A Surface Electromyogram Evaluation of the Postural Freedom Effects in Laparoscopic Surgery

Horacio M. Pace-Bedetti, Jose L. Martinez-de-Juan *Member, IEEE-EMBS*, Andres Conejero and Gema Prats-Boluda, *Member, IEEE*

Abstract— **It has been demonstrated that laparoscopic procedures benefit patients in terms of recovery time, exposure to infections and trauma. Nevertheless, it increases the number of problems for the surgeons, including the frequency and duration of awkward postures for surgeons. The repetition of these movements is considered the main cause for musculoskeletal disorders in surgeons´ upper limbs. The goal of this study is to evaluate the muscular activity and muscular fatigue effect produced by both, a conventional instrument and an instrument provided with the Postural Freedom (PF) feature; which consists in a ball socket articulation that allows a variable handle-to-shaft angle, on a conventional laparoscopic pistol-grip handle. Seventeen participants were evaluated during a static simulation using both instruments. Surface electromyography was used to compare the instruments in terms of muscular activity in each target position and muscular fatigue produced in the muscles trapezius, deltoids, biceps, and flexor carpi radialis. Trapezius and deltoids were the muscles most affected. Entrance and exit targets and targets facing the participants showed the higher muscular activity values. The PF prototype reduced muscular activity in all the muscles and in the majority of the target positions showing a reduction greater than 70% of the activity required by the trapezius and deltoid muscles in comparison to the conventional tool. Muscular fatigue was produced by both instruments but it presented lower frequency values with PF prototype. The results indicated that the use of conventional instruments impacts negatively on muscular activity during laparoscopic procedures, in terms of positions adopted. The PF feature in laparoscopic instrumentation reduced the muscular activity and also decreased the signals of muscular fatigue in the muscles evaluated in comparison with the conventional tool.**

I. Introduction

Minimally Invasive Surgeries (MIS), is one of the main surgical advances in the last three decades. There are many advantages of MIS over open conventional surgery: less postoperative pain, shorter recovery time, lower risk of infection and reduction of trauma are some of them [1], [2].

However, for surgeons, these procedures have some complications. MIS procedures require more effort, concentration, cause more mental stress than open procedures, and force surgeons to adopt non-neutral postures with phalanges, hands, wrists and arms [3], [4]. Poor ergonomic postures accelerate muscle fatigue and pain because, outside the neutral range, muscles require more energy to generate the same contractile force than in neutral positions [3]. This is the reason why MIS have been commonly associated with higher muscular fatigue, higher levels of discomfort, and higher risk of occupational cumulative trauma injury than open procedures [3], [4].

This study tested the implementation of a Postural Freedom (PF) feature that allows surgeons to reduce the amount of non-neutral postures during MIS procedures. The hypothesis of the work was as follows: if they are allowed to perform unrestricted movement on MIS procedure, surgeons would adopt better positions for their musculature to reach the same target. The term Postural Freedom was used to identify the feature that allows this freedom of movements. In order to evaluate it, a prototype with the PF feature was compared with a conventional instrument with similar characteristics.

The goal of the experiment was to assess the performance that the PF feature had on the musculature in comparison to the fixed conventional pistol grip handle. The symptoms evaluated during a static laparoscopic simulation were muscular activity levels and localized muscular fatigue on trapezius, deltoids, biceps brachii, and flexor carpi radialis.

II. Materials & Methods

A. Participants

During this study, seventeen participants (7 women and 10 men) without previous experience in laparoscopic surgery were evaluated in a static laparoscopic simulation. Expert surgeons of the Hospital La Fe (Valencia, Spain) supervised the participants´ postures. The eligibility criteria were ages from 25 to 50 and heights ranging from 150 to 190cm. Participants did not have any muscular pathology or numbness that caused difficulties with movement of their upper limbs. Both women and men were included in the study without gender discrimination. They performed the experiment with their dominant arm (14 right handed and 3 left handed). Left handed participants performed the study clockwise and right handed counterclockwise in order to obtain similar results from both groups.

B. Instruments

The control instrument had a conventional pistol-grip handle (AdTec® Single Use, Braun, Germany). A specific PF prototype (Fig. 1, left) was designed for this experiment. The PF prototype was 3d printed (Zortrax M200,Zortrax, Poland) using the same handle configuration as the control instrument but variable handle-to-shaft angle created with a

H. M. Pace-Bedetti and A. Conejero Rodilla are with the Instituto de Diseño y Fabricación (IDF), Universitat Politècnica de València (UPV). Camino de Vera, s/n, 46022, Valencia, Spain (e-mail: horaciopacebedetti@gmail.com, ancoro@idf.upv.es).

J. L. Martinez-de-Juan and G. Prats Boluda are with Centro de Investigación e Innovación en Bioingeniería (CI2B), Universitat Politècnica de València (UPV). Camino de Vera, s/n, 46022, Valencia, Spain (corresponding autor by e-mail: jlmartinez@eln.upv.es, geprabo@ci2b.upv.es).

ball-socket articulation connecting both handle and shaft. This variable handle-to-shaft angle was the only difference between instruments. Grip was blocked in both instrument in order to avoid activity resulting from different grasp exertions. The volunteers´ hand size was not considered relevant since both handles had the exact same configuration.

The experiment required a 5 mm port of entry (Endopath XCEL® bladeless trocar, Ethicon, USA), a conventional box-trainer and a 360° degree template (Fig.1. right) which was centered below the trocar access. Similar test was used by other authors to compare laparoscopic instruments [5].

C. Experimental setup

The Institutional Review Board of the UPV approved the recording protocol. The aim of the study was reported to all volunteers, who signed a consent to participate according to the experimental setup used. The muscles evaluated during this experiment were trapezius (upper fibers), deltoids (anterior fibers), biceps (long head) and flexor carpi radialis. Two Ag-AgCl bipolar disposable electrodes were located on each muscle to acquire a signal, following the SENIAM recommendations [6]. The reference electrode was a stainless steel plate placed on the wrist of the dominant arm.

During the experiment, the participants maintained the position at each target (red dots Fig.1) for 55 seconds to verify if there is any difference in short-term periods between both instruments. Five seconds rest between targets were used as a transition between positions in order to identify each movement during the analysis. Two targets at the beginning and the end of the experiment (entrance and exit targets) were included in order to simulate the instrument exchange in real surgery. The participants were guided during the whole test and expert surgeons of La Fe Hospital of Valencia (Spain) supervised the positions in order to evaluate actual surgery positions. The experiments were performed inside a Faraday cage.

D. Signal Acquisition

Surface Electromyography (sEMG) was used in order to analyze the muscular activity in each target and to quantify the muscular fatigue after the whole experiment. The sEMGs were amplified and filtered with a commercial bioamplifier GrassP511®. Cut off frequencies were 3Hz and 1 kHz. The sEMG signals were acquired at 5 kHz sample frequency, by means of NI-USB-6229 card (National Instruments ®, Texas USA). An adhoc software was designed and developed by our group for acquiring and analyzing signals in LabView (National Instruments ®, Texas USA).

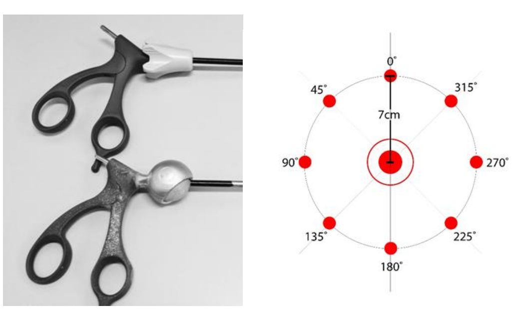

Figure 1. Instruments tested during the experiment (left). Control instrument (above). PF prototype (below). And the 360° degree template used during static laparoscopic (right).

E. Signal Analysis

Two parameters were worked out from sEMG signals: root mean square (RMS) and median frequency (Fmed). RMS values showed the level of physiological activity in the motor unit during contractions [7]. Frequency values were used to identify muscular fatigue [8].

RMS, in 2 seconds windows, was normalized with respect to the RMS value obtained in Entrance target with the control instrument for each participant, in order to show results in percentage. Fmed, was calculated from the Power Spectral Density (PSD), computed as an average of the PSD (Welch´s periodogram) forming windows of 2 seconds.

After testing for normality using D´Agostino-Pearson normality test, unpaired t tests with Welch´s correction were carried out in order to determine the difference between both sEMG parameters from the instruments in each position. The calculations were performed using a confidence level of 95% ($p<0.05$).

III. Results

Fig. 2 shows raw EMG signals; it is possible to observe the level of physiological activity (mV) during contractions with the control instrument in each muscle. The highest myoelectrical activity values are present in trapezius and deltoids muscles. The initial and final minutes were rest positions used to identify the noise and interferences during the experiment.

Two issues were discussed during this study: the first issue is related to the effect that PF had on the muscular activity required in the muscles evaluated; and the second issue is about the muscular fatigue involved in these processes and how PF could improve this symptom.

To identify the effect produced by PF in the muscular activity, Fig. 3 shows RMS (%± SE) normalized values at each target with the PF prototype (light bars) and the control instrument (dark bars). As mentioned, the values are presented as a percentage normalized with respect to the control instrument value at the Entrance target. This target forced participants to activate all the muscles.

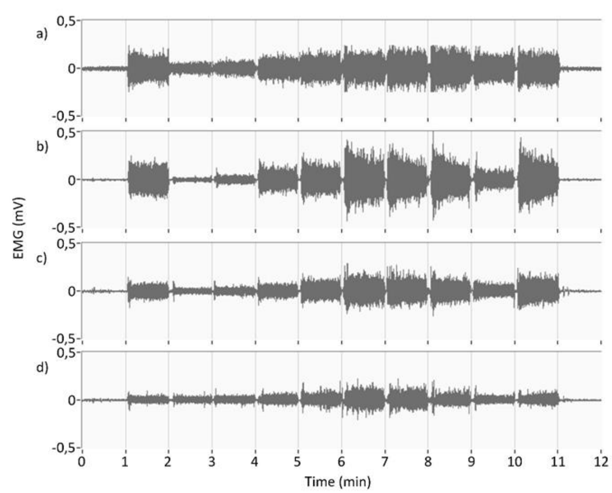

Figure 2. Raw signal of one participant during the experiment with control instrument. Each minute represents a target. The muscles a) trapezius, b) deltoids, c) biceps and d) flexor carpi radialis are presented.

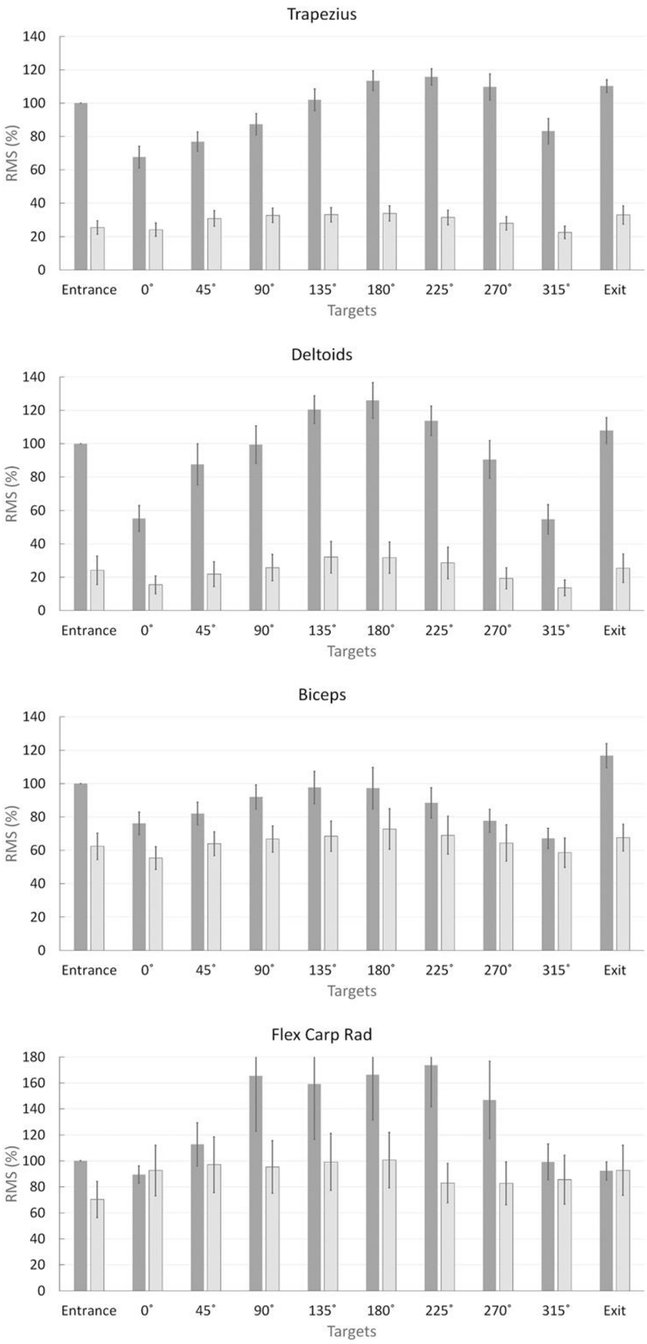

Figure 3. RMS (% ± SE) values of muscles studied at each target. Dark bars represent the control instrument values and light bars the PF prototype values.

The most unfavorable positions (higher RMS values) were generally presented at Entrance and Exit target and targets located facing the participants (135°, 180°, and 225°). These positions were also the most unfavorable with the PF prototype instrument, however they presented lower RMS values in comparison with the control instrument. The values presented significant differences (p<0,05) between the PF prototype and the control instrument in almost all the targets evaluated. The targets which difference was not significant were presented in biceps (targets 270° and 315°) and flexor carpi radialis (targets 0°, 45°, 315° and Exit).

Entrance and Exit target were used to evaluate muscular fatigue when using the PF prototype and the control instrument. These targets required similar body position but the Entrance target was measured at the beginning of the experiment and the Exit target was measured after 10 minutes of effort. Muscular fatigue was assessed by means of the median frequency (Fmed).

Table 1 presents Fmed values during the Entrance and Exit targets in each muscle. The last column indicates the Fmed difference between both targets, the fall in the Fmed values is an indicator of muscular fatigue [9]. The control instrument results showed significant falls in frequency values of all muscles. While the PF prototype results showed significant falls only in deltoids and biceps frequency values. Moreover, the differences in Fmed from Entrance to Exit target (last column) are lower with the PF prototype.

IV. Discussion

Different studies already indicated the forced non-neutral positions as the main cause of musculoskeletal problems for laparoscopic surgeons [3], [4]. In our experiment, the results showed the control instrument highest activity in muscles trapezius and deltoid (Fig. 2a and 2b), and the positions most unfavorable at targets: Entrance, 135°, 180°, 225°, 270°, and Exit (Fig. 3). This study agreed on pointing the fixed handle-to-shaft angle as the cause of high muscular activity, because the fixed handle-to-shaft angle forced participant to abduct and stretch the arm to reach the targets. Similar conclusions were presented by other authors evaluating the pistol-grip handle instrument [5].

In order to evaluate the effect of the PF feature, the activity results of the conventional instrument were compared to the PF prototype. As mentioned, trapezius and deltoids muscles were most affected while using the control instrument, mainly at targets facing the participant and at Entrance and Exit targets. At those targets, the PF prototype reduced the muscular activity required between 70-74 % in trapezius, and between 73-76 % in deltoids (Fig. 3). In biceps muscle, the reduction on muscular activity with the PF prototype at those targets was between 25-42%, and in flexor carpi radialis between 37-52% (Fig. 3).

TABLE I. Fmed values, average and standard deviation (SD), caused by both instruments in all the muscles

Muscle	**Instrument**	**Average ± SD (Hz)**		
		Entrance target	***Exit target***	***Difference***
Trapezius	Control	60,5±1,2	57,7±1,0	2,8*
	PF prototype	39,0±1,3	40,2±0,9	-1,3
Deltoids	Control	69,0±1,5	64,4±1,0	4,6*
	PF prototype	59,6±0,7	58,1±0,7	1,5*
Biceps	Control	58,7±1,3	54,1±1,0	4,6*
	PF prototype	50,5±0,8	45,9±0,9	4,6*
Flex Carp Rad	Control	77,7±2,0	65,7±2,9	11,9*
	PF prototype	54,9±1,4	53,2±1,7	1,7

* Significant differences (p <0,05)

The low muscular activity reduction showed on biceps and flexor carpi radialis by the PF prototype had different reasons. Bicep muscle is in charge of forearm flexion, which was necessary to maintain the instrument inside the abdomen. This means that this position was forced by the point of entrance, not by the instrument.

In the case of flexor carpi radialis, it is one of the muscles in charge of wrist abduction and wrist flexion. These movements were necessary to insert fingers into the rings of the instrument handle, and both instruments had the same handle configuration.

Overall the results indicated that, if a surgeon uses the conventional pistol grip instrument, it is preferable to reach targets located between 0° and 45°. With the PF prototype, surgeons could reach different targets regardless of its location and relax their musculature once the target is reached. In 2004, an study evaluating a needle driver with variable handle-to-shaft angle at 0°, 40° or 80° provided similar results [5]. The goal of the study was to identify the optimal ergonomic handle-to-shaft angle for suturing. The authors also identified the fixed handle-to-shaft angle as the main cause of great abduction at the shoulder and flexion of the elbow. The fact that they did not find significant differences between angles 40° and 80° could means that surgeons had their own optimal handle-to-shaft angle for suturing, and the use of PF could be an effective solution.

In 2017, an study evaluating an instrument that rotated 360° transversely to the shaft of the handle [10] indicated that this instrument reduced the muscular activity on biceps and flexor carpi radialis, but it was not reduced in trapezius and deltoid muscles, which are considered essential to reduce the musculoskeletal disorders in back and shoulder. The results presented by the PF prototype in trapezius and deltoids muscles indicated that this feature could be a key factor to reduce the muscular activity on these muscles.

Regarding muscular fatigue evaluation, a frequency parameter (Fmed) was calculated for Entrance and Exit targets (Table 1). According to the Joint Analysis of the Spectra and Amplitudes method (JASA), muscular fatigue is detected when the electrical activity generated by the muscle increases and the frequency values fall [11]. This method was used because it discriminates between fatigue-induced and force-related changes in the EMG signal. Table 1 shows Fmed values of both instruments at the Entrance and Exit targets. The normalized RMS results of Entrance and Exit target were included in Fig. 3.

According to JASA method, the control instrument presented indicators of muscular fatigue in trapezius, deltoids, and biceps muscles. In contrast, the PF prototype showed indicators of muscular fatigue in deltoids, biceps, and flexor carpi radialis. These results suggested that muscle fatigue was produced after 10 minutes of experiment with both instruments. Nevertheless, considering that muscular fatigue is directly related to force exerted [12] it is possible that the lowest values of muscular activity presented by the PF prototype could increase the operation time necessary to cause muscular fatigue on surgeons.

V. Conclusion

The PF is a feature easily implemented to laparoscopic instruments and beneficial for the surgeons' musculature. The reduction of fatigue and muscular activity has the potential to increase the effectiveness of laparoscopic procedures and reduce the risk of mistakes during longer procedures. A limitation of this study is that the PF prototype precision was not evaluated during the experiment. This is an important issue for future research because the lab observation suggests that the precision with the PF prototype could be improved.

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