INTRODUCTION

Conventional imaging techniques for diagnosis and detection of breast cancer deform the breast by applying external forces. The mechanical nature of breast tissue is not taken into account because the biomechanical behavior of soft tissue is not fully understood [1]. Pathology has different elastic properties from healthy tissue and the characterization of the mechanical nature of tissue may serve as a diagnostic tool, which may improve the prognosis for breast cancer patients. The purpose of this study is to noninvasively estimate the in vivo force-deformation behavior of normal breast tissue undergoing mild compression.

Deformation Mechanics: The breast is a composite of mechanically different materials. It is composed of several tissue types: glandular, fibrous and adipose (fat). The mammary gland is composed of 5-10 separate branching glands. The structural arrangements consist of 12-18 lobe systems branching from the nipple. The ductal system comprises about 10-15% of the total breast mass. The remaining 85% is mostly adipose tissue [2]. Both adipose and glandular tissues obtain their elasticity from elastic fibers. The mechanical nature of soft tissue is described in terms of its stress-strain relationship.

METHODS

Tissue deformation studies were conducted in vivo, with the breast under mild uniaxial compression, using a specially designed coil-compression device. MRI (3D-SPGR) was used to detect displacement of regions of interest (i.e., landmarks). Imaging was done with each subject lying on her side with the right breast compressed in the medial-lateral direction (see figure 1). In this configuration, displacement and normal stress were experimentally evaluated.

RESULTS AND DISCUSSION

Displacement and Deformation: Subjects were imaged with a range of compressions. The widths and percent of deformation of the breast are given in Table 1.

<table>
<thead>
<tr>
<th>Uncompressed Width (mm)</th>
<th>Compressed Width (mm)</th>
<th>% Compression in Y Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>80</td>
<td>20.0</td>
</tr>
<tr>
<td>77</td>
<td>57</td>
<td>26.0</td>
</tr>
</tbody>
</table>

TABLE 1. Percent compression in the direction of the applied force.

In mechanics, the displacement vector \( \mathbf{D} \) represents the displacement of a point \( (P) \) located at \( (x, y, z) \) in the original volume, to a displaced point \( (P') \) located at \( (x', y', z') \) in the deformed volume. The displacement vector is

\[
\mathbf{D} = u \mathbf{i} + v \mathbf{j} + w \mathbf{k}
\]

where the vector components are

\[
\begin{align*}
u &= x' - x, \\
v &= y' - y, \\
w &= z' - z.
\end{align*}
\]

Strain is evaluated from the vector components. Figure 2 shows the vector components of specific regions of interest in breast tissue as the whole breast is compressed from 5 to 15%.

FIGURE 2. Components of displacement vector for landmarks.

In the graphs, the Y-axis is the Medial-Lateral direction (direction of applied force), the X-axis is in the Cranial-Caudal direction, and Z-axis is from the nipple to chest wall.

Force Measurements: For the in vivo stress studies, the sensor array was placed on the top plate in contact with the breast about 1.5 inches from the nipple with sensor connectors at least 2 cm away from the breast to minimize artifacts. The sensors were calibrated and conditioned before and after imaging and the calibration curves show that \( B_s \) does not effect the accuracy of the sensors. Stress data (i.e. force per area) is reported in Table 2.

TABLE 2. Normal stress data from three sensors

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Force (N)</th>
<th>Stress (N/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>38.8 x10¹</td>
<td>364.5</td>
</tr>
<tr>
<td>2</td>
<td>9.81 x10¹</td>
<td>60.8</td>
</tr>
<tr>
<td>3</td>
<td>88.3 x10¹</td>
<td>547.4</td>
</tr>
</tbody>
</table>

REFERENCES