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Ergonomic assessment of a new hand tool design for laparoscopic surgery based on surgeons' muscular activity

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ABSTRACT

Laparoscopic surgery techniques are customarily used in non-invasive procedures. That said traditional surgical instruments and devices used by surgeons suffer from certain ergonomic deficiencies that may lead to physical complaints in upper limbs and back and general discomfort that may, in turn, affect the surgeon's skills during surgery. A novel design of the laparoscopic gripper handle is presented and compared with one of the most used instruments in this field in an attempt to overcome this problem. The assessment of the ergonomic feature of the novel design was performed by using time–frequency analysis of the surface electromyography (sEMG) signal during dynamic activities. Singular Spectrum Analysis (SSA) was used to decompose the sEMG signal and extract the median frequency of each muscle to assess muscle fatigue. The results reveal that using the proposed ergonomic grip reduces the mean values of the muscle activity during each of the proposed tasks. The novel design also improves the ease of use in laparoscopic surgery as it minimises high-pressure contact areas, reduces large amplitude movements and promotes a neutral position of the hand, wrist and forearm. Furthermore, the SSA method for time–frequency analysis provides a powerful tool to analyse a prescribed activity in ergonomic terms. The proposed methodology to assess muscle activity during surgery activities may be useful in the selection of surgical instruments when programming extended procedures, as it provides an additional selection criterion based on the surgeon's biomechanics and the proposed activity.

1. Introduction

Laparoscopic surgery techniques (LST) are widely used in numerous types of surgeries nowadays due to the proven benefits for the patients and the cost savings for health centres. However, the surgeons' surgical instruments and devices suffer from certain ergonomic deficiencies that often produce physical complaints in the upper limbs and general discomfort that may adversely affect the surgeon's skills during surgery (Alleblas et al., 2017). Two general factors contribute to these problems: the prolonged static postures and a higher activity with upper limb muscles in uncomfortable postures (McDonald et al., 2014; Dalager et al., 2017; Lowndes and Hallbeck, 2014; Tsafrir et al., 2015), leading to numbness or tingling in the arms or hands. These prolonged static postures are strongly related to musculoskeletal disorders and, therefore, special attention must be paid to ensure occupational health and safety for the surgeon.

Adequate instruments must be used to achieve a comfortable working position for the upper limbs and to reduce the muscle activity and fatigue related to the prolonged postures adopted by the surgeon. In this sense, surgeons, designers and engineers have been working together to obtain standard anthropometric measurements to improve the designs of laparoscopic instrumental for LST (Yu et al., 2016b; Sun et al., 2014; Hallbeck et al., 2017). New instrument designs must consider ergonomic aspects during surgery, as widely proven in the literature (Choi, 2012; Alleblas et al., 2016; Tung et al., 2015). However, conventional devices and surgical instruments used in LST lack ergonomic criteria to reduce muscle fatigue in surgeons. Among the documented ergonomic limitations affecting the minimally invasive approach are operational issues with instrument design (González et al., 2015), force feedback (Smit et al., 2017), stresses caused by monitor placement (Berguer et al., 2003; Yu et al., 2016a; Harada et al., 2018), and perceptual challenges. Van Veelen and Meijer (1999) reported MIS-related surgeon discomfort rates of 40% to 60%; larger survey studies on the subject haven reported symptoms (often persistent) related to MIS in the 12% to 18% range. They also revealed that poor design of laparoscopic surgery instruments lead to work-related diseases among surgeons relating to hand and upper limb discomfort, hand paraesthesia and temporary compression neuropathies of the fingers. More recently, several studies conducted by Yu et al. (2016b,a) show that modern

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Fig. 1. Tool handle of the laparoscopic gripper developed in the ERGOLAP Project.

instruments have unnatural handling characteristics as a result of poor ergonomic design. These studies found that inadequate adjustment of the handle to the ergonomics of the human hand result, for example, in too higher forces and too smaller movements of the fingers to move the grip. This leads to fatigue or cramping in the surgeon's hands. Studies such as Sutton et al.'s (2014) highlight this by exposing how surgeons with a smaller hand size had to treat their hands more often and experienced more musculoskeletal complaints compared to surgeons with larger hands. As Trejo et al. (2007) point out in their study, one of the leading causes of surgeon post-surgery pain or numbness is the non-neutral postures adopted during the MIS procedure caused by poor ergonomic design. Cuschieri (1995) set the basis and described how surgical fatigue resulting from poor design could lead to mental exhaustion, increased irritability, impaired surgical judgement and reduced dexterity. Studies such as that of Van der Peijl and Herder (2001) found that an inadequate adjustment of the handle to the ergonomics of the human hand leads to uncomfortable positions of the arm and small finger movements with excessive manipulation forces. Another reason for discomfort, according to the study by Aitchison et al. (2016) is neck and shoulder stress from looking at the monitor. The surgeon has no direct control over his direction of vision when an assistant holds the endoscope, which can lead to communication problems and disturb the surgeon's eye–hand coordination. Besides, the laparoscopic image is often unstable due to tremors and sudden movements of the surgical assistant, as the task is often a time-consuming and tiring one performed in a confined space, which leads to non-ergonomic circumstances. Other studies confirm this by pointing out that sustained postures without sufficient recovery time are risk factors for fatigue and musculoskeletal injuries during surgery (Szeto et al., 2012).

Several studies have superficially investigated the opening and closing of the surgical instruments in quasi-static conditions (Maithel et al., 2005), the force and motion in instrument handling (Horeman et al., 2014), the hand and finger kinematics (Pérez-Duarte et al., 2014; Loukas and Georgiou, 2011) and the surface Electromyography (sEMG) activity during different laparoscopic procedures and with different laparoscopic graspers (Berguer et al., 2003; Judkins et al., 2006; Szeto et al., 2013; Dufaug et al., 2016; Zhang et al., 2017). Some studies such as that of Berguer et al. (1998, 1999), Emam et al. (2001, 2002), Quick et al. (2003), applied surface electromyography (sEMG) analysis to demonstrate that different handle designs transmitted various stresses to the forearm muscles. However, in the studies mentioned above, the sEMG data processing was performed under the supposition of isometric contractions and, therefore, considering the sEMG signal as a stationary signal. Muscle contractions performed by surgeons during their activity are dynamical, and therefore, non-stationarity must be considered to assess the functionality of the hand tool properly. There is a gap in the literature concerning time–frequency analysis in the assessment of muscle fatigue during laparoscopic surgery and also, in the comparison of different dynamic tasks and instruments. The objective of this work is to compare a novel design of the handle of the laparoscopic gripper with one of the most used instruments in this field by using time–frequency analysis techniques to evaluate ergonomics during dynamic activities. Singular Spectrum Analysis (SSA) was used to quantify time–frequency parameters to assess the performance of the novel design. SSA is a non-parametric technique that decomposes an original time series into a set of additive components. The grouping of these components allows not only to separate the interest signal from noise but to group the different components according to several criteria based on the information given by them. The use of SSA techniques enables isolating noise and retrieving time–frequency parameters to perform an ergonomic assessment of the tool based on physiological criteria.

2. Materials & methods

2.1. Description of the evaluated tool design

A novel gripper design for laparoscopic surgery (Fig. 1) has been used in this study (EU patent number EP10382362). This gripper was the result of the ERGOLAP Project (Ergolap Project, 2008-2010), developed by some authors of this work coordinated by the Centro de Cirugía de Mínima Invasión Jesús Usón (CCMIJU) and the Instituto de Biomecánica de Valencia (IBV).

The design and development of the gripper depicted in Fig. 1 is based on an ergonomic study conducted with 135 surgeons during their training periods on LST in the CCMIJU. The design guidelines considered in this study considered a sizeable palmar grip surface, high precision and high turning capacity. The results of the study and design assessment have been collected in the work of González et al. (2015). In that work, the surgeon's satisfaction while using the tool was studied and assessed qualitatively. Accordingly, the idea of a grip controlled by rings (as in a pair of scissors, for instance) was neglected.

The design of the gripper proposed in Fig. 1 allows gripping the tool in both power and precision modes. A power grip allows handling the tool firmly yet apply force if necessary. A precision grip allows for an accurate rotation and orientation but pressure at the end of the tool. The proposed design overcomes some ergonomic problems present in other types of Minimally Invasive Surgical (MIS) grippers according to the design criteria of the ERGOLAP Project, aimed at designing ergonomic criteria to reduce fatigue during MIS interventions and thus, to reduce the risk of suffering occupational diseases such as thenar injuries. In this sense and from an ergonomic point of view, a neutral position of the wrist is easily achieved as the design allows the entire palm to take part in the grasping. The gripper has been designed

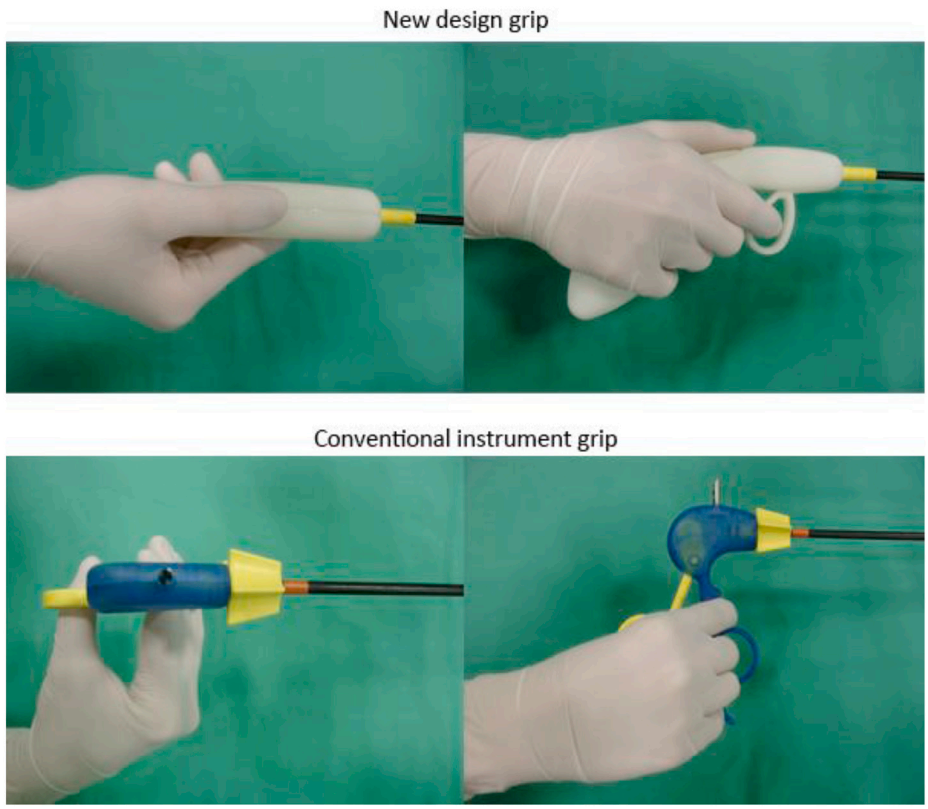
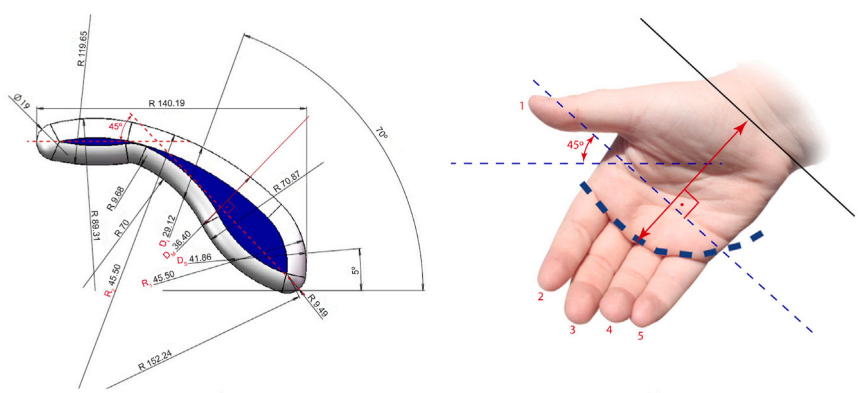


Fig. 2. Comparison of the grip of the new design developed in the ERGOLAP Project (top) and the Ring handle with ratchet rotatable from Richard Wolf GmbH (Knittlingen, Germany), product number 8393.0004 (bottom).



a) b)

Fig. 3. (a) Parameters used in the study. (b) Guidelines for the determination of the handle position.

to distribute the surface pressures among the palm and the fingers equally, i.e., the surface of the gripper has been optimised to provide a major contact with the whole hand to reduce wrist flexo-extension movements, tendon lengthening, elbow distension and to reduce the shoulder range of motion. The length and the diameter of the gripper have been increased compared to traditional MIS grippers for a better adjustment of the different hand sizes and a higher contact surface for the fingers and to reduce pressure in localised areas, especially in the thumb (see differences in the grip between tools in Fig. 2).

Regarding the geometrical design developed within the ERGOLAP Project (Fig. 3a), there are three significant parameters: inferior diameter (D_I), middle diameter (D_M) and superior diameter (D_S). Middle diameter is defined as the diameter at the inflexion point of the handle curvature. This position also determines the relative position of the hand with respect to the handle during the grip. Also, for surgeons, this diameter matches the line defined between the third and fourth metacarpal phalanx (Fig. 3b). Inferior and superior diameters correspond to the narrower and broader parts of the handle, respectively. These diameters, as shown in Fig. 3b, match the line defined by the second and third phalanx for D_I and the line defined between the fourth and fifth phalanx for D_S. Another feature of this handle is the angle between the handle and the rod's clamp, set to 45 ° (Fig. 3b). This angle is a design constraint that must remain fixed, regardless of the size of the handle or the surgeon's hand, as it is a recommended value in previous studies (Van Veelen et al., 2003) approved by all surgeons who participated in the ERGOLAP Project. In this sense when the entire palm is involved in gripping the handle, it is easier to achieve a neutral position of the wrist, which reduces fatigue and, therefore, the risk of injuries over time. The gripper has a thumb-actioned wheel to spin the end of the tool on its axis; a clockwise movement is obtained by abducting the thumb over the wheel and a counter-clockwise by adducting it Regarding the tool's use, the gripper has a trigger to open and close the forceps: by flexing the distal and middle phalanx of the index finger the forceps opens, and it closes by extending the distal and middle phalanx of the index finger. The customised tool can be manufactured according to the Palm Length Measured (PLM) value, which is the most appropriate anthropometric value as proven in a previous study (González et al., 2018). This value allows obtaining scaled models for different hand sizes in a 3D CAD environment.

2.2. Experimental setup

A sample of ten volunteer subjects with neither previous surgical experience nor medical training was selected to assess the functionality and the ergonomics of the new design. Subjects were informed about the research procedures before they gave informed consent, following the ethical standards of the declaration of Helsinki. The experimental procedure was approved by the Local Ethics Committee at the University of Extremadura Their ages varied from 24 to 28 years (mean age = 26 ±2.7, years), and the distribution of the sample population by sex is 2 female and 8 male.

The subjects completed four sequences of hand–eye coordination exercises commonly used in surgeon's training tasks (see Fig. 4), using the two instrument handles in a random order in each task to reduce the influence of the dominant hand in the perception of fatigue. The instrument was a common ring handle (Richard Wolf GmbH 8393.0004) made by Richard Wolf GmbH (Knittlingen, Germany, see Fig. 3, bottom), and the new design of handle presented in Ergolap Project (2008-2010) and González et al. (2015) (Fig. 3, top). The ring handle instrument (CE 33121) was selected as it was one of the most common in laparoscopic surgery. Subjects were not informed about the properties of the handles, i.e. the new prototype remained unknown for them. The above conditions ensured equity in the assessment of muscle fatigue, as neither the order nor the predisposal to manage the handle with the dominant hand were reflected in the sEMG signal.

2.3. Description of the tasks

As mentioned above, each task was performed by using the two laparoscopic handle designs at the same time, one in the dominant hand and the other in the non-dominant one, to simulate a real case of laparoscopic surgery (Fig. 5). The subject was asked to place chickpeas in a place holder according to the sequences proposed the experiment (see Fig. 4). Both arms had to be used to achieve the objective of retrieving a continuous muscle activity in each arm. The subjects were asked to use the right hand to place the chickpeas in the right-hand side of the placeholder and the left hand for the left-hand side. The subjects could fill the middle column with either of the hands. Chickpeas were used as they are non-deformable and irregular in shape, an ability trained in regular laparoscopic exercises. Each task had a maximum time of five minutes, with no prior training period. If the subject completed the exercise within the set time, he/she was asked to continue with the same exercise until the 5 min were up. Once the subject had completed the four exercises, they were given a 20-minute break to reduce the effects of muscle fatigue. They were then asked to perform the same tasks again, this time changing the handles between hands. With this, the muscle activity in the use of the new design for both the dominant and non-dominant arms could be assessed in similar conditions.

2.4. Data acquisition

The assessment of the ergonomic characteristics of the traditional and the new handle design is based on the analysis of muscle activity during an everyday operation in laparoscopic surgery. The sEMG signal of the primary effector muscles (*brachioradialis*, *extensor digitorum*, *extensor carpi ulnaris*, *anterior deltoid* and *upper trapezius*, for both arms) was recorded for the selected tasks (Fig. 4). The electrode placement was performed by following the standards given by the SENIAM (Hermens et al., 1999) or the well-known work of Konrad (2005) for the muscles not referenced by the SENIAM.

The sEMG signals were recorded by means of Delsys® Trigno® system at a sampling frequency of 2 kHz. Twelve channels were used to measure the sEMG signal of the six main effector muscles of both arms that domain the movement in laparoscopic surgery (see Fig. 6 for further details). sEMG signals were acquired during each subject's experiment (Fig. 5) with the Delsys® EMGworks® (version 4.1.1) and processed in Matlab (The MathWorks, Inc.).

2.5. Data processing & analysis

The raw sEMG signal was rectified and filtered to obtain the signal envelope. A Singular Spectrum Analysis (SSA) based filter was applied to obtain the signal trend, also known as the envelope according to the SENIAM standards (Hermens et al., 1999). The proposed methodology to de-noise the signal and to retrieve the envelope proved to be more effective and retained more information than traditional methods, such as root mean square (RMS), moving average (MOVAG) or low-pass Butterworth filtering (for further details see Romero et al. (2015)). SSA is a non-parametric technique of time series analysis based on multivariate statistics principles. By applying this method, the given signal can be decomposed into an additive set of independent time series. The resulting set of series can be interpreted as a trend representing the signal mean at each instant, a set of periodic series and an aperiodic noise (Golyandina et al., 2001).

The main advantage of using this technique lies in the structure of the electromyography signal. Electromyography signals are non-stationary, and traditional methods, such as Fast Fourier Transform (FFT) or Butterworth filtering, may fail for dynamic contractions or being based on the analyser's suppositions of frequencies to filter. Other techniques, such as Wavelets need a wide selection of parameters to design the filter. On the contrary, SSA provides a powerful tool to obtain the signal trend (envelope). Although SSA also needs to select several parameters, such as window length or the number of series to reconstruct the signal, this process can be automated for this type of signals (see Romero et al., 2015). In this work, the sEMG envelope was obtained by following the procedure described in Romero et al. (2015). This signal is referred to as $f_{EMG}(t)$ and will be used later to evaluate the performance of the tool.

2.6. Evaluation of EMG parameters to assess fatigue

EMG fatigue detection has been a high-interest research field during the last decade. In the clinical arena, its early detection may prevent injuries or assist the diagnosis of neuromuscular diseases. The most common quantification methods are based on the power spectral density of the denoised signal (the envelope or the trend mentioned above) relating the content of low and high frequencies.

Once the sEMG signal was filtered, the power spectral density (PSD) was calculated using Welch's overlapped averaged periodogram method by averaging 0.5 s and using 50% overlapped Hamming-windowed epochs.

The median frequency was assessed at different percentages of task completion to assess muscle fatigue. The median frequency (MDF) is a frequency value at which the EMG power spectrum is divided into two regions with an equal integrated power. It can be expressed as:

$$MDF = \sum_{k=1}^{MDF} PSD_k = \sum_{k=MDF}^{N} PSD_k = \frac{1}{2}\sum_{k=1}^{N} PSD_k \tag{1}$$

In order to evaluate the performance of each tool, for each task $j \in [0, 4]$ and each muscle $i \in [0, 6]$, the normalised root-mean-square, or normalised averaged activity level, value was obtained:

$$nrms_{i,j} = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(\frac{f_{EMG,i}(t_n)}{f_{EMG}^{max}}\right)^2} \tag{2}$$

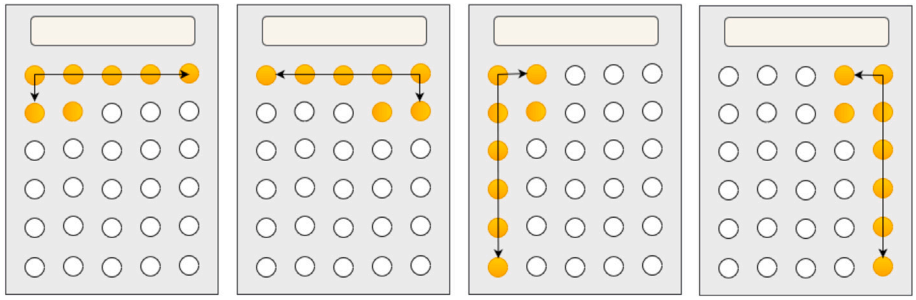


Fig. 4. Description of the 4 tasks developed to assess the functional and ergonomic characteristics of the handle. From left to right: (1) Left to right and up to down. (2) Right to left and up to down. (3) Up to down and left to right. (4) Up to down and right to left.

Fig. 5. Left: Position of the volunteer during the recorded experiment using both tools. Right: Detail of the place holder during the different exercises.

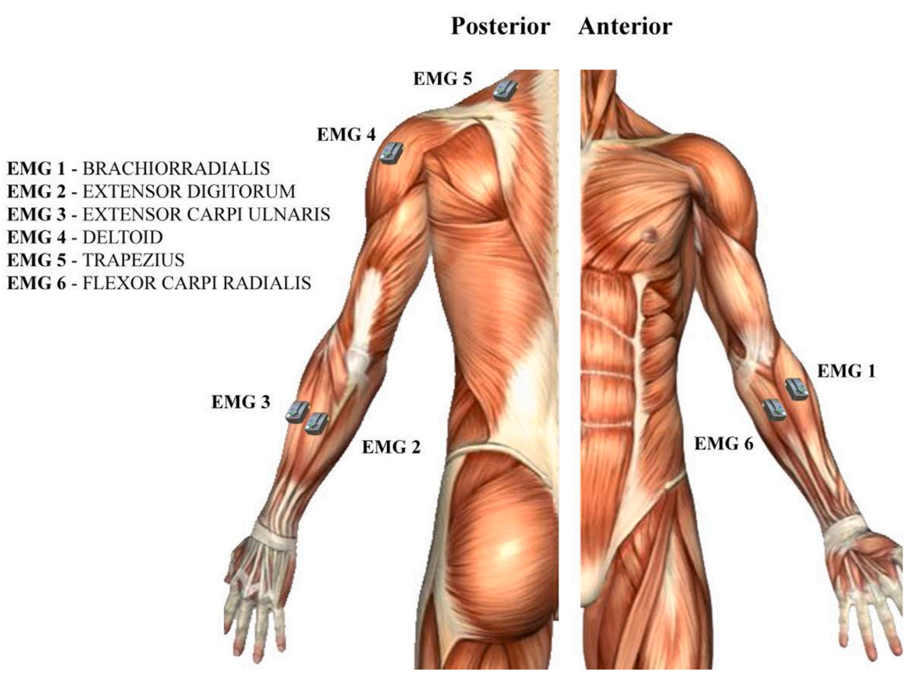


Fig. 6. sEMG sensors placement. Posterior and anterior view.

where N is the number of samples of the $f_{EMG}(t_n)$ signal of each i muscle normalised to the maximum value obtained in all tasks, f_{EMG}^{max}.

3. Results

The mean values of the NRMS for all the subjects and each of the four tasks are shown in Fig. 7. The NRMS value provides the mean value of the muscle activity developed during each exercise. Several studies confirm that a higher level of NRMS (higher muscle activity) is related to a high probability of suffering a pathology in the muscle–skeletal system (Lundberg et al., 1994; Enoka and Duchateau, 2008; Visser and van Dieën, 2006). In general terms, the novel design has proven to provide lower levels of RMNS than the traditional one when performing the same exercise. Therefore, the muscle effort and the metabolic cost are lower in this case, and the probability of suffering an injury is reduced. These differences may suppose a significant advance, as in long periods of activity (as, e.g. in surgery), lower muscle activity is related to lower fatigue, and, therefore, with a higher performance

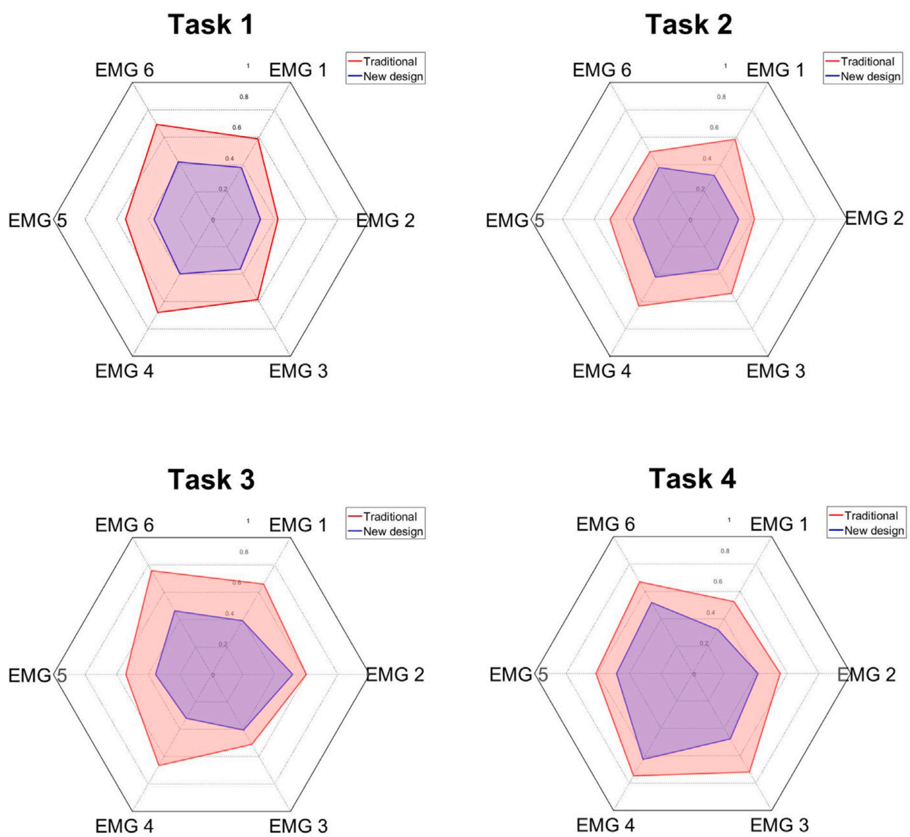


Fig. 7. Web diagrams of the NRMS values for the different muscles and different tasks for all the subjects. EMG1: *brachiorradialis*. EMG2: *extensor digitorum*. EMG3: *extensor carpi ulnaris*. EMG4: *deltoid*. EMG5: *trapezius*. EMG6: *flexor carpi radialis*. Red region: Traditional design. Blue region: Proposed design. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

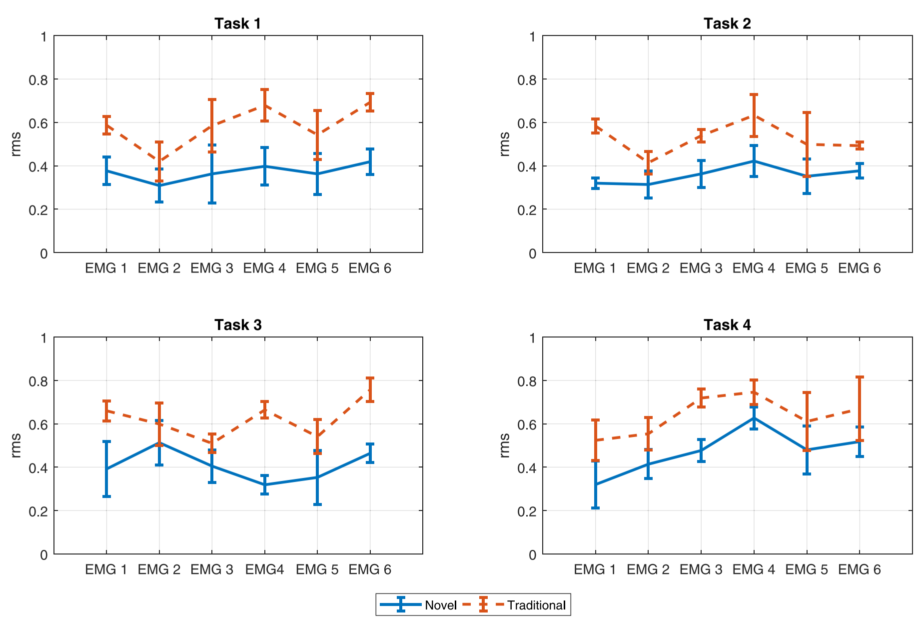


Fig. 8. Dispersion values (mean ± standard deviation) of the NRMS in the proposed tasks for the different muscle groups using the proposed hand tools. EMG1: *brachiorradialis*. EMG2: *extensor digitorum*. EMG3: *extensor carpi ulnaris*. EMG4: *deltoid*. EMG5: *trapezius*. EMG6: *flexor carpi radialis*. Red dashed line: Traditional design. Blue solid line: Proposed design.

of the surgeons during their activity. Specifically, Fig. 7 shows that RMS levels are lower in task 1 than in task 4, which was performed after 20 min of prolonged activity. In the novel design, the muscles with the lower activity are *extensor carpi ulnaris* and *extensor digitorum*. These muscles are prone to suffer tendinopathy and tenosynovitis due to contribution to wrist flexion and extension dependent on forearm position, so the novel design ensures less likelihood of suffering these pathologies during prolonged activities. Furthermore, considering the dispersion values represented in Fig. 8, the novel design outperforms the results obtained using the traditional handgrip.

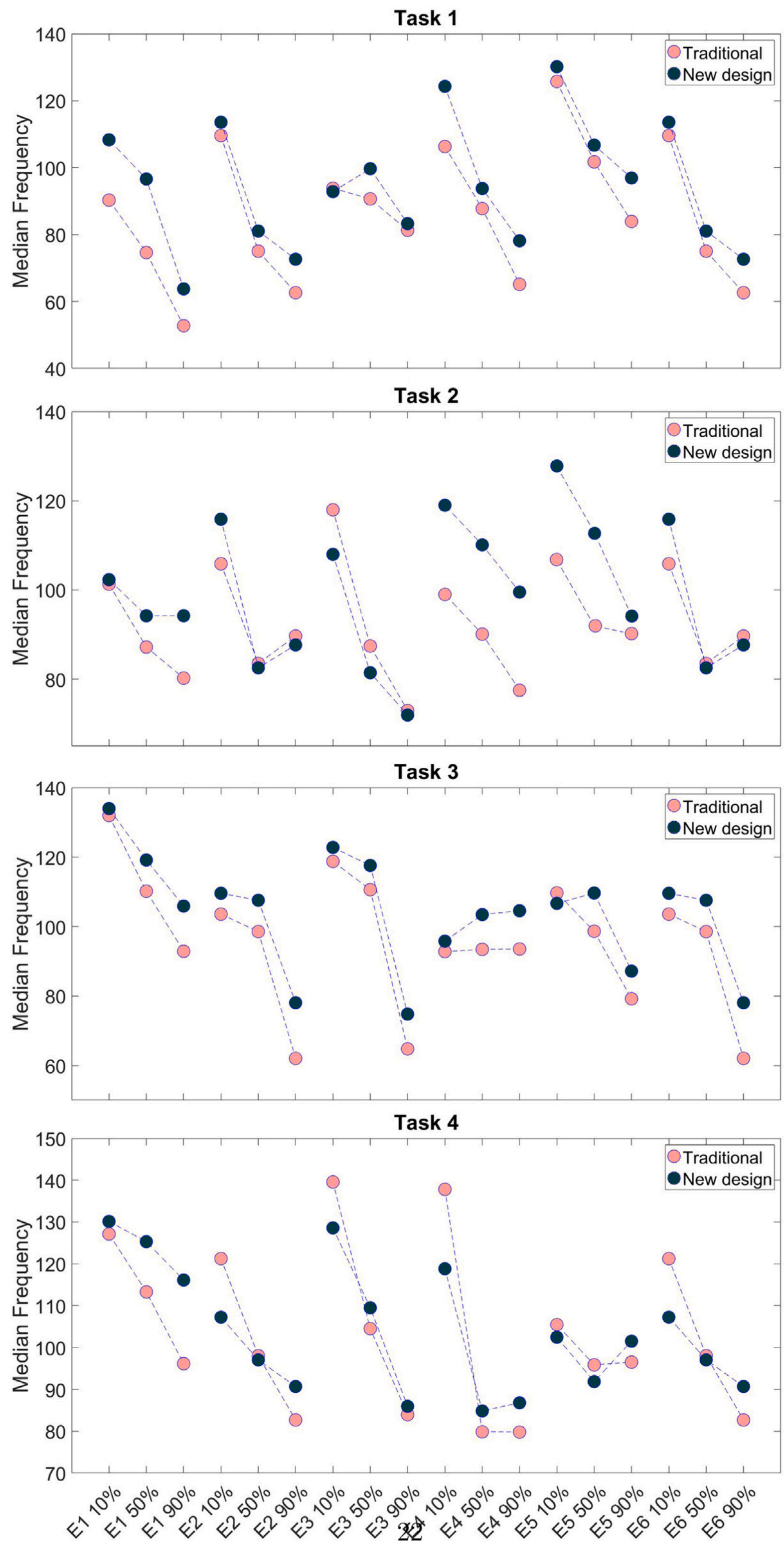


Fig. 9. MDF values of the different muscles and subjects for the different tasks. From left to right: *brachiorradialis, extensor digitorum, extensor carpi ulnaris, deltoid, trapezius, flexor carpi radialis*. Red: Traditional design. Blue: Proposed design. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The MDF is studied to ascertain whether the novel design reduces muscle fatigue. The evolution of MDF at different percentages of task completion (10%, 50% and 90%) are depicted in Fig. 9 for each muscle. MDF value provides an estimate of muscle fatigue just looking at the trend. This trend has a physiological meaning with scientific evidence (Merletti et al., 1990; Merletti and Farina, 2006; Cifrek et al., 2009), in which neuro-muscle-system activates high resistance motoneurons (type I) to face the task or exercise. This type of motoneurons have a particular lower activation frequency than the others and, therefore, sEMG enables knowing when and how much are active. As MDF decreases, higher muscle fatigue is observed in the subject.

Fig. 9 shows how, in general terms, the MDF diminishes throughout the task, i.e. at 10% of the task, the frequency content of the signal is higher than at 90%. In this sense, results suggest that the novel design delays muscle fatigue compared to the traditional one. This can be observed in Fig. 7, where most of the MDF values are higher for the novel design than the traditional ones in the different tasks and the various muscles. Specifically, for task 1, the novel design fatigues less than the traditional one. For the *extensor digitorum*, *trapezius* and *flexor carpi radialis* muscles, results are similar except by the end of the task (90%), where the novel design outperforms the results in terms of fatigue.

Regarding task 2, results are similar for both tools in the *extensor carpi ulnaris*, *extensor digitorum* and *flexor carpi radialis* muscles. This may be due to the very demands of the task, in which the grasping movement requires significant effort in the muscles responsible for the wrist flexo-extension and the forefinger for pinching. However, the novel design has higher values for MDF than the traditional one in the *trapezius* and *deltoid* muscles. This may reduce the number of injuries in the neck/back for tasks similar to 1 and 2.

Regarding tasks 3 and 4, MDF shows no significant differences between designs, although the novel design provides higher values of MDF in the *trapezius* and *deltoid* muscles at the end of each task, and, therefore, a lower fatigue at the final stages and the end of the task.

4. Discussion

In this research, as indicated above, the objective pursued was twofold. On the one hand, a new design of the handle of the laparoscopic forceps was presented and compared with one of the most widely used instruments in this field. On the other hand, time–frequency analysis techniques have been used in this study to assess ergonomics during dynamic activities. In this sense, the results obtained from the novel design assessed in this study showed that they outperform the traditional design with a conventional ring grip at different levels of muscle stress. Specifically, lower activity in the *extensor carpi ulnaris* and the *extensor digitorum* has been reported. The reduced activity in these muscles may prevent injuries such as tendinopathy and tenosynovitis, and therefore the novel design minimises the risk of suffering the pathologies mentioned above during prolonged activities. It is also remarkable that previous studies analysing the MDF show significant differences in tasks 1 and 2, which may also contribute towards reducing the number of neck and/or back injuries.

Regarding tasks 3 and 4, the MDF shows not as relevant differences between designs, although the novel design yields higher values of MDF in the *deltoid* and *trapezius* muscles at the end of each task, and therefore, lower fatigue at the end stages and at the end of each stage. Results depicted in Fig. 7 are similar to those presented by Matern et al. (2004). In their work, they used web diagrams to show the performance of the five instruments used. Furthermore, Sancibrian et al. (2014) also presented a study in which normalised EMG signals where compared. The protocols used were recently collected by Li et al. (2016) in their guideline for ergonomic evaluation of laparoscopic instrument handles. However, the analysis of EMG signals does not consider their dynamic evolution, and therefore fatigue could not be assessed.

The results of this study reveal that the proposed ergonomic grip of the tool achieves considerable advantages in terms of muscle effort and also improves the ease of use in laparoscopic instruments, as it minimises high-pressure contact areas, reduces the high amplitude movements and provides a neutral position of the hand, wrist and forearm. Nevertheless, the most significant contribution of the work is related to the methodology itself. In this paper, the authors presented a method to assess muscle fatigue during dynamic contractions. Works such as that of Sancibrian et al. (2014), Moont (2003) or Matern et al. (2002) use traditional filtering techniques or signal normalisation based on maximum voluntary contractions (MVC). By doing so, additional assumptions over the signal must be imposed, as the filtering frequencies or the validity of the MVC itself (Halaki and Ginn, 2012). The state of the signal overall has been assessed with MDF to obtain a measurement of the signal's performance during the task and to overcome this situation. MDF was assessed at different percentages of task completion for various muscles and different subjects. As the task was long enough to observe tendency, their work styles and force exertion did not appear to influence the appearance of muscle fatigue. A lower MDF value indicates the appearance of muscle fatigue. The natural tendency is for there to be lower values at the end of each sample, as seen in Fig. 9 where a higher position of the curves indicates better performance of the tool. Another possibility to study the performance of the tools is to assess the rms of the filtered signal through the test and between subjects. By doing so, the general performance of the tool is obtained, avoiding the normalisation of the signals and related problems, as shown in Halaki and Ginn (2012). By assessing all muscles involved in the activity, the web diagram sheds light on the fatigue and the reduction of muscle activity by using different tools. In this sense Fig. 7 gives an idea of the performance (lower values of rms results in a less fatiguing tool) and figure Fig. 8 an idea of the dispersion of the previous results. For example, by using the novel prototype an important reduction of *deltoid's* contribution to movement is observed. The same occurs for the *brachiorradialis*. In addition, in this research, SSA has proven to be a powerful tool to extract relevant information from a noisy signal during dynamic contractions, and no assumptions were needed on the original time series. Only the values of window length and reconstruction groups must be established, but even those can be automated, as shown in Romero et al. (2015). This technique, combined with the analysis of the median signal, could be useful to extract fatigue maps over continued activities. Although here, the methodology supported the use of the novel grip design, and it could be helpful to plan long surgeries using different hand grips to minimise the specialist's fatigue during the activity.

Last but not least, the work has some limitations worthy of mention. Tests were carried out by inexperienced volunteers. Nevertheless, the assessment of the novel design may benefit from the data acquisition of professional volunteers. More specific and intricate tasks such as suturing could further assess the ergonomic features of the handle tool in situations close to those found in the operating room. A larger size of the sample is also required to generalise results, combined with task-specific surveys to correlate the obtained results with the qualitative assessment of the experts/volunteers. Furthermore, the objective assessment of the laparoscopic handle was conducted using only EMG signals. The combined use of EMG signals and kinematic data (recorded by using goniometers, accelerometers or optical tracking of markers placed in anatomical landmarks of the subject) may provide further information to assess this type of instrument during complex interventions.

5. Conclusion

Here, the authors assessed a novel design of the laparoscopic gripper handle and compared it with one of the most used instruments in this field. The assessment of the ergonomic feature of the novel design was performed by using time–frequency analysis of Electromyography (EMG) signal during dynamic activities using SSA. This technique decomposes the EMG signal to extract the median frequency of each muscle to assess muscle fatigue. This technique is particularly relevant in the analysis of dynamic contractions as there is no assumption on the features of the signal. The combination of this technique with the study of the median frequency signal could be useful to extract fatigue maps over continued activities. The planning of complex and extensive surgical intervention could be benefit from this approach. Regarding the presented laparoscopic gripper, the results of this study reveal that the proposed ergonomic grip of the tool provides significant advantages in terms of muscle effort, i.e., fatigue is reduced during the proposed activities for both the dominant and non-dominant hands. Further experiments, including more complex training techniques, must be done to generalise conclusions. Nevertheless, results are promising from the ergonomic point of view for the novel design.

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