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ORIGINAL ARTICLE

Impact of a motorised articulated laparoscopic needle holder with ergonomic handle on the gesture smoothness: a pilot study

Amandine Dufaug^{1✉} • Laurent Goujon¹ • Christine Barthod¹

Abstract

Purpose: The objective of this study is to assess the smoothness of a laparoscopic gesture performed with a motorised articulated instrument in comparison with a conventional one.

Methods: One right-handed laparoscopic expert surgeon has been recruited for this study. He performed ten vesicourethral anastomoses, in a pelvic stand, using two kinds of laparoscopic instruments (standard and motorised) for different operating room conditions, especially table height adjustments. A 3-axis accelerometer and cameras are used to record information on the dominant upper limb motions during the tasks.

Results: Two different methods are applied in order to evaluate the gesture smoothness. Both are using the acceleration data of the elbow collected during the surgical procedure. The first method uses the first-order derivative of the acceleration and is called log dimensionless jerk. The second one is based on the acceleration's Fourier spectrum and is called SPARC. For similar surgical trials of 2.5 stitches, the two methods tend to show that the gesture smoothness is globally improved by using the motorised articulated laparoscopic needle-holder.

Conclusions: These preliminary results give a first indication on the benefit of the motorisations and articulations of a surgical instrument on the gesture performance. They have to be validated with more trials.

Keywords

Gesture smoothness • Motorised and articulated instrument • Laparoscopy • Minimal invasive surgery

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Introduction

The minimally invasive surgery, especially laparoscopy, represents an important evolution of the surgical practice. It benefits patients by reducing the bleeding, the infection risk and the healing duration compared with open surgery [1]. It also presents well-identified drawbacks for the surgeons. Indeed, the instrument's length, essential to reach the operating site, leads the surgeon to adopt non-ergonomic postures, such as shoulder elevation and abduction, that create increased efforts, pains occurrence and work-related musculoskeletal disorders development [2] [3] [4]. Moreover, the fixed position of the trocars causes a lack of manoeuvrability increasing these previous risks [5] [6].

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Ergonomic recommendations have been proposed such as the adaptation of the operating room environment, especially the table height, and new instrument handle designs [7]. Nonetheless, these adjustments have little effect on the instrument manoeuvrability.

Several technical solutions have been proposed to overcome this limitation such as articulations at the tip of the instrument or articulated handles leading to an increased intracorporeal mobility for limited upper limb movements [8] [9] [10]. More recently, motorised articulated instruments have appeared on the market. As described by Sánchez-Margallo, they provide new functionalities to improve the range of movement and surgeon's ergonomics [6]. The Dex™ (Dex Surgical, France) is one of these devices. Its impact on ergonomics has yet been shown in terms of gesture accuracy, surgeon's posture and muscular solicitation [11] [12] [13].

The aim of this study is to compare the laparoscopic gesture smoothness while using the Dex™ instrument in several representative operating room conditions with a standard laparoscopic working configuration using conventional instruments. The smoothness is a good indicator of the gesture performance quality, narrowly linked to the procedure success [14]. In the literature, it is recommended to not apply the smoothness measures to entire rhythmic tasks but to specific patterns of movements [15]. To our knowledge, the present preliminary study is the first to evaluate the use of a motorised articulated instrument in terms of smoothness.

The materials and methods used for the comparative study of smoothness are firstly described. Results are then presented and discussed. A conclusion is finally proposed on the contribution of the motorised instrument on the gesture smoothness.

Materials and methods

Participants

One right-handed surgeon was recruited for this study. He is an expert surgeon in the meanwhile of Hiemstra *et al.* [16]. He performed suturing tasks using both standard laparoscopic (Std) and motorised articulated (Dex™) needle holders.

Laparoscopic needle holders

The standard laparoscopic needle holder (Tonglu Kanger Medical Instrument Co., Ltd) presents a non-articulated shaft, a one-mobile jaw tool and a V-type axial handle [17]. It can be mobilised among four degrees of freedom. The tool locking is ensured by a rack whilst the opening is allowed by a spring.

The Dex™ motorised articulated needle holder presents seven degrees of freedom whose one is located at the instrument handle [18]. This particular articulation allows the surgeon to both orientate the distal tool of the instrument and reduce the shoulder abduction during the procedure. Three motorisations ensure the opening of the jaws, the unlimited rotation of the tool and the flexion of the instrument's tip.

Experimental setup

For the study requirements, it is essential to create a working environment which is representative of the operating room. In order to be as reproducible as possible between each trial, the patient is replaced by a training box, called pelvitrainer (Fig. 1).

Fig. 1 Vesicourethral anastomosis pelvitrainer

The pelvitrainer contains a simplified representation of the pelvic anatomy after a radical prostatectomy. Two silicon phantoms are used to represent the bladder and the urethra. In order to reproduce several typical working conditions, it is installed on an adjustable height table. The top face of the pelvitrainer (representing the patient abdominal wall) can thus be set from 50 % to 90 % of the surgeon's elbow height [17] [19].

In order to display the intracorporeal gestures on a monitor placed in front of the surgeon, a camera is placed into the box (Fig. 2). Two trocars are inserted through incisions performed in the top face of the box. They create an access to the surgical site for the instruments.

Fig. 2 Vesicourethral anastomosis procedure set up

Task

The expert surgeon performed a vesicourethral anastomosis into the pelvitrainer. This surgical gesture ends a radical prostatectomy [20]. It consists in suturing the bladder with the urethra (Fig. 1). A stitch is composed of several phases: jab the semi-circular needle into the phantom, rotate it and pull it out of the soft tissue.

For each kind of working configuration (standard or motorised), the surgeon performed the task for five different working heights. Each trial is followed by a break. For the task realisation, the surgeon used a standard or the Dex™ needle holder in the dominant hand and a standard instrument in the contralateral hand for the ambidexterity conservation. The order of the task realisation was randomised for both used instrument and table height.

The task duration has been fixed equal to 5 min which has been considered long enough to quantify the gesture smoothness on several suturing stitches.

Smoothness definition and implementation

The smoothness is a characteristic feature of a trained movement and increases with motor learning and spatiotemporal coordination [15]. A smooth movement presents continuity whatever its duration and amplitude are. It corresponds to a single peaked speed profile [14]. Intermittencies disturb the speed profile by adding zero-speed time lapses, corresponding to successive acceleration/deceleration or null-acceleration [15].

A smooth gesture was initially empirically defined as the minimal value of the third-order derivative of the position, called jerk [21]. The more the jerk value is important, the less the gesture is considered as skilled and coordinated. A dependence of the jerk with the signal amplitude and duration is indicated [15]. Due to this dependence, most of the jerk-based methods failed to compare smoothness between two equivalent gestures performed by a unique subject or two different ones [22] [23]. A correct smoothness measure is thus defined to be dimensionless, with no dependence to signal duration and amplitude [15].

In order to fit with this dimensionless specification, Hogan et al. proposed a formula based on the temporal position signal to quantify the smoothness (Eq. 1) [22].

$$LDLJ = \log \left(\frac{(t_2 - t_1)^3}{v_{peak}^2} \int_{t_1}^{t_2} \ddot{x}(t) dt \right) \quad (1)$$

LDLJ corresponds to the dimensionless jerk, t_1 , t_2 to the temporal interval limits, v_{peak} to the maximal speed and $x(t)$ to the position.

Balasubramanian *et al.*, in 2015, compared different methods of smoothness quantification, based on jerk analysis, and classified them in terms of technical properties such that: validity, sensitivity, reliability and practicability [15]. The LDLJ method is considered as the most relevant jerk based method. Nonetheless it presents a lack of reliability due to noise sensitivity.

These authors proposed a spectral method, called SPARC, which is less sensitive to signal noise than jerk-based methods. The obtained scalar value is directly linked to the number of submovements or intermittencies. The SPARC quantity, computed from the Fourier spectrum of the signal (Eq. 2), is also dimensionless [15].

$$SPARC = - \sum_{k=1}^{K_c-1} \sqrt{\left(\frac{1}{K_c-1} \right)^2 + (\Delta \hat{V}[k])^2} \quad (2)$$

SPARC corresponds to the spectral arc length, $\Delta \hat{V}[k]$ to the Fourier spectrum magnitude normalized by the maximal magnitude and K_c to the discrete Fourier transform index which is narrowly linked to the chosen cut-off frequency.

These methods are recommended to be applied on particular gestures of same finality [15].



Data acquisition

The LDLJ and SPARC analyses are performed from acceleration acquisition using a three-axis accelerometer (ACL300, Biometrics, Ltd) fixed at the lateral epicondyle of the humerus. It allows following the shoulder's circumduction moves. The orientation of each axis is presented in Fig. 3. Each output is connected to a Datalog (MWX8, Biometrics, Ltd). The corresponding signals (converted in g) are transmitted by a Bluetooth protocol to a laptop through dedicated software at a sampling rate of 1000 Hz.

Fig. 3 Accelerometer's axes orientation

Two cameras are placed in front and in the lateral side of the surgeon in order to record his arms motion, especially the dominant one.

Data exploitation

From the acceleration signal, the LDLJ method application imposes to compute the acceleration module by a quadratic summation of the 3-axis components before to apply the first-order derivative in order to obtain the jerk.

As the evolutions of SPARC and LDLJ values with smoothness are opposite, we choose to use the absolute value of the SPARC in the following analysis.

During the different exercises, the surgeon does not perform the same number of stitches (Table 1). This leads to a different number of movements (and submovements) which can be associated to a wrong perception of the smoothness.

Table 1 Number of stitches performed for each task

Working height	50%	60%	70%	80%	90%
Standard	3	5	4	4.5	3.5
Dex™	3.5	3.5	3.5	4	2.5

The exercises are thus subdivided in order to compare the smoothness corresponding to the different working conditions for similar suturing sequences in terms of number of performed stitches. The chosen sequence then consists in 2.5 stitches which correspond to the minimal number of stitches practiced during an exercise (Dex at 90% of elbow height). It is important to notice that the gestures performed by the surgeon to realise the stitches are not perfectly similar between each trial.

Results

The equivalent sequences of 2.5 stitches, acquired for different working heights from 50% to 90% of the surgeon's elbow height, are analysed in order to compare the impact of each kind of instrument on the gesture smoothness.

The LDLJ method is firstly applied on the data. The results are reported in Fig. 4.

Fig. 4 LDLJ analysis on a set of 2.5 stitches versus working heights for standard (STD) and Dex instruments

The analysis of the trials performed with the Dex™ shows that its use globally leads to a decrease of the LDLJ value comparatively with the standard condition for each working height, expected the 60% of the elbow height.

The relative changes computed from the smoothness obtained for the two working configuration are reported in Table 2.

Table 2 Relative change in LDLJ computation

Working heights	50%	60%	70%	80%	90%
ϵ_{rel}	0.09	-0.09	0.07	0.04	0.01

The SPARC analysis is then applied on the acceleration data (Fig. 5).

Fig. 5 SPARC analysis on a set of 2.5 stitches versus working heights for standard (STD) and Dex instruments

The smoothness variations with the working heights are different of the one computed using the LDLJ method. Nonetheless, similarly to the LDLJ analysis, the DexTM use leads to a weaker value than the standard configuration for all working heights except the 60%.

Table 3 Relative change in SPARC computation

Working heights	50%	60%	70%	80%	90%
ϵ_{rel}	0.06	-0.10	0.22	0.16	0.14

For both LDLJ and SPARC analyses, the weaker value obtained for the standard working configuration corresponds to a working height equals to 60% of the elbow height whilst the maximal smoothness is reported for the DexTM configuration for a working height of 70% of the elbow height

For the standard instrument, the worst value is reported with both methods for the 50% of elbow height condition. The condition leading to the worst value is not the same for the DexTM instrument: 50% for SPARC and 90% for LDLJ.

Discussion

The results obtained during this preliminary study show a tendency to a gesture smoothness improvement when the DexTM instrument is used. Nonetheless, the results in terms of smoothness have to be carefully linked with the performed movements.

For a simple movement, with well-controlled components, an increase of LDLJ or SPARC values is unquestionably linked to a decrease of the gesture smoothness. For a more complex movement, such as a suturing, the number of submovements is not exactly the same between two trials. This effect is more important as the number of performed stitches varies that's why the subject has thus to focus on same finality tasks containing specific similar sets of movements.

Moreover, if the stitch phases are well identified (jab, turn and pull the needle into the tissue), the preparation phase is composed of a lot of sub-movement, that can be different each time, which leads to a misestimating of the smoothness.

In conclusion, an increase in the LDLJ or SPARC values can be due to a smoothness decrease, an increased number of motion components or intermittencies (due to static phases) into the motion signal.

Therefore, in order to evaluate the impact of the instrument on the gesture, it is important to correlate the previous results to the surgeon's feeling (Table 4) and the arm motions analysis, available through the external cameras (Table 5).

Table 4 Comfort felt by the surgeon for both working configurations

Working heights	50%	60%	70%	80%	90%
Comfort	poor	← good →			poor

Table 5 Visual quantity of movement of the right upper limb (elbow) for both working configurations

Working heights	50%	60%	70%	80%	90%
Posture	static	← dynamic →		static	

In Fig. 4, concerning the standard instrument, the evolution of the smoothness evaluated by LDLJ as a function of the working height is consistent with the surgeon's feeling, assuming that comfort and smoothness are linked. For the Dex, are globally consistent with the surgeon's feeling, except for the working height corresponding to 60% of the surgeon's elbow height.

For the SPARC analysis, both standard and DexTM configurations present results close to the surgeon's feeling, except for the highest working condition. However, in this case, the surgeon's arms movements are quasi-static and the number of submovements is strongly decreased. It shows that both SPARC and LDLJ indicators are not reliable enough to quantify the surgeon comfort, and further analysis have to be done.

For both LDLJ and SPARC analyses, the condition which leads to the smoother gesture in standard configuration corresponds to the one which is the less soliciting for the muscle (60% of the elbow height) [13]. A possible link between comfort and smoothness can be hypothesised. With both methods, the maximal smoothness is reported for the DexTM configuration for the working height usually used by the surgeon's in operating room (70% of the elbow height) [13]. This observation leads to the question of the training influence on the smoothness for the DexTM instrument.

The relative changes computed for the LDLJ method are smaller than the one reported when using the SPARC method. It means that the SPARC method allows a better discrimination of the smoothness changes occurring as the working configuration is modified (from the standard to the Dex instrument).

Conclusion

The manoeuvrability reduction introduced by the laparoscopic surgery leads to adoption of awkward static postures. By introducing articulation and motorisation on the surgical instruments, designers aim to improve the laparoscopy ergonomics. The DexTM needle holder, with its articulated handle, has thus been analysed in terms of gesture smoothness, in order to apprehend its influence on the quality of gesture performance. Two methods, called LDLJ and SPARC, have been identified and applied on motion data (acceleration).

The implementation of both methods tends to show that the use of the DexTM increases the gesture smoothness. Nonetheless, the SPARC method seems to be more appropriate to highlight the smoothness variation between both working configurations. The SPARC evolution is consistent with the surgeon's feeling, except for the table height equals to 90% of the surgeon's elbow height. Indeed, the SPARC method indicates an increased smoothness for the highest working condition. As the surgeon's movement becomes quasi-static (corresponding to a decrease of the submovements number and to an increase of intermittencies) for this working height, the computed smoothness increased. So we can see that the smoothness by itself is not a sufficient indicator to evaluate the surgeon's comfort. It has to be completed by a complementary EMG analysis [13].

Despite the recommendation concerning the table height done at the early 2000 [17] [19], 46 % of the surgeons place the patient abdominal wall at a height superior to the elbow level despite the associated risks for them in terms of work-related musculoskeletal disorders development [24]. This paper allows showing that the working height impacts not only the comfort but also the gesture smoothness and, in consequence, its quality of performance, narrowly linked to the success of a surgical procedure.

Although the preliminary status of this analysis, we consider that the obtained results are a first and important step towards the validation of a motorised instrument as the DexTM to improve suturing performance. Studies with more participants have to be carried out to verify the impact of such an instrument on smoothness as well as its implication in muscular activity and fatigue.

Compliance with Ethical Standards

Conflict of interest: the authors have no conflict of interest to disclose.

Research involving Human Participants and/or Animal: Yes

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Figure 1

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Figure 2

[Click here to access/download;Figure;Fig2.jpg](#)



Figure 3

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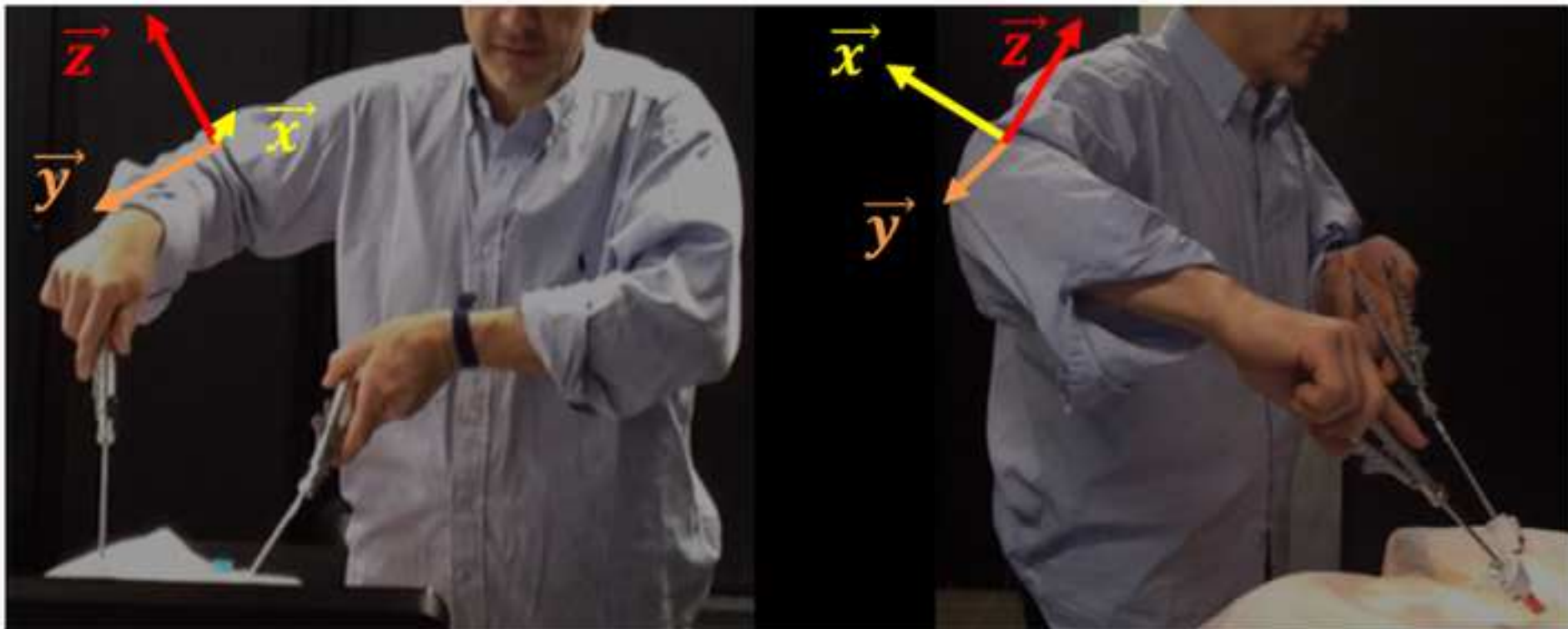


Figure 4

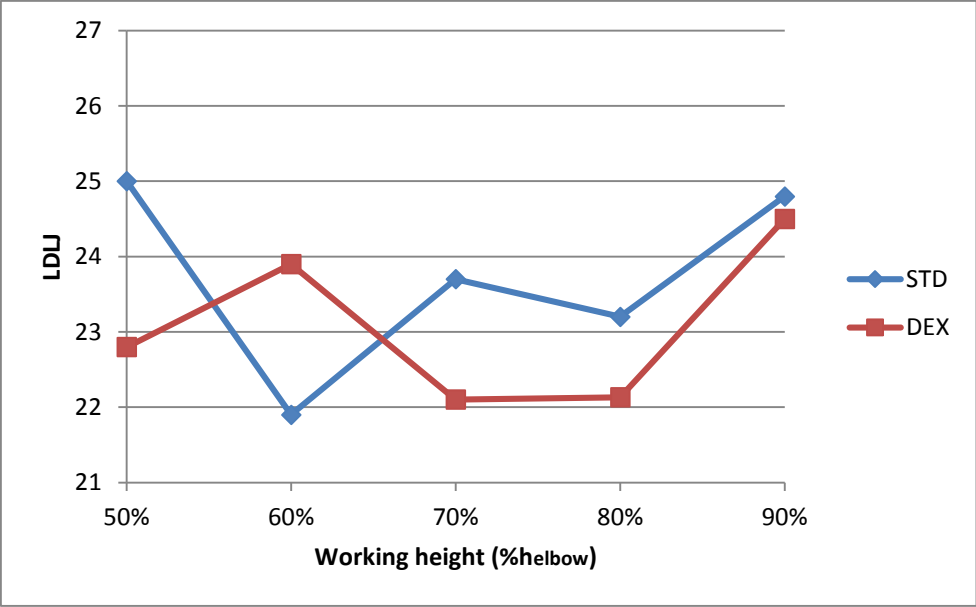


Figure 5

