UNRAVELING THE BIOMECHANICS OF NITINOL BONE STAPLES: A COMBINED EXPERIMENTAL AND NUMERICAL INVESTIGATION

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Introduction

Nitinol bone staples showed to be a safe and effective option for internal fixation, demonstrating even superior characteristics in terms of usability, surgery time and post-surgery recovery time compared to traditional stainless-steel staples [1]. Nitinol staples recover their initial shape after being inserted into the predrilled holes, either owing to the super-elastic or to the shape-memory proprieties of Nitinol (i.e., super-elastic and shape-memory Nitinol staples, respectively) to pull the fractured bones together and apply a compressive force [2]. Despite the promising clinical results of both types of staples, most biomechanical investigations have focused on shape-memory devices. Few studies have been conducted on super-elastic staples. In this context, this study combines experimental tests and finite element (FE) analysis to assess the mechanical performance of commercially available Nitinol staples and determine their unique super-elastic properties, which are influenced by specific thermo-mechanical processing operations [3]. The ultimate goal is to develop a better understanding of the mechanical characteristics of these devices for successful treatment.

Methods

The two commercially available super-elastic Nitinol bone staples (Arthrex, USA and Johnson & Johnson, USA) shown in Fig. 1A (staples 1 and 2) were investigated. An experimental four-point bending test was conducted at 37°C to characterize their mechanical response by fixing each staple within two blocks (Fig. 1B), according to the standard ASTM-F564-17 for the testing of metallic bone staples. The tensile testing machine E3000 (Instron, USA) was adopted to apply three cycles of displacements (rate 0.5 mm/s) and to measure the generated force. Fig. 1C shows the adopted experimental set up, indicating (1) the custom-made temperature-controlled bath, (2) the four-point bending apparatus and (3) the staples fixing blocks. Geometrical models of the staples were obtained by micro computed tomography. FE models replicating the experimental tests were implemented in Abaqus Standard (Dassault Systèmes, FR). The super-elastic constitutive model was adopted for the Nitinol and in absence of material data a FE-based material calibration framework was developed to deduce the values of the constitutive model parameters.

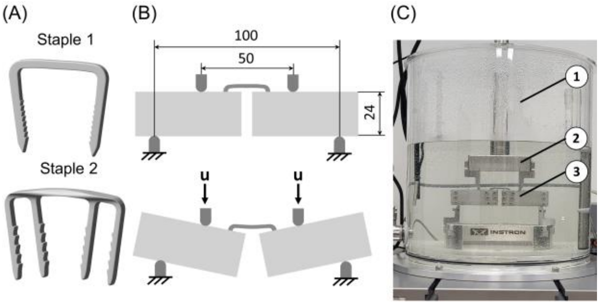

Figure 1: (A) Two commercially available staples; (B) Testing scheme; (C) Experimental set-up.

Results

Fig. 2 shows the four-point bending test curves obtained both experimentally and numerically (using the material calibration framework). The forces of staples 1 and 2 in the implantation configuration (legs and the bridge forming an angle of 90°) were experimentally found to be 68.4 N and 84.8 N, respectively (Fig. 2). The FE model approximated well the experimental curves ($R^2 > 0.99$) and the obtained Nitinol parameters differed between the two staples, indicating a different thermo-mechanical processing and chemical composition [3].

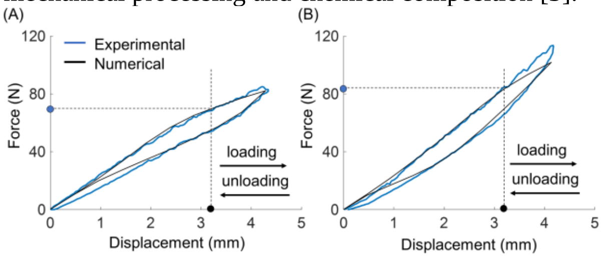

Figure 2: Experimental and numerical four-points bending curves of (A) staple 1, (B) staple 2.

Discussion

The results of this study highlighted the different mechanical response of the two investigated staples, which are attributed to a combination of different geometry and material characteristics. In the future, the calibrated FE staple models can be used to support device design, avoiding time and cost associated with prototype manufacturing and testing, and to optimize the geometry and material characteristics, improving the effectiveness of the treatment.

References

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2. Russel et al, J Mater Eng Perform, 18:831–835, 2009.
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Acknowledgements

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