Consistent Osteoalignment is Critical for Precise Measurements of Patellar Kinematics During Imaging Studies

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Introduction

Patellofemoral (PF) joint pain is often associated with PF maltracking in clinical settings. Yet even static measurements of PF malalignment have remained difficult. Quantifying PF joint malalignment remains highly controversial due to the variability of results within individual studies as well as among studies. Much of this variability may stem from the relationship between the final measurements and the methods used to obtain and analyze the images. Thus, a methodology for obtaining images with consistent reference osteoalignment and axis definition is critical.

In this study we defined a standard patellar reference plane (SPRP), based on 3D MRI data. Then we measured the variability of specific PF clinical angles as a function of image plane location and orientation relative to the SPRP. Additionally, in a more detailed study, we measured the variability of the angle between the anterior (and posterior) femoral condylar line and the transepicondylar line as a function of scan location.

Methods

Five normal adult volunteers (3 males and 2 females) with no history of knee pain were imaged in a supine position at full knee extension using a 1.5T GE CX MRI. A 3D fast-GRE sequence was used to image the knee joint. The voxel size was 0.625 x 0.625 x 1.0 mm.

After obtaining the static 3D image set of the knee, MIPAV software was used to systemically adjust the position and orientation of a 2D image plane that transected the 3D image set (Medical Image Processing, Analysis, & Visualization, NIH, Bethesda, MD, USA). A SPRP was found to contain the midtransverse patella and was perpendicular to the patella median ridge and parallel to the distal aspect of the femoral condyle.

The first experiment studied the magnitude of artifact produced by altering the image plane location and orientation in order to simulate various subject alignments within the magnet. The lateral PF angle (LPFA) [Merchant et al. (1974)] and the patellar tilt angle (PTA) [Schutzer et al. (1986)] were measured in the reference plane and in twelve other planes. Four of these were 5 and 10 mm above and below the reference plane (Fig 1A). Four of these were rotated ± 5° and ± 10° from the reference plane about the z axis (anterior-posterior axis), which simulated hip abduction and adduction (Fig 1B). Four of these were rotated ± 5° and ± 10° from the reference plane about the x axis (medial-lateral axis), which simulated hip extension and flexion (Fig 1C).

**Figure 1:** The standard patellar reference plane was perpendicular to the posterior edge and crossed the geometric center of the patella (Point C). Planes were A) ± 5,10 mm from the reference plane, B) rotated ± 5,10° about the z-axis, and C) rotated ± 5,10° about the x axis.
The second experiment (all 10 knees) studied the effect of selection of reference points such as anterior and posterior margins of the femoral condyles, on the variability of specific clinical measures. Thirty axial images were obtained through the distal femur and PF joint (from 10mm above to 20mm below the patella center). The reference epicondylar line was defined as a line between the prominence of lateral epicondyle and the sulcus of medial epicondyle. The anterior reference line was a line connecting the most prominent aspects of the medial and lateral trochlear facets and the posterior reference line was a line connecting the posterior aspects of the femoral condyles. The angle between the transepicondylar and the anterior reference line (anterior angle $\alpha$, Fig 2) and also the angle between the transepicondylar and the posterior reference line (posterior angle $\beta$, Fig 2) were measured from 2D image slice.

![Diagram](image)

**Figure 2**: $\alpha$; the anterior angle between the anterior reference line and the transepicondylar line $\beta$; the posterior angle between the posterior reference line and the transepicondylar line

**Results**

**Experiment 1**

Visually, the LPFA (Fig 3A) had less variability as compared to PTA (Fig 3B). The variability caused by z-axis rotation (which simulated hip abduction and adduction) caused the greatest variability in PTA compare to the variability caused by x-axis rotation (not shown) and superior-inferior translation.

![Graphs](image)

**Figure 3**: LPFA(A) and PTA(B): Each column represents a different subject and the z-axis value is the difference in the PTA as relative to the standard patellar reference plane. X-axis rotation caused minimal variation and is thus not shown.
Experiment 2

We found that the anterior angle was highly variable both within individual subjects and across subjects (Fig 4). In this range the standard deviation ranged from 1.4 degrees to 2.9 degrees. In the range of -5 mm to 8 mm from the patellar center, it appears as if the anterior angle is fairly consistent, but no individual subject showed such a consistent pattern. In comparison the posterior angle was highly consistent both within individual subjects and across subjects in the range of 5 mm to 20 mm below the patellar center (Fig 4). In this range the standard deviation was less than 1 degree. Thus, we concluded that the variance seen in the PTA was due to the fact that the images simulating various subject alignments encompassed the anatomy mostly in this more variable region.

Discussion

Our results demonstrate that much of the variability in commonly measured PF joint clinical angles may be due to variations in anatomy, the image plane location and orientation. The amount of change seen in a specific clinical measure, when the scan plane location and orientation is altered, is directly related to the variability of the anatomy that defines it and the visual interpretation of this anatomy. Thus, the analysis of patellofemoral relationships should be made using an accurately defined imaging plane. If not, the results may be misleading and indicate patellar malalignment that does not exist, or alternatively abnormal cases may be shown as normal.

Clearly a more robust and consistent method for osteoalignment relative to the imaging plane is warranted. This can be accomplished through more precise image plane selection, possibly through the use of a positioning jig, the utility of such a jig would need to be tested on subjects of various sizes, or by using computer aided techniques to reformat 3D images based on the careful evaluation of landmarks and image plane location and orientation. Work is ongoing in defining the variability over smaller orientation and location changes in the imaging plane and defining the variability over a wide range of subjects.

References