



Ergonomic analysis of laparoscopic and robotic surgical task performance at various experience levels

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Abstract

Introduction Traditional laparoscopic surgery (TLS) has increasingly been associated with physical muscle strain for the operating surgeon. Robot-assisted laparoscopic surgery (RALS) may offer improved ergonomics. Ergonomics for the surgeon on these two platforms can be compared using surface electromyography (sEMG) to measure muscle activation, and the National Aeronautics and Space Administration Task Load Index (NTLX) survey to assess workload subjectively.

Methods Subjects were recruited and divided into groups according to level of expertise in traditional laparoscopic (TLS) and robot-assisted laparoscopic surgery (RALS): novice, traditional laparoscopic surgeons (TL surgeons), robot-assisted laparoscopic surgeons (RAL surgeons). Each subject performed three fundamentals of laparoscopic surgery (FLS) tasks in randomized order while sEMG data were obtained from bilateral biceps, triceps, deltoid, and trapezius muscles. After completing all tasks, subjects completed the NTLX survey. sEMG data normalized to the maximum voluntary contraction of each muscle (MVC%), and NTLX data were compared with unpaired *t* tests and considered significant with a $p \leq 0.05$.

Results Muscle activation was higher during TLS compared to RALS in most muscle groups for novices except for the trapezius muscles. Muscle activation scores were also higher for TLS among the groups with more experience, but the differences were less significant. NTLX scores were higher for the TLS platform compared to the RALS platform for novices.

Discussion TLS is associated with higher muscle activation in all muscle groups except for trapezius muscles, suggesting greater strain on the surgeon. Increased trapezius muscle activation on RALS has previously been documented and is likely due to the position of the eye piece. The differences seen in muscle activation diminish with increasing levels of expertise. Experience likely mitigates the ergonomic disadvantage of TLS. NTLX survey data suggest there are subjective benefits to RALS, namely in the perception of temporal demand. Further research to correlate NTLX data and sEMG measurements, and to investigate whether these metrics affect patient outcomes is warranted.

Keywords Robot-assisted laparoscopic surgery · Laparoscopic surgery · Ergonomics

Minimally invasive surgery has become the mainstay in a variety of surgical disciplines. In addition to smaller incisions, laparoscopy has well-documented benefits for patients including shorter length of hospitalization, decreased

post-operative pain, lower rates of post-operative wound complications, and a quicker return to work [1–3]. However, recent data also suggest unintended consequences of laparoscopy for surgeons including musculoskeletal pain due to increased physical strain [4, 5]. A large survey among minimally invasive surgeons reported that 87% of surgeons practicing laparoscopy experienced subjective physical pain or discomfort [6]. These symptoms correlated most closely with case volume.

Robotic platforms have the potential to enhance surgeon dexterity and technical ability through the use of improved visualization, greater degrees of freedom, and tremor reduction [7]. Robotics may also mitigate some of the physical challenges posed by laparoscopy by allowing surgeons to

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operate from a seated neutral position. Subjective reports have identified promising evidence of ergonomic benefit associated with robotic surgery, however, this has not been objectively quantified to date. A comparison of muscle activation during live surgery using the traditional laparoscopic surgery (TLS) and robot-assisted laparoscopic surgery (RALS) platforms demonstrated a significantly elevated muscle activation in the former [8]. Lee et al. performed a comparison of laparoscopic and robotic surgical platforms in novices performing dry-lab tasks using surface electromyography (sEMG), and identified potential ergonomic advantages associated with the robotic platform [9].

We sought to obtain objective and subjective evidence of ergonomic differences to the surgeon between the laparoscopic and robotic platforms. Surface electromyography (sEMG) was utilized to objectively measure muscle strain, and the National Aeronautics and Space Administration Task Load Index (NTLX) was used to subjectively characterize musculoskeletal load. sEMG involves placing electrodes directly over the skin of a muscle group to capture its electrical signals, which is indicative of the level of muscle activity. It is a widely used tool in human factors and ergonomic research in a variety of disciplines, and has been used by many of the landmark investigations in the nascent field of surgical ergonomics [9–11]. The NTLX is a validated multidimensional rating scale that measures the experience of workload in six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration [12, 13].

Using these tools, our group has studied how patient factors, surgeon factors, and different surgical platforms affect ergonomics to the surgeon. We have shown that tasks described in the fundamentals of laparoscopic surgery (FLS) program identify ergonomic differences between surgical platforms [14]. We have objectively demonstrated that ergonomic challenges associated with laparoscopic and open surgery exist, as well as ergonomic differences between minimally invasive surgical platforms [15]. In the current study, we hypothesized that the robotic platform would be associated with significantly less ergonomic stress to the surgeon compared to the laparoscopic platform for surgeons of each of the experience levels, as measured objectively by sEMG of the bilateral biceps, triceps, deltoid, and trapezius muscles, and as measured subjectively by the NTLX instrument.

Materials and methods

Subject recruitment

Under an IRB-approved protocol, 31 subjects with varying degrees of laparoscopic and robotic experience were recruited to participate in this study. The subjects were

divided into three groups: (1) novices with no clinical experience in either laparoscopic or robotic platform (< 100 laparoscopic cases and < 50 robotic cases); (2) traditional laparoscopic (TL) surgeons (> 100 laparoscopic cases but < 50 robotic cases); (3) and robot-assisted laparoscopic (RAL) surgeons (> 100 laparoscopic cases and > 50 robotic cases).

Surface electromyography (sEMG)

sEMG electrodes were used for the assessment of muscle activation. Electrodes were placed over the bellies of the biceps, triceps, deltoid, and trapezius muscles bilaterally to test overall muscle activation during task performance. These muscle groups have been identified to be active during the most common actions used in laparoscopic and robotic surgery [6, 9].

Each subject performed three FLS tasks: peg transfer, pattern cutting, and intracorporeal suturing. These tasks were performed using a trainer box with a 30° Storz laparoscope or the da Vinci Surgical System® (dVSS) standard platform (Intuitive Surgical, Incorporated; Sunnyvale, CA). Laparoscopic and robotic graspers, scissors, and needle-driver instruments were used. Each task was performed three times on each surgical platform by each subject, and the order of both the tasks and the surgical platforms was randomized. We have previously published on the details of sEMG data collection [8].

Maximal voluntary contraction (MVC)

MVC is the voltage generated by a specific muscle group during a maximal contraction. In order to allow for comparison across subjects, a %MVC is used. This is calculated by dividing the sEMG measurement for a given task by the MVC for that muscle group for that individual. The primary outcome variable in this study was the %MVC. Further details of sEMG measurement and %MVC calculation have been described previously [8].

Data analysis

Continuous sEMG data were collected from each muscle group as the subject performed each of the tasks. The %MVC was calculated for each muscle group during each task repetition. Overall mean %MVCs were calculated for each muscle group and each task on the TLS and RALS platforms, and those values were compared using two-sided paired student's *t* tests. A *p* value of < 0.05 was considered the threshold of statistical significance for differences seen in this study.

National aeronautics and space administration task load index (NTLX)

Each subject completed the NTLX survey after performing all tasks on each platform. This is a well-validated, multidimensional assessment tool that expresses data on a subject’s perception of mental or cognitive workload across six distinct domains: mental demand, physical demand, temporal demand, performance, effort, and frustration [12]. Mean workload values from each of the six domains were calculated and compared between the TLS and RALS platforms using two-sided paired student’s *t* tests with *p* < 0.05 as the threshold for significance.

Results

Thirty-one subjects of varying degrees of expertise were recruited for this study. 14 novices, 12 TL surgeons, and 5 RAL surgeons. Comparative %MVC values are displayed in Fig. 1.

Among novices, the laparoscopic platform consistently had a higher %MVC for most muscle groups in all three tasks, except for the right trapezius muscle which showed increased activation on the robotic platform for the peg transfer and pattern cutting tasks (5.80 ± 2.62 , *p* = 0.04, and 6.62 ± 2.48 , *p* < 0.01, respectively). Conversely, trapezius muscle activation was greater on the laparoscopic platform compared to the robotic platform for the intracorporeal suturing task (8.76 ± 3.26 , *p* = 0.01). In the TL group, a similar pattern arose with increased muscle activation on the laparoscopic compared to the robotic platform. With

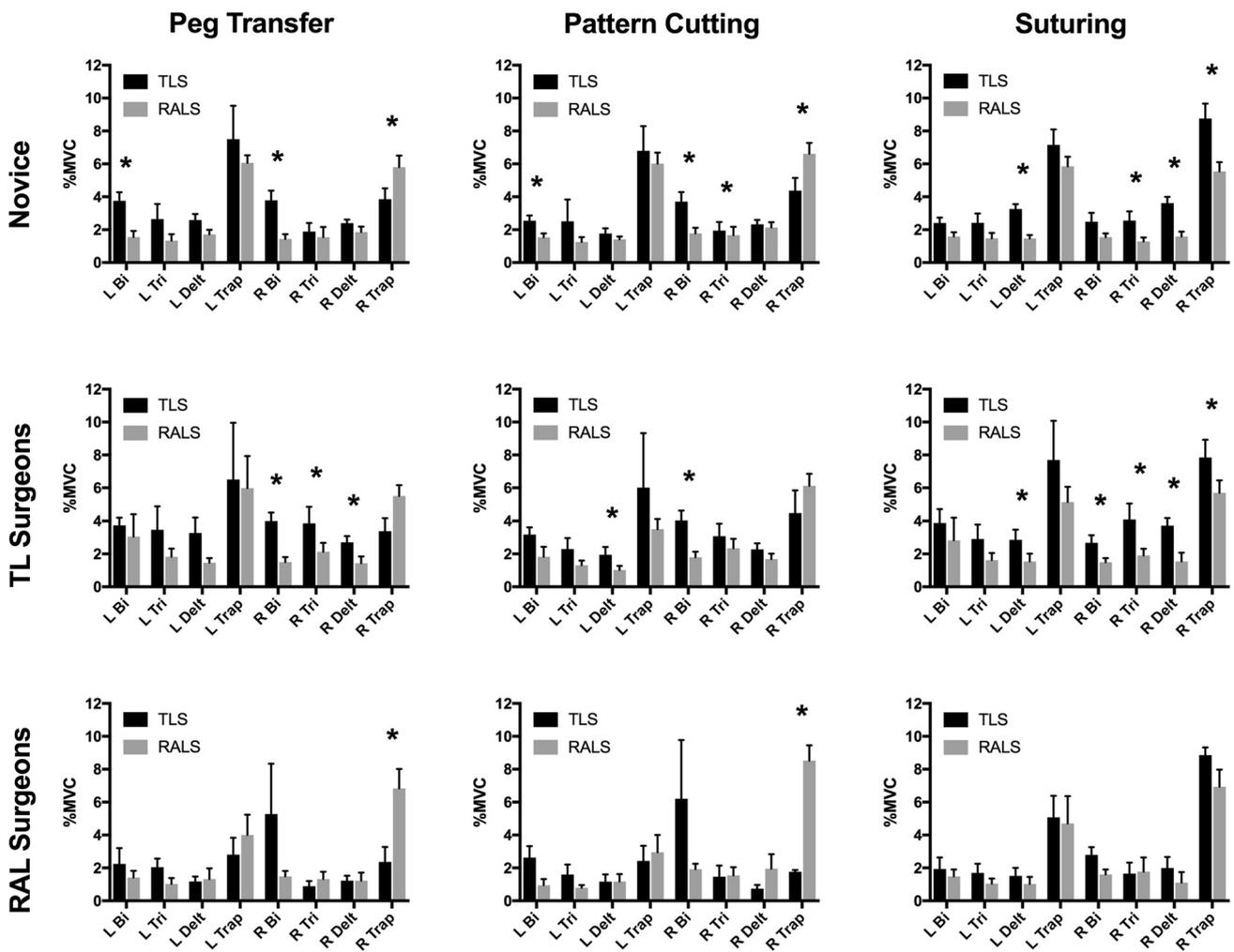


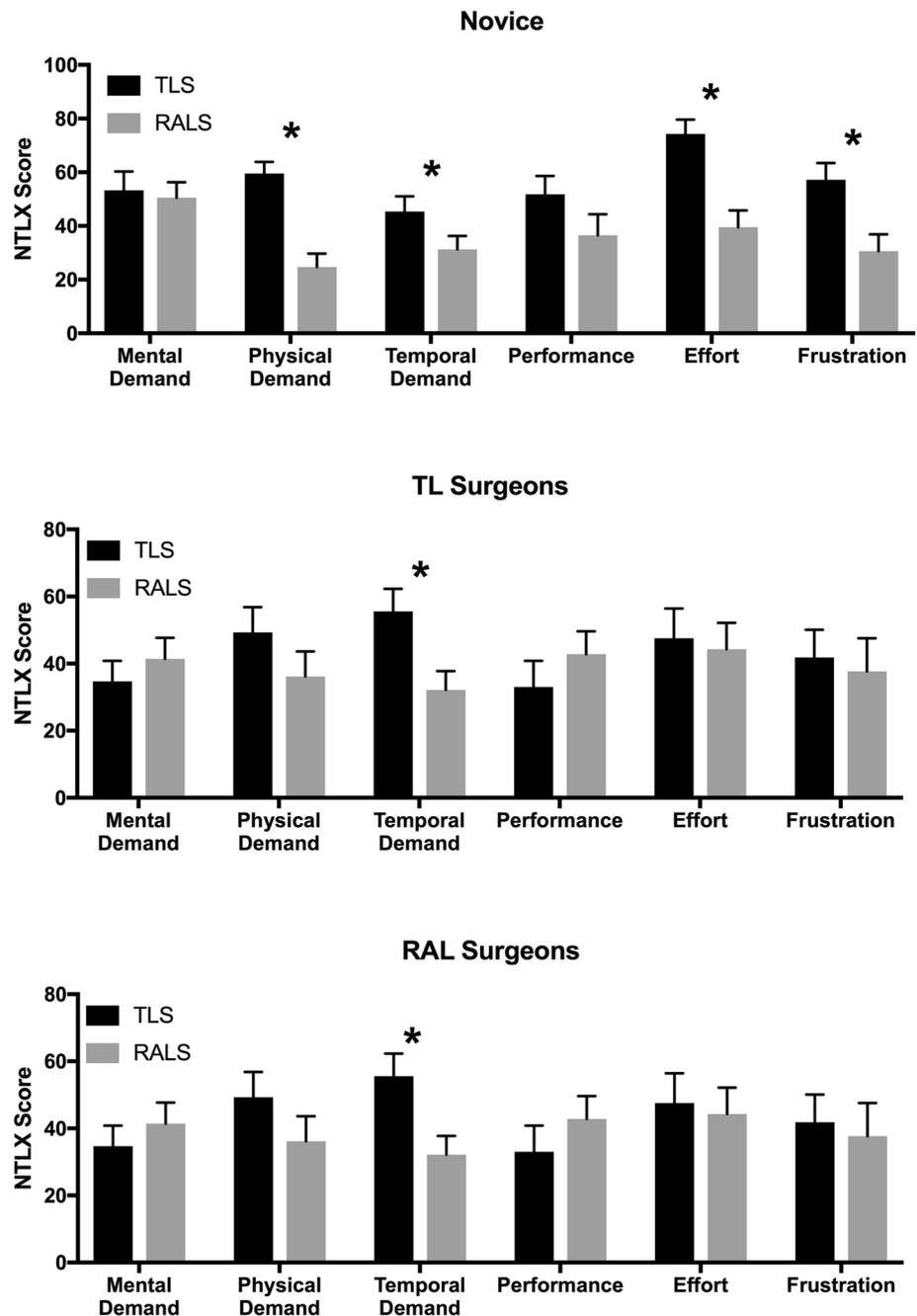
Fig. 1 Mean muscle activation, as quantified by %MVC during traditional laparoscopic surgery (TLS), and robot-assisted laparoscopic surgery (RALS), by muscle group and surgical task. **p* < 0.05

regard to trapezius muscle activation, %MVCs were greater for the robotic platform compared to the laparoscopic platform for the peg transfer and pattern cutting tasks, but not for the intracorporeal suturing task. Of these comparisons, only the right trapezius showed statistically significant levels of activation (7.85 ± 3.73 , $p = 0.04$). In the RALS group, muscle activation was greater on the laparoscopic platform compared to the robotic platform, although none of the comparisons were statistically significant. The only statistically significant difference in the RALS group was for the right trapezius muscle for the peg transfer and pattern cutting

tasks, which demonstrated greater activation on the robotic compared to the laparoscopic platform (6.84 ± 2.64 , $p = 0.04$, and 8.52 ± 2.07 , $p = 0.01$).

The NTLX survey scores were greater for laparoscopic platform compared to the robotic platform in the novice group, with statistical significant differences achieved for four of the six categories: physical demand, temporal demand, effort, and frustration (59.50 ± 16.25 , $p < 0.01$; 45.36 ± 21.22 , $p = 0.02$; 74.29 ± 19.98 , $p < 0.01$; and 57.21 ± 23.47 , $p < 0.01$, respectively) Fig. 2. The only difference that reached statistical significance among the TL

Fig. 2 Mean National Aeronautics and Space Administration Task Load Index (NTLX) scores for novices, traditional laparoscopic (TL) surgeons, and robot-assisted laparoscopic (RAL) surgeons during traditional laparoscopic surgery (TLS), and robot-assisted laparoscopic surgery (RALS). $*p < 0.05$



subjects was for temporal demand on the laparoscopic platform compared to the robotic platform (48.83 ± 16.24 , $p=0.02$), while none reached significance for the RALS group.

Discussion

While the introduction of laparoscopic surgery has improved the patient experience and their outcomes, a growing evidence base has associated TLS with musculoskeletal pain and other symptoms for the operating surgeons. There is potential for robot-assisted surgery to offer ergonomic benefit to the operating surgeon. Single-subject data from our group have shown that laparoscopic procedures are associated with increased activation of the biceps, triceps, and deltoid muscles bilaterally compared to robot-assisted procedures. Early studies directly comparing laparoscopic and robotic surgical platforms among a pooled cohort in a dry-lab setting have also suggested an ergonomic benefit to the robotic platform. It has previously been unclear whether experience on either the laparoscopic or robotic platforms acts to mitigate or amplify these ergonomic effects.

This controlled-setting dry-lab study builds upon our previous findings in the clinical environment. The analysis of muscle activation in subjects performing FLS tasks showed that laparoscopy is associated with significantly higher levels of activation in all muscle groups except in the trapezius muscle. Activation in the trapezius muscles was elevated on both platforms, but to a greater degree on the robotic platform. This difference was only found to be statistically significant in the novice cohort for the peg transfer and pattern cutting tasks, and in the TLS cohort for suturing. This difference in trapezius strain is consistent with previous findings [9, 11]. This is likely due to the strain specific to the configuration of the dVSS surgeon's console. Future robotic designs should be engineered to allow for more flexible head and neck posturing during surgery, potentially alleviating this ergonomic effect.

With regard to the effect of experience on muscle activation, the differences seen in muscle activation diminish with increasing levels of robotic experience, and the only significant differences noted in the expert group were the elevated levels of trapezius activation during robotic task performance. These findings could suggest that high levels of robotic surgery experience mitigate to some degree the ergonomic disadvantage associated with laparoscopic surgery. Conversely, this effect is not noted in experienced laparoscopic surgeons with no robotic experience. It should be noted, however, that the sample size of the RALS group was relatively small, which is a limitation

of the study and prevents us from drawing more definitive conclusions. Future studies recruiting more subjects will help shed more light on the effect of experience on ergonomics.

The results from the NTLX survey suggest that the objective ergonomic benefits provided by the robotic platform are also accompanied by subjective benefits, particularly with regard to the temporal demand associated with performing surgery. While this study and others like it have shown that increased EMG-measured muscle activation is associated with the subjective experience of strain, further study in this area remains to be done. The connection of muscle strain and fatigue among workers is well understood, but no studies to our knowledge in the medical literature have examined the effects of these factors on surgeon health outcomes and patient outcomes. In addition, various interventions have been documented to improve worker ergonomics, but the study of their use among surgeons is only nascent.

In conclusion, performing surgical tasks on a laparoscopic platform was associated with higher muscle activation in multiple muscle groups compared to a robotic platform. The difference between laparoscopy and robotic system was more pronounced in subjects with less experience on both platforms, but they do not disappear among TL surgeons. The trapezius muscles did not follow this pattern, demonstrating more activation on the robotic console although this may be due to the non-adjustable eye piece on older robot systems. NTLX surveys provided subjective data that correlated with the quantitative sEMG measurements. This study contributes to a growing body of literature showing ergonomic benefit of robotic surgical platforms to the operating surgeon.

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Compliance with ethical standards

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