INDENTATION OF VOLAR FOREARM SKIN USING ELLIPSOIDAL PROBES

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INTRODUCTION

Human skin is a complex multi-layer material, which exhibits non-linear stress-strain, orthotropic and viscoelastic characteristics [1]. The measurement of its mechanical properties is important in many diverse areas such as the design of artificial skin [2] and surgery simulation [3].

Skin *in vivo* is also in a state of anisotropic tension, which varies depending on body location, age and physical build. A surgeon must consider the lines of principal tension – relaxed skin tension lines (RSTL) – on a patient's body prior to making an incision. Incisions made parallel to the RSTL heal better than those made perpendicular to the RSTL [4]. A procedure to help identify RSTL would help surgeons plan incisions better.

Indentation tests have frequently been used to determine *in vivo* mechanical properties of skin [5,6]. Indentation experiments are relatively easy to set up because there are fewer gripping issues compared to in-plane stretching or compression of skin *in vivo*. However, results from these indentation tests do not report on any anisotropic characteristics of skin due to the axi-symmetrical set-up of the experiments. A purely computational study has indicated the possibilty of measuring anisotropic properties using axially asymmetric indenters [7].

The aim of this study is to measure the anisotropic response of volar forearm skin by performing indentation tests using ellipsoidal probes.

METHODS

A force-sensitive micro-robot probe was used for the indentation tests [8]. Three ellipsoidal probes were used in the tests; all with minor axis lengths of 1 mm and major axes lengths of 2, 5 and 10 mm. The aspect ratios of the probes were, therefore, 2, 5 and 10. The volunteer placed their arm on a support with the volar forearm facing down. An area midway along the centre of the volar forearm was indented 1.5 mm by the probe. The speed of the probe was 0.4 mms^{-1}. Two tests were performed with each probe. One test where the skin was indented with the major axis of the probe aligned with the transverse axis of the arm (0^{o}) and one test with the major axis of the probe aligned with the longitudinal axis of the arm (90^{o}). On the volar forearm, RSTL are approximately perpendicular to the longitudinal axis of the forearm. For the 1 x 10 mm probe, additional indentations were carried out with the major axis of the probe at 30, 60, 120 and 150^{o} to the transverse axis of the arm. Each test was repeated 6 times. The mean and standard deviation of the indenter force as a function of the indentation depth were calculated.

RESULTS AND DISCUSSION

For the ellipsoidal probe with an aspect ratio of 10, the force/indentation response was stiffer when the major axis was orientated 90^{o} to the RSTL of the volar forearm than when the major axis was aligned with the RSTL. For ellipsoidal probes with smaller aspect ratios, there was no noticeable difference between the responses (Figure 1).

When the aspect ratio of the probe was 10, the mean force at 1 mm indentation monotonically increased as the angle between the major axis and the RSTL increased from 0 to 90^{o}. The force decreased as the angle was further increased from 90 to 150^{o}.

The results presented here agree qualitatively with the computational results reported in [7]. The potential of measuring the anisotropic material properties of skin *in vivo* using indentation with ellipsoidal probes is clearly demonstrated. To be able to avail of the benefits of the relative simplicity of indentation and measure anisotropic properties is a major advantage over other experimental protocols.

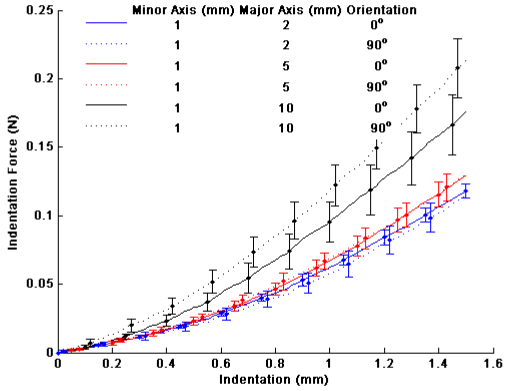

Figure 1: Mean and standard deviation of the Force/Indentation response for different ellipsoidal probes with major axis orientated parallel to (0^{o}) and perpendicular to (90^{o}) the RSTL on volar forearm.

CONCLUSIONS

Using ellipsoidal probes in indentation tests on volar forearm skin allows in-plane anisotropic properties to be measured. Work is ongoing in using FE models in parallel with the experiments to determine material model parameters of skin. This procedure will also be applied to other areas of skin on the body.

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