FINGER PAD SHAPE IN LUMP DETECTION

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MOTIVATION

Fingertip palpation is a frequently practiced medical procedure for locating hidden structures such as lumps in soft tissues. At present, there is little understanding of which physical parameters are important during the palpation process and the finger's sensitivity to those parameters. Measuring detection limits and modeling the mechanical interaction between the finger and tissue will provide insight into the perceptual process and may supply a means to optimize palpation.

Adams et al. [1976] measured perceptual limits for detecting small hard balls in soft rubber models. They varied parameters such as ball size, stiffness, and depth. However, they did not examine the mechanical interaction between the finger and the model. Dandekar and Srinivasan [1995], on the other hand, modeled the finger pad when contacting rigid objects. These results are not immediately applicable to palpation, where the finger pad and tissue have similar compliance.

The goal of the experiment presented here is to measure skin deformation at the force level when a ball embedded in a soft rubber model can be detected. First we determined these minimum force levels. We then photographed the finger in profile to determine the deformation of the finger pad at these forces.

EXPERIMENTAL METHODS

Apparatus. Figure 1 shows the apparatus used in the experiment. Rubber models containing hard plastic balls were raised against the subject's finger using a linear actuator. The models were constructed by filling a glass box (10 cm x 10 cm x 5 cm) with a soft, clear silicone rubber (G.E. RTV6166). The stiffness of the rubber (Young's modulus = 3 KPa) was similar to breast and lung tissues commonly palpated. To determine if detection levels and finger deformations changed with ball diameter, two sizes were used (19 mm and 13 mm). An additional model was created containing no ball. The subject's finger was held fixed relative to the actuator by a constraint device that supported the hand and was glued to the fingernail. A camera looking through the side of the model was used to take photographs of the fingertip and ball profiles. The skin deformation and ball location could be determined from the photographs. The photographs were digitized with a resolution of 14 μm.

![Figure 1. Experimental Apparatus.](image)

Protocol. A forced choice experiment determined the minimum force level required to detect the presence of the ball. For each trial, one of the models was placed on the actuator and raised at a velocity of 10 mm/s against the finger until a given force was reached. The position was held constant and the subject was asked if they felt the ball. Eight force levels were chosen for each ball size based on preliminary studies. Ten trials were completed at each force level with each ball size and forty were conducted using the model containing no ball. The order of presentation was randomized. Once detection levels were calculated, photographs were taken with and without the ball at the 50% and 99% detection force levels.

RESULTS

Detection Thresholds. The cumulative distribution curves resulting from the experiment are shown in Figure 2.
The integral of the Gaussian function was least-squares fit to the data points; the dashed line indicates the 50% level where subject could on average detected the ball in half the trials. The forces at this level for the 19 and 13 mm balls were 1.34 N and 1.75 N, respectively. The 99% detection levels were 1.98 N and 2.51 N.

Figure 2. Detection Threshold Curves.

**Finger Pad Deflection.** Figure 3 shows the profile of the fingertip extracted from the photos when contacting the model with and without the 19 mm ball. The fingernail was used to align the profiles. The curved lines at the bottom show the location of the ball relative to the finger. The deformation induced by the ball can be seen as the difference between the curves. Table 1 shows the maximum relative deflection for the two ball sizes.

Table 1. Maximum Deflection (mm) from No Ball Case.

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<thead>
<tr>
<th></th>
<th>50% Force</th>
<th>99% Force</th>
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<tbody>
<tr>
<td>19 mm</td>
<td>0.404</td>
<td>0.761</td>
</tr>
<tr>
<td>13 mm</td>
<td>0.330</td>
<td>0.585</td>
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Figure 3. Fingertip Profiles with 19 mm Ball.

A seventh order polynomial, \( y = p(x) \), was fit to each fingertip profile and the curvature, \( K(x) \), along the finger was calculated using

\[
K(x) = \frac{p''(x)}{[1+(p'(x))^2]^3}
\]

Figure 4 shows this curvature information with the 19 mm ball at the 50% and 99% force levels and the corresponding no ball cases. The ball causes the fingertip to flatten out and created a characteristic region of high curvature near the tip of the finger that increased in magnitude as the finger indents to higher forces. Similar analysis was carried out for the 13 mm 50% and 99% force levels. Table 2 compares the maximum value of the curvature for the 19 mm and 13 mm ball cases.

Figure 4. Curvature of Profiles with 19 mm Ball.

<table>
<thead>
<tr>
<th></th>
<th>50% Force</th>
<th>99% Force</th>
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<tbody>
<tr>
<td>19 mm</td>
<td>0.231</td>
<td>0.288</td>
</tr>
<tr>
<td>13 mm</td>
<td>0.232</td>
<td>0.294</td>
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Table 2. Maximum Curvature (mm\(^{-1}\)) of Finger Profiles.

**DISCUSSION**

Although the minimum forces required for detection and relative maximum deformations were different for each ball size, the maximum curvature was very similar. This suggests that the ball is detected by change in maximum curvature. Future work will investigate how contact interaction and detection changes as additional parameters such as ball stiffness and depth, rubber stiffness, and indentation velocity are varied.

By taking photographs of the finger at different angles, the 3D shape of the finger at detection then can be estimated. These shapes can be used in finite element models to determine the pressure distribution on the finger pad at detection. This will provide further insight to the mechanical interactions that occur during palpation.

**REFERENCES**
