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A cadaveric investigation into the demographic and bony alignment properties associated with osteoarthritis of the patellofemoral joint

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ABSTRACT

Background: Patellofemoral joint osteoarthritis is common, although circumstances dictating its evolution and pathogenesis remain unclear. Advances in surgical technique have improved the ability to modify long-bone alignment in the coronal, sagittal, and axial planes. However, to our knowledge, there is no significant long-term data available in regard to the relationship between anatomic alignment parameters most amenable to surgical modification and patellofemoral joint osteoarthritis.

Methods: Five-hundred and seventy-one cadaveric skeletons were obtained from the Hamann–Todd osteological collection. Mechanical lateral distal femoral angle, medial proximal tibial angle, tibial slope, femoral version, tibial torsion, the position of the tibial tubercle relative to the width of the tibial plateau, trochlear depth, and patellar size were measured using validated techniques. A previously published grading system for patellofemoral joint arthritis was used to quantify macroscopic signs of degenerative joint disease.

Results: Increasing age (standardized beta 0.532, $p < 0.001$), female gender (standardized beta 0.201, $p = 0.002$), and decreasing mechanical lateral distal femoral angle (standardized beta −0.128, $p = 0.025$) were independent correlates of increased patellofemoral joint osteoarthritis. A relatively more laterally positioned tibial tubercle trended towards predicting patellofemoral joint osteoarthritis (standardized beta 0.080, $p = 0.089$).

Conclusions: These findings confirm that patellofemoral joint osteoarthritis is strongly associated with increasing age and female gender. Valgus alignment of the distal femur, a relatively more lateral location of the tibial tubercle, and a shallower trochlear grove appear to have modest effects on the development of patellofemoral joint osteoarthritis.

1. Introduction

Patellofemoral joint arthritis (PFJA) is one of the most common causes of knee pain. It typically manifests as anterior pain and crepitus. Between 30 and 79% of individuals over 60 years of age have some form of PFJA [1–3]. Symptoms may be exacerbated with increasing flexion, when patellofemoral joint (PFJ) contact pressures become greatest [4].

However, despite its prevalence, the factors which cause certain individuals to develop PFJA remain poorly defined [5]. The pathogenesis of osteoarthritis in the PFJ is similar to other forms of osteoarthritis. As an arthrodial joint, the chondral surfaces are lined with articular cartilage made up of a solid phase (collagen, glycosaminoglycans), and a liquid phase (fluid matrix). The joint pressure in the liquid phase is distributed against the solid phase, which exerts a balanced counterpressure, providing a cushioning effect across the articular cartilage surface in response to mechanical loading. However, this interface may become disrupted at the articular surface, which incites a cascade of events ultimately resulting in osteoarthritis [6,7]. Such damage to the articular cartilage can occur as a result of metabolic or anatomic causes. Metabolic conditions such as inflammatory disease and infection have been well-established as accelerants to disease progression [8].

However, there exists limited information regarding anatomic alignment parameters associated with PFJA. For these reasons, we determined it would be clinically relevant to review a well-organized osteological database and characterize which demographic and anatomic parameters are associated with PFJA, paying special attention to criteria which have the potential to be modified through orthopaedic surgery. Accordingly, we designed an experiment using cadaveric skeletons and asked the following questions: 1) How do age, race, gender and height influence the development of PFJA? 2) What anatomic alignment parameters are associated with the development of PFJA?

Abbreviations: PFJ, patellofemoral joint; PFJA, patellofemoral joint arthritis; mLDFA, mechanical lateral distal femoral angle; MPTA, medial proximal tibial angle; TT–TG, tibial tubercle–trochlear grove distance; TT–TP, tibial tubercle- tibial plateau ratio; JRF, joint reactive force.

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2. Methods

2.1. Cadaveric specimens

Cadaveric skeletons from the Hamann–Todd Osteological Collection (Cleveland, OH) were acquired. This collection contains approximately 3000 complete, disarticulated human remains that have been catalogued in a well-organized database containing age at the time of death, race, gender, and height. Six-hundred and twenty-five specimens were randomly selected for analysis. Specimens chosen were between the ages of 40 and 79 years at time of death. Samples were excluded on the basis of incomplete skeletons or demographic information, evidence of periarticular fracture, rheumatologic or metabolic disorders, or infection [9]. In total, 54 unique exclusions were made, and 571 specimens were used for primary analysis.

2.2. Anatomic measurements

Measurements of anatomic alignment parameters were conducted based on previously validated techniques. Mechanical lateral distal femoral angle (mLDFA) and medial proximal tibial angle (MPTA), as described by Paley [10], were used to quantify coronal deformity. To measure mLDFA, femurs were rested on the posterior aspect of the distal femoral condyles; in cases where femoral version was not great enough to allow for the bone to lie flat, the proximal and distal femurs were equally elevated on the table surface such that the femoral head did not touch the surface of the table. Coronal photographs were taken, and exported into the ImageJ software package (National Institutes of Health, Bethesda, MD). A best-fit circle was circumscribed over the femoral head, and the center was calculated with basic formulae. A line was then drawn across the distal femoral condyles. Another line was then drawn from the mathematical center of the femoral head through center of the femoral condyles. Finally, mLDFA was calculated as the lateral angle between the line from the center of the femoral head to the center of the femoral condyles and the line across the distal femoral condyles (Figure 1).

MPTA was also calculated according to the technique described by Paley [10]. Tibiae were oriented such that the medial and lateral plateaus rotationally matched with the medial and lateral femoral condyles in knee extension. A coronal photograph was obtained. ImageJ software was used to measure MPTA as the medial angle between a line along the tibial plateaus, and a line from the center of the tibial spines to the center of the tibial plafond (Figure 2).

Tibial slope was measured according to a technique adapted from Dare et al. [11] Digital representations of each bone were created with a MicroScribe 3D-digitizer apparatus (Immersion Co, San Diego, CA). Specimens were oriented vertically and were leveled in the coronal and sagittal planes to 90° based on the center of the proximal tibial shaft. A digital laser level and magnetic angle protractor (Johnson Level and Tool Manufacturing Corporation, Mequon, WI) were used to ensure that each plane was level to $\pm 1°$. Using a mobile telescopic stylus, the center of the anterior and posterior aspects of the medial tibial plateau was found (Figure 3). Coordinate data was exported to excel and the medial tibial slope was calculated as the arctangent of the difference in vertical displacement divided by the difference in horizontal displacement. Tibial slope in the posterior direction was defined as positive.

Femoral version was calculated according to previously validated methodology [12], and measured as the axial-plane angle between the posterior aspect of the femoral condyles and the center of the femoral neck. Femoral version in the anteverted direction was defined as positive. Tibial torsion (axial rotation) was measured using a previously reported methodology, and involved calculating the angle between the distal tibial plafond and an angle that bisected the center of the medial and tibial plateaus [13]. Tibial torsion in the external direction was defined as positive.

Figure 1. Mechanical lateral distal femoral angle (mLDFA) was calculated as the lateral angle (red angle) between the distal femoral condyles (blue line), and a line that passed from the center of the femoral condyles to the center of femoral head (yellow line). The mLDFA (red angle) was calculated to be 88° in this example.

In order to calculate medial/lateral position of the tibial tubercle, a simulated measurement using the concept of tibial tubercle–trochlear grove distance (TT–TG) was established. Based on the methodology of Camp et al., tibiae were oriented flat on the measuring surface, and cameras were positioned axially at the top of each bone [14]. A line through the widest portion of the tibial plateau was established (TP), and another perpendicular line was created that originated at the most medial aspect of the tibial plateau, and spanned to the most anterior portion of the center of the tibial tubercle (TT). TT and TP distances were measured, and the ratio of the tubercle distance to the tibial plateau distance (TT–TP) was calculated (Figure 4). A larger TT–TP ratio signified a relatively more lateral tibial tubercle.

Trochlear depth was measured by the medial and lateral flange heights using the MicroScribe digitizer. Femurs were rested on the laboratory benchtop, the most anterior aspects of the medial and lateral femoral condyles, as well as the deepest point along the trochlear grove was calculated according to protocol previously described by Gillespie et al. (Figure 5) [15] The MicroScribe digitizer captured coordinate data based on the position of a mobile telescopic stylus. Using a technique adapted from previous osteological experiments that also evaluated bony landmarks in space, virtual representations of each bone were generated [16]. The vertical distances between respective landmarks were calculated using Excel spreadsheets (Microsoft Co., Redmond, WA). Using a mathematical modeling technique of the distal femur, maximum trochlear depth was obtained by using medial and