

# Critical Force Thresholds for Laparoscopic Grasping as an Indicator of Tissue Damage

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## Abstract

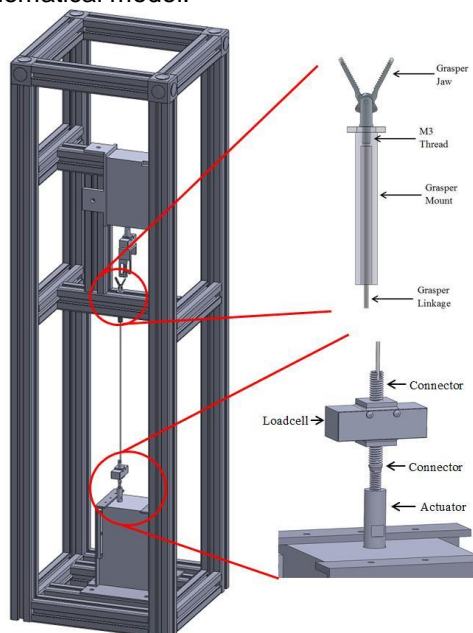
Advances in Minimally Invasive Surgery (MIS) have led to increasingly complex procedures being performed. Although uncommon, iatrogenic tissue damage contributes significantly to morbidity and mortality rates. Using a bespoke tissue grasping rig, samples of porcine colon were grasped using a typical atraumatic laparoscopic grasper. The force relaxation was observed over the grasping force range at the tip (0 - 7 N). The results showed that above a critical threshold of 2.55 N there is a dramatic change in tissue response with little relaxation. Histological analysis has shown that for key points over this force range the tissue's histological architecture is altered. This work highlights the need to further understand tissue-tool interaction in MIS, and the potential for a real-time damage analysis.

## Introduction

An increasing number and range of laparoscopic operations are being performed, in turn increasing the risk of iatrogenic tissue damage from diathermy burns and inappropriate traction and force application. With new tools, manufacturers have typically focussed on the functionality of the design rather than the need to understand the tissue-tool interface in order to prevent tissue damage [1]. Research has been conducted, both *in-vivo* and *ex-vivo*, to investigate the various tissue properties encountered during typical abdominal surgery [2, 3]. These studies only show how the tissue responds to relatively low stresses. Previous methods of quantifying tissue damage include histological staining, observation of chemicals and changes in tissue appearance, such as colour or surface profile [4 - 6]. However these methods required post-analysis which can take long periods of time, and in the case of histology, samples need to be taken which is not appropriate in all scenarios. There is a need to further understand tissue damage, to improve the design process of surgical tools. Also a reliable method of tissue damage analysis is needed, which can be performed in real-time without the need for excision and removal of tissue.

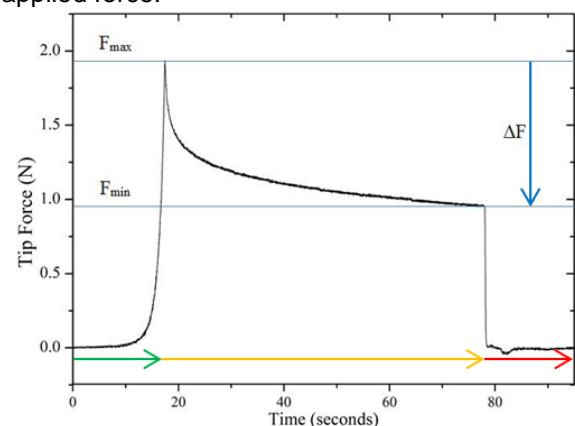
## Methods

A custom tissue grasping test rig (see *Figure 1*) was used to grasp samples of porcine colon for set jaw forces (0 - 7 N) for 60 seconds. This force was measured along the grasper shaft and converted to forces at the jaw tip using a mathematical model.



*Figure 1* – The test apparatus used to grasp tissue samples.

Once the set grasp force was reached the grasper position was held, and the force drop due to the tissue relaxation,  $\Delta F$ , was observed over the grasp time (see *Figure 2*). This was then calculated as a percentage of the maximum applied force.



*Figure 2* - Force relaxation characterisation graph showing  $\Delta F$  (blue), force ramp-up (green), position hold (orange) and grasp release (red).

## Results

The force relaxation,  $\Delta F$ , was plotted against the maximum applied force (see *Figure 3*). The

results show that below the critical threshold,  $\Delta F$  decreases gradually, until 2.11 N, where the amount of relaxation suddenly decreases. Beyond 2.55 N the force relaxation does not exceed 20%. This suggests there is an inherent threshold in the tissue beyond which the mechanical response of the tissue changes.

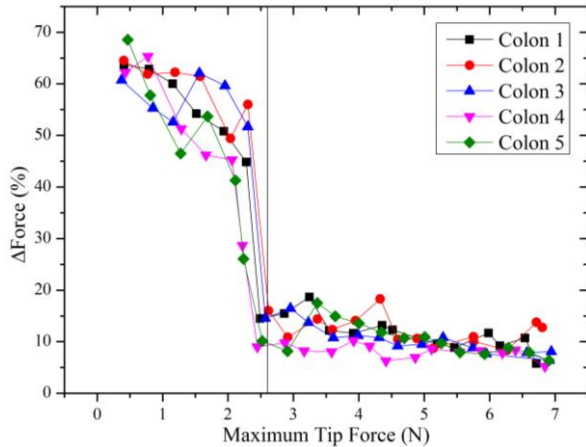


Figure 3 - Force relaxation correlated against maximum applied tip force.

## Discussion

The force relaxation results were compared with histological analysis of the porcine tissue samples (see Figure 4). The results indicate that for low forces, the tissue layers remain intact, including the outer muscle layer. Beyond the threshold force the muscle layers begin to breakdown, starting with disruption to the top layer of muscle, moving to deeper indentations. Finally at the maximum forces, the muscle layers have been completely destroyed, leaving only the submucosa and mucosa layers behind.

## Conclusion

The results highlight an inherent grasping force threshold in the tissue, beyond which the response breaks down. This has been supported by histological analysis of the tissue samples, showing damage to the outer muscle layers. This work has highlighted the possibility of an alternative method for damage quantifications, using real-time force monitoring. In addition, further understanding of the tissue-tool interface, and how this affects tissue damage, can help in the design and development of atraumatic surgical tools.

## References

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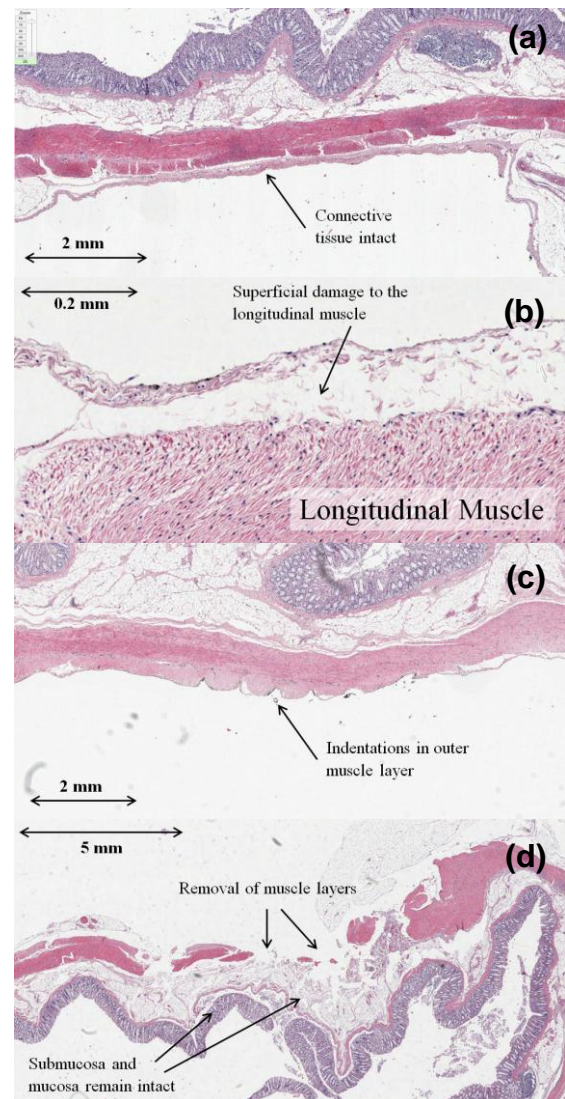


Figure 4 – Histological results, (a) low force grasp (no damage) (b) 2.11 N (minor damage) (c) 2.55 N (deep indentations) (d) 6.95 N (severe damage).