Coll. Antropol. **32** (2008) 3: 875–879
Original scientific paper

Morphometric Alteration of Femoral Condyles Due to Knee Osteoarthritis

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ABSTRACT

Aim of this study was to estimate how knee osteoarthritis (OA) affects the shape of femoral condyles by comparing the radiuses of condylar curves between healthy and OA knees. Seventeen female and five male patients with established diagnosis of knee OA were included in the study. Radiuses of medial and lateral condylar curves were calculated from the side view knee X-ray by original mathematical equation and compared to referent values of healthy knees, after adjusting to body height. The average radiuses of condylar curves were between 52.6 ± 6.2 and 17.6 ± 3.5 mm medially, and between 43.3 ± 8.4 and 15.4 ± 3.7 mm laterally, for 0° and 90° femoral flexion contact points, respectively. The OA knees had longer curve radiuses medially and laterally at 0°, 10°, and 20° femoral flexion contact points in comparison to the healthy sample (P<0.001; t-test). Our results suggest that the shape of the femoral condyles in OA knees is changed. It should be aware not only in researching of OA etiology, but also in designing of knee endoprostheses, in a manner to achieve better individual sizing.

Key words: *knee, condyle, radius, orthopedics, osteoarthritis.*

Introduction

This study is scientific continuitation of our previous study[1] where we have measured sizes of the femoral condyle curves in healthy male and female population. We have employed the same method for calculation of curve diameters in arthritic, eburnated knee condyles. Therefore, this research is designed to compare radiuses of osteoarthritic (OA) and healthy femoral condyles.

It is not known what has early happened, primary knee OA or alteration of articular surfaces. The fact is that in OA articular shapes are compromised, and one makes the other worse. Characteristic changes of OA include cartilage degeneration, subhondral sclerosis and osteophyte formation around the margin of the articular surface (Figure 1), but morphological changes of OA knees are not unique (varus or valgus axes, more or less flatened condyles, level of joint narowing, etc).

Knee OA is a final common pathway for mechanically induced knee joint failure and it depends of condition of articular cartilage as mechanic puffer resistant on compression and friction loads[2,3]. Generally, the etiology of OA is poorly understood. Dieppe and Kirwan[4] suggest a multifactorial model of OA etiology. Factors such as age, race, and sex together with other systemic factors influence a person's susceptibility to OA. The knee OA has a strong female bias – 7:1 and it is strongly associated with obesity – 1,4:1. Risk of the knee OA increases by 35% for every 5 kg of weight gain[5]. The relation between joint shape and OA has not been fully elucidated and only few empirical data exist.

Special curving of the femoral condyles is important for the knee mechanics[6]. The geometry of the articular surfaces can affect the location of the contact points dur-

Received for publication February 6, 2007

Fig. 1. An X-ray of severe knee osteoarthritis.

ing knee motion and ultimately affect the stabilizing of the knee under compressive loads[7]. Some researches have chosen cones, arches and hemispheres to model joint surfaces, or at most, they have used a polynomial approximation to mimic knee joint surfaces[8]. All those studies of on condylar shape, and almost all employed mathematical models of the knee joint are based on 2D (planar) knee joint description. Studies how to define joint surface geometries have been scarce and, consequently, anthropometric studies on joint surfaces have been rather poor, especially studies concerning pathologically altered joint surfaces.

Aim of this study was to estimate how the knee osteoarthritis affects the shape of femoral condyles and to compare the radiuses of condylar curves between healthy and OA knees.

Patients and Methods

Patients

Twenty two participants were (five males and seventeen females) included in to study. The patients with primary knee OA, selected for implantation of total knee endoprosthesis according inclusion criteria, were randomly chosen. All participants willingly took part in this study after the explanation of the test procedure. The study was performed during the years 2005 and 2006 at Department for orthopedic, Clinical Center Sarajevo, and the study was approved by Ethics Committee of Ljubljana Medical Faculty. Inclusion criteria were clinically and radiologicaly proved knee OA of unknown etiology. Exclusion criteria were patients with known history of reumatoid arthritis, trauma, infective arthritis, etc. The average age of participants was 63.6 ± 10.6 (54–76) years, BMI 31.1 ± 3.5 (27–38) points, with average duration of symptoms of 9.1 ± 7.4 (1–25) years. Note that participants are mostly obese persons, since non-obese knee OA patients are very rare.

Methods

The pure side view X-ray of the OA affected knee in extended position was reproduced in real size on the computer digitalized scan (Vidar VXR-12 CCD scanner; 600 dpi, 256 gray levels[9], CorelDRAW 9®; Microsoft, Seattle, USA, Figure 2.).

The part of the femoral condyles, that articulates with tibia in a range of knee flexion from 0° up to 90° is commonly described as a segment of ellipsoidal curve[10–12]. The lines perpendicular to the two neighboring tangents at spots M and N determine the center of the curve (circle, ellipse), and the radius of that curve segment – $R\alpha$[13,14] (Figure 3).

Radiuses – $R\alpha$ were calculated for each 10° segment of the medial and lateral condylar curves.

$$X_R = [Y\alpha_{+10} - Y\alpha + tg(90-\alpha)X\alpha - tg(80-\alpha)X\alpha_{+10}] / [tg(90-\alpha) - tg(80-\alpha)],$$

$$Y_R = tg(90\text{-}\alpha)X_R + Y\alpha - tg(90\text{-}\alpha)X\alpha,$$

$$X\alpha = A/(1+(B^2/(tg\ \alpha)^2\ A^2))^{1/2},$$

$$Y\alpha = B/(1+(A^2(tg\ \alpha)^2/B^2))^{1/2};\ \alpha = 0°, 10°, 20°, 30°\ldots 90°,$$

$$R\alpha = [(X\alpha - X_R)^2 + (Y\alpha - Y_R)^2]^{1/2}.$$

The »Knee Roll« is locally developed software[15] based on above described equations, and object-oriented programming language C#2.0 for Microsoft 9X® and XP® (Microsoft, Seattle, WA, USA). Its output is a radius of the condylar curve ($R\alpha$) for each 10° segment, from 0° up to 90° articulating point.

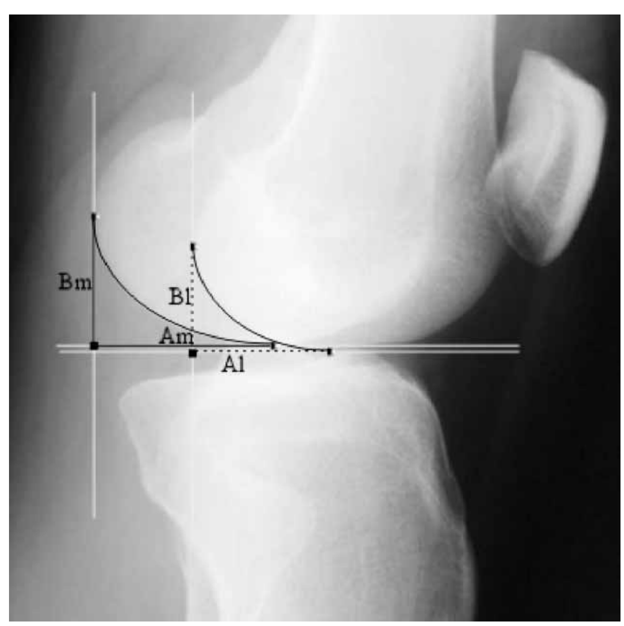

Fig. 2. Side view knee X-ray with outlined femoral articulating contours and diameters of ellipse, A and B; medially (solid lines) and laterally (dotted lines).

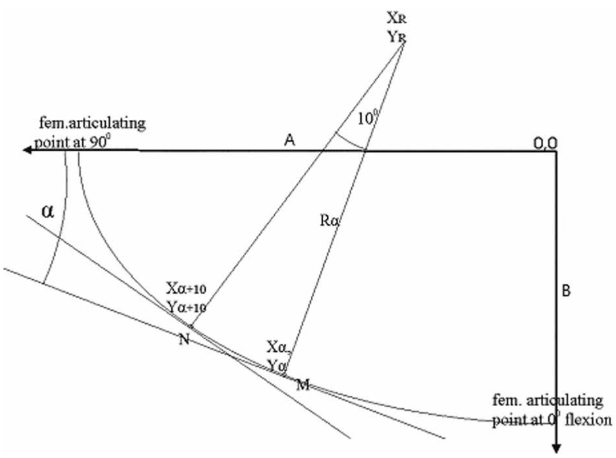

Fig. 3. Radius of condylar curve – Rα is defined with angle α and diameters of ellipse A, B.

Statistics

The Independent samples t-test (equal variance, normal distribution) was used for analysing Rα differences between group of participants with OA knees and referent vallues of unaffected knees, measured by the same method and adjusted by body height, with p=0.001 as a cut off value[16]. Other statistical methods were excluded (Man-Whitney, Wilcoxon's test sum of ranges, etc.), since theirs sensityvity had ben lower then sensityvity of t--test. The collected data were processed by Microsoft Excel® for Windows (Microsoft, Seattle, USA).

Results

The average radiuses of condylar curves were between 52.6 ± 6.2 and 17.6 ± 3.5 mm medially, and between 43.3 ± 8.4 and 15.4 ± 3.7 mm laterally, for 0° and 90° femoral flexion contact points, respectively. Before comparison to the referent values to healthy controls (data captured from Biscevic M, Hebibovic M, Smrke D)[1], the radiuses were adjusted to body height. The OA knees had significantly longer curve radiuses at 0°, 10°, and 20° femoral flexion contact point in comparison to the healthy sample, both medially and laterally (p<0.001, Table 1). Otherwise, there was no difference of side view shape between normal and OA knees, except in the area of terminal extension where OA condyles were more flattened (Figure 4).

Discussion and Conclusion

The results of this study suggest that shape of the femoral condyles in OA knees is changed. A relative high deviation of Rα within each segment, approximately a one sixth of Rα, even after adjusting to body height, suggests out that the shapes of the condylar curves differ considerably amongst OA patients, probably due to inhomogeneity of the group. The results of this study pointed significant difference in length of radiuses of condylar

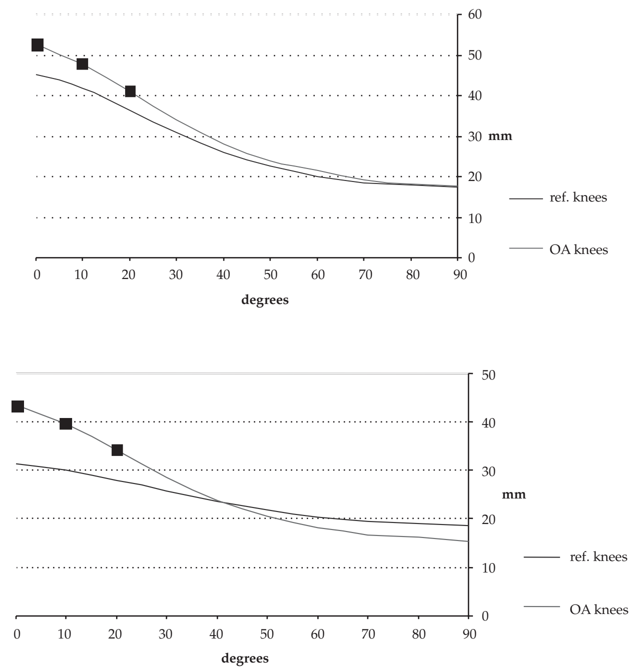

Fig. 4. Radiuses length of osteoarthritic (OA) and referent knees, medial condyle (upper part), and lateral condyle (lower part); (squares-for statistically significant differences in radius lenght).

curves between OA and normal knees at 0°, 10°, and 20° femoral flexion contact point. Otherwise, the OA knees have had more flattened condyles in the contact area of terminal extension (Table 1.), the area which is mostly loaded during the daily activities.

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 (Rα=?), there is pure sliding joint motion. If the center of joint motion lies on the surface of the moving limb (Rα=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 occurs at extension contact area[16], where curve diameters are longer. Altered shape of rubbed condyles increases surface gliding relative to rolling at the tibio-femoral surface, causing »circulus vitiosus« of joint failure, so even small changes in joint kinematics during lifetime could make joint more susceptible to OA[17]. The shape of knee condyles has been studied comprehensively in relation to OA etiology and treatment. 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 alteration in bony contours at X ray (osteophytes, joint narroving, sclerosis, and cysts)[18].

TABLE 1
RADIUSES OF MEDIAL AND LATERAL CONDYLAR CURVE – Rα, FOR OSTEOARTHRITIC (OA) AND REFERENT KNEES

Knee angle	medial				lateral			
	OA	referent	t	p*	OA	referent	t	P*
0°	52.6 ± 6.2	45.3 ± 6.7	5.58	0.000	43.3 ± 8.4	31.2 ± 5.1	6.70	0.000
10°	47.8 ± 4.6	41.7 ± 5.3	6.09	0.000	39.5 ± 6.6	29.9 ± 3.9	6.80	0.000
20°	40.8 ± 3.6	36.2 ± 3.3	6.00	0.000	34.0 ± 4.8	27.9 ± 2.5	5.86	0.000
30°	33.7 ± 3.5	30.7 ± 2.2	3.92	0.001	28.4 ± 4.8	25.6 ± 1.7	3.38	0.003
40°	27.9 ± 3.6	26.0 ± 2.3	7.61	0.160	23.8 ± 3.8	23.5 ± 1.9	0.44	0.665
50°	23.8 ± 3.8	22.4 ± 2.6	1.73	0.980	20.5 ± 3.8	21.7 ± 2.3	–1.43	0.166
60°	21.8 ± 4.8	19.9 ± 2.8	1.46	0.158	18.2 ± 3.9	20.3 ± 2.6	–2.61	0.017
70°	19.1 ± 3.6	18.4 ± 2.8	0.92	0.367	16.7 ± 4.0	19.4 ± 2.8	–3.06	0.006
80°	18.2 ± 3.6	17.7 ± 2.9	0.68	0.502	16.1 ± 3.9	19.0 ± 2.9	–3.29	0.004
90°	17.6 ± 3.5	17.2 ± 2.8	0.58	0.568	15.4 ± 3.7	18.4 ± 2.8	3.78	0.001

* probability $p<0.001$ (Independent Samples t-Test with two tailed distribution)

It has also been hypothesized that joint shape, influencing joint biomechanics, could increase the risk of OA. Bone remodeling and altering of joint shape have a role in the etiology of OA[19]. Yoshioka[20] has studied the shape of distal femur and noted a large natural variation in shapes that could be involved in the genesis of the knee OA. Cooke[21] has presented evidence that varus and valgus deformities can result from the shape of distal femur and proximal tibia that precede any OA change and have suggested that such deformities may be risk factors for knee OA. It has been also suggested that bone remodeling may be a response to OA in an attempt at joint repair and stabilization forming a »negative feed back«, that could slow the progress of OA. This is supported by the observation that marginal osteophytes decrease varus--valgus instabilities and may also decrease anterior-posterior translation.

In paleopathologic comparative analysis, Shepstone[22] has related the shape of medial condyle to knee OA.

The group with eburnated medial condyles had relatively broader condyles (especially the medial condyle), a narrower intercondylar notch with a more medial rather than lateral, anterior twist, a straighter and less concave lateral edge to the lateral condyle and a more symmetric patellar groove.

The shape of the distal femur may, therefore be very pertinent in etiology of knee OA.

To the best of our knowledge, a quantitative analysis of the shape of the distal femur (rather then an analysis of individual morphological measurement) has not been conducted with respect to knee OA.

Comprehensive biomechanic characteristic of the knee is always topical, especially in improving the aloplastic knee constructions, treatment of the knee instability and prevention of knee arthritis[23,24]. The design of knee prostheses that more closely resemble the normal joint anatomy and achieve better individual sizing has been unsuccessful. The lack of adequate mathematical knee model is one of the reasons for unsolved rather common problems of current knee endorpostheses: loosening, wear, abrasion, pitting, fracture, radiolucency, insufficient range of motions[10].

The current study offers the mathematical approximation of the shape of arthritic, eburnated femoral condyles by the original equation for calculating the radiuses of femoral curves.

Limitations of this study could be a relatively small number of participants, the way of data collection, discounts of potential effects of axial rotation, and approximation of the real condylar curve. However, in spite of the mentioned limitations, curve delineation is an approximately accurate only to 1–2 mm[11]. A new comprehensive study using this model on smaller contours that would include larger number of carefully selected participants, more sophisticated radiological tools, like computerized tomography could improve above-mentioned limitations in the future.

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MORFOMETRIJSKE PROMJENE FEMORALNIH KONDILA UZROKOVANE OSTEOARTRITISOM KOLJENA

S A Ž E T A K

Cilj ovog rada je procijeniti utjecaj osteoartritisa koljena na oblik femoralnih kondila usporedbom radijusa kondilarnih krivulja zdravih i osteoartrotičnih koljena. Sedamnaest ženskih i 5 muških pacijenata sa klinički i radiološki potvrđenom dijagnozom osteoartritisa koljena je uključeno u studiju. Radijusi zakrivljenosti medijalnog i lateralnog kondila femura su izračunati na osnovu postraničnog RTG snimka koljena, originalnom matematičkom formulom, te uspoređeni sa referentnim vrijednostima nakon izjednačavanja po tjelesnoj visini. Prosječna dužina radijusa kondilarnih krivulja bila je $52,6 \pm 6,2$ i $17,6 \pm 3,5$ mm medijalno, te $43,3 \pm 8,4$ i $15,4 \pm 3,7$ mm lateralno, za kontaktne točke na 0°, odnosno 90°. Osteoartrotična koljena su imala duže radijuse zakrivljenosti na medijalnom i lateralnom kondilu na 0°, 10° i 20° kontaktnim točkama u usporedbi sa zdravim ispitanicima ($P<0,001$; t-test). Naši rezultati ukazuju da je oblik femorlanih kondila kod osteoartrotičnih koljena promijenjen. To treba imati u vidu ne samo kod razmatranja etiologije osteoartritisa, nego i kod dizajniranja koljenih proteza u cilju preciznijeg određivanja veličine proteze.