Measurement of Abdominal Retractor Loading and its Effects on the Surgeons Arm

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Abstract: *A load measuring apparatus integrated into an abdominal retractors and its methodology are presented. The measured forces offer new knowledge in the fields of surgery and may be useful in the design of new retractors and fixing frames as well as the investigation of tissue loading during surgical intervention. Effort required to hold the retractor is quantified for the surgeons forearm and the approximation of muscle fatigue can be evaluated with respect to the duration of surgical intervention.*

Keywords: *Abdominal retractor, measurement, muscle fatigue*

1. Introduction

Open cavity or deep surgery is a commonplace practice in surgical intervention. The successful execution of such operations requires the use of various instrumentation which has evolved to facilitate particular interventions. Common apparatus are surgical retractors intended to move or prevent soft tissues and/or organs from obstructing the surgeon during intervention. These retractors come in many forms and configurations [1]. In many situations, the retractor is held in place by an assistant surgeon. This can involve considerable effort from the assisting surgeon, particularly if the operation may take a long time. Currently, there have not been significant contributions regarding the forces involved with the use of such devices. Only forces for general grasping by fingers are discussed [2]. Understanding these forces could assist surgeons in planning for surgery and also contribute to the design of new retractors and investigate their effects on soft tissues and organs. This article attempts to measure the loading of the retractor and quantify the effort the assistant surgeon must put forth over a fixed interval during the gallbladder surgery.

2. Measuring methodology

After consulting medical staff at the faculty of medicine the1st surgical unit in Bratislava Slovakia it was decided that a Mikulicz deep surgery retractor, see Fig. 1, would be modified to incorporate a miniature, high precision force transducer which would record data during surgical intervention. The same modification has been done for the Fritsch retractor too. The force transducer was strategically mounted to measure axial loading between the handle and blade. The chosen transducer has an effective measuring range of 2 – 200 N and is powered by a remote data logger (EMS600) recording at a rate of 10 Hz over 100 sec. intervals. The data was then transferred to PC via SD card. The device was calibrated by suspending OIML R111:2004 compliant, class M2 weights from the end of the force transducer fixed to a purpose built vice. Measurements were taken during operation of the gallbladder.

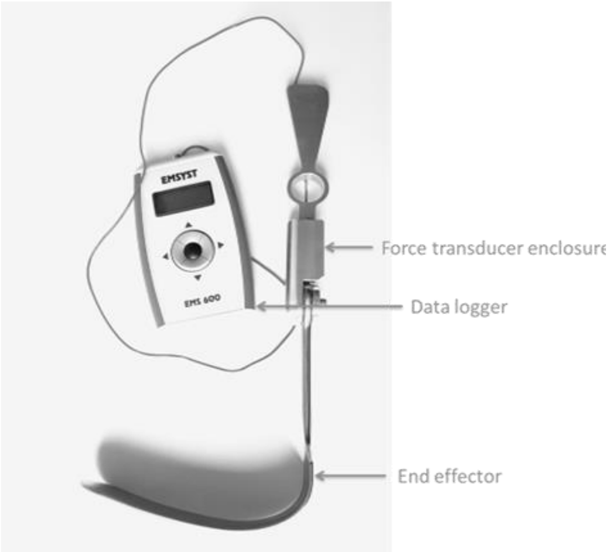

Fig.1. Modified deep surgery retractor (end effector) incorporating force transducer (enclosure) and data logging unit EMS 600

3. Experimental results

Several measurements were performed during gallbladder surgery where the Mikulicz and Fritsch retractors were used to hold the inner organs and the skin by the female assistant, see Fig. 2.

Fig.2. Measurement setting during gallbladder surgery

The typical measurement time sequence can be observed in Fig. 3 below.

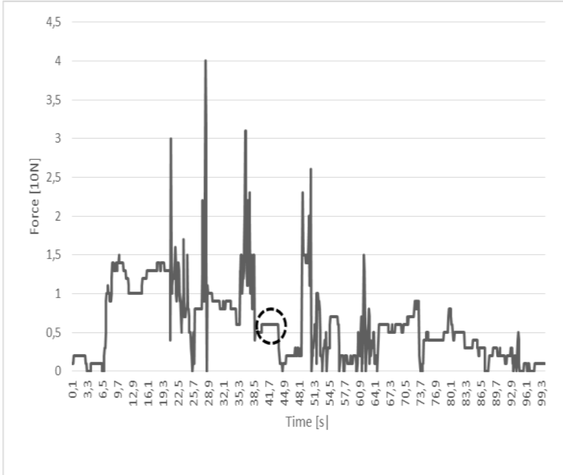

Fig.3. Axial force measured between the blade and handle of the Miculitcz deep surgery retractor.

From data obtained from the above mentioned measurements, a standard statistical analysis was performed resulting in an average loading of 6,06 N with a maximum measured value of 40 N, the standard deviation of 5,07 N and the coefficient of variation of 83,7%. This maximum measured force corresponds to the maximum pulling force that a female fingers can produce [2]. Due to the balance between external measured force (holding force) and the muscle tension we can predict that if the static external force exerts longer than usual relaxation time without any movement then we will assume that isometric conditions are satisfied. Any movement of fingers will be registered by the sensitive force transducer.

4. Muscle fatigue

Muscle fatigue is defined as the loss of a muscles ability to generate force. It can be a result of vigorous exercise but abnormal fatigue may be caused by barriers or interference with the different stages of muscle contraction. Three basic contractions can occur during activity: concentric, eccentric and isometric. The concentric and eccentric contractions produce tension resulting in the motion of body segments. In this case, the work done by the muscle is dynamic. Isometric contraction refers to “the same measure” of contraction. In this case the work done is static. This is important because tension is still supplied by the muscle to equalize external forces, as is particularly necessary when holding a surgery retractor. Energy is still expended by the muscle (for such "static" work) to produce the tension that resists the load.

The muscle contraction is ensured by the sliding of actin filaments along myosin filaments within the sarcomere. The myosin filaments pulling along the actin filaments is controlled by ATP (Adenosine Triphosphate) molecules, that hydrolyze to ADP (Adenosine Diphosphate) and inorganic phosphate, releasing energy, and calcium ions, that allow to build the cross bridges between actin and myosin filaments. If ATP molecules are missing, the cross bridges will not be built and myosin filaments will relax [3].

An isometric contraction of a muscle generates tension without changing length, see Fig. 3. It means the lack of ATP molecules and no source of internal energy. If the duration of isometric contraction is long enough, the muscle will not generate sufficient force due to the above mentioned mechanism.

The maximum muscle force or tension that can develop during isometric conditions is defined as:

$$F_m = T = k_m.PCA \qquad (1)$$

where PCA is the physiological cross-sectional area of the muscle, the range of the maximum values of k_m is 20–100 N/cm^2 [4].
The real response of muscle during isometric contraction can be modeled by the simple Maxwell model as follows

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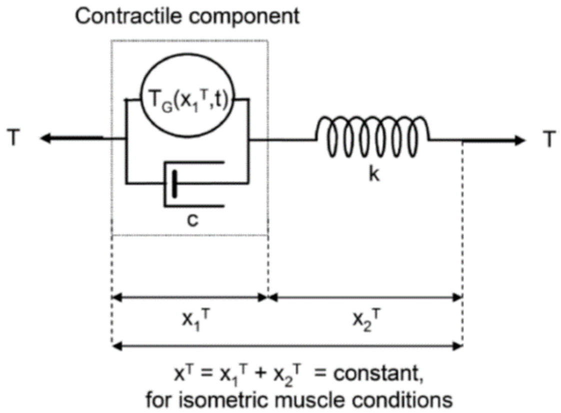

Fig.4. Maxwell model of isometric contraction [4]

The isometric deformation condition can be written

$$x^T = x_1^T + x_2^T = constant \qquad (2)$$

or

$$\frac{dx^T}{dt} = \frac{dx_1^T}{dt} + \frac{dx_2^T}{dt} = 0 \qquad (3)$$

Applying the initial condition: *T(0)=T₀, t=0* and *$T_G(t)$=constant* we will get the solution

$$T(t) = (T_0 - T_G)e^{-t/\tau} + T_G \qquad (4)$$

where $\tau = \frac{c}{k}$ is the relaxation time, c is the damping constant, k is the spring constant and T_G is the inner tension generator of contractile component in the Maxwell model, Fig. 4. The graphical representation of deformation and tension in the Maxwell model are presented in Fig.5.

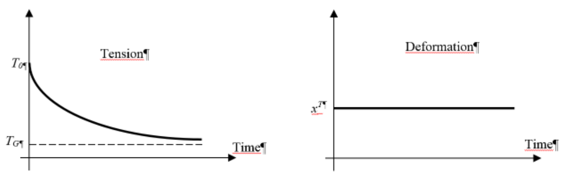

Fig.5. Tension and deformation in isometric condition

Usually the relaxation time reaches the value of several hundreds of milliseconds [4]. Then for example for the relaxation time of 100 ms and the time duration of 3 s we will get the muscle tension $T(3) = 9.36\,x10^{-14}(T_0 - T_G) + T_G \cong T_G$ that is practically constant due to constant applied load, see dashed black circles in Fig.3.
Due to this results and the limit Rohment curve for static endurance vs. relative exertion [4, 6] we can propose the quantification of muscle fatigue which can be calculated in the sense of Miner´s rule for cumulative damage [5]. It states that if there are k different isometric exertion levels with the corresponding maximum time at the i-th level is t_i^{max} and its real duration is t_i, then the damage fraction is

$$C = \sum C_i = \sum \frac{t_i}{t_i^{max}} \qquad (5)$$

C_i is the fraction of life consumed by exposure to the cycles at different exertion levels. In general, when the damage fraction reaches 1, the failure occurs.

Muscles must resist external forces when holding the retractor, see Fig. 2. The static work (with constant applied force) means that ATP molecules are missing and the cross bridges between myosin and actin filaments are not building. All dynamical processes (the flow of ATP molecules and calcium ions) cease if the duration of constant external load is longer than 1-2 seconds. Identifying the constant portions of the curve with the durations longer than 3 seconds – the dashed black circles in Fig.2 are places where muscle fatigue starts to accumulate.

5. Conclusions

The load measuring apparatus integrated into an abdominal retractors and its methodology has been presented. The measured forces offer new knowledge in the fields of surgery and may be useful in the design of new retractors and fixing frames as well as the investigation of tissue loading during surgical intervention. The new proposal of muscle fatigue assessment has been proposed. Effort required to hold the retractor is quantified mathematically for the surgeons forearm and the approximation of muscle fatigue can be evaluated with respect to the duration of surgical intervention.

To verify the proposed muscle fatigue assessment would be verified by the experimental measurement of muscle potentials for isometric condition in clinical conditions and making the referential (laboratory) measurements.

Acknowledgments

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