VIBRATION ARTHOGRAPHY OF THE KNEE TO DETECT CARTILAGE LESIONS

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INTRODUCTION

Knee arthroscopy and MRI are the current standards used to accurately diagnose intraarticular pathology. Arthroscopy is considered the gold standard but is invasive, while MRI is not invasive it is relatively expensive. A portable, rapid, inexpensive, and noninvasive method to diagnosis cartilage pathology would be extremely valuable. Vibration arthrography maps joint vibrations to intraarticular events during joint motion. We designed and developed a vibration arthrography system to detect and to measure the vibrations produced during specific knee movements. This is a preliminary report of the results in detecting intraarticular lesions of the knee.

METHODS

In vitro testing: Six fresh-frozen human cadavers were used. Three accelerometers (Model 3032A miniature quartz shear LIVM accelerometer, Dytran, Chatsworth, CA) were positioned on the skin around the knee. The optimum positions for signal acquisition were determined on the medial and lateral joint lines and the inferior patellar pole. Lesions were simulated within the knee joint by inserting small plastic screws into the femoral condyle at various locations such that the screw head would articulate with the tibial plateau at different flexion angles. Vibrations recorded by the accelerometers were captured during knee flexion and extension under load.

In vivo normal subjects: After IRB approval and consent, 10 normal adult volunteers were tested. Each subject performed the following maneuvers (repeated 3 times): chair-rise, squat, step-up, step-down, a standing lower leg swing with hips flexed at 90°, and an active knee extension in the seated position. To measured knee flexion angle, electromagnetic sensors (3SPACE FASTRACK, Polhemus, Colchester, VT) were strapped to the surface of the thighs and shins. The data from normal subjects was used to develop a baseline filter to identify pathologic vibrations.

In vivo patients: After IRB approval and consent, 6 adult patients scheduled to undergo arthroscopy of the knee with an existing joint pathology were recruited. Knee joint vibrations and flexion angle were recorded as described for normal volunteers. The patient’s pathology was recorded during arthroscopy for comparison with vibration analysis.

Signal processing: Pathologic vibrations were divided into discrete high frequency spikes and sustained coarse vibrations using a cutoff frequency of 5 Hz. To determine the location of the lesion, the accelerometers that recorded the earliest and the strongest abnormal signal were identified with the assumption that a vibration produced by a lesion would be picked up most clearly in the nearest accelerometer. The flexion range at which the abnormal signal was detected was also noted. These data were combined to generate a signal pattern for each intraarticular pathology.

RESULTS

Fig 1: The patient with a tear of the medial meniscus in the middle third generated a large spike on the medial sensor between 30° and 60° of knee flexion.

TABLE 1

<table>
<thead>
<tr>
<th>Signal type</th>
<th>Sensor</th>
<th>Flexion range</th>
<th>Surgical finding</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Large single spike</td>
<td>Patellar</td>
<td>60–90°</td>
</tr>
<tr>
<td>2</td>
<td>Large single spike</td>
<td>Lateral</td>
<td>30–60°</td>
</tr>
<tr>
<td>3</td>
<td>Small single spike</td>
<td>Medial</td>
<td>30–60°</td>
</tr>
<tr>
<td>4</td>
<td>No abnormal signal</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>5</td>
<td>Sustained coarse signals</td>
<td>Lateral</td>
<td>0–45°</td>
</tr>
<tr>
<td>6</td>
<td>Sustained coarse signals</td>
<td>All</td>
<td>0–45°</td>
</tr>
</tbody>
</table>

DISCUSSION

Data collected from cadaveric specimens helped in design optimization. Data collected from normal subjects was used to develop the dynamic knee activities that would be useful to analyze and to identify normal patterns that were then filtered out from data collected from patients with knee pathology.

The correlation of the preliminary results with specific joint pathology is promising. Meniscal tears were linked to high frequency vibration spikes while degeneration of the articular cartilage surface generated a course of more sustained lower frequency vibration.

We plan on testing a larger cohort of patients to compile a database of “vibration patterns” that are generated from each distinct lesion. We are also testing the sensitivity of the system to detect more subtle lesions and to track the progress of lesions over time. Finally we are exploring additional knee maneuvers as certain lesions such as meniscal tears may need special maneuvers (e.g. McMurray’s test) to elicit the abnormal vibration.

REFERENCES: