Variations of Femoral Condyle Shape

Mirza Biščević¹, Mujo Hebibović² and Dragica Smrke³
¹ Department of Orthopedics and Traumatology, University Hospital Center, University of Sarajevo, Sarajevo, Bosnia and Herzegovina
² Electrotechnical faculty, University of Sarajevo, Sarajevo, Bosnia and Herzegovina
³ Department of Traumatology, University Hospital Center «Ljubljana», Ljubljana, Slovenia

ABSTRACT

The aim of this study is to mathematically approximate the shape of the femoral articulating line and compare radiiuses of condylar curves within and between males and females. Ten male and ten female participants were included in the study. Radiiuses of medial and lateral condylar curves were calculated from the side view knee X-ray by original mathematical equation. Average radiiuses of condylar curves were between 4.5 and 1.7 cm medially, and between 3.2 and 1.8 cm laterally, for 0° and 90° flexion contact point respectively. Males had longer curve radiiuses of both condyles (p<0.05). Differences turned out to be statistically insignificant after adjusting to body height. Even small changes in the joint geometry during lifetime could make a joint susceptible to osteoarthritis or injuries. Approximation of the radiiuses of femoral condyle curves is a useful method in anthropometric, radiological and virtual calculations of the knee geometry, and other ellipsoidal structures in human body, like wrist, scull segments, dental arches, etc.

Key words: knee, condylar curves, joint geometry, orthopedics

Introduction

The knee is the biggest, most complicated and most incongruent joint in human body. Because the knee is located between the body's two longest lever-arms, it sustains high forces, and it is susceptible to chronic diseases and injuries. Although males sustain harder labor and sports activities, the majority of chronic knee diseases and injuries have strong female bias: knee osteoarthritis (OA), anterior crucial ligament rupture, patellar pain syndrome, iliotibial band friction syndrome, Tibial stress fractures. It could be speculated that small alterations in the joint shape during lifelong period could make a knee susceptible to those pathological conditions.

The profile shape of the femoral condyles (Figure 1), between 0° – flexion contact point and 90° – flexion contact point, is commonly described as the ellipsoid curve, so-called «evolventa». Radiiuses of the anterior part of the evolventa are longer in comparison to the radiiuses of the posterior part of the evolventa. The line which connects the ends of all the radiiuses (centers of all curve segments), so called «evoulta» is letter «J» shaped, and it is smaller than the evolventa.

Special curving of the femoral condyles is important for the knee mechanics. The geometry of the articular surfaces can affect the location of the contact points during knee motion and ultimately affect the stabilizing of the knee under compressive loads.

Studies how to define joint surface geometries have been scarce and, consequently, anthropometric studies on joint surfaces have been rather poor. Also, the development of prostheses that more closely resemble the normal joint anatomy has been unsuccessful. Some re-
searches have chosen cones, arches and hemispheres to model joint surfaces, or at most, they have used a polynomial approximation to mimic knee joint surfaces. All those studies of condylar shape, and almost all employed mathematical models of the knee joint are based on 2D (planar) knee joint description.

Aim of this paper was to mathematically approximate the femoral articulating line and calculate the radiiuses of medial and lateral condylar curves.

**Participants and Methods**

*Participants*

Twenty healthy Caucasian participants, ten males and ten females, were included in the study. The participants were consistent sample of volunteers from the student population of the city of Sarajevo. All participants willingly took part in this study and signed an informed consent after the explanation of the test procedure. The study was performed during September 2004 at Department for Orthopedics and Traumatology, University Hospital Center Sarajevo.

Inclusion criteria were: age 20–32 years, non-obese person; body mass index (BMI)<25 kg/m², negative history of right knee injury, complains of patellofemoral pain symptoms, or neurological or neuromuscular disorders, full range of right knee active motions, and grade 5 of hamstrings and quadriceps muscle force, negative Lachman’s, posterior drawer, varus/valgus, and McMurray’s tests and absence of any X-ray visible changes of the right knee. The average age of participants was 24.45±4.56 years and there was no statistically significant difference between genders (t-test, p=0.385) (Table 1).

*Methods*

The side view X-ray of the right knee in extended position was reproduced in real size on the computer digitized scan (Vidar VXR-12 CCD scanner, 600 dpi, 256 gray levels, CorelDRAW 9®, Microsoft, Seattle, USA).

The tangents were drawn on the medial and lateral condylar curves at 0° and 90° articular contact points.

The anterior distal part (fourth quadrant) and posterior proximal part (second quadrant) of the femoral condyles are quarters of a circle, with diameters approximately 4 and 2 cm diameters, respectively (Figure 2).

The «third quadrant», posterior distal part of the femoral condyles, which articulates with tibia in a range of knee flexion from 0° up to 90°, is quarter of ellipsoidal curve. It is mathematically defined with its wider and narrower diameters A and B respectively (Figure 3).

The lines perpendicular to the two neighboring tangents at spots M and N determine the center of the curve (circle, ellipse), and the radius (Ra) of that curve segment (Figure 4).

Radiiuses (distances between evolventa and evoluta) were calculated for each 10° segment of the medial and lateral condylar curves.

\[
X_R = \frac{[Y_{a+10}-Y_a+\tan(90-\alpha)X_a-\tan(80-\alpha)X_{a+10}]}{[\tan(90-\alpha)-\tan(80-\alpha)]}
\]

\[
Y_R = \tan(90-\alpha)X_R + Y_a - \tan(90-\alpha)X_a
\]

\[
X_a = A\left(1+(\frac{B^2}{\tan^2(\alpha)})A^2\right)^{1/2}
\]

---

**Table 1**

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>31</td>
<td>190</td>
<td>88</td>
<td>20</td>
<td>169</td>
<td>61</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>187</td>
<td>85</td>
<td>22</td>
<td>175</td>
<td>56</td>
</tr>
<tr>
<td>3</td>
<td>24</td>
<td>180</td>
<td>80</td>
<td>29</td>
<td>169</td>
<td>55</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>182</td>
<td>71</td>
<td>20</td>
<td>178</td>
<td>59</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>180</td>
<td>75</td>
<td>20</td>
<td>176</td>
<td>62</td>
</tr>
<tr>
<td>6</td>
<td>23</td>
<td>179</td>
<td>80</td>
<td>20</td>
<td>165</td>
<td>58</td>
</tr>
<tr>
<td>7</td>
<td>27</td>
<td>180</td>
<td>81</td>
<td>23</td>
<td>169</td>
<td>59</td>
</tr>
<tr>
<td>8</td>
<td>32</td>
<td>176</td>
<td>67</td>
<td>24</td>
<td>168</td>
<td>58</td>
</tr>
<tr>
<td>9</td>
<td>24</td>
<td>187</td>
<td>73</td>
<td>26</td>
<td>174</td>
<td>58</td>
</tr>
<tr>
<td>10</td>
<td>21</td>
<td>183</td>
<td>81</td>
<td>32</td>
<td>169</td>
<td>58</td>
</tr>
<tr>
<td>X±SD</td>
<td>25.4±4.8</td>
<td>182±4.3</td>
<td>78±6.5</td>
<td>23.6±4.2</td>
<td>171±4.2</td>
<td>58±2.1</td>
</tr>
</tbody>
</table>

---

Fig. 2. Femoral condyle contours in sagittal plane divided in quarters.
\[ Y_\alpha = B/(1+(\alpha^2/B^2))^{1/2}; \alpha = 0°, 10°, 20°, 30°...90° \]

\[ R_\alpha = [(X_\alpha-X_R)^2+(Y_\alpha-Y_R)^2]^{1/2} \]

Derived equation is based on the calculation of coordinates of ellipse and its tangent contact spot, and intersection spot between lines perpendicular on two neighboring tangents at contact spots\(^{12}\).

The «Knee Roll» is original software\(^{13}\) based on above described equations, and its output is a radius of the condylar curve (Ra) for each 10° segment, from 0° up to 90° articulating point.

The Independent samples t-test (equal variance, normal distribution) was used for the analyses of differences of Ra, Icr and the rolling percentage between males and females, with \(p=0.05\) as a cut off value\(^{14}\). The Wilcoxon’s non-parametric unimpaired test was employed to confirm results of t-test. The sum of ranks in one group out of 78–132 interval (10, 10 sample) pointed to a difference between the examined groups (\(p<0.05\)). The collected data were processed by Microsoft Excel\(^{15}\) (Microsoft, Seattle, USA) software.

**Results**

When analyzing medial and lateral condylar curve radiiuses, from 0° to 90° flexion contact point, it has to be noticed that all radiiuses reduce. Otherwise, the anterior part of femoral condyles is less curved than the posterior.

**TABLE 2**

<table>
<thead>
<tr>
<th>Knee angle</th>
<th>Male (mm)</th>
<th>Female (mm)</th>
<th>Total sample (mm)</th>
<th>(p^*)</th>
<th>Sum of male ranks**</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>46.2±8.8</td>
<td>44.4±5.1</td>
<td>45.3±6.7</td>
<td>0.590</td>
<td>98</td>
</tr>
<tr>
<td>10°</td>
<td>42.2±6.6</td>
<td>41.3±4.2</td>
<td>41.7±5.3</td>
<td>0.729</td>
<td>96</td>
</tr>
<tr>
<td>20°</td>
<td>36.1±3.8</td>
<td>36.3±3.0</td>
<td>36.2±3.3</td>
<td>0.884</td>
<td>105</td>
</tr>
<tr>
<td>30°</td>
<td>30.2±2.2</td>
<td>31.1±2.4</td>
<td>30.7±2.2</td>
<td>0.364</td>
<td>118</td>
</tr>
<tr>
<td>40°</td>
<td>25.3±2.1</td>
<td>26.6±2.5</td>
<td>26.0±2.3</td>
<td>0.212</td>
<td>122</td>
</tr>
<tr>
<td>50°</td>
<td>21.7±2.5</td>
<td>23.2±2.6</td>
<td>22.4±2.6</td>
<td>0.227</td>
<td>129</td>
</tr>
<tr>
<td>60°</td>
<td>19.2±2.8</td>
<td>20.7±2.8</td>
<td>19.9±2.8</td>
<td>0.250</td>
<td>119</td>
</tr>
<tr>
<td>70°</td>
<td>17.7±3.0</td>
<td>19.1±2.8</td>
<td>18.4±2.8</td>
<td>0.279</td>
<td>117</td>
</tr>
<tr>
<td>80°</td>
<td>17.0±3.0</td>
<td>18.4±2.8</td>
<td>17.7±2.9</td>
<td>0.296</td>
<td>118</td>
</tr>
<tr>
<td>90°</td>
<td>16.5±2.9</td>
<td>17.8±2.7</td>
<td>17.2±2.8</td>
<td>0.293</td>
<td>118</td>
</tr>
</tbody>
</table>

* probability \(p<0.05\) (Independent Samples Test with two tailed distribution)

** sum of ranks in male group for medial condyle (Wilcoxon’s test) out of 78–132 interval
The average radiuses of the medial condylar curve decrease from 45 mm, at 0° flexion contact point, to 17 mm, at 90° flexion contact point (Table 2). In the same interval, the average radiuses of the lateral condylar curve decrease from 31 mm to 18 mm (Table 3). This implies more round shape of lateral condyle in comparison to the medial condyle.

Males have significantly bigger femoral condyles and radiuses of its condylar curves in comparison to females (p<0.05). The differences turned out to be statistically insignificant after adjusting to body height (Table 2, 3). That insignificance was very close to the borderline p-value 0.05 on the lateral condyle for segments 40°–70°.

More elliptic medial condyle is bigger, with average dimensions of wider and narrower diameter (A and B) 33 and 24 mm, respectively (Figure 5).

### Table 3

<table>
<thead>
<tr>
<th>Knee angle</th>
<th>Male (mm)</th>
<th>Female (mm)</th>
<th>Total sample (mm)</th>
<th>p*</th>
<th>Sum of male ranks**</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>31.7±2.6</td>
<td>30.7±7.1</td>
<td>31.2±5.1</td>
<td>0.691</td>
<td>109</td>
</tr>
<tr>
<td>10°</td>
<td>30.6±2.3</td>
<td>29.3±5.3</td>
<td>29.9±3.9</td>
<td>0.463</td>
<td>131</td>
</tr>
<tr>
<td>20°</td>
<td>28.9±1.8</td>
<td>27.9±2.9</td>
<td>27.9±2.5</td>
<td>0.101</td>
<td>120</td>
</tr>
<tr>
<td>30°</td>
<td>26.7±1.6</td>
<td>24.5±2.4</td>
<td>25.6±1.7</td>
<td>0.117</td>
<td>129</td>
</tr>
<tr>
<td>40°</td>
<td>24.7±1.9</td>
<td>22.3±1.3</td>
<td>23.5±1.9</td>
<td>0.070</td>
<td>130</td>
</tr>
<tr>
<td>50°</td>
<td>22.9±2.2</td>
<td>20.6±2.0</td>
<td>21.7±2.3</td>
<td>0.070</td>
<td>131</td>
</tr>
<tr>
<td>60°</td>
<td>21.5±2.4</td>
<td>19.2±2.5</td>
<td>20.3±2.6</td>
<td>0.051</td>
<td>132</td>
</tr>
<tr>
<td>70°</td>
<td>20.6±2.6</td>
<td>18.3±2.8</td>
<td>19.4±2.8</td>
<td>0.074</td>
<td>132</td>
</tr>
<tr>
<td>80°</td>
<td>20.1±2.7</td>
<td>17.8±2.9</td>
<td>19.0±2.9</td>
<td>0.088</td>
<td>121</td>
</tr>
<tr>
<td>90°</td>
<td>19.5±2.6</td>
<td>17.3±2.8</td>
<td>18.4±2.8</td>
<td>0.089</td>
<td>121</td>
</tr>
</tbody>
</table>

* probability p<0.05 (Independent samples test with two tailed distribution)
** sum of ranks in male group for lateral condyle (Wilcoxon’s test) out of 78–132 interval

The average radiuses of the medial condylar curve decrease from 45 mm, at 0° flexion contact point, to 17 mm, at 90° flexion contact point (Table 2).

In the same interval, the average radiuses of the lateral condylar curve decrease from 31 mm to 18 mm (Table 3). This implies more round shape of lateral condyle in comparison to the medial condyle.

Males have significantly bigger femoral condyles and radiuses of its condylar curves in comparison to females (p<0.05). The differences turned out to be statistically insignificant after adjusting to body height (Table 2, 3). That insignificance was very close to the borderline p-value 0.05 on the lateral condyle for segments 40°–70°.

More elliptic medial condyle is bigger, with average dimensions of wider and narrower diameter (A and B) 33 and 24 mm, respectively (Figure 5).

**Discussion**

This study has found out that average radiuses of the medial condylar curve, from 0° to 90° flexion contact point, are longer and decrease by more than 2.5 times in comparison to the lateral curve radiuses which decrease less than a half time in the same interval. Otherwise, the medial condyle is bigger and much more oval than the lateral. Similar results were reported by other authors who measured radiuses of the condylar curves.

Gender differences in radiuses of the condylar curves were noted, as well. Male condyles and their radiuses were larger, but that difference became insignificant for both condyles after adjusting to body height. A relative high deviation of Ra within each segment, approximately a seventh of Ra, even after adjusting to body height, points out that the shape of the condylar curves is probably not equal within or between the examined groups. If the examined groups had been larger, it could have been expected that the radiuses of the condylar curves differed significantly.

Anatomy, shape and structure of joint bodies are base for all biomechanical researches. In equilibrium, shape is result of function and it can help as a model in deductive-analytical analyzing of function and clinical consequences. For instance, the geometry of the articulating contact points, and radiuses of condylar curves determine anatomical center of joint motion. If joint center is infinitesimally far from joint contact surface (Ra=8), there is pure sliding joint motion. If the center of joint motion lies on the surface of the moving limb (Ra=0), there is rolling contact, a condition in which there is no sliding and, therefore, minimum friction losses or wear. Significantly more sliding and arthritis occur at extension contact area, where curve diameters are longer. Different shapes of condylar curves could be one of, at least theoretical, explanations for strong medial side bias in knee OA.

The shape of knee condyles has been studied comprehensively in relation to osteoarthritis (OA) etiology and treatment. The relation between joint shape and OA has not been fully elucidated and few empirical data exist. It is well accepted that an alteration in joint shape occurs as a result of OA. Indeed, one feature of the original Kellgren and Lawrence OA scoring system was an alter-
Yoshioka has studied the shape of distal femur and dyles, as well, in a manner to compare radiuses of the ployed in analyzing of arthritic, eburnated knee con-
teses other worse. biomechanical relations are compromised, and one mak-
knee OA or mechanical disorder. The fact is that in OA respect to knee OA.
phological measurement) has not been conducted with distal femur (rather than an analysis of individual mor-
pertinent in etiology of knee OA. To the best of our
rather than lateral, anterior twist, a straighter and less
tively broader condyles (especially the medial condyle),
crease anterior-posterior translation.
Cooke has related the shape of medial condyle to knee OA.
crease varus-valgus instabilities and may also de-
remodeling may be a response to OA in an attempt at
joint repair and stabilization forming a negative feed-
to, that could slow the progress of OA. This is sup-
ported by the observation that marginal osteophytes de-
back«, that could slow the progress of OA. This is sup-
ported by the observation that marginal osteophytes de-

The method described in this research could be em-
ployed in analyzing of arthritic, eburnated knee con-
dyles, as well, in a manner to compare radiuses of the
destructed condyles with the clinical and radiological
severity score of the knee OA.

REFERENCES

Cilj ovog rada je matematički aproksimirati oblike femoralnih zglobnih linija i usporediti radiuse kondilarnih krivulja unutar i između muškaraca i žena. U studiju je uključeno deset muških i deset ženskih sudionika. Radijusi medijalnih i lateralnih kondilarnih krivulja izračunati su pomoću originalnih matematičkih formula, a na osnovu bočnih rendgenskih snimki koljena. Prosječni radiusi kondilarnih krivulja iznosili su za kontaktne točke 0° fleksije 4.5 cm medijalno i 3.2 cm lateralno, a za kontaktne točke 90° fleksije 1.7 cm medijalno i 1.8 cm lateralno. Muškarci su imali duži radijuse krivulja oba kondila (p<0.05). Nakon usklađivanja sa tjelesnom visinom razlike su se pokazale statistički beznačajne. Male promjene u geometriji zgloba za vrijeme života mogu učiniti zglob podložnim osteoartritisu i ozljedama. Aproksimacija radijusa femoralnih kondilarnih krivulja je korisna metoda u antropometrijskim, radiološkim i virtualnim izračunima geometrije koljena te ostalim elipsoidnim strukturama u ljudskom tijelu kao što su zapešće, segmenti lubanje, zubni lukovi itd.