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# Biomechanical Evaluation of the Phases during Simulated Endotracheal Intubation (ETI): Pilot Study on the Effect of Different Laryngoscopes

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*Abstract*— **Endotracheal Intubation (ETI) is a common airway procedure used to connect the larynx and the lungs through a windpipe in patients under emergency situations. The process is carried out by a laryngoscope inserted into the mouth, used to help doctors in visualizing the glottis and inserting the tube. Currently, very few studies on objective evaluation of the biomechanics of the doctors during the procedure have been done. Additionally, these studies have been concentrated only on the overall performance analysis, without any segmentation, with a consequent loss of important information. In this paper, the authors present a preliminary study on a methodology to objectively evaluate and segment the biomechanical performance of doctors during the ETI, using surface electromyography and inertial measurement units. In particular, the validation has been performed by comparing three kinds of laryngoscopes involving an expert doctor. Finally, results are presented and commented.**

## I. Introduction

Endotracheal Intubation (ETI) is a procedure used to connect the larynx and the lungs in patients under emergency situation. A tube is inserted to create an airway and to allow a regular breathing after traumas [1]. This practice is carried out using a laryngoscope: it is a medical instrument inserted into the mouth to support the placement of the windpipe. Proficiency in the ETI is of paramount importance to avoid damages in the oral cavity. Actually, the statistics show a high number of consequences and complications after the intubation [2]-[3]. A good training for the doctors and paramedics is then necessary. Standard training is carried out using a mannequin, with the presence of an expert doctor who evaluates the timing and the movements of the trainee, eventually giving advices and showing the right procedure. The main limitations are two: first, the mannequin is not a real patient and cannot reproduce, for example, movements of the head or tongue that often affect the insertion of the laryngoscope [4]. Second, the evaluation of the trainee is done subjectively, relying exclusively on the experience of expert doctors, whose time is also very limited. In the last years advanced robotics system have been developed to simulate patients and possible contingencies, like the WKA-4 robotic system developed in Waseda University [5]. WKA-4 presents improved mechanisms with high-fidelity simulated human anatomy, and a Virtual Compliance Control that reproduces the stiffness of the human's muscles. While a more realistic and sensorized simulated patient is important to understand the effects on the patient himself, it is not able to measure the performance of the doctor during the practice. The proposed paradigm is to add sensors also on the trainee: information can be used by the assessor for a more objective and accurate evaluation. Posture and motions analysis has already demonstrated to be an indicator of the performance in simulated medical procedures [6]. In this paper the authors present an objective procedure to evaluate the biomechanics of doctors during the practice of ETI by a combination of surface electromyography (sEMG) and motion analysis. In particular, the sEMG is used to evaluate the amount of muscle force during the exercise. The motion analysis, carried out by Inertial Measurement Unit (IMU), is used to study the amount of movements during the exercise. Currently, only few works have been published on the evaluation of airway procedures by placing sensors on the subject [7]-[8]. However, they do not show any correlation in time between the motion and the muscle utilization, working only on the values of the entire procedure: important information on the segmentation of the practice is lost. By an analysis based on the entire exercise, only general recommendations could be given to perform better, without information on the precise point of poor performance. Our rationale is based on the fact that during the ETI there are phases in which movements and forces are balanced differently; for example, during the insertion of the tube, to guarantee the exact placement of the windpipe, the forearm and hand present high muscle activity and no movements, resulting in an isometric contraction.

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Additionally, previous works did not present analysis on the thumb muscle, which is especially stressed during the intubation, according to the medical doctors that assisted us during the experiment. Finally, we have added this information and included in the results. In order to verify the methodology, we have performed a simulated ETI with three different laryngoscopes, one standard and two with included video-camera and LCD monitor, using an airway mannequin, involving an expert medical doctor. The structure of this article is as following: after the Introduction session, the Materials and Methods paragraph explains the details of the hardware and methodology used to analyze the data from the sEMG and IMUs. After, the Results section presents the analysis and discussion. Conclusions close the paper with some ideas on future applications and works.

## II. MATERIALS AND METHODS

### A. Sensors Hardware

The surface electromyography has been recorded for left hand, arm and shoulder, for a total of 4 channels, as showed in Fig. 1. In particular, the sensors have been placed on the left Abductor Pollicis Brevis (L-APB), left Extensor Carpi Ulnaris (L-ECU), left Flexor Carpi Radialis (L-FCR) and left Biceps Brachii (L-BB). We used DE-2.1 sensors from Delsys Inc., together with the amplifier Bagnoli TM 16-channel system (Delsys Inc., USA). The sampling frequency was fixed at 1000Hz and the gain k=1000. The inertial measurement units were placed on the left hand (IMU01), left forearm (IMU02), left arm (IMU03), left shoulder (IMU04) and on the backbone (IMU05), in order to analyze the wrist and elbow joints, as showed in Fig. 1. The IMU used for this experiments, named WB-4, has been developed by our group and consists in a 9-axis wireless system able to measure the acceleration, angular velocity and magnetic field in 3D. Sampling frequency was fixed at 200Hz. The paper referred in [9] presents the details of the hardware. Data of IMUs and sEMG were synchronized with a time stamp, due to the different sampling frequency.

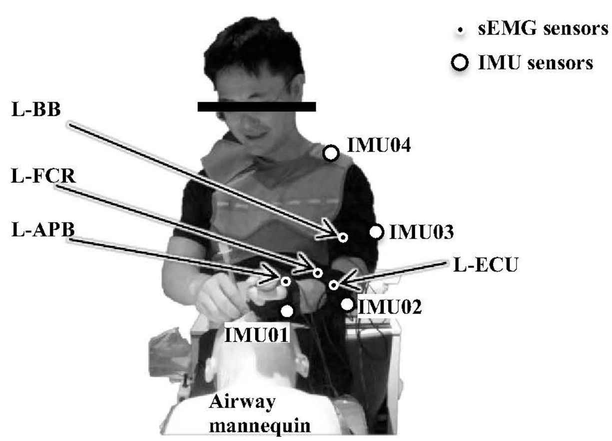


Fig. 1. Location of the electromyography and IMU sensors

### B. Laryngoscopes

In order to validate the proposed methodology, we have asked the subject to try three different laryngoscopes, as showed in Fig.2, with a standard mannequin for airway practices:

1. L01: Fiber Optic Laryngoscope, Welch Allyn (NY, USA) with curved blade. This is a standard laryngoscope.
2. L02: McGRATH® MAC Video Laryngoscope, Aircraft Medical Limited (Edinburgh, United Kingdom). This is a model released in 2010; it comes with a high resolution video-camera and an original Macintosh type blade.
3. L03: AWS-S100, PENTAX (Tokyo, Japan). Released in 2006, it is a rigid video laryngoscope for intubation, equipped with a specialized laryngoscope blade, called Intlock ITL-S.


Fig. 2. Different Laryngoscopes used in the experiment.

### C. Protocol

The experiment was carried out with one expert medical doctor, male, right handed. We asked him to sign an informed consent. The experiment was performed in accordance with the ethical standard defined by the committee of Waseda University and in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. Additionally, the experiment was videoed. After the explanation session, the sEMG and IMU sensors were placed on the subject, and the Maximum Voluntary Contraction (MVC) for the muscles under observation was recorded [10]. The subject repeated each task 6 times. Before starting the exercise, we asked the subject to stay immobile and relaxed for 5 seconds in order to record the EMG baseline.

### D. Data Analysis

Data from IMU were filtered by a modified Extended Kalman Filter with adaptive covariance matrix [11]. In this work we have considered the net joint angular speed $|\boldsymbol{\omega}(t)|_{WR}$ and $|\boldsymbol{\omega}(t)|_{ELB}$, respectively in the wrist and elbow joints: they are indicative of the amount of motion of the joints [6]. The $|\boldsymbol{\omega}(t)|$ is defined in (1):

$$|\omega(t)| = \sqrt{\omega^2{}_r(t) + \omega^2{}_p(t) + \omega^2{}_y(t)} \quad (1)$$

where the $\omega_r(t)$, $\omega_p(t)$ and $\omega_y(t)$ are the angular velocities in the roll, pitch and yaw directions. From the visual analysis of the signals, together with the recordings of the video, we could recognize three main phases of interests: Phase 1 (Ph01) - insertion of the laryngoscope into the mouth; Phase 2 (Ph02) - insertion of the tube through the laryngoscope; Phase 3 (Ph03) - removal of the laryngoscope. Fig. 3 shows the three phases for the sEMG(t) of the L-ECU and the RMS of $|\boldsymbol{\omega}(t)|_{WR}$. Data from the sEMG were filtered and denoised using a denoising filter based on an estimation of the baseline noise [12]. The RMS signals (100ms window) were normalized with respect to the MVC, $sEMG^{MVC}(t)$. After the segmentation into the three phases Ph01, Ph02 and Ph03 mentioned before, the averaged values were calculated for the three laryngoscopes

L01, L02 and L03, on all the repetitions R01 to R06, and for each muscle under observation.

The combination of the data from the IMU and sEMG signals has been analyzed by a proposed dimensionless Isometric Contraction Index ICI, as in (2):

$$ICI(t) = \frac{sEMG^{MVC}(t)}{\omega(t)_{NORM}} \quad (2)$$

where the $\boldsymbol{\omega}(t)_{NORM}$ is the normalized angular velocity with respect to the average value, related to the joint activated by the muscle. Finally, group means of each phase, for the average sEMG and ICI, were compared for significance using a one way ANOVA.

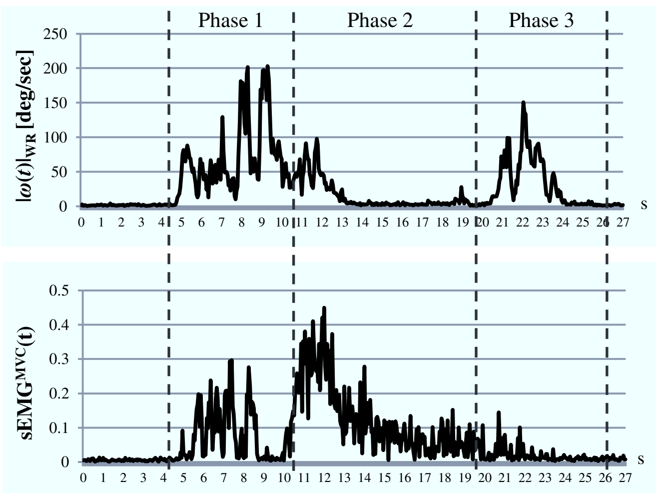

Fig. 3. Example of the three phases for L-ECU sEMG and wrist $|\boldsymbol{\omega}(t)|_{WR}$

## III. Results and Discussion

Fig 4 shows the comparison for the laryngoscopes L01 to L03 of the average sEMG and proposed index ICI values during the phases Ph01, Ph02 and Ph03, in addition to the total average, for the L-ECU muscle. The double asterisk indicates a significance with p<0.01. The total values show significant difference between the standard model L01 and the McGRATH® MAC Video Laryngoscope L02: in particular, L01 is the one that needs bigger use of left ECU, while L02 is stressing the muscle less than 10% of the MVC in average, with the smallest contraction index. The analysis by phases shows important information related to the biomechanics of the subject. Phase Ph01 does not present any significant difference between the three models; it means that the insertion of the laryngoscope was not affected by the model. Ph02 is the phase with the higher value of sEMG and ICI: during the insertion of the tube, the doctor needs to keep the wrist fixed with high muscle activation. The L02 had the average sEMG at similar levels for Ph01 and Ph02: an explanation from this analysis could be that with the L02 the doctor kept the same amount of activation during the Ph01 and Ph02, while he changed the amount of motion, keeping a fixed position, during the Ph02. Finally, the Ph03 did not show any difference between the L02 and L03, but L01; the standard model had also higher contraction index and muscle usage during the removal of the laryngoscope.

Fig. 5 presents the comparison for the L-FCR muscle: the differences resulted significant only for the Ph02 and the total, and only between the standard laryngoscope L01 and the other two video laryngoscopes L02 and L03, both for the averaged sEMG and the ICI. Additionally, L02 and L03 present the same behavior in having smaller values of sEMG and ICI for the Ph02 with respect to the Ph01; it means that the insertion of the laryngoscope is the action that impacts more the L-FCR, both in term of muscle usage and contraction index.

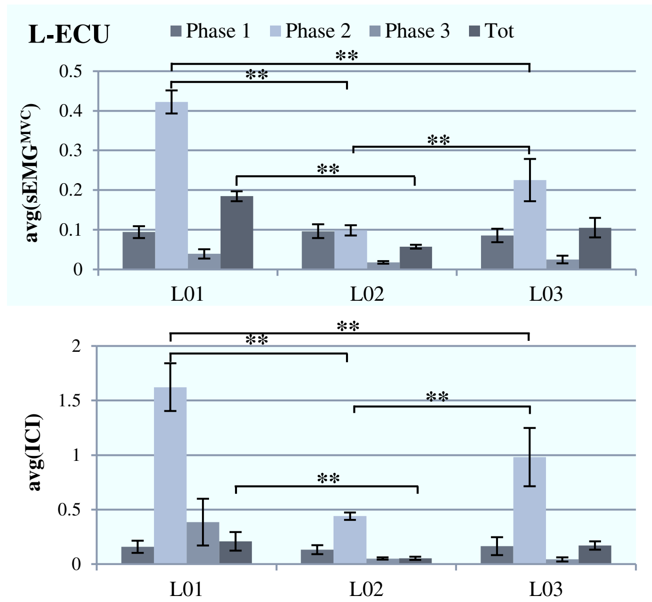

Fig. 4. Averaged sEMG and ICI for L-ECU muscle

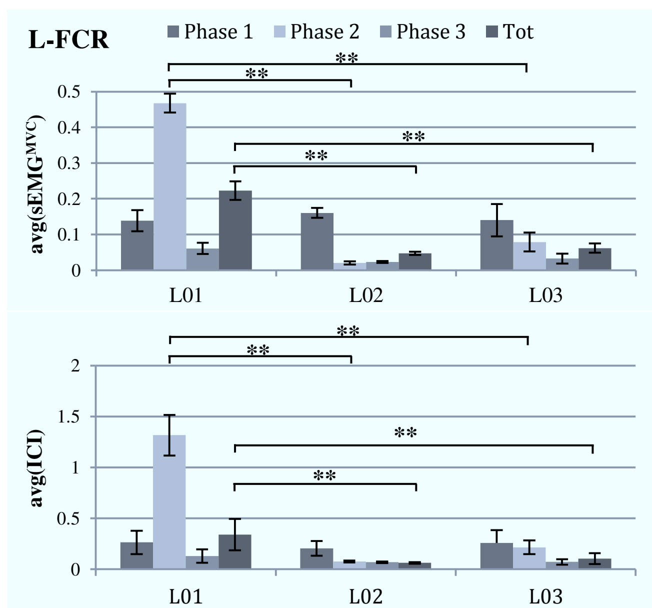

Fig. 5. Averaged sEMG and ICI for L-FCR muscle

Fig. 6 is the comparison for the Biceps Brachii. In this case the ICI is calculated with respect to the $|\boldsymbol{\omega}(t)|_{ELB}$. The totals for the sEMG are always below the 10% of the MVC. The differences are present only for the phase Ph02 for both the sEMG and ICI, but, differently from the L-ECU and L-FCR, it was not possible to differentiate significantly the L01 to L03.

Finally, Fig. 7 shows only the analysis of the sEMG for the APB, because we did not place any IMU on the thumb. There are significant differences between the L01 and L02 for the Ph02 and the total average, and between the L02 and L03 for the Ph03. Generally, from muscle point of view, the McGRATH® MAC Video Laryngoscope is the one performing better also for the L-ABP.

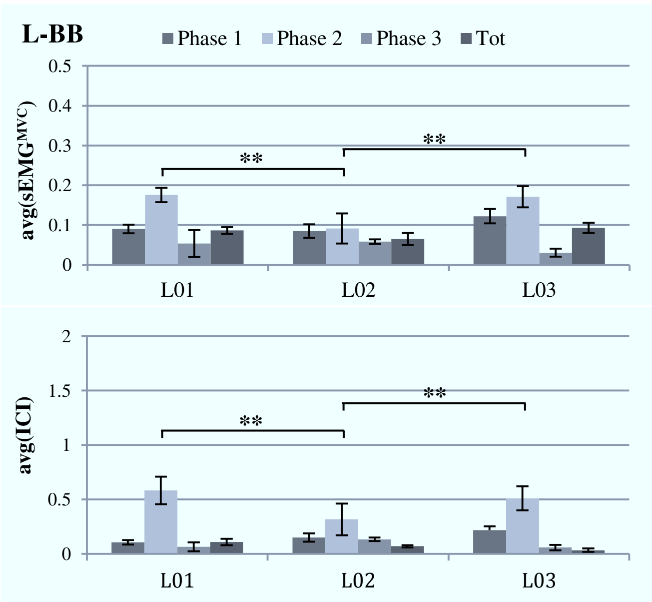


Fig. 6. Averaged sEMG and ICI for L-BB muscle

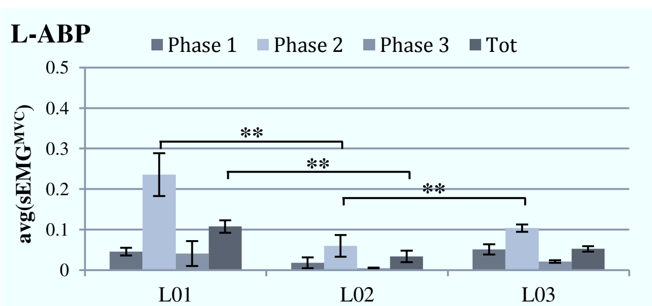


Fig. 7. Averaged sEMG for L-APB muscle

## IV. Conclusions

In this paper the authors suggested a methodology to analyze the performance of trainees during Endotracheal Intubation practice, using the combined information from surface electromyography and motion. A proposed index of isometric contraction, together with the investigation by segmentation by phases of interest, show that ergonomics of the doctor can be analyzed in detail. The comparison between three different laryngoscopes was performed to validate the methodology: results present significant difference in muscle stress and isometric contraction index between the standard laryngoscope and models equipped with a video-camera. In particular, the laryngoscopes with video-camera seem to facilitate the work of the physicians from biomechanical point of view, especially during the insertion of the tube. Future works will include an analysis involving additional muscles in the shoulders and chest, and more subjects, especially to verify the results of the thumb muscle. Additionally, comparison between novices and experts could be analyzed to individuate the points of poor performance and eventually tutoring. From the hardware point of view, the main complaint from the subject was related to the wired sEMG apparatus, and we will consider using a wireless system. Finally, the combined use of WKA-4 robotic system to have a fully sensorized training set could be considered.

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