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Surgeons' physical discomfort and symptoms during robotic surgery: a comprehensive ergonomic survey study

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Abstract

Background It is commonly believed that robotic surgery systems provide surgeons with an ergonomically sound work environment; however, the actual experience of surgeons practicing robotic surgery (RS) has not been thoroughly researched. In this ergonomics survey study, we investigated surgeons' physical symptom reports and their association with factors including demographics, specialties, and robotic systems.

Methods Four hundred and thirty-two surgeons regularly practicing RS completed this comprehensive survey comprising 20 questions in four categories: demographics, systems, ergonomics, and physical symptoms. Chi-square and multinomial logistic regression analyses were used for statistical analysis.

Results Two hundred and thirty-six surgeons (56.1 %) reported physical symptoms or discomfort. Among those symptoms, neck stiffness, finger, and eye fatigues were the most common. With the newest robot, eye symptom rate was considerably reduced, while neck and finger symptoms did not improve significantly. A high rate of lower back stiffness was correlated with higher annual robotic case volume, and eye symptoms were more common with longer years practicing robotic surgery ($p < 0.05$). The symptom report rate from urology surgeons was significantly higher than other specialties ($p < 0.05$). Noticeably, surgeons with higher confidence and helpfulness levels with their ergonomic settings reported lower symptom report rates. Symptoms were not correlated with age and gender.

Conclusion Although RS provides relatively better ergonomics, this study demonstrates that 56.1 % of regularly practicing robotic surgeons still experience related physical symptoms or discomfort. In addition to system improvement, surgeon education in optimizing the ergonomic settings may be necessary to maximize the ergonomic benefits in RS.

Keywords Robotic surgery · Ergonomics · Da Vinci · Survey · Physical symptom · Discomfort

The use of robotic surgery systems is rapidly and continuously increasing as more surgical specialties including gynecology, urology, general surgery, and cardiac surgery have started using this new technology in their patient care [1, 2]. When compared to traditional manual laparoscopy platforms, current robotic surgery systems have several unique features that present only in robotic surgery. These features include the built-in three-dimensional (3D) stereoscopic display for better visualization, articulating robotic instruments for better dexterity, motion scaling for higher precision, and hand tremor reduction for improved instrument stability [1]. Benefiting from these enabling technologies, several minimally invasive surgical procedures—radical prostatectomy, partial nephrectomy, cystectomy, and pyeloplasty in urology [3–6], hysterectomy,

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sacrocolpopexy, and myomectomy in gynecology [7–9], cholecystectomy and colorectal procedures in general surgery [10, 11], mitral valve repair and revascularization in cardiac surgery [12, 13], lobectomy in thoracic surgery [14], and transoral procedures in head and neck surgery [15]—are commonly performed in robotic surgery. Several clinical studies demonstrated that robotic surgery provided patients with complex conditions such as heart disease, cancers of the prostate, cervix, uterus, and rectum with benefits including greater precision, smaller incisions with lower risk of infection, decreased blood loss and reduced transfusions, less pain and discomfort, shorter hospitalization and quicker recovery time [16–20].

Another unique feature of robotic surgery systems is improved ergonomics for surgeons practicing robotic surgery. Rather than standing and operating on patients at the operating table, a primary surgeon performs procedures while seated at the surgeon console which is equipped with various ergonomic adjustments. The most recent surgeon console allows surgeons to adjust the height and tilt of the stereoscopic viewer, the height of the arm rest, and position of the pedals according to the operating surgeon's body size. Surgeons can place their lower arms on the arm rest in order to reduce upper arm strain. Considering possible ergonomic advantages, it is commonly perceived that the robotic surgery platform provides surgeons with a more ergonomically favorable work environment when compared to traditional open and laparoscopic surgeries [21, 22]; however, it is still not clear the actual benefits to robotic surgeons regarding ergonomics [23].

There are a limited number of ergonomic investigations in robotic surgery using survey instruments. A few studies have used ergonomic surveys with gynecology surgeons to investigate the ergonomic issues that were associated with laparoscopic and robotic surgeries. Symptom report rates varied among these studies. A study conducted by Franasiak et al. [24] showed that 88 % of gynecologic oncologists reported experiencing physical discomforts that were caused by their MIS practices. This study did not separate laparoscopic and robotic surgeries. McDonald et al. [25] reported that the robotic group had higher symptom rates (72 %) than the laparoscopic group (57 %) and abdominal group (49 %). Plerhoples et al. [26] performed a survey study with surgeons in multiple specialties. Approximately 69 % of participants reported physical symptoms or discomfort. Of these 69 % who reported experiencing symptoms, 55.4 % (38 % of total participants) attributed their physical symptoms to their laparoscopic practice, while 36.3 % (25 % of total) to open surgery and 8.3 % (5.5 % of total) to robotic surgery.

To better understand the ergonomics associated with robotic surgery, this survey study was conducted to investigate what types of physical discomforts or symptoms surgeons in different specialties regularly practicing robotic surgery as primary surgeons could experience, how different generations of robotic surgery systems and other factors influence surgeons' symptom reporting, and which robotic system components should be improved for healthier ergonomics in robotic surgery.

Methods

This study protocol was approved by the Institutional Review Board (IRB) at Johns Hopkins University School of Medicine. A survey invitation, containing a link for anonymous participation, was sent by administrators of the Society of Robotic Surgery (SRS), the American Association of Gynecologic Laparoscopists (AAGL), and the Endo-Urological Society (EU) to their members from March to December of 2013. Because each society used their own e-mail distribution list which the authors of this paper do not have access, the exact number of e-mail invitations sent out was not available to report in this paper. Additional invitation e-mails were sent to the robotic program directors of several domestic and international institutes, and the survey link was shared among surgeons practicing robotic surgery in their institutes. As noted in the first introduction page of the online survey, the completed survey served as the consent to participate in this research study.

Potential participants were required to satisfy the following two qualification requirements: (1) completion of residency training and (2) performing more than 10 robotic procedures per year as the primary surgeon. Participation in this survey was voluntary and also anonymous. These qualifications were included in the invitation e-mail and again on survey introduction page to ensure that the survey responses would be obtained from regularly practicing robotic surgeons who completed their residency training. Using the data obtained from questions 5 and 6 asking about participants' monthly case volume and percentage for each type of surgery, we estimated yearly robotic case volume for each participant. Based on this information, the responses from those who did not seem to satisfy the participation requirement of performing 10 robotic procedures per year were removed from the data set for further data analysis.

The online survey was composed of 20 questions in four categories: demographics, systems, ergonomics, and physical symptoms. Questions required various types of responses including single or multiple choices and single or multiple numeric answers. The questions and answer types are listed in Table 1. All data obtained from this online survey were exported in Microsoft Excel format for statistical analysis using Statistical Package for the Social

Table 1 Survey configuration

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

[a] Answer: (SN): Single numeric answer, (SC) single choice, (MN): Multiple numeric answers, (MC) multiple choices

Sciences (SPSS) version 22 (IBM Corp, Amonk, NY). Statistical data analysis was performed using Student's *t* test, Chi-square and binary, multinomial, and ordinal logistic regression to investigate the distribution of reported answers as well as correlation between different questions (e.g., robotic case volume and physical symptom report rate). The statistical significance was considered with $p < 0.05$.

Results

Five hundred and sixteen surgeons completed the survey. Among them, 84 participants indicated they performed less than 10 robotic procedures per year. Therefore, their survey data were excluded from the analysis to ensure that the results represent what experienced robotic surgeons report.

Demographics

The demographic information of 432 surgeons is summarized in Table 2. Approximately 71 % of the surgeons were male. Average age and height of all participants were 48 years old and 175 cm. In regard to participants' surgical specialties, 68 % of total participants were from gynecology, 20 % were from urology, 8 % from general surgery, cardiac, and colorectal, and approximately 3 % indicated other specialties such as otolaryngology, pediatric, and vascular surgeries. The average monthly case volume as the primary surgeon (performing 50 % or more of any procedures) was about 21 cases. The average yearly robotic case volume was 114.5 ± 129.4 cases and was significantly higher than the average yearly case volume of laparoscopic and open surgeries (75.5 ± 97.1 and 40.5 ± 83.0, respectively) ($p < 0.05$). The average length of practice in robotic surgery was almost 5 years, and the average post-residency practicing years were close to thirteen and a half years.

System

Responses related to system and ergonomic settings are illustrated in Table 3. A total of 80.8 % of participants reported using a da Vinci Si system as the primary robotic

Table 2 Participants' demographic information

Demographic questions	Data
Age, years, mean (SD)	47.61 (9.2)
Height, cm, mean (SD)	174.99 (9.4)
Gender, *n* (%)	
Male	305 (71.3)
Female	123 (28.7)
Specialty, *n* (%)	
General surgery	27 (6.3)
Gynecology	295 (68.5)
Urology	88 (20.4)
Other	21 (4.9)
Monthly case volume, mean (SD)	20.96 (16.6)
Yearly case volume distribution among surgical platforms, mean (SD)	
Robotic	114.5 (129.4)
Laparoscopic	75.5 (97.1)
Open	40.5 (83.0)
Endoscopic	17.2 (45.6)
Hybrid	4.0 (13.3)
Years of robotic surgery, years, mean (SD)	4.68 (2.7)
Years of post-residency practice, years, mean (SD)	13.48 (9.5)

Table 3 System, chair, and ergonomic adjustment

System and ergonomics	Data, *n* (%)
Robotic systems	
da Vinci standard	19 (4.4 %)
da Vinci S	63 (14.7 %)
da Vinci Si	345 (80.8 %)
Chair features	
Wheels	404 (93.7 %)
Back support	341 (79.1 %)
Adjustable height	418 (97.0 %)
Rotation	397 (92.1 %)
How often do you adjust the ergonomic settings	
Every case	174 (40.6 %)
Quite often	72 (16.8 %)
Infrequently	140 (32.6 %)
Never	44 (9.3 %)

system for practice, while 14.7 and 4.4 % of participants reported that their primary systems were da Vinci S and standard, respectively. The chairs used by surgeons during robotic surgery had several common features including wheels (94 %), adjustable height (97 %), back support (80 %), and seat rotation (92 %). About 40 % of participating surgeons reported adjusting their ergonomic settings at the surgeon console at every case, 16 % reported quite often, and 33 % indicated infrequently. Approximately 10 % of surgeons reported that they made no adjustment to their ergonomic settings.

Ergonomics

The responses for ergonomics-related questions are summarized in Table 4. When asked to rate their confidence level on how well their console ergonomic settings are set for the most optimal ergonomics, the average confidence level was 3.66 with 5 for most confident. While the majority (81.8 %) of participating surgeons had their ergonomic settings stored at the surgeon console, about 13 % reported that they did not store the setting. Concerning how helpful the ergonomic features of the surgeon console are for reducing physical strain, the average level of perceived helpfulness was about 4 with 5 indicating the most helpful. Regarding the communication using the system's microphone–speaker system between the primary surgeon who sits at a surgeon console and other OR team members including bedside assistants during robotic surgery procedures, the communication difficulty level was reported at 2.87 with 5 as the most difficult and 0 as having no difficulty. When performing robotic surgery, about two-thirds of participating surgeons removed their shoes for better control of the foot pedals. Among 3D vision, master controller, ergonomic settings, pedal design, finger clutch, and microphone–speaker system, participants were also asked to indicate which robotic system components would require more improvement for better ergonomics. The summary of the responses is shown in Fig. 1. Twenty-six percent of participating surgeons expressed the need for improvement in the current microphone and speaker system. Improvement on the pedal design, finger clutch, and

Table 4 Other ergonomic questions

Other ergonomics	Data
Confidence level of the ergonomic settings (5: most confident), mean (SD)	3.66 (1.0)
Ergonomic settings stored, *n* (%)	
Yes	350 (81.8 %)
No	54 (12.6 %)
The feature is not available	24 (5.6 %)
Helpfulness level of the ergonomic features (5: most helpful), mean (SD)	3.97 (1.4)
Communication difficulty with mic./speaker (5: most difficult), mean (SD)	2.87 (1.4 %)
Shoe removal, *n* (%)	
Yes	287 (67.4 %)
No	139 (32.6 %)

ergonomic settings at the surgeon console was suggested by 18, 16, and 15 % of participating surgeons, respectively, while 10 % were satisfied with the current system. Eight and seven percent of participants noted the master controller design and 3D vision system, respectively, required improvement for better ergonomics.

Physical symptoms

More than half of participating surgeons (236, 56.1 %) indicated that they experienced physical discomfort or symptoms which they specifically attributed to their practice in robotic surgery. Figure 2 shows frequently reported physical symptoms and associated body parts. It was found that physical discomfort or symptoms of the fingers (185, 78.4 %) or neck (176, 74.6 %) were reported by the majority of those 236 surgeons. Fifty-three percent (125) reported symptoms at the upper back with frequent reporting of upper back stiffness (61). Experiencing symptoms at the lower back (101, 42.8 %), eye (80, 33.9 %), and wrist (78, 33.1 %) were indicated as well. Among various symptoms such as pain, fatigue, stiffness, and numbness, the most commonly reported symptoms and body locations were neck stiffness (79, 33.5 %), finger fatigue (77, 32.6 %), eye fatigue (71, 30.1 %), and upper back stiffness (61, 25.8 %).

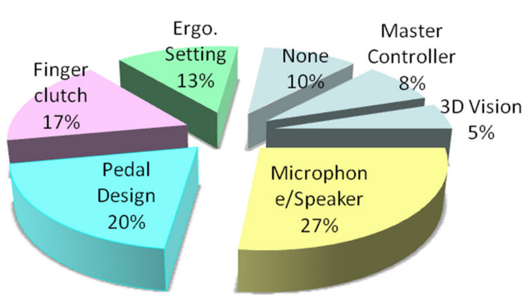

Fig. 1 Robotic surgery system components for improvement

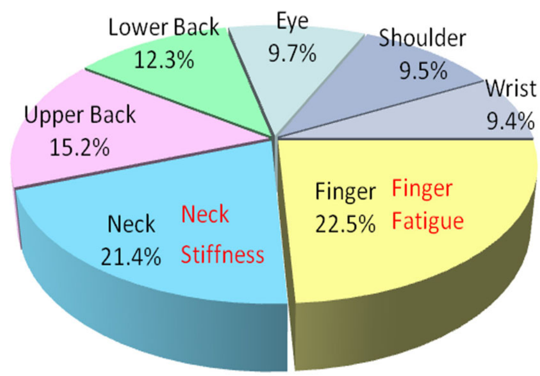

Fig. 2 Body parts experiencing physical symptoms or discomfort

Surgeons were asked when these symptoms bothered them and what actions they took to minimize the symptoms. The responses are summarized in Table 5. Among the 56.1 % who reported experiencing physical symptoms or discomfort, more than half of them (57.5 %) indicated that they were bothered with their symptoms immediately after performing surgery. About a third (36.0 %) experienced discomforting strain while performing an operation and 6.4 % had persistent symptoms. To minimize their symptoms, one-third of them (36.0 %) simply ignored the problem, another one-third (31.8 %) changed the ergonomic settings, and one-third (32.2 %) took a break.

Table 5 Timing of physical symptoms and strategies to minimize the symptoms

Physical Symptoms	Data
When do these symptoms bother you? *n* (%)	
Immediately after performing surgery	136 (57.6 %)
While performing surgery	85 (36.0 %)
Persistently	15 (6.4 %)
How do you attempt to minimize these symptoms? *n* (%)	
Ignore the problem	85 (36.0 %)
Take a break	75 (31.8 %)
Change ergonomic settings	76 (32.2 %)

Correlation with physical symptoms

Table 6 summarizes the physical symptom reporting rates with different annual robotic case volume ranges and the surgical case load distribution among robotic, laparoscopic, and open surgeries. For high-volume robotic surgeons, defined here as performing over 100 robotic cases annually, almost 70 % of their case volume was robotic surgeries. Low-volume robotic surgeons with fewer than 50 annual robotic cases performed more laparoscopy (48 %) than open surgeries (22 %) or robot surgery (30 %). Because many surgeons perform more than one type of operations including open, laparoscopic, and robotic surgeries, it is always challenging to exactly understand to what degree the reported symptoms are caused by robotic surgery. This limitation is further addressed in the discussion section. When we correlated the physical symptom rates with robotic case volume ranges, there was no statistically significant correlation between these two variables and this result demonstrated that the physical symptom report rate was not greatly influenced by different robotic case volumes and varying distribution among surgical platforms.

When we examined the physical symptom reporting by participants' surgical specialties, we found that urology surgeons' physical symptom rate was significantly higher than other specialty surgeons ($p < 0.05$) (Fig. 3). While approximately half of the participants from gynecology and general surgery reported experiencing physical symptoms, 70 % of urology surgeons reported physical symptoms. When we compared the annual robotic surgery case volume between these specialties, we found that the average annual case volume for urology surgeons was 207, while gynecology and general surgery participants had 80 and 90 robotic cases per year, respectively. This difference was found to be statistically significant ($p < 0.05$).

We investigated the correlation between the symptom reporting rate from question 17 (Have you ever had any physical discomfort or symptoms you would specifically attribute to your robotic operating?) and various demographic factors. No correlation between the symptom rate and each demographic factor was statistically significant ($p > 0.05$).Of note, no correlation found between surgeons' age and the symptom rate demonstrated that surgeons'

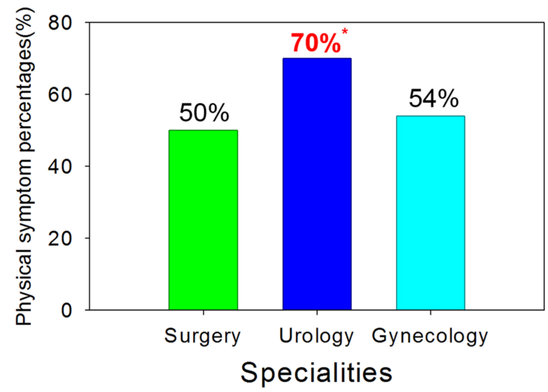

Fig. 3 Physical symptoms by surgical specialties

discomforts did not necessarily increase with advanced age and increased surgical practice period. However, we found several interesting results when specific physical symptom reporting (e.g., eye symptom or lower back symptom rates) was correlated with other factors including several demographic factors. Figure 4 shows the correlation between the lower back symptom reporting and annual robotic case volume. A significantly high rate of lower back stiffness was reported by surgeons whose annual robotic case volume was greater than 200 ($p < 0.05$). There was no difference in the lower back symptom reporting by those whose robotic case volume was between 10 and 100 and those whose case volume was between 101 and 200 cases per year. When the eye symptom rate was correlated with practicing years, we found that surgeons with longer practicing years reported higher eye symptom rate ($p < 0.05$) (Fig. 5). While the eye symptom correlation with robotic surgery practicing years may simply reflect surgeons' age and years of work, it is still unclear whether 3D vision system increases surgeons' eye fatigue when compared to conventional 2D vision system in laparoscopy.

We also investigated whether different robotic systems influenced the physical symptom rates. When we correlated eye fatigue rate with the generation of robotic system, we found that the eye symptom reporting was significantly decreased with the Si system which is equipped with enhanced high-definition visualization ($p < 0.05$) (Fig. 6). We examined whether the physical symptom rates would

Table 6 Physical symptom rates with various annual robotic case volumes and their surgical case load distribution among robotic, laparoscopic, and open surgeries

Annual robotic case volume	Number of surgeons	Symptom rate (%)	Robot case %	Lap case %	Open case %
10–50	155	60.6	30	48	22
51–100	100	52.0	52	31	17
101–200	101	59.4	66	20	14
Over 200	65	46.2	73	14	13

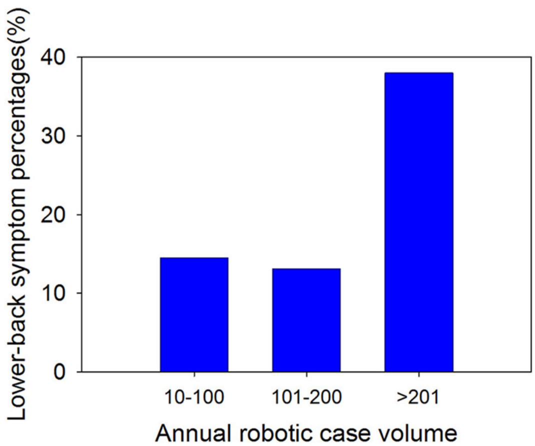

Fig. 4 Correlation between lower back symptoms and annual robotic case volume

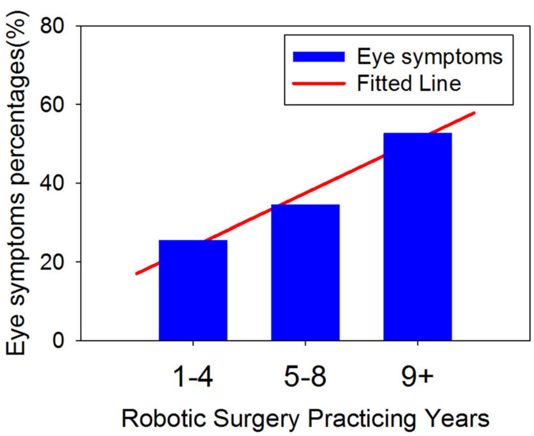

Fig. 5 Correlation between eye symptoms and years practicing robotic surgery

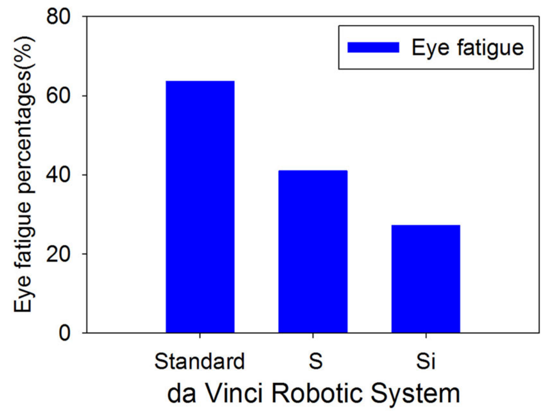

Fig. 6 Correlation between the eye fatigue reporting and da Vinci robotic system generations

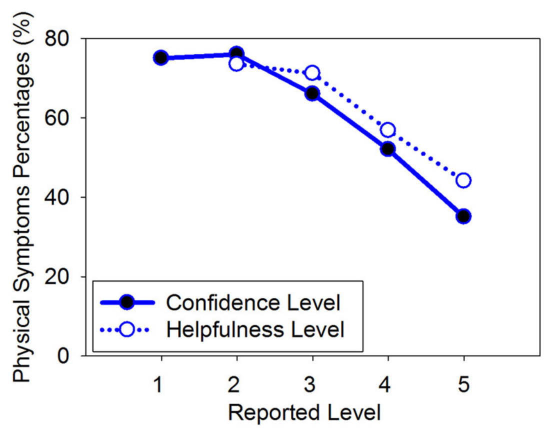

Fig. 7 Correlation between physical symptom reporting and confidence level in managing ergonomic settings and the helpfulness level for improved ergonomics

be correlated with the confidence level in the ergonomic settings and their helpfulness in reducing symptoms (Fig. 7). Our results showed that the robotic surgeons who expressed higher confidence about managing ergonomic settings reported lower physical symptom rates ($p < 0.05$). Similarly, surgeons who reported a higher helpfulness level of ergonomic features also reported lower physical strain ($p < 0.05$). Because we had few participants who reported the helpfulness level at 1, data with helpfulness level 1 and 2 were combined together for statistical analysis and plotting the graph.

Discussion

Considering a surgeon's seated posture and several adjustable ergonomic settings that are available at the surgeon consoles of recent da Vinci systems, the physical ergonomic stresses associated with robotic surgery were generally expected to be very minimal when compared with traditional open and other minimally invasive surgeries. However, it was surprising to observe that more than half (56 %) of the robotic surgeons who participated in this online survey study reported that they experienced physical symptoms or complications which they specifically attributed to their robotic surgery practices. According to a similar ergonomic survey study in laparoscopy, 86.9 % of laparoscopic surgeons in general surgery reported experiencing physical symptoms or complications [27]. Although the symptom report rate in robotic surgery is lower than the rate in laparoscopic surgery, 56 % is still a very high rate and more scientific investigations should take place in order to substantially lower this rate.

Several studies have demonstrated the ergonomic advantages in robotic surgery when compared with traditional laparoscopic surgery. These advantages are improved upper-body posture, lower physical and mental workloads, and effort level with robotic surgery [28–33]. Berguer and Smith [34] investigated the correlation between the ergonomics of robotic and laparoscopic techniques with surgeon experience and task complexity. Expert surgeons reported lower discomfort and difficulty in robotic surgery, and the ergonomic advantages of robotic surgery were more frequently noticed during the performance of more complex tasks. Recently, Lee et al. [35] studied the physical and cognitive workloads exhibited by surgeons performing six surgical training tasks in laparoscopic and robotic surgeries. The results showed that robotic surgery was significantly less challenging in physical and cognitive workloads with novices and robotic expert surgeons; however, this was not the case with laparoscopic expert surgeons.

There are also a few research studies discussing potential ergonomic shortfalls including increased body part discomfort in the neck, less ergonomically favored body postures in the trunk, increased upper arm motion, and high body strain in robotic surgery [36, 37]. Lee et al. [35] showed that novice robotic surgeons might use the arm rest adversely and exhibit greater muscular activation at the trapezius muscles during task performance in robotic surgery. Additionally, the higher muscular activation of the thenar compartment was observed during robotic suturing and cutting tasks.

When comparing the ergonomic reports from this robotic survey study and a previously published laparoscopy ergonomic survey study [27], the neck symptom was interestingly one of the mostly commonly reported symptoms in both laparoscopy (42 %) and robotic surgery (75 %). Regarding the strain relief strategies, approximately 60 % of both laparoscopic and robotic surgeons took a break or changed their posture or the ergonomic settings of the robot. The remaining (40 %) simply ignored the physical symptoms. Laparoscopic surgeons with higher case volume reported higher symptom rate; however, this was not the case in robotic surgery. The participants in the laparoscopic surgery survey had twice the average annual case volume (laparoscopy 212, robotic surgery 115) and twice the average practicing years (laparoscopy 10 year, robotic surgery 5 years). The laparoscopic survey study demonstrated that surgeons who well aware of laparoscopic ergonomic recommendations applied the knowledge into their practice more actively in order to improve their OR work environment, but the correlation between the awareness level and physical symptom rate was not investigated. In our robotic survey study, the surgeons who were highly confident that their ergonomic settings were set for the best ergonomics and felt that these ergonomic features were very helpful for reducing their physical strains actually reported lower symptom rates.

When comparing between surgical specialties, it was found that urology surgeons reported significantly higher physical symptom rates than other specialty surgeons. It is not yet clear why the symptom rate was higher with urology surgeons; however, this is possibly related to other factors such as case types, difficulty, and length as well as amount of suturing involved, blood loss, or working in the pelvis in addition to their higher robotic case volume. Unfortunately, these other factors could not be obtained from our current survey data for further investigation. Acknowledging that increased surgical time and the complexity–difficulty of the surgery would substantially affect surgeons' fatigue, a future survey study instrument would ask more detailed information regarding their cases such as types of procedures, average case duration, and degree of case complexity.

In this survey study, physical symptoms were most commonly reported at the fingers and neck. Due to the absence of tactile feedback at the master controller of the surgeon console, some robotic surgeons might close their fingers excessively when holding objects with instruments. During the performance of suturing and knot-tying tasks, surgeons must squeeze their grip to hold a needle in place because there is no locking mechanism which is present with open and laparoscopic needle holders. Neck stiffness is possibly caused by maintaining a static posture of the neck for extended period of time to control the robot at the surgeon console. Neck stiffness was a common problem with laparoscopic surgeons as they keep a monitor at a fixed position during laparoscopic surgeries [27]. Laparoscopic surgeons have more occasions to articulate their neck while performing tasks such as an instrument exchange. During robotic surgery, surgeons must look through the console's vision system to maintain control which requires them to maintain their neck position in a fixed place for extended period of time.

The communication-related challenges in robotic surgery must be overcome. The most commonly suggested robotic surgery system component for improvement was the microphone-speaker system. The difficulty in communications between the primary surgeon who sits at a surgeon console and other OR team members including bedside assistants using the system's microphone/speaker system was reported at 2.87 with 5 for most difficult and 0 for no difficulties. The first three generations of da Vinci surgical systems have a microphone and speakers for bedside assistants mounted at the vision cart. When the vision cart is placed at a remote location from the OR table, communication becomes more challenging. The most recent version of da Vinci system (Xi) has a microphone and speakers at the patient cart, and this setup may provide OR team members with better communication. The Xi system utilizes a new patient cart design which allows the arms to rotate as a group to be used for multi-quadrant surgeries and the new vision cart with an integrated energy generator; however, the surgeon console is very similar to the da Vinci Si system. As such, the ergonomics features included in this newer system would not be expected to differ from the previous one.

This survey study has some limitations. As many surgeons perform procedures using various surgical platforms, it could be difficult to identify the specific cause of certain symptoms. Though our survey questions regarding symptom report specifically requested to limit reports to the symptoms caused by robotic surgery, responses still remain subjective and identifying the origination of reported symptoms is difficult. Due to the smaller subject population in robotic surgery and shorter time period since the first introduction of robotic surgery technology, when compared with open and laparoscopic surgeries, the study results could not represent long-term effects of the ergonomics associated with robotic surgery. Similar to other ergonomics-related surveys, the surgeons experiencing any physical symptoms might be more likely to participate to this survey study which may lead to selection bias. Participant qualifications of this survey included performing at least ten robotic cases per year as the primary surgeon. This criterion was used in order to collect ergonomic data from those who perform robotic surgery procedures on a regular basis. However, the minimum number was not chosen based on solid data such as a minimal number of cases in order to maintain the surgeon's credential as a robotic surgeon in United States hospitals. With different minimum case criteria, the participant pool and results of this study may have changed as well.

We discovered that the robotic surgeons who expressed higher confidence in regard to managing ergonomic settings and perceived higher helpfulness of such features for achieving improved ergonomics reported lower physical symptom rates (Fig. 6). This result emphasizes the importance of knowledge regarding sound ergonomic settings and its application to a surgeon's daily practice to make their OR environment ergonomically more favorable and to minimize their physical ergonomic strains. Comparing with laparoscopy, there is no scientific investigation on optimal ergonomic settings in robotic surgery. Regarding laparoscopy, van Veelen et al. [38] developed ergonomic guidelines with five focus areas including handheld instrument design, monitor positioning, foot pedal positioning and its use, operating room table height, and surgeon's body posture. Similar ergonomic guidelines on how to achieve the surgeon's optimal body posture by utilizing the current available ergonomic setting options at the surgeon console should be established based on objective and quantitative research data. Authors found a simple ergonomic guideline for the da Vinci system, but this was not practical because the guideline was for the first generation of the da Vinci system which lacks several additional ergonomic settings that are available with the more recent two versions [39]. Once a more comprehensive guideline is developed, systematic ergonomic investigations using biomechanical tools such as motion analysis and electromyography systems should take place to examine the true benefits of better ergonomics in robotic surgery across surgical specialties, age, and gender of operating surgeons. Research investigations about the effect of learning curve on ergonomic discomfort changes could also provide important information as surgeons would feel less anxious and more confident with improved skill learning. Finally, any formal robotic surgery training programs should include this crucially important knowledge about optimal ergonomic guidelines so that any surgeon starting their training in robotic surgery would have the knowledge to maintain sound body posture and to minimize any physical strains while acquiring the best skill set.

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Compliance with ethical standards

Disclosures G. I. Lee, M. R. Lee, I. Green, M. Allaf, and M. R. Marohn have no conflicts of interest or financial ties to disclose.

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