The exact number of email invitations sent out was not available to report because each society used their email distribution lists which were not accessible by the authors. Therefore, the survey response rate could not be calculated. The invitation email contained a link for anonymous and voluntary participation through a survey website. The completed participation in this survey served as the consent to be in this research study as written on the first page of the online survey. After 2 weeks from the first email invitation, additional reminder emails were sent out.

There were 2 qualification requirements for potential participants: 1) completion of residency training, and 2) performing more than 10 robotic cases per year as a primary surgeon. These qualification requirements were clearly stated in the survey invitation email as well as in the first introductory page of the online survey to encourage potential participants to check if their previous training and experiences in robotic surgery are sufficient enough to answer the survey questions as experienced robotic surgeons. Additionally, we estimated yearly robotic volume for each participant using the data from question 5 (What is the total number of cases you perform per month as primary surgeon [performing 50% or more of the procedure]?) and question 6 (What is the percentage for each type of surgery?). The survey data from those whose estimated annual robotic case volume were fewer than 10 were excluded from further analysis.

The survey instrument was developed to include 20 questions in 4 categories: demographics, systems, ergonomics, and physical symptoms (**Table 1**). Several questions of this survey instrument were used in a previous laparoscopy-related ergonomics survey which one of the authors of this paper was co-authored [21]. Once our instrument was drafted, it was reviewed by several surgeons to confirm the clarity and conciseness of the questions. Participants could respond to questions in various ways including yes/no, single or multiple choices, or numeric value depending on each question. Using Statistical Package for the Social Sciences (SPSS) version 22 (IBM Corp., Armonk, NY, USA), several statistical data analyses including student t-test, χ^2 test, and binary, multinomial, and ordinal logistic regression were performed. The statistical significance was considered at $p<0.05$.

Table 1. Survey instrument

Categories	Questions
Demographics	1. What is your age? 2. What is your height? 3. What is your gender? 4. What is your specialty? 5. What is the total number of cases you perform per month as a primary surgeon (performing 50% or more of the procedure)? 6. What is the percentage for each type of surgery? 7. How many years have you been practicing robotic surgery?
Robotic systems	8. Which robotic system do you primarily use for your practice? 9. What type of features does your chair for robotic surgery have? (Please check all that apply.) 10. How often do you adjust the ergonomic settings of the surgeon's console?
Ergonomics	11. How confident do you feel that your ergonomic settings are set for the best ergonomics? 12. Do you have your ergonomic settings stored at the surgeon's console? 13. How helpful are the ergonomic features of the surgeon's console for reducing your physical strain? 14. Have you experienced any difficulty in microphone/speaker communication with your OR staff when you are sitting at the surgeon's console? 15. Which robotic system components would need more improvement for better ergonomics? (Please check all that apply.) 16. Do you take off your shoes when operating pedals of the surgeon's console?
Physical symptoms	17. Have you ever had any physical discomfort or symptoms you would specifically attribute to your robotic operating? 18. If you answered yes to question 17, which of the following apply? 19. When do these symptoms bother you? 20. How have you attempted to minimize these problems?

OR, operating room.

RESULTS

Two hundred ninety-six gynecologic surgeons completed the survey. The survey data from 7 participants whose estimated annual robotic case volume was less than 10 were removed from the dataset for further data analysis.

1. Demographics

The average age of 289 gynecologic surgeons who regularly practice robotic surgery was 48 years old, and their average height was 174 cm. Among them, 60% were male surgeons. Approximately 90% of survey participants marked their sub-specialty as gynecology (n=260), 7.6% as gynecology-oncology (n=22), and 2.4% as urogynecology (n=7). Participating surgeons reported performing around 17 cases monthly in average as a primary surgeon who performed 50% or more of any procedures. Regarding the yearly case distribution among surgical approaches, robotic surgery was the most popular (98 cases), laparoscopy was the second (73 cases), and other surgical approaches followed with fewer case numbers. Participating surgeons reported practicing for an average of 13 years after the completion of their residency training and practicing robotic surgery for around 4 years until the time of their participation.

2. Physical symptoms

Fifty-four percent of participating gynecologic robotic surgeons (156 surgeons) reported experiencing physical symptoms or discomfort. **Table 2** summarizes the discomforting body parts and their frequencies of symptoms. The physical symptom or discomfort at the fingers and neck were the most commonly reported by the majority of the 156 participating surgeons.

Table 2. Discomforting body parts and reported rate

Body parts	Frequency (%)
Finger	134 (85.9)
Neck	112 (71.8)
Upper back	86 (55.1)
Lower back	65 (41.7)
Shoulder	57 (36.5)
Wrist	58 (37.2)
Eye	43 (27.6)

More specifically, finger fatigue and neck stiffness were the most prominent physical challenges experienced by robotic surgeons. The symptoms or discomfort experienced at the upper back, lower back, wrist, and eye symptoms were also marked with lower reporting rate.

Among the 54% of the surgeons who reported experiencing symptoms, 52.7% of those stated that they had these physical symptoms immediately after performing surgery, 38.8% while performing surgery, and 8.5% had persistent symptoms. Regarding what surgeons did to minimize their physical symptoms bothering them during their surgical performances, 32.7% tried to change the ergonomic settings to have better ergonomic posture, and 33.3% took a break for a short period while 34% of them took no action and simply tried to ignore their problem.

3. Robotic surgical systems

It was found that the majority (85%) of the participating surgeons reported using the da Vinci Si system, which is the third generation of da Vinci system series and the most recent system at the time of conducting this survey, as their primary robotic surgical system. The second generation (da Vinci S) system was used by 11.8% while the first version of the da Vinci was still used by 3.4% of survey participants. Regarding the chairs used at surgeon console, there were several common features such as wheels (97.6%), adjustable height (97.6%), seat rotation (94.8%), and back support (84.2%). Regarding the question asking how often the participating surgeons adjusted the ergonomic settings at surgeon console, 38.7% reported adjusting the settings at every case, 16.0% quite often, 34.2% infrequently, and 11.1% responded that they never adjust ergonomic settings.

4. Ergonomics

When the participating surgeons were asked to respond to how confident they felt that their ergonomic settings were optimized for the best ergonomics, the average confidence level was reported at 3.7 out of 5 which indicated most confident. Most participating surgeons (85.7%) answered that they stored the ergonomics settings in their account at the surgeon console. The subjective helpfulness level of ergonomic features of surgeon's console for reducing their physical strain was reported at 4.0 out of 5 in average. Concerning the challenges in communication with operating room staff through the robot's microphone/speaker system when they are sitting at the surgeon's console, the communication difficulty was rated at 2.8 out of 5.0 indicated experiencing no difficulty and 5 indicated the most difficulty. Over 70% of participating gynecologic surgeons reported that they took off their shoes when they operated the pedals of the surgeon console. **Fig. 1** shows the surgeons' suggestions on which robotic system components should be improved for better ergonomics in robotic surgery. The microphone/speaker system of the current robotic surgical system was ranked the highest need for change by 26.5% of the survey participants, and the foot pedal design followed (17.7%). Improvement on the finger clutch mechanism was proposed by 15.9%, ergonomics settings by 15.0%, master controller by 7.9%, and 3D vision by 7.0% of participating surgeons.

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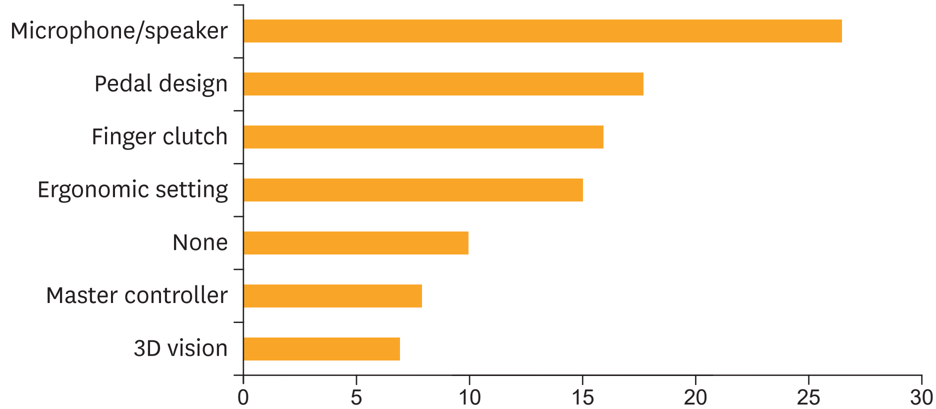

Fig. 1. Robotic surgery system components for improvement.
3D, three-dimensional.

5. Correlation analysis

When the physical symptom reporting rate was correlated with the annual robotic case volume, it was found that the participants with higher robotic case volume reported significantly lower symptom rates compared to those with low case volume ($p<0.05$) (**Fig. 2**). Among the gynecologic surgeons who operated more than 200 robotic cases per year, only 34% reported experiencing physical symptoms or discomfort. However, around 60% of those performing 50 robotic cases or fewer reported that they are experiencing symptoms or discomfort.

The physical symptoms rate was correlated with the confidence level of their ergonomic setting for optimal posture and its subjective rate on the helpfulness of ergonomic features in reducing symptoms (**Fig. 3**). We found that the gynecologists with higher confidence reported lower physical symptom rate ($p<0.05$). Likewise, the surgeons who acknowledged higher helpfulness level of ergonomic features in reducing symptoms reported lower physical strain ($p<0.05$).

When eye fatigue rate was correlated with the generations of the robotic system, the eye symptom report was significantly decreased with da Vinci Si robot users ($p<0.05$) (**Fig. 4**). According to Intuitive Surgical, Inc., da Vinci Si system is equipped with more enhanced HD visualization when compared to the previous da Vinci Standard and S systems.

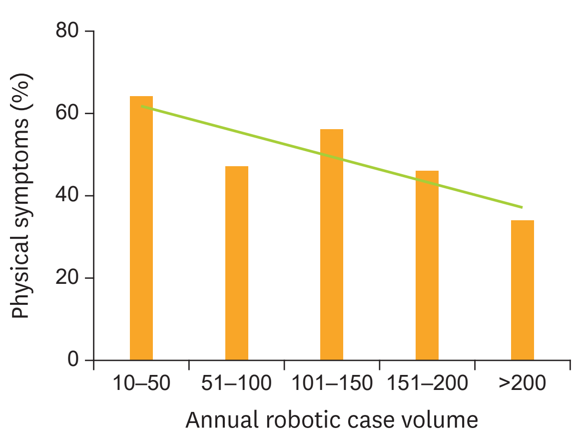

Fig. 2. Correlation between physical symptoms and annual robotic case volume.

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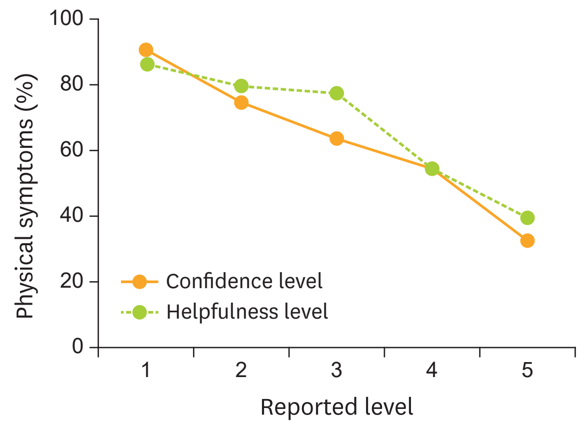

Fig. 3. Correlation between physical symptoms and the confidence level in ergonomic setting management and the helpfulness level for better ergonomics.

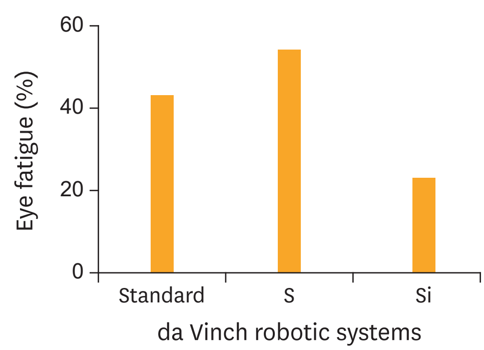

Fig. 4. Correlation between the da Vinci robotic system generations and eye fatigue reporting. Standard, first generation; S, second generation; Si, third generation.

DISCUSSION

Our survey study demonstrated that more than a half (54%) of survey participants reported experiencing physical symptoms or discomfort which were attributed to their surgical practice in robotic surgery. A similar ergonomic study which was conducted with general surgeons primarily performing laparoscopy reported that 86.9% of survey participants noted experiencing physical symptoms or discomfort [21]. Given the differences in the nature, complexity, and length of surgical procedures between general surgery and gynecologic surgery are considerable, direct comparison of these 2 survey studies may have some limitations. However, there were a couple of interesting points for further discussions and investigations. Our symptom report rate in gynecological robotic surgery was significantly lower than laparoscopy in general surgery. This data may support the statement that the ergonomic environment in robotic surgery is more favorable than manual laparoscopy in reducing operating surgeons' physical strains. However, the symptom reporting rate at 54% shows that the ergonomics in robotic surgery should be improved further. For laparoscopy, the surgical case volume was found to be the primary factor influencing surgeons' symptom reporting rate. The general surgeons who had higher annual case volumes reported higher symptom report rate than those surgeons with lower case volumes. Our survey data showed a contrary trend. Those with higher robotic case volume had lower symptom report rate. While the exact reason for this is unknown, authors surmise that high volume gynecologic surgeons

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might figure out personalized ergonomic settings at the surgeon console to minimize any physical strains which they might experience while performing robotic procedures.

A couple of studies have investigated the ergonomics of gynecologic robotic surgery using survey tools. Franasiak et al. [22] conducted a physical ergonomics survey study of minimally invasive surgery through the Society of Gynecologic Oncology. The survey results reported that 88% of surgeons experienced physical discomforts that were associated with MIS including robotic and laparoscopic surgeries. This study did not differentiate the physical strains caused by robotic surgery or laparoscopic surgery. McDonald et al. [23] completed a similar ergonomic survey study for comparing the physical ergonomics of robotic, laparoscopic, or abdominal surgery. They reported that physical symptom rate of the robotic surgery group was higher (72%) than those of laparoscopic (57%) and abdominal surgery group (49%). This study noted a robotic surgery approach and female sex as major risk factors for physical discomfort; however, it did not provide any detailed discussion of how these risk factors might be related to actual physical discomfort.

Additional body-size specific ergonomic investigations should be conducted to investigate whether the current surgeon console design still works well with the surgeons who are smaller or taller for there are more female surgeons in gynecology. Though not from the results of this survey study, the authors anecdotally observed that some female surgeons, whose heights were relatively shorter than others, demonstrated an ergonomic challenge. Because the chairs used with the robotic system could not be lowered enough for them to keep their feet resting on the pedal platform, they maintained a tip-toe posture, especially when pressing down the pedals. This motion did not activate the pedal correctly in a few situations even when operating surgeons felt that the pedal was pressed enough for activation. After experiencing this difficulty, these female surgeons tended to sit at the front edge of the chair to ensure that their heels could touch the pedal platform. While seated in this position, the operating surgeons were in a crouching position which could push the wheeled chair away from the surgeon console. To avoid losing the chair, the surgeons engaged lower back muscles to keep the chair in the necessary position. This awkward posture can cause more physical strain on the lower back, and the unstable seated position can cause an increased risk of the wheeled chair sliding away from the operating surgeon. Currently, the pedal platform of the surgeon console moves in anterior-posterior directions only. If this pedal platform were also able to move in the up-down directions, this ergonomic risk with shorter surgeons may be minimized. We observed similar posture related ergonomic issues with tall surgeons as well. We did not have enough data points to statistically compare how tall surgeons' symptom reports differed from one another. However, several tall surgeons who participated in this survey study reported more physical symptoms. For a few surgeons were significantly taller than others, we surmised that the range of their ergonomic settings might not be wide enough to accommodate the taller height. These surgeons might be required to use a crouching position as the console's viewer height simply could not be raised any higher.

This survey study has some limitations. Because the subjects' participation in this survey study was voluntary, self-selection bias is present and unavoidable as it is commonly expected that the surgeons undergoing any physical symptoms might be more likely to respond to this survey study. This is a very common issue among ergonomics-related surveys. Because it is common that a surgeon performs procedures utilizing several different surgical approaches, identifying the specific causation of particular symptoms could be difficult and not straightforward. Therefore, our participants might respond subjectively even though our questions specifically asked for the symptoms caused by robotic surgery. This survey instrument was designed to be

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used for all the robotic surgeons who practice robotic surgery. Authors realized that vaginal surgery should be included as a type of the surgical platform when this instrument was used with gynecologic surgeons after collecting data from the participants from the AAGL and SRS. This omission will be corrected when authors redesign this survey instrument for more detailed and in-depth ergonomics investigations with gynecologic surgeons such as correlating the intensities and frequencies of symptom into case volumes, types of surgeries, and the generation of robotic systems including the newly released Xi platform. Because the size of the user population in robotic surgery is substantially smaller and the period of the use of this technology in surgery is much shorter when compared with open and laparoscopic surgeries, the current data reported in this study cannot represent any long-term effects in robotic surgery ergonomics. Regarding the case volume related qualification requirement of at least 10 robotic cases per year as the primary surgeon, this minimum case requirement was for collecting data from those who perform robotic surgery procedures on a regular basis. Additionally, this 10-case criterion was not selected based on solid data such as a credentialing requirement in the United States hospitals. Authors acknowledge that different minimum case criteria may change the participant pool and results of this study.

Authors recognized that the questionnaire used in this study could include a question on how unique robotic system features including 3D vision system and articulating instruments helps in reducing physical symptom rates. The questions regarding the timing of the experienced discomfort could be improved to differentiate brief complaints during or right after surgery from repetitive strain as a cumulative issue. Additionally, we did not use standardized pain/discomforted questionnaires asking not only body parts but also levels of pain or discomfort because this addition would make our survey instrument too long. Such standardized questionnaires can be used in future ergonomic research studies in conjunction with physiological assessment tools such as electromyography system to further objectively as well as subjectively investigate the physical symptoms and discomfort at the specific body parts where surgeons reported experiencing the symptoms.

Our study demonstrated that those who expressed higher confidence that their ergonomic settings at the surgeon console was set for optimal posture and this ergonomic feature helped them in reducing physical strains reported significantly lower physical symptom report rate. These results propose to establish a guideline to assist robotic surgeons and identify the optimal operating posture at surgeon console and to implement this guideline into robotic surgery training programs to maximize the ergonomic benefits offered in robotic surgery.

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