Journal of Biomechanics xxx (xxxx) xxx

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Short communication

3D printed clamps improve spine specimen fixation in biomechanical testing

Frédéric Cornaz [a,b], Marie-Rosa Fasser [a,b], José Miguel Spirig [a], Jess G. Snedeker [a,b], Mazda Farshad [a], Jonas Widmer [a,b,*]

[a] Department of Orthopaedics, Balgrist University Hospital, Zurich, Switzerland
[b] Institute of Biomechanics, ETH Zurich, Zurich, Switzerland

ARTICLE INFO

Article history:
Accepted 24 October 2019
Available online xxxx

Keyword:
Biomechanical spine testing fixture

ABSTRACT

This study presents an anatomically customizable fixation technique for biomechanical spine experiments using a 3D printed clamping system. The aim of this study is to evaluate the feasibility and compare the fixation rigidity of the novel technique to PMMA potting with and without screw augmentation. For this purpose, 16 thoracic and lumbar functional spine units of bovine, porcine, ovine and human cadavers (4 each) were consecutively fixed with all three techniques and loaded in six degrees of freedom. The combined relative movement between the cranial and caudal vertebral body and their corresponding fixtures were recorded using a 3D motion capture system. The 3D printed clamps did provide multiple advantages, showed no failures and the fixation rigidity was superior to potting in all loading directions and superior to screw-augmented potting in two of six loading directions ($p < 0.05$). In conclusion, the here proposed novel fixation method showed equal to superior properties in comparison to both other methods used in this study. When considering all characteristics of 3D printing, 3D printed fixtures can be an effective alternative to potting.

1. Introduction

For biomechanical experiments on spinal cadavers, mounting of the vertebral bodies in a test rig is often necessary. Rigid fixation of the specimens is crucial to apply well defined loading conditions and to record accurate positional data.

Most commonly, vertebral bodies are mounted using a technique called potting, which uses solidifying materials like polymethylmethacrylate (PMMA), Wood's Metal, polyester resin or dental stone. Screws, pins or other connecting tools are frequently inserted into the vertebral bodies to increase anchoring stability. Literature validating or comparing different potting techniques and materials for biomechanical spine testing is scarce, in spite of its regular use (Amin et al., 2015; Kim et al., 2006; Pfeiffer et al., 1996). The advantage of this method is simple availability and a fixture with a large bearing surface reducing stress concentrations at anchored anatomical subregions.

However without specific measures, exact specimen orientation is difficult to achieve and anatomical structures below the liquid level are embedded and not accessible for later experiments. Furthermore, the specimens are exposed to elevated temperatures by exothermic reactions (e.g. PMMA, up to 113 °C) or due the use of melted materials (e.g. Woods's Metal, melting point 73 °C) (Amin et al., 2015). During potting with PMMA and Wood's Metal, the surface temperature of the intervertebral discs (IVD) was measured not to exceed 26 °C (Amin et al., 2015), but it remains unclear, if property changing heating of other anatomical structures occurs (Wang et al., 2005). Biomechanical changes have been documented due to intrusion of polymer resin into vertebral bodies (Pfeiffer et al., 1996). The insertion of screws, pins or other connecting tools into vertebrae prior to potting could interact with the biomechanical integrity of the specimens and can be problematic in experiments with instrumentation.

As 3D printing technology becomes more available and less costly, it could be used to produce fixtures with similar bearing

Abbreviations: AC, axial compression and decompression; AR, axial rotation; AS, anteroposterior shear; FE, flexion-extension; FSU, functional spine unit; IVD, intervertebral disc; LB, lateral bending; LS, lateral shear; PBS, phosphate buffered saline; PLA, polylactic Acid; PMMA, polymethylmethacrylate; ROM, range of motion; SA-potting, screw-augmented potting.

* Corresponding author at: Balgrist University Hospital, Department of Orthopaedics, University of Zurich, Institute for Biomechanics, ETH Zurich, Balgrist Campus, Lengghalde 5, CH-8008 Zurich, Switzerland.

E-mail address: jonas.widmer@hest.ethz.ch (J. Widmer).

https://doi.org/10.1016/j.jbiomech.2019.109467
0021-9290/

surfaces as potting. This methods could provide more exact specimen orientation, simple access to selected anatomical structures and application of compressive force between different parts of the fixtures while omitting specimen heating.

The aim of this study was to evaluate the feasibility of a proposed 3D printed clamping system for biomechanical spine testing and to compare the mechanical effectiveness of this novel technique to potting and screw-augmented potting (SA-potting). We hypothesized that this technique would be both feasible and mechanically effective.

2. Material and methods

2.1. Storage, dissection and preparation

Thoracic and lumbar functional spine units (FSU) were used in this study. Bovine, porcine and ovine fresh frozen cadavers were obtained from the veterinary hospital, originating from healthy animals deceased from heat stroke. Additionally, three fresh frozen human cadavers were utilized (Science Care, Phoenix, AZ, USA) after ethical approval by the local authorities (BASEC Nr. 2017-02018).

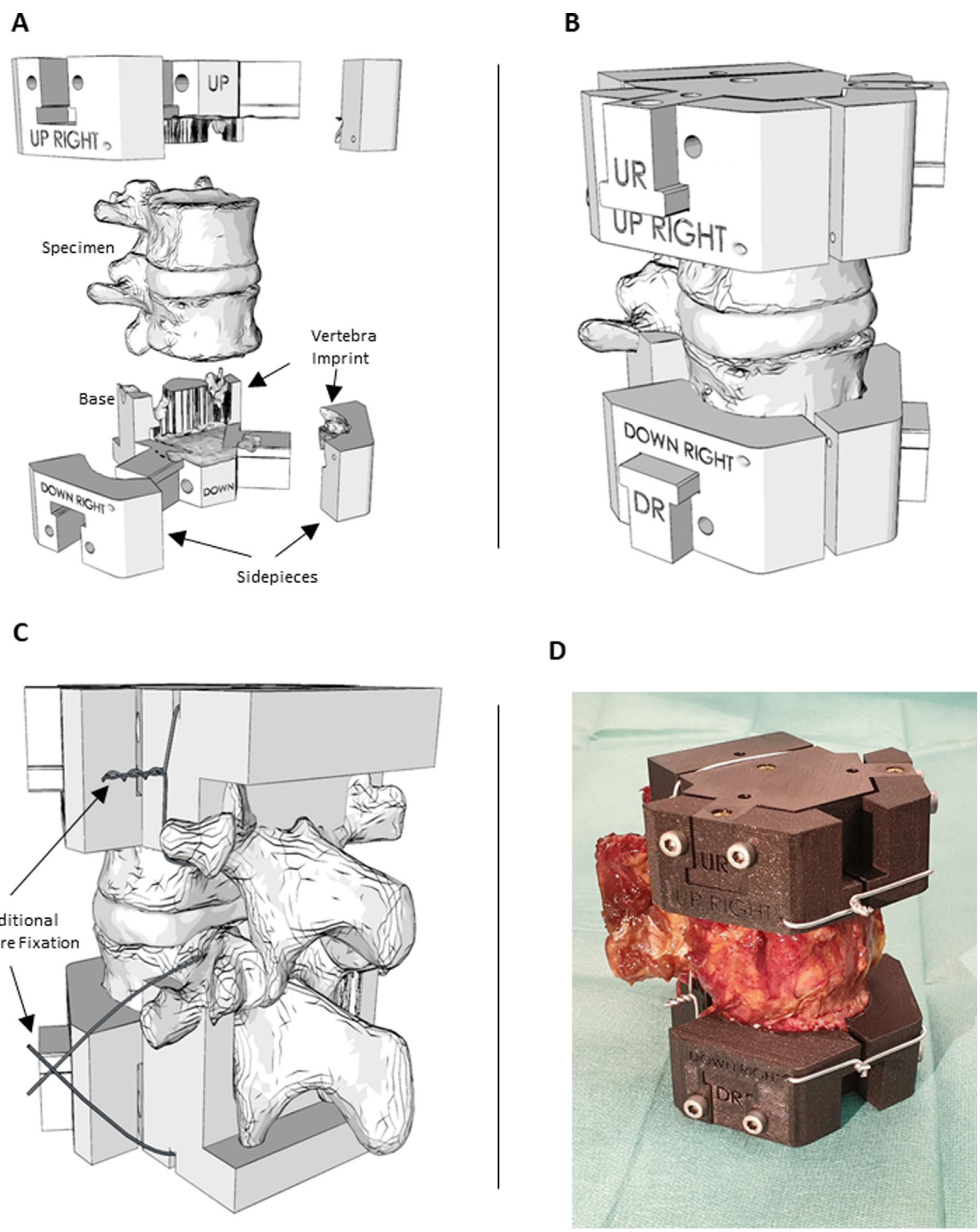

Fig. 1. (A) The 3D printed clamp consisting of a base part and two side pieces at a 60° angle. (B) The assembled clamp firmly embeds the specimen. (C) To provide additional stability, a wire is threaded through the foraminal window, wrapped around the pedicles and the base part. (D) The 3D printed clamps can be mounted into the test rig using the threads and pin holes at the bottom of the base parts.

Please cite this article as: F. Cornaz, M. R. Fasser, J. M. Spirig et al., 3D printed clamps improve spine specimen fixation in biomechanical testing, Journal of Biomechanics, https://doi.org/10.1016/j.jbiomech.2019.109467