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Ergonomic Surgical Practice Analysed through sEMG Monitoring of Muscular Activity

Amandine Dufaug
Univ. Savoie Mont Blanc
SYMME
F-74000-Annecy
FRANCE
Email: amandine.dufaug@univ-smb.fr

Christine Barthod
and Laurent Goujon
Univ. Savoie Mont Blanc
SYMME
F-74000-Annecy
FRANCE

Nicolas Forestier
Univ. Savoie Mont Blanc
LIBM
(EA 74 24)
F-73370-Le Bourget du Lac
FRANCE

***Abstract*—The success of any surgical intervention is narrowly linked to the operating comfort of the surgeon. Nicknamed "chicken wings", the typical posture adopted by a practitioner during a laparoscopic intervention leads to cervical, shoulders and back pains. To avoid such a posture is one of the main challenge of medical devices designers. Instruments length, lack of articulations as well as non-adapted tables heights have to be reconsidered to surgeon's benefit.**

Moreover, the smoothness of the gesture is of great deal for the surgeon. It allows a more accurate gesture by reducing the disjointed contractions of the muscles.

It has been observed that the recourse to an articulated instrument, the Dex™, leads to shoulder's adduction. The influence of its articulations, especially handle's one, on the surgeon's comfort, has to be quantified.

This influence is confronted to several working conditions representative of operating room situations. An optimal surgical environment is proposed through the analysis of electromyography on shoulder's muscles and of elbow's acceleration.

I. Introduction

Improving the patient's care, laparoscopy presents ergonomic drawbacks for the surgeon [1 - 4]. It affects especially the shoulders, at rotator cuff level, and the back, at nape and lumbar levels. Cognitive workload imposes the surgeon to be highly concentrate on his gesture making abstraction of his own comfort [5], [6].

Due to the instruments lengths, and non-adapted tables heights, he adopts deleterious posture, known as "chicken wings". Moreover, the lack of distal articulations, as well as the reduced entry point to the patient's abdomen, imposes an increase of the upper limb's range of motion to realise a task of high-precision. The resulting constraints on his anatomical structures lead to pathologies with permanent effects, called work-related musculoskeletal disorders (WRMSD).

In this context, articulated and/or motorised instruments as well as telemanipulated robots have appeared on the market [7 - 9]. They have been all designed with the same aim to reduce laparoscopy's painfulness but their architectures, functionalities, sizes and costs are different.

The Dex™ (Dextérité Surgical™, France) is a 7-degree of freedom (DOF) motorized instrument dedicated to laparoscopic procedures. One of its specificities is an articulated handle which mobilises the instrument's shaft in rotation. This additional mechanical liaison offers to the surgeon different orientations of work on the intra-corporeal surgical site. The influence of such an articulated and motorised instrument on the surgeon's comfort has to be quantified, in realistic conditions of work.

Moreover, tables heights are unsuited for over than $95\ \%$ of the surgeons [10]. This is a non negligible criteria. Ergonomic recommendations have been clearly detailed in several publications [10], [11]. Remained mainly unknown, they are generally not applied in practice. Van Veelen et al. have identified an optimal correlation between surgeon's size and patient's abdominal wall (PAW) positioning [11]. The top of the PAW has to be placed between $70\ \%$ and $80\ \%$ of the surgeon's elbow height. Considering an abdominal sagittal depth comprised in the $30 - 40\ \mathrm{cm}$ interval, recommended tables heights can be deduced. Adequate tables for all surgeons sizes are not always available on the market. Women are particularly concerned by this problem [12]. Platforms can be used, even if they often present ergonomic problems [10] [12]. Other solutions have also been developed [13].

Following the protocol established by Van Veelen et al., Standard (Std) and Dex-configurations are set up for five working heights. This aims to define an optimal environmental and instrumental working situation. The evaluation of each configuration is done using electromyography (EMG) electrodes, to quantify the muscle involvement, known as activity, and a 3-axis accelerometer, to characterize the gesture smoothness.

Materials needed for the study and the methods required to analyse activities and motions are described in a first part. Results and graphs will be discussed in a second one. The last part will be dedicated to the conclusions and perspectives.

II. Materials and Methods

An unique right-handed male surgeon participates to the present preliminary study. Recognised by one's peer, with insight on his practice, he is considered as an expert in both Std and Dex-laparoscopy.

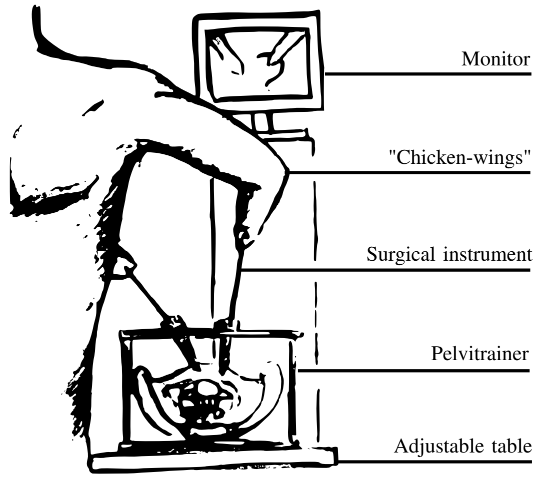


Figure 1: Surgical environment and surgeon's strategy.

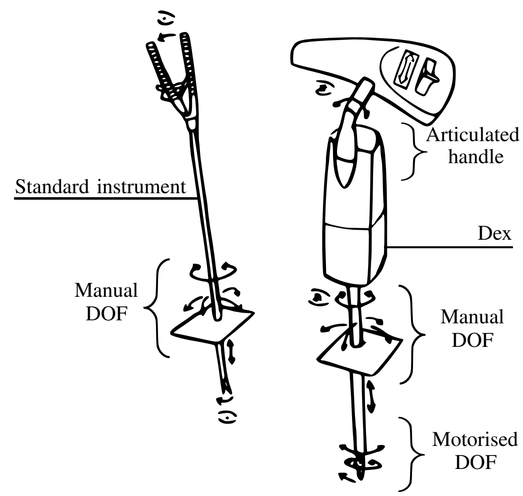


Figure 2: Standard and Dex instruments.

A. Physiopathology of laparoscopy

Discomforts and injuries directly linked to the practice are reported by 87 % of the surgeons [12]. Indeed, muscles mobilisation leads to solicitation of muscular fibres, reorganisation and fatigue apparition [14]. Pains enduring outside the operating room are common, synonymous of WRMSD.

1) Cervicalgia: An unilateral contraction of Upper Trapeziuses (UT) leads to shoulder elevation whilst a bilateral one put the head in extension. Both are found in laparoscopy due to the chicken wings posture and monitor display (Figure 1). UT solicitations are associated with nape pains, often described as felt symptoms by surgeons.

2) Rotator cuff injury: The recourse to shoulder's extreme gestures compresses the anatomical structures. Keeping non-ergonomic arm positions on long time laps, according to ergonomic recommendations, ends to compress the rotator cuff, leading to serious pathologies [15].

3) Muscles of interest: Two groups of muscles, involved in these pathologies, are monitored. The first one is composed of both Upper Trapeziuses (right and left: RUT, LUT). Lateral and Anterior fascicles of the right Deltoid (RLD, RAD), involved in the shoulder's abduction and antepulsion, form the second one.

B. Surgical representative environment and task

To set up realistic operating room (OR) conditions is essential to obtain a representative evaluation of the asked task in terms of operating comfort (Figure 1).

1) Surgical instruments: Standard instruments are generally designed with an unique distal articulation, the tool's opening/closure. Routinely used by the surgeon, a V-type handle forceps (Tonglu Kanger Medical Instrument Co., Ltd) is used for the task's realisation. It is defined as the reference for the present study (Figure 2).

The Dex™, a 7-DOF articulated and motorised needle holder, is used as comparative instrument on equivalent tasks. The three distal motorised articulations are key elements of this innovative device (Figure 2). Specific to this device, the proximal handle's DOF has been created in order to rotate the Dex™ shaft around the trocar axis. A simple wrist pronation, or supination, allows to shift from right-left deflection of the distal tool to up-down one.

2) Configurations: Laparoscopic interventions require ambidextrous capability. Two instruments are used. Whatever the configuration is, Std or Dex, a standard instrument is held by the left hand of the surgeon. It assists the one manipulated by the right hand. Indeed, the Dex™ is recommended to be used in one side because of the risk to increase command complexity by combining two motorised instruments.

3) Suturing exercise: A radical prostatectomy is simulated. It consists in extracting the prostate of the urinary duct of the patient. The vesicourethral anastomosis ends the intervention by sewing the bladder to the free urethra, with a semi-circular needle. Ten 5-minute exercises, corresponding to each working situation (combination of work condition and instrument configuration), are focussed around this specific task of suture.

4) Patient's simulation: The patient's low abdomen is represented by a specific simulator, called pelvitrainer. It contains anatomical models: a pelvis (3B Scientific) on which are fixed a bladder and an urethra (Dextérité Surgical™, France). The top is holed by two trocars, one for each instrument.

A camera is directly included in the pelvitrainer. It is connected to a screen placed in front of the surgeon. The operating conditions are then respected with no possible direct view of the pelvic cone.

5) Working specifications: An adjustable table is used to reproduce the operating bed. Several heights are imposed to the surgeon following the protocol defined by Van Veelen et al. with specific distances between the surgeon's elbow and the patient's abdominal wall (PAW). They are referenced on the Table I.

Table I: Working conditions.

Reference	A	B	C	D	E
Height condition [% h_{elbow}]	50	60	70	80	90
Abdominal wall height [cm]	61	68	78,5	91	102

Different working situations are proposed to the surgeon with a 5-minute rest between two successive exercises in order to limit muscular fatigue. Randomisation is important to not impute evolutions of the muscular response to increasing difficulty of the task.

C. EMG analysis

Non-invasive surface electrodes are used to realise the EMG monitoring. They detect the action potentials (AP) spread along the muscular fibres through the skin. They are particularly useful for the study of external muscles.

1) From electrodes to PC: A surface electrode is composed of two active patches. A differential amplification between these two sites allows the elimination of noise [16].

Surface EMG for a non-invasive assessment of muscles (SENIAM) recommendations have to be followed during the protocol elaboration. They have been elaborated by experts in the field of ergonomics [17]. The two active parts of an electrode have to be patched on the same muscular fibres, on the muscle belly, following a specific mapping.

The 5 required electrodes (SX230-1000, Biometrics Ltd, UK) are linked to a Datalog unit (MWX8, Biometrics Ltd, UK). An electrical mass is affixed on the left wrist. Data are collected on a PC through a wireless Bluetooth connection. The EMG signal magnitudes are displayed in real time on the Biometrics software interface. They are then exported to be post-treated by CAPTIV (TEA, France) or/and MATLAB software.

2) Data processing: Once imported on CAPTIV software, the signals are synchronized with the videos recorded during exercises (front and lateral views of the surgeon as well as pelvic one). The parts of the signals which are non representative of the practice are identified, thanks to videos, and excluded of the analysis.

The signal corresponding to the exercise is then rectified using root mean square (RMS) treatment. A temporal sliding window of 25 ms is applied for the computation.

The Exposure Rate (E_{rate}) is obtained via Equation 1, where the limits of the interest time laps are defined as t_0, t_f and S_{RMS} symbolises the RMS post-treated signal. Expressed in mV, it quantifies the muscular solicitation. It is a kind of averaged AP amount received by a muscle during a specific task.

$$E_{rate} = \int_{t_0}^{t_f} \frac{S_{RMS}}{(t_f - t_0)} dt \qquad (1)$$

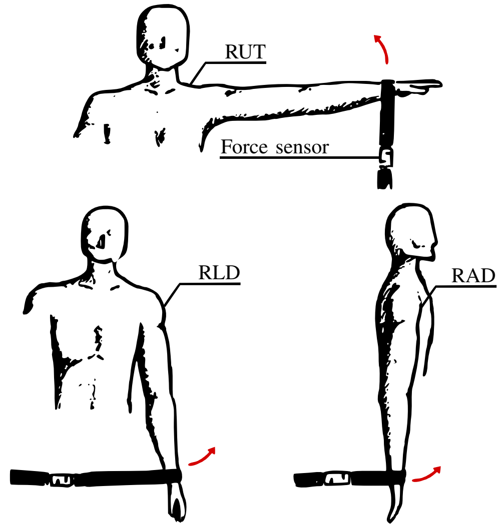


Figure 3: MVC monitoring setup.

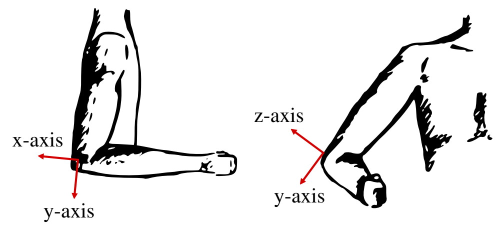


Figure 4: Acceleration monitoring referential setup.

D. Maximal Voluntary Contractions

1) Specific experiment: Called MVC, these contractions are the reflect of the muscular solicitation under maximal voluntary force production [18].

To avoid operator-dependant methods a protocol using a force sensor is applied. Pulleys and straps linked to wall, ground or weights are attached to the surgeon's upper limb segments. The sensor can thus monitor the force exerted by the surgeon.

MVC are recorded during specific tasks aiming to solicit the muscles in their main direction of work. Pure movements, in which they are involved, are reproduced. The setup is represented in Figure 3.

Three successive measures of MVC are done. The force measurement is coupled with EMG recording. This allows to obtain a direct information on the produced effort and to encourage the surgeon to surpass the precedent trial. The EMG corresponding to the highest recorded force are selected as MVC for each muscle.

The signal is then post-treated as others EMG signals, using Equation 1.

2) Normalised Exposure Rates: In order to compare the muscular solicitations between several trials or surgeons, it is compulsory to normalise them with respect to the maximal

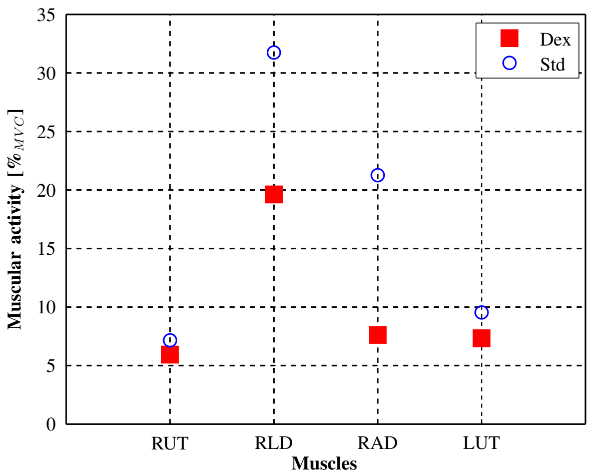


Figure 5: Std and Dex comparison for C-condition.

Table II: Dex activity's reduction for C-condition.

Muscle	RUT	RLD	RAD	LUT
Activity reduction [%]	17,06	38.19	64.16	23.12

Figure 6: Surgeon's posture in Std and Dex configurations.

muscular solicitation that each muscle can produce voluntary. Called Normalised Exposure Rate, this quantity is the reflect of the muscular activity reported to the own capability of the surgeon. Expressed in $\%_{MVC}$, it will be used for the following analysis.

E. Smoothness characterisation

A 3-axis accelerometer (ACL300, Biometrics Ltd) is affixed on the lateral epicondyle. Axes are oriented such that y-axis is on the humerus prolongation, x-axis point backward and z-axis is directed in lateral direction. This is presented in Figure 4.

Signals are recorded simultaneously with EMG, connected to the same Datalog. They are post-treated using MATLAB software, in order to quantify and characterise the movements of the surgeon. This method has already been applied to compare expert and novice ability during a dedicated laparoscopic task on a model [19].

III. Results and Discussion

A. Instruments comparison through muscular solicitations

In practice, the expert surgeon is aware of the influence of an non-ergonomic posture on the WRMSD development risk. He has organised his workspace in order to reduce his operating discomfort. He uses routinely an adjustable table and a platform. It appears that his workspace corresponds to a PAW height between C and D-conditions. Depending on the patient abdominal size, he adapts PAW height thanks to the Trendelenburg angle [10].

1) OR conditions: From surgeon's habits and Van Vellen et al. recommendations, the comparison of both configurations is lead for a PAW altitude equals to 70 % of the surgeon's elbow height. Figure 5 presents the results corresponding to this condition.

Standard configuration being considered as the reference in terms of muscular involvement, results clearly show that the muscles of the shoulder complex (trapeziuses and right deltoid) have a reduced activity in Dex-configuration.

The significant activities reductions due to Dex™ use are presented in Table II.

In order to be able to discuss this influence of the Dex™ on muscular solicitations, a video analysis is done (Figure 6). On the face view, an adduction of the shoulder is observed with the articulated instrument. Lateral Deltoid is thus at rest. On the profile view, with the Dex™, the surgeon's arm is parallel to his trunk nay lightly backward, indicating a weak solicitation of the anterior fascicle of the same muscle. A depression of the shoulder is also observed, indicating a relaxation of UT.

Moreover, the reduction of movements magnitude due to Dex™ articulations (at handle level and in intra-corporeal), observed on video analysis, limits the shoulder's elevation as well as scapula tipping and rotation. This corresponds to a reduction of muscular solicitations too.

To summarize, for conditions close to the surgeon's routine one, the Dex™ presents advantages for the comfort by reducing the muscular involvement at nape and shoulders levels as well as dominant arm's pronation.

2) Variation of PAW heights: The five conditions have been randomly proposed to the surgeon. This aims to cover a maximum of operating situations in order to understand the adopted strategy, in terms of posture, and propose the optimal PAW for both instruments configurations.

The results are presented in Figure 7 for the muscles involved in cervicalgia and in Figure 8 for the ones acting on rotator cuff injuries.

It is interesting to note that the lower the table is, the weaker the trapeziuses solicitations are, excepted for a very low table position. This last working condition imposes an arm extension and scapula tipping which is linked to trapeziuses solicitations. This phenomenon is observed principally in the dominant arm in Dex-configuration and for both arms in Std-one.

The lower activity for right and left upper limbs is obtained with both kinds of instruments for B-condition (Figure 7).

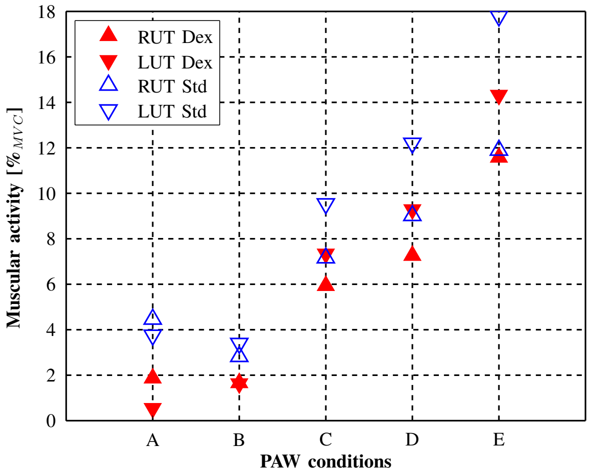


Figure 7: Upper Trapeziuses muscular activities.

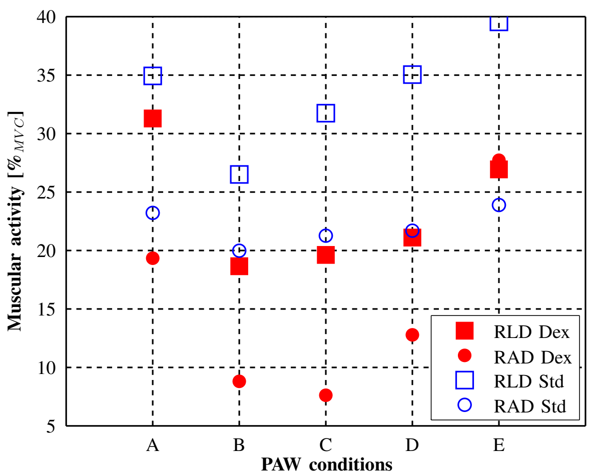
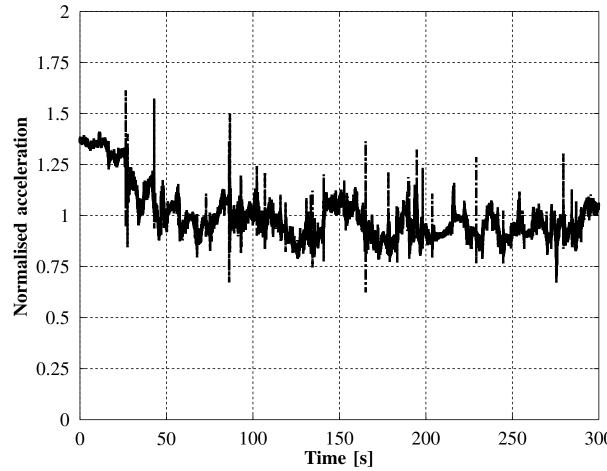
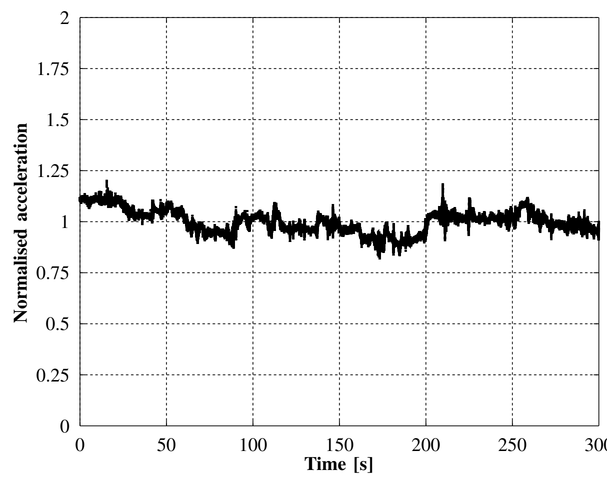


Figure 8: Right Deltoid muscular activity.



(a) Standard configuration



(b) Dex-configuration

Figure 9: Normalised quadratic sum of x, y and z accelerations in B-condition.

Whatever the PAW height is, Anterior and Lateral fascicles of the right Deltoid are less solicited in Dex-configuration than in Std-one except for the extreme height (Figure 8). The Anterior Deltoid presents an equivalent solicitation for E-PAW height. The articulated handle permits the surgeon to limit the abduction and elevation of shoulder by allowing an arm antepulsion.

It is nonetheless important to notice that antepulsion is less deleterious than abduction for a similar non-ergonomic angle of the articulation. The Dex™, by allowing to adopt a new strategy for high PAW, limiting abduction, offers real ergonomic benefits to the surgeons.

B. Gesture smoothness: a preliminary study

A continuous, smooth and accurate gesture is associated to limited accelerations whilst tremors or disjointed movements are put into evidence by high acceleration levels. In this case, a lack of precision can appear as well as a surgeon discomfort.

The accelerometer's signals, presented in Figure 9, are thus analysed for the optimal condition previously defined for this session (B-PAW).

Higher accelerations are recorded for Standard laparoscopy. The baseline seems to presents more variations and high peaks are regularly presented. This is typical of disordered accelerations linked to difficulties to fulfil a gesture with standard instrument where the Dex™ permits, thanks to its handle articulation, a shoulder's comfort and, through its motorised articulations, a reduction of upper limbs movements and pronounced wrist rotations. Non-ergonomic positions at limit angles don't permit to have thin gestures, the muscles anatomy leads to disjointed movements.

It is interesting to notice that the opening of the instrument's jaw corresponds to some peaks. The presence of a spring in the opening system of the V-type handle, creates a shake which is visible at elbow level. These repeated mechanical shocks could potentially induce wrist and hand tendinopathy.

The objective of further analyses is to define an index able to characterise the smoothness of the gesture from accelerometer signals.

IV. Conclusion

Two configurations, using different laparoscopic instruments, have been compared in five working conditions using EMG electrodes and a 3-axis accelerometer. The standard instruments used present a classical architecture. The obtained results can thus be extended to similar devices with an axial V-type handle. The articulated and motorised one owns some specificities due to its design. Extensions of the results to similar instruments are not possible without a complementary study.

The five heights imposed to the surgeon during the different exercises have permit to identify an optimal working condition. The PAW height that limits the most the muscular involvement in both configurations is at 60 % of the surgeon's elbow height. Coherently with previous studies lead in this field, the lower height is not the most favourable for the surgeon's comfort [11].

In this optimal working condition, the study shows that the use of motorisations and handle's articulation significantly reduces the activities of the upper limbs muscles. Less solicited, the muscles has probably less risks to develop fatigue and WRMSD. This has to be verified by complementary studies.

The accelerations measured at elbow's level show a real difference between both configurations at optimal height condition. The trajectory realised with the Dex™ tip is more fluid and probably less deleterious for upper limb muscles. The resulting operating gesture leads probably to more accuracy.

Several prospects are aimed to fulfil the analysis. Firstly, to characterise the smoothness through acceleration analysis, a dedicated index has to be proposed. Secondly, the accuracy of the gesture in both configurations have to be quantified. A protocol using "Flock Of Birds", an electromagnetic tracking device, could be defined in order to follow the instrument's tool trajectory on a dedicated workspace. Finally, all theses results should be confirmed by a multi-surgeon and multi-centric study.

Acknowledgment

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