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Electromyography of the Sternocleidomastoid and Forearm Muscles during Laparoscopic Surgery (LS) and Robot-Assisted Laparoscopic Surgery (RALS)

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Competing interests

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All other authors have no competing interests to declare that are relevant to the content of this article.

Author Contributions

MD conceived and designed the study, conducted the statistical analyses, collected and processed the EMG data and drafted the manuscript. LH, CG and DS provided methodological guidance, supervised the research process, and contributed to data interpretation and manuscript revision. All authors approved the final version of the manuscript and agree to be accountable for all aspects of the work.

Ethics approval

This study was granted approval by Lancaster University and the Health Research Authority

Materials and Methods

Ethics and Participants

This study was approved by the Lancaster University Faculty of Health and Medicine Research Ethics Committee (FHM-2025-4948) and the Health Research Authority (25/HRA/1385) and was prospectively registered at Clinicaltrials.gov (NCT06978309) before the recruitment of the first participant. All study participants provided written informed consent before experimentation, and all experiments were conducted following the *Declaration of Helsinki revision of October 2024* and Good Clinical Practice. Participants in this study participated voluntarily and at no point were they under pressure to remain part of the study or were forced to continue participating (as in line with the *Declaration of Helsinki revision of October 2024 and Good Clinical Practice*). Participants could withdraw at any time without consequence, and this autonomy was communicated throughout the study.

Inclusion Criteria

Surgeons taking part in this study had to be over the age of 18 to ensure that their participation is legally valid.

Participating surgeons were signed off as being competent at performing RALS and LS to ensure that competence with the technology and the techniques were correctly assessed.

Surgeons that took part in this study must have obtained a Certificate of Completion of Training (CCT). This allowed for confidence that they were proficient in performing surgical practice.

Exclusion Criteria

Procedures with major complications (above 50% more time than the average for that surgery).

Surgeon suffering from significant co-morbidities (such as heart disease or other advanced chronic conditions) that could affect the results of the study due to this obstructing normal surgical performance.

Surgeons suffering from significant musculoskeletal injury or disorder that may cause the surgeon to deviate from their normal practice or obstruct optimal performance.

Anything the investigator feels will affect the quality of the data obtained or the safety of experimentation/those involved.

Group characteristics

Altogether, 9 surgeons participated in this study, with 1 surgeon participating in both groups, meaning that the RALS group consisted of n=3 and LS group consisted of n=7 with specialties of colorectal, general and hepatobiliary surgery. Subject demographics are presented in the table below.

Table 1. Surgeon demographics for both groups. Data shown as mean ± SD.

		RALS (n=3)	LS (n=7)	*p* Values
Age (Years)		48 ± 7	47 ± 7	0.724
Body Mass (kg)		84.7 ± 10	79.5 ± 13.9	0.589
Height (cm)		176 ± 7.64	172 ± 6.77	0.379
BMI (kg/m^2)		27.2 ± 1.07	26.8 ± 10.4	0.732
Handedness (Left, Right)		1,2	0,7	n/a
Average Glove Size		7.76 ± 0.289	7.07 ± 0.838	0.277
Muscle Pain In the Last Year	**Shoulder**	1	3	n/a
	Neck	1	3	n/a
	Wrists/ Hands	None	1	n/a
	Upper Back	None	2	n/a
Estimated METs / Week (ml/kg/min)		7800 ± 5234	3445 ± 4418	0.137
General Health	**Excellent**	1	1	n/a
	Very Good	None	4	n/a
	Good	1	1	n/a
	Fair	1	None	n/a
Years of Experience		5.3 ± 2.52	17.9 ± 6.82	0.017

Table one above demonstrates when comparing the demographic information of the groups, table one above shows that there was no difference in the mean age of the groups with 48.3 ± 4.1 and 46.6 ± 2.62 years respectively (p=0.724). Table one above also demonstrates that there was no difference in mean body mass (kg), height (cm) or body mass index (BMI) (kg/m^2) or glove size (p>0.05). The handedness of the surgeons was also compared with the surgeons being right-handed, the only exception was one surgeon in the RALS group. From the self-report questionnaires, one surgeon in the RALS group reported shoulder pain and one reported neck pain, but no wrist/ hand or upper back pain was reported. In the LS group 3 surgeons reported shoulder pain, 3 reported neck pain, 1 reported wrist/ hand pain and 2 reported upper back pain in the last 12 months. IPAQ questionnaire data revealed there was no difference in estimated METs/week between groups with the RALS group expending on average 7800 ± 3022 METs/week and the LS group expending on average 3445 ±1670 METs/week (p=0.137). In the RALS group when reporting on general health (on a scale from excellent-poor), 1 surgeon reported having excellent health, 1 good and 1 fair. In the LS group 1 surgeon reported excellent health, 4 very good, one good and one fair. Finally, when comparing years of experience performing RALS and LS respectively in the groups, the RS group had significantly less experience performing RS (5.33 ±1.45 years) than the LS group had performing LS (17.9 ± 2.58; p=0.017).

Study Design and Overview

Consultants across three different surgical specialties were invited to take part in the study (Colorectal, general, and hepatobiliary). They were invited by one NHS foundation trust in the UK, East Lancashire Hospital Trust (ELHT). All surgeons had completed training and regularly performed laparoscopic or robotic procedures.

Surgeons completed three standardised questionnaires: the International Physical Activity Questionnaire (IPAQ) (Sember *et al.,* 2020), the Nordic Musculoskeletal Questionnaire (NMQ) (Pugh *et al.*, 2015) and the 36-Item Short Form Health Survey (SF-36) (Wu *et al.*, 2015). These were completed to contribute to the demographic information of the surgeons in terms of general health, physical activity levels, and level of musculoskeletal pain, but to also ensure participants were safe to take part in the study. Each questionnaire was scored using the standardised scoring systems. Surgeons who suffered from significant mental and/or musculoskeletal conditions that affected their ability to participate in their normal surgical practice were excluded from taking part in the study. Standard operating procedures were followed whether part of the LS or RS group with the addition of the EMG sensors to the surgeons. There was no hindrance to the surgeon's ability to perform the procedures when wearing the EMG sensors.

Before surgery commenced, whilst the patient was in the anaesthetic room being anaesthetized, the researcher set up the research laptop and connected the EMG wireless sensors (Trigno, Delsys, Inc., Boston, MA, US) to the laptop, ensuring EMG protocols were followed in preparation to attach the sensors to the surgeon when they entered the theatre. The laptop and EMG base station theatre set-up are displayed below in figure one

Figure 1. Theatre set-up of investigator's laptop and EMG base station.

During both LS and RALS, surgeons would scrub up as part of normal "scrubbing" procedures and then before the gown and gloves were put on by the surgeon, the researcher applied the electrodes to the forearms and sternocleidomastoid bilaterally after scrubbing with an alcohol wipe and shaving off any hair from the area with a razor, ensuring not to touch the sterile skin of the surgeon. SENIAM guidelines are not available for placement of electrodes on the sternocleidomastoid and forearm muscles, so a placement was devised from guidance of placement on alternative muscles. This ensured that sensors were located over the contracted belly of the muscle which for the sternocleidomastoid was located 50% between the origin and insertion. The forearm muscle placement was on the mid-forearm's anterior aspect. Both placements ensured that the electrode was aligned with the orientation of the muscle fibers. An example of this placement is shown below in Figure 2. The surgeon then put on the gown, gloves, and on a sterile surface was instructed to conduct isometric maximal voluntary contractions (MVCs) used to compare the average electrical activity of muscles during surgery to their MVC.

Figure 2. Example of EMG sensor placement on the sternocleidomastoid and forearm muscle groups bilaterally

Laparoscopic Surgery

The laparoscopic surgery was performed using the laparoscopic stack system available in the operating theatre. This was conducted using surgeons' preferred instruments (scissors, staples, graspers, zero-degree, or thirty-degree angled cameras and energy delivering dissectors). Laparoscopic ports were produced to allow for the instruments and camera to be introduced and navigated by a trained assistant. The surgeon gave clear instruction to assistants when required. The laparoscopic stack was placed in the surgeons' perceived most optimal position, meaning the position of the stack varied in height and distance from the table, surgery to surgery. The surgeon maintained a standing position throughout surgery, ensuring the operating table remained at an optimal height for the surgeon. The monitor location that displayed the endoscope image was determined by the surgeon. This may also mean variation from surgery to surgery based on surgeon comfort.

Robot-Assisted Laparoscopic Surgery

The robot used within the surgeries was whichever robot was available to the surgeon in theatre (da Vinci Xi; Intuitive, Sunnyvale, CA, and da Vinci X; Intuitive, Sunnyvale, CA). Depending on which procedure was performed, surgeons used three or four arms of the robot to access the patients' cart. The procedures were performed with the standard laparoscopic tools, but the procedures were performed by the surgeon sat at the robot's console with their arm rests and seat height adjusted to perceived optimal position.

Figure 3. Surgeon posture while performing RALS.

Electromyography

Muscle activity was recorded bilaterally using EMG from two muscle groups: The forearm muscles and the sternocleidomastoid muscle (neck). The forearm muscles were selected for investigation due to their important role in fine motor movements of the hands and pronation/ supination (Rubio *et al.*, 2024; Gazzoni *et al.*, 2014). The sternocleidomastoid was selected due to its role in posture regulation and chronic neck pain when performing functional movements (Wolff *et al.*, 2022). The skin that lies over the top of the muscle belly was prepared by shaving the area to remove any hair and was cleansed with a 70% isopropyl alcohol pad. Although neither the forearm muscles nor the sternocleidomastoid muscle sensor placement guidance is detailed within the Surface EMG for a Non-Invasive Assessment of Muscles (SENIAM) guidelines (Merletti and Torino, 1999), surface EMG wireless sensors (Trigno, Delsys, Inc., Boston, MA, US) were placed considering this guidance and other advice that was utilized to follow comparable principles of placement (placed on the contracted belly of the muscle). This ensured reliability between each surgery and inter-muscle reliability from other research (Hermens *et al.*, 2000; Young *et al.*, 2011; Falla *et al.,* 2002).

To assess the reliability of EMG, the coefficient of variation (CV) was calculated for each muscle group bilaterally, providing insight into the inter-test reliability. This was calculated both at rest and during an MVC. A lower CV means greater reliability and acceptable results were based on similar research in the field (Brown, 1998). The sternocleidomastoid EMG CV at rest was 8.1% and 7.9% for the right and left side, respectively. The forearm EMG CV at rest was 6.9% and 8.2% for the left and right, respectively. When tested during MVC the sternocleidomastoid showed average variations of 18.3% for the right and 16.1% for the left and the CV data for the forearms showed 15.9% for the right and 19.2% for the left. All data was within the commonly acceptable level of variability (Fauth *et al.,* 2020; Norcross *et al.,* 2010; Balshaw *et al., 2017;* Trentzsch *et al.,* 2023).

The surgeon then performed their isometric MVC of both muscle groups bilaterally before beginning the surgery and data were recorded. Data were collected for 120 s at four 30-minute intervals. The EMG data was collected at a sampling frequency of 2000 Hz. This was filtered through a high-pass (10 Hz) and low-pass (500 Hz) filter. After this stage the raw data was smoothed using root mean squared (RMS) (EMG Works, Delsys Inc., Boston, MA). The final step was averaging out the RMS EMG from each collection period to be normalized to the previously collected MVC EMG and quantified as $\%MVC_{RMS}$.

Surgical Procedures

With the aim of enabling comparison between surgical procedures, data were collected within 2-minute collection windows at four points during the surgery: 30 minutes, 60 minutes, 90 minutes and finally 120 minutes. This was done to reduce the effect of surgery duration. All laparoscopic procedures, including robotic procedures, begin with the surgeons creating trocars (laparoscopic ports in the abdomen) so the beginning of the timing of the surgery began when the first incision was made to create the first trocar as is standard procedure. If the surgeon took a break during the procedure, the timer would be stopped until the surgery resumed. Due to the nature of the general surgical specialty, there is interchange between procedures performed by general surgeons and hepatobiliary and colorectal. The surgeons' lists included the following procedures: General (repair of right inguinal hernia and medial arcuant ligament release), colorectal (anterior resection of rectum, abdominal perineal resection, right hemicolectomy, Hartmann's Procedure), hepatobiliary (partial excision of liver and cholecystectomy).

Colorectal

Anterior resection of rectum: With the patient in a lithotomy position (or modified). Using the laparoscopic camera the sigmoid colon and rectum are mobilized. This is done by dissecting the presacral and dividing lateral attachments. Next arteries and veins in the area (inferior mesenteric artery and vein) are litigated at the appropriate point, with the rectum and sigmoid colon being transected using laparoscopic staplers. The colorectal anastomosis is performed using circular staples or alternatively hand-sewn once another small incision has been created around a trocar. In the meantime, a stoma may be introduced to divert waste. The resected specimen is then removed from the abdomen and after inspection the trocar sites are then closed.

Right colectomy: With the patient lying supine on the table, the right colon and usually the terminal ileum are fixed by dividing peritoneal attachments. The right colic, ileocolic and the right side of the middle colic vessels are divided and then ligated. Next transection of the ileum and transverse colon takes place, with ileotransverse anastomosis being created to ensure that the bowel continues to be attached. The specimen is then removed and taken for pathological analysis. Finally, the abdomen is irrigated with the area being checked for hemostasis and the abdomen wall is closed at the laparoscopic ports.

Hartmann's procedure: This procedure of sigmoid colon resection begins with the mobilization of the sigmoid colon, with the blood vessels ligated and the diseased section of the colon being removed. The distal end of the colon formed a rectal stump, with the proximal end being used as an end colostomy. The colostomy is secured when the trocar sites are closed with the aim to remove all the diseased portions of the colon whilst successfully creating a safe colostomy.

Abdominoperineal resection: This treatment primarily focusses on cancers and other diseases of the lower rectum. This procedure involved removing a portion of the sigmoid colon, anus and rectum in its entirety. Usually, it is conducted with a combined approach of an abdominal and perineal approach. During the stage of abdominal dissection, the mesorectum is separated and the sigmoid colon is mobilised. During the perineal stage, the anal canal and other soft tissues are removed from the site. After this, the perineal incision is closed, and the proximal end of the sigmoid colon is brought through the wall of the abdominals for a permanent colostomy to be created.

Hepatobiliary

Partial Excision of Liver (Hepatectomy): This procedure involves removing a diseased portion of the liver. The goal of this procedure is to remove the localised disease of the liver and ensure that the remaining liver is healthy enough to regenerate and restore full function. Once the ports have been inserted and the abdomen inflated with gas, the surgeon will identify the diseased site of the liver using the endoscope. Ultra sonic energy devices and dissectors are then used to systematically perform the excision along the planned line. The resected portion of the liver is then removed from the site which often requires a larger incision to be made on one of the ports to remove the specimen.

Cholecystectomy: This procedure involves the removal of the gallbladder. It is a treatment for diseases such as cholelithiasis and cholecystitis. Once the laparoscopic ports have been introduced and the abdomen has been filled with gas, the surgeon identifies the cystic artery and cystic duct using the endoscope. These structures are then clipped and divided. After this, the gallbladder if dissected from the liver and removed through the site of the laparoscopic port. It is then placed in a specimen bag.

General surgery

Repair of Right Inguinal Hernia: This procedure repairs the breakdown of the abdominal wall, which has led to a protrusion of the contents of the peritoneum or abdomen. When entering the surgical site, the surgeon will carefully place the abdomen's contents back into an optimal position whilst ensuring that no breakdown of the structures occurs. Once the contents are back in their intended location, a surgical mesh is used on the inner lining of the abdominal wall to repair the defect.

*Medial Arcuant Ligament Release: T*he main goal of this procedure is to reduce decompression of the celiac artery, located just below the diaphragm. The surgeon will identify the location of the medial arcuant ligament and then using specialist tools the dense ligament will be systematically transected to release the pressure on the artery. This will take place superior to the celiac plexus but inferior to the aorta. This will allow the artery to be fully released. The use of intraoperative ultrasound may be utilised to confirm that there has been a full restoration of blood flow and that there is not any remaining compression.

All these procedures were conducted using a multitude of steps that must be seamlessly completed then transition into the next for both laparoscopic and robotic variations. The various comparisons that can be made throughout each of these surgeries (POIs) but also the differences allow for there to be analysis when comparing RALS and LS.

Distribution of Procedures

Both groups completed different types of surgical procedures that have comparable elements in terms of techniques but also provide their own unique challenges. As well as the type of procedure, data was also examined for predicted estimated time of each surgery as shown in Table 2. below. Data presented in text as mean number of hours ± SD in brackets. There was no difference in the mean predicted surgery length for RALS (4.14 ± 1.41) and LS (4.03 ± 1.53) procedures overall (p=0.947). for robot-assisted procedures there were four partial excisions of liver (5 ± 2), one cholecystectomy (2), two anterior resections of rectum (4.5 ± 0.707), three right hemicolectomies (4.33 ± 0.577), three abdominoperineal resections (4 ± 0) and one medial arcuant ligament release (2). The laparoscopic procedures included five partial excisions of liver (4.8 ± 1.1), three cholecystectomies (2 ± 0), four anterior resections of rectum (5 ± 1.15), one right hemicolectomy (5.5), one right inguinal hernia repair (2), one Hartmann's procedure (4) and one hemicolectomy (3).

Table 2. Summary of Case Distribution and Predicted Operating Times for RALS and LS

	RALS	LS	*p* Value

Surgery Type	Partial Excision of Liver	Cholecystectomy	Anterior Resection of Rectum	Right Hemicolectomy	Abdominoperineal Resection	Medial Arcuant Ligament Release	Partial Excision of Liver	Cholecystectomy	Anterior Resection of Rectum	Right Hemicolectomy	Right Inguinal Hernia Repair	Hartmann's Procedure	Hemicolectomy
Surgeries (n)	4	1	2	3	3	1	5	3	4	1	1	1	1
Mean Predicted	5.00 ± 2.00	2.00	4.5 ± 0.71	4.33 ± 0.58	4.00 ± 0.00	2.00	4.80 ± 1.10	2.00 ± 0.00	5.00 ± 1.15	5.50	2.00	4.00	3.00

Surgery Length (Hours)			
Combined Mean Predicted Surgery Length (Hours)	4.14 ± 1.41	4.03 ± 1.53	0.95

Statistical Analysis

Sample size determination

There was a predicted sample difference of 20% in terms of muscular activity between the RS and LS groups based on previously conducted research (Epstein *et al.*, 2018). Sample size was calculated in R Studio using the 'pwr' package and the 'pwr.f2.test' function. With a maximum of ten predictor variables, a large effect size (Cohen's d=0.8), α=0.05, and a desired statistical power of 0.90, this resulted in a sample size of 30 (RALS n= 15, LS n= 15). This was calculated for the right-sided muscle activation in RS compared to LS.

Statistical Analysis

All analyses were conducted using Jamovi version 2.3.21. Data is presented in text and tables as means and standard deviations (SD) unless otherwise stated. Alpha level is reported as exact p values and not described dichotomously as 'significant' or otherwise as recommended by the American Statistical Association (Hurlbert *et al.*, 2019). Effect sized for the linear mixed effects models are reported using conditional and marginal R^2 when considering the overall model fit. Cohen's D is used for specific pairwise comparisons (Lakens., 2013).

Analysis of participant characteristics of Table 1. was conducted using student's t-test. When comparing age, body mass, height, glove size and years of experience between groups, this data was found to be normally distributed. A Mann-Whitney U test was used to analyse the difference between the groups' BMI and estimated expenditure of METs/ week as thesis data were not normally distributed. When comparing the mean surgery length for RALS and LS procedures a Mann-Whitney U test was conducted as data violated normality of distribution.

The normality of distribution of the EMG $\%MVC_{RMS}$ data was examined using a Shapiro-Wilk test. Data was not normally distributed so a linear mixed-effects model was conducted with a subsequent restricted maximum likelihood (REML) estimation and Type III fixed-effects tests. The linear mixed-effects model was conducted with surgery type (RALS vs LS), side of the body (left vs right), time (30, 60, 90 and 120 minutes) and muscle group (sternocleidomastoid vs forearm) as fixed effects and surgeon code as a random effect. This was then used to examine the differences in muscle activation in RS and LS when comparing the sampled time points.