

EFFECT OF SKIN MOVEMENT ON FIBEROPTIC TRANSDUCER MEASUREMENT OF TENDON FORCES

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INTRODUCTION

Komi et al. (1996) described minimally invasive measurement of *in vivo* tendon forces using a fiberoptic transducer. This technique involves passing a fiberoptic cable transversely through the tendon and recording the intensity of light transmitted, which is modulated by the force in the tendon. A decrease in fiberoptic output signals an increase in tendon force, since compression of the fiberoptic cable results in decreased light power. The required instrumentation is inexpensive and easy to implement. However, an *in situ* calibration scheme is required to relate tendon force to transmitted light. Erdemir et al. quantified fiberoptic force measurement errors resulting from potential discrepancies between calibration and experiment conditions (load rate, cable movement), but the effect of skin movement relative to tendon on raw transducer output and on force predictions remains unclear. The aim of our study is to supply this information, which is necessary for reliable *in vivo* measurements.

METHODS

Three cadaver foot specimens were tested using the Dynamic Gait Simulator (DGS; Sharkey and Hamel, 1998). The DGS reproduces the movement of the foot and ground reaction forces during the stance phase by prescribing knee kinematics and applying muscle forces to the extrinsic tendons. A fiberoptic cable (dia. 0.5 mm, Toray Ind. Inc.) was passed through the Achilles tendon about 2 cm proximal to its calcaneal insertion (Finni et al., 2000) and

attached to a transmitter-receiver unit (Agilent Tech. Inc.) as described by Komi et al. (1996). Fiberoptic transducer output and Achilles tendon force (ATF) were simultaneously collected for each walking trial. Each specimen was tested under two conditions: with the skin surrounding the insertion site intact and with skin dissected away (Figure 1). Four trials were completed for each condition.

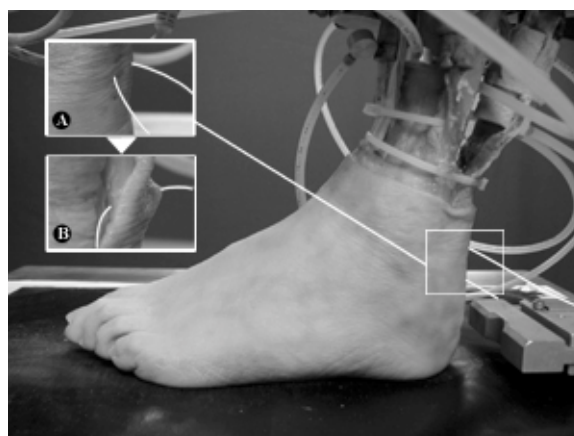


Figure 1. A foot specimen mounted in the DGS. The fiberoptic cable is highlighted for display purposes. Insertion site is magnified for (A) skin intact (B) after skin removal.

The influence of skin movement on tendon force predictions was assessed for one specimen by calculating calibration constants from calibration trials (0 N to 1000 N ramp loading-unloading of the Achilles tendon) and applying them to fiberoptic data of simulated walking. Four calibration trials were completed with the foot positioned at neutral and $\sim 10^\circ$ of dorsiflexion, before and after skin removal.

RESULTS AND DISCUSSION

Output ranges of the fiberoptic transducer were higher for all specimens when the skin was intact (Figure 2). This was likely due to relative movement between skin and tendon, which bent the cable and decreased the transmitted light intensity. Achilles tendon force estimations using the fiberoptic transducer showed that skin movement had a distorting rather than amplifying effect (Figure 3). Predictions using calibrations performed at different ankle angles were substantially different when the skin was intact. On the other hand, skin removal resulted in reasonably accurate and repeatable force estimates regardless of ankle joint angle during calibration.

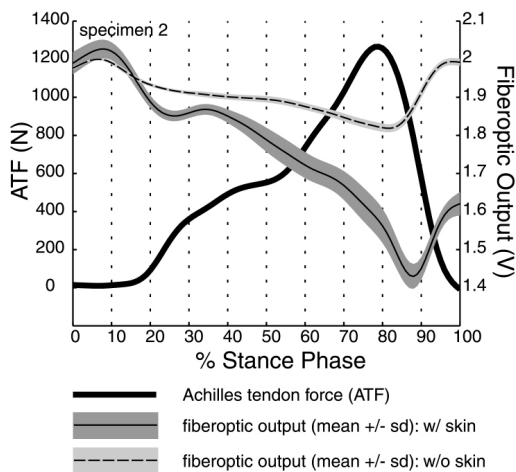


Figure 2. Fiberoptic output and Achilles tendon forces for a representative specimen. ATF was nearly identical within specimens.

Skin movement during *in vivo* tests may differ from that observed in cadaver specimens in this study. Nevertheless, the distorting effect of skin seems to be higher than the 2 % of peak forces reported by Finni et al. (2000). Ankle angle at which the calibration data was collected affected ATF predictions, indicating a coupling between skin movement and joint angle. It is therefore advisable to complete *in vivo* calibrations at different ankle angles and apply correction factors. The performance of

the fiberoptic transducer on exposed tendon validates its utility as a tool for tendon force measurements when a direct force measurement is not feasible, and skin effects can be compensated for during calibration.

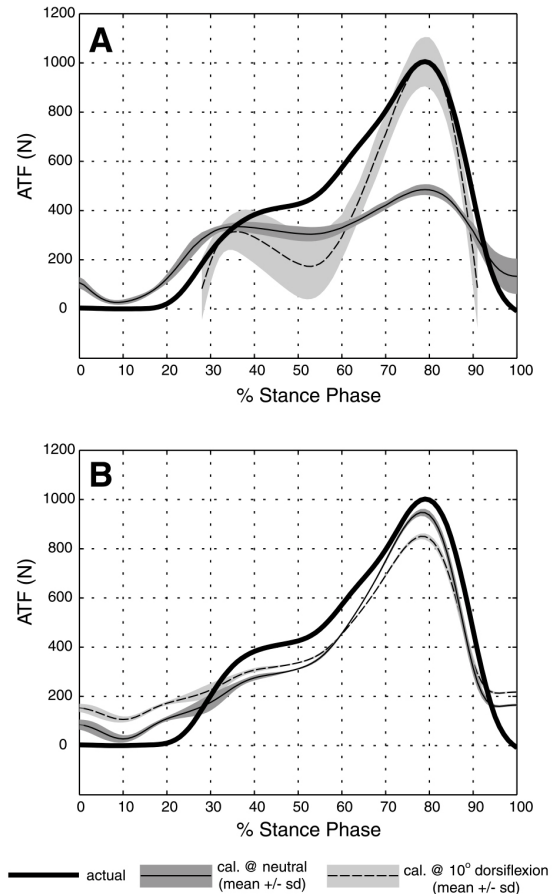


Figure 3. Achilles tendon force predictions for specimen 3: (A) w/ skin, and (B) w/o skin. Calculated forces are shown only for voltages within the calibration range.

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