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Technical Note

Quantification of material slippage in the iliotibial tract when applying the partial plastination clamping technique

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A B S T R A C T

The objective of this study was to evaluate the potential of the partial plastination technique in minimizing material slippage and to discuss the effects on the tensile properties of thin dense connective tissue. The ends of twelve iliotibial tract samples were primed with polyurethane resin and covered by plastic plates to provide sufficient grip between the clamps. The central part of the samples remained in an anatomically unfixed condition. Strain data of twelve partially plastinated samples and ten samples in a completely anatomically unfixed state were obtained using uniaxial crosshead displacement and an optical image tracking technique. Testing of agreement between the strain data revealed ongoing but markedly reduced material slippage in partially plastinated samples compared to the unfixed samples. The mean measurement error introduced by material slippage was up to 18.0% in partially plastinated samples. These findings might complement existing data on measurement errors during material testing and highlight the importance of individual quantitative evaluation of errors that come along with self-made clamping techniques.

1. Introduction

In 1967, Michael Abrahams recommended never using crosshead displacement to determine strain data of tendons because these data are limited by factors such as material slippage in the clamping region (Abrahams, 1967). Almost half a century later, however, it is still common to determine strain data using crosshead displacement in bone and soft tissue biomechanics.

Various modifications of the existing clamping techniques were introduced to minimize material slippage (Ng et al., 2005a). Roughened steel clamps (Wilhelm, 1974), cryo clamps (Merican

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et al., 2009; Riemersa and Schamhardt, 1982), clamps with high friction surfaces (Kiss et al., 2009; Ng et al., 2005b; Reyes et al., 2014), pneumatic clamps (Matthews et al., 1996; Ng et al., 2005a) and custom-made clamps that use the principles of form and force closure (Schechtman and Bader, 1997, 2002; Shi et al., 2012; Wu et al., 2004) were developed to address this issue. However, these techniques have limitations concerning a quantitative description of the measurement error introduced by material slippage. The partial plastination technique is an alternative technique that was optimized for testing thin connective tissues (Hammer et al., 2012; Steinke et al., 2012). In these previous studies, the slippage-minimizing potential was only described qualitatively (Steinke et al., 2012).

The aim of this short communication is to provide technical instruction on the partial plastination technique, and to assess the technique's reliability by quantifying material slippage and the corresponding measurement errors. We started from the premise that an optical strain measurement technique independent of the crosshead displacement is capable of measuring strains without the influence of material slippage. The study design was adapted from Butler et al. (1984), who described an optical strain-measurement technique to determine uniaxial deformation of connective tissue without material slippage. In this report we present quantitative data (obtained from new experimental measurements) on the amount of material slippage by comparing grip-to-grip with optical strain data of human iliotibial tract specimens.

2. Materials and methods

2.1. Sample preparation

Eight iliotibial tract specimens were obtained from eight body donors (4 males, 4 females, mean age 39.3±23.5 years). The university's ethics committee "Ethik-Kommission an der Medizinischen Fakultät der Universität Leipzig" approved this study (protocol number 156-10-1207-2010). All tract specimens were removed from the region with most parallel fibers and sectioned parallel to the fiber direction in two to three samples each, resulting in 22 iliotibial tract samples (Fig. 1A). Twelve samples were plastinated partially. The ten remaining samples in an anatomically unfixed condition, further named non-plastinated samples, were used to estimate the effectiveness of the partial plastination technique. For storage prior to material testing, all samples were precooled at 3 °C before shock-freezing them at −85 °C.

2.2. Partial plastination technique

Gelatin (10% by volume) and a template made of aluminum were mounted on the central part of the tract samples to protect these areas from the plastination chemicals (Fig. 1B). The ends of the tract samples were dehydrated in acetone before they were primed with polyurethane resin, prepared with a ratio of 1/1/3 with RENCAST FC52 Isocyanate/FC52 Polyol/Ceramic Powder (RenShape solutions, Huntsman International LLC, Salt Lake City, USA) (Fig. 1C). The primed ends were then immediately covered with Pertinax plates (PF CP 201, Dr. Müller GmbH, Ahlhorn,Germany) before the resin cured. The Pertinax plates helped reinforce the stability of the plastinated ends that were to be clamped in the material-testing machine. The aluminum template and the gelatin were then removed under running water at 37 °C, releasing the unfixed central part of the iliotibial tract samples (Fig. 1D). A more detailed description of the partial plastination technique can be found elsewhere (Hammer et al., 2014; Steinke et al., 2012).

2.3. Sample clamping and strain measurement

Prior to material testing, all samples were thawed and moistened in physiological saline. Immediately before material testing, the samples were dried carefully with a paper towel and coated with white acryl-base color and a graphite spray to enable the optical strain measurements. Uniaxial tensile testing was carried out using a Z20.0 testing machine with a 5 kN load cell (Zwick GmbH & Co. KG, Ulm, Germany). Steel clamps with a rough surface were used for the plastinated samples. Rubber-covered clamps were applied for the samples that remained entirely in the unfixed condition to prevent premature failure at the clamping site. The grip-to-grip strain was calculated as the ratio of the crosshead displacement and the initial length of the samples between the clamps (69.4±2.1 mm). The optical strain data were obtained using the digital image correlation technique (DIC), utilizing 2-D video capturing (capturing rate 2 fps; resolution 2448×2050 pixel, Fig. 2B), provided by the Aramis video camera system (GOM—Gesellschaft für Optische Messtechnik mbH, Braunschweig, Germany; Fig. 2A and B). High-resolution images of side-on views of the samples' surfaces were captured throughout the measurements. The optical strain values were calculated by tracking the distance between two defined marker areas, which were set in proximity to the clamps (Fig. 2C). Briefly, each marker area shows a specific pattern of speckled black dots that can be clearly identified and tracked automatically by the video camera system in a series of consecutive images. The ratio of the current distance and the original distance between the two markers give the optical strain. For more details on the DIC procedure, readers can refer to Cheng et al. (2007).

2.4. Study protocol

All measurements included a preconditioning procedure of 20 cycles in a load range of 10 to 100 N, followed by a final cycle until material failure. Material failure was defined as a decrease in tensile load of more than 30%. The crosshead speed was 10 mm/min for preconditioning and the final cycle. Machine and optical strain values were recorded simultaneously for each sample (Fig. 3).

2.5. Reliability of the partial plastination technique

To assess the reliability of the partial plastination technique, the agreement between grip-to-grip and optical strain data was obtained using the Bland and Altman technique (Bland and Altman, 1986) as recommended by Aspden (2005) and McLaughlin (2013). Mean values and standard deviations (SD) of the differences (d) between grip-to-grip and optical strain were calculated. Differences were determined at nine time