

Body size influence on weight-bearing surface of the knee

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The aim of the study was to determine the measurements of meniscus and weight-bearing surface in the knee joint, proportions and correlations between the meniscus area and the weight-bearing surface of tibia. **Methods and results.** In total, 136 knees (68 right and 68 left) of 40 male and 28 female human cadavers were investigated in 1999–2001. Body length and morphological indices of tibial plateau and menisci for left and right knees of each cadaver were examined and analysed. The mean values were as follows: in males, the right medial meniscus (MM) occupied 6.4 cm², left MM 6.5 cm²; the area of right lateral meniscus (LM) was 6.1 cm² and left LM 6.2 cm²; in females, right MM occupied 5.0 cm², left MM 5.1 cm², the area of right ML was 4.5 cm² and left ML 4.5 cm². In males the right MM occupied 55.7%, left MM 56.8%, the right LM 71.0% and left LM 71.8% of the total weight-bearing surface of the knee. In females, the right MM occupied 55.9%, left MM 54.7%, right LM 68.9%, left LM 70.5%. A male 173 cm high with the average body weight 80 kg has a 1.99 kg/cm² pressure on the weight-bearing surface of tibia in the knee. Additional 40 kg increase the pressure in the knee 1.5 times (up to 2.98 kg/cm²), while after total medial meniscectomy weight pressure on the medial part of tibial plateau increases 2.3 times (up to 4.5 kg/cm²). Lateral meniscectomy increases weight pressure on the lateral tibia plateau 3.5 times (up to 6.9 kg/cm²).

Conclusions. The medial meniscus occupies 55–56% of the medial weight-bearing surface of tibial plateau (no sex differences). The lateral meniscus occupies 70–71% of the lateral weight-bearing surface of tibial plateau (no sex differences). Total meniscectomy changes the pressure on a square unit of tibia significantly and might be a reason for degenerative changes in the knee, while some overweight should not be the main agent of osteoarthritis in a healthy knee.

Key words: meniscus, surface area of lateral meniscus, surface area of medial meniscus, body weight pressure on square unit, tibial plateau, weight-bearing surface

INTRODUCTION

The knee is one of the most frequently injured joints because of its anatomical structure, its exposure to external force, and the functional demands placed on it (1, 2). Successful diagnosis of knee injuries is impossible without a perfect understanding of the normal knee anatomy. Nevertheless, not all details of clinical and functional anatomy are completely understood. Moreover, there is not much information on the measurements of the internal structures of human knee joint and its relation with different pathologies of the knee.

The structures of the knee joint are divided into osseous, intraarticular and extraarticular soft tissues. Over the last few decades much emphasis has

been placed on the intraarticular ligaments (3, 4), whereas the menisci, tibial plateau and tibiofemoral load transmission are less studied. In the 19th through 20th century the knowledge about menisci gradually evolved from a perception of them as an inactive and functionless structure to the view that they are a vital and multifunctional component of the knee (5, 6). Biomechanical, experimental and clinical researches demonstrated a significant role of menisci in the joint (compensation of incongruity of femoral and tibial articular surfaces, amortisation, shock absorption and joint stabilisation, as well as helping the distribution of synovial fluid throughout the joint, preventing capsular and synovial impingement during movement in the joint) (1–8).

A classical paper that properly led to the view that meniscectomy is followed by gonarthrosis was published by E. Tapper and N. Hoover as far back as 1969 (9). The article has been cited extensively and followed by a number of long-term follow-up clinical studies that concluded as follows: partial meniscectomy is better to compare with total resection (3, 10–16). However, till now there are no detailed investigations enough to prove a multiple relationship between the morphological and functional peculiarities of knee structures, tibiofemoral load transmission and the specific pathology of the knee joint (1, 4).

Experimental researches demonstrated the menisci to play a significant role in joint lubrication (11), shock absorption (12, 13) and joint stabilization (14). During *in vitro* axial loading, meniscectomy leads to a large reduction in contact areas in the femorotibial joint and an increase in the peak stress on tibial cartilage (10, 15–18). Moreover, there is a linear correlation between the increase in peak stress on the tibial joint surfaces and the amount of meniscus tissue removed. It is generally believed that osteoarthritic changes very strongly depend on the meniscus load transmission function and its impairment.

The purpose of this study was to determine the measurements of tibial plateau and menisci, to evaluate changes in tibiofemoral load transmission after meniscectomy. The following tasks were raised up: to measure menisci and weight-bearing surface in the knee; to find proportions and correlations between the meniscus area and the weight-bearing surface of tibia; to calculate theoretically the body

weight pressure on a square unit of the weight-bearing surface of tibia.

MATERIALS AND METHODS

In total, 136 knees (68 right and 68 left) of 40 male and 28 female human cadavers were investigated at the Vilnius Morgue of Forensic Medicine and Department of Anatomy, Histology and Anthropology of Vilnius University in 1999–2001 (Table 1). The age of males ranged from 19 to 92 years (mean, 52.6) and of females from 30 to 86 years (mean, 57.2). Body length and the following morphological indices of the body, tibial plateau and menisci for the left and right knees of each cadaver were examined (Figs. 1, 2) and analysed:

1. Surface area of lateral meniscus (AreaMenLat), using a transparent film laid down of a surface area and later put on the graph paper for calculating whole and incomplete quadrates of the paper.
2. Surface area of the lateral side of tibial plateau excluding the meniscus area (AreaTibLatExMen), using a transparent film.
3. Surface area of the total lateral side of tibial plateau (AreaTibLat), using a transparent film.
4. Surface area of the medial meniscus (AreaMenMed), using a transparent film.
5. Surface area of the medial side of tibial plateau excluding meniscus area (AreaTibMedExMen), using a transparent film.
6. Surface area of the total medial side of tibial plateau (AreaTibMed), using a transparent film.

Table 1. Descriptive statistics for measurements of left and right knee of male and female menisci and tibial plateau

Knee measurement (R – right, L – left)	Males							Females					
	M	SD	V	Min	Max	p*	M	SD	V	Min	Max	p*	
AreaeMenLat (in cm ²)	R	6.1	1.14	1.29	4.5	8.5	0.71	4.5	0.68	0.47	3.50	6.0	1.00
	L	6.2	1.12	1.25	4.3	8.6		4.5	0.83	0.69	3.13	6.1	
AreaTibLatExMen (in cm ²)	R	2.5	0.64	0.41	1.1	3.9	0.90	2.1	0.42	0.18	1.4	2.9	0.54
	L	2.5	0.69	0.47	1.3	4.4		1.9	0.56	0.31	1.4	3.1	
AreaTibLat (in cm ²)	R	8.6	1.36	1.86	5.6	11.1	0.85	6.6	0.85	0.73	4.8	7.9	0.77
	L	8.7	1.57	2.47	5.5	11.6		6.5	1.15	1.32	4.8	8.6	
AreaMenMed (in cm ²)	R	6.4	1.22	1.48	3.3	8.9	0.91	5.0	0.82	0.67	3.9	6.5	0.93
	L	6.5	1.20	1.43	4.6	9.1		5.1	1.09	1.19	3.8	6.6	
AreaTibMedExMen (in cm ²)	R	5.1	1.25	1.57	2.5	8.5	0.73	4.0	0.83	0.69	3.0	5.3	0.63
	L	5.0	1.40	1.95	2.5	9.0		4.2	0.78	0.61	2.9	5.8	
AreaTibMed (in cm ²)	R	11.6	1.71	2.93	8.1	14.3	0.77	9.0	1.46	2.13	6.9	11.7	0.75
	L	11.5	1.70	2.90	7.5	14.9		9.3	1.43	2.05	6.6	11.5	
AreaMenLat/ AreaTibLat (in %)	R	71.0	6.0	0.4	59.2	83.9	0.80	68.9	4.8	0.2	59.6	76.2	0.82
	L	71.8	4.7	0.2	61.5	81.5		70.5	5.7	0.3	59.0	78.0	
AreaMenMed/ AreaTibMed (in %)	R	55.7	8.0	0.6	30.2	72.2	0.85	55.9	4.1	0.2	47.5	60.3	0.84
	L	56.8	8.3	0.7	35.7	71.1		54.7	6.2	0.4	40.3	63.0	

p* – value of significance of difference between the same measurement of right or left knee of certain sex.

In addition, several derivative indices for both knees of both sexes were calculated from the above-mentioned measurements:

7. The proportion of the lateral meniscus area to the total lateral tibial plateau (per cent) was calculated dividing the surface area of the lateral meniscus by the surface area of the total lateral side of tibial plateau and multiplying the ratio by 100 ($\text{AreaMenLat} / \text{AreaTibLat}$).

8. The proportion of the medial meniscus area to the total medial tibial plateau (per cent) was calculated dividing the surface area of the medial meniscus by the surface area of the total medial side of tibial plateau and multiplying the ratio by 100 ($\text{AreaMenMed} / \text{AreaTibMed}$).

The data were computed using the standard programs of statistical packages (SPSS, EXCEL). Descriptive statistics for each measurement was calculated and a correlation analysis of Pearson's correlation coefficients was made. The statistical significance of the differences between the same measurements of right and left knee, as well as between male and female data was determined according to Student's t test.

RESULTS

The mean male body length was 173.7 cm (SD = 8.84) and ranged between 153 cm (Min) and 210 cm (Max). Female body length fluctuated between 148 cm (Min) and 174 cm (Max, mean 160.4 cm (SD = 8.29)). There were no statistically significant differences between all measurements of right and left knees for both male and female individuals (Table 1): in most cases p strongly exceeded 0.05 (variation of p ranged from 0.04 to 1.0). For this reason we calculated the "average measurement" for the menisci and tibial plateau of the study contingent as an average size of the same measurement derived from the right and left knees of male as well as female individuals.

The surface area of the menisci and tibial plateau of male knees was significantly larger as compared

to the same indices of female knee (Table 2): in most cases $p < 0.001$. This difference is well known and coincides with a bigger size of the male body and its more pronounced skeletal robustness. Nevertheless, nearly no sexual difference was found between the proportion of the lateral meniscus area to the total lateral tibial plateau ($p = 0.20$) as well as the proportion of the medial meniscus area to the total medial tibial plateau ($p = 0.52$).

A detailed analysis of both knees of male and female individuals showed that the medial side of the right or left knee in most cases exceeded the same indices on the lateral side (Tables 1, 2). The surface area of the total medial side of tibial plateau (AreaTibMed) exceeded the same dimension on the lateral side of the right or left knee on average 1.33 times ($p < 0.001$). The difference was particularly great between the surface area of the medial side of tibial plateau excluding the meniscus area (AreaTibMedExMen) and the same dimension of the lateral side of a knee: AreaTibMedExMen exceeded AreaTibLatExMen of the right or left knee on average twice ($p < 0.001$), whereas the surface area of the medial meniscus (AreaMenMed) of the right or left knee as compared to the lateral one (AreaMenLat) was only slightly and insignificantly bigger ($p = 0.25$ for the right and $p = 0.36$ for the left knee). These findings showed that the proportion of the lateral meniscus area to the total lateral tibial plateau ($\text{AreaMenLat} / \text{AreaTibLat}$) was evidently and significantly greater ($p < 0.001$) as compared to the proportion of the medial meniscus area to the total medial tibial plateau ($\text{AreaMenMed} / \text{AreaTibMed}$) of the right (71% versus 55.7%) or left (71.8% versus 56.8%) knee or its average (71.4% versus 56.2%). Hence, the lateral meniscus occupies relatively much more place on the tibial plateau as compared to medial one, though the absolute surface area of the lateral meniscus is even somewhat smaller than the surface area of the medial meniscus.

The influence of body size on the weight-bearing surface in the knee was calculated theoretically. Presuming that body weight pressure on a square unit of tibial plateau in the knee is equal in the lateral and

Table 2. Descriptive statistics for averages of both knee measurements of male and female menisci and tibial plateau

Average measurement of left and right knee	Males					Females				
	M	SD	V	Min	Max	M	SD	V	Min	Max
AreaMenLat (in cm ²)	6.2	1.12	1.126	4.3	8.6	4.5	0.74	0.55	3.1	6.1
AreaTibLatExMen (in cm ²)	2.5	0.66	0.44	1.1	4.4	20	0.49	0.24	1.4	3.1
AreaTibLat (in cm ²)	8.7	1.46	2.13	5.5	11.6	6.5	0.99	0.98	4.7	8.6
AreaMenMed (in cm ²)	6.4	1.20	1.44	3.3	9.1	5.0	0.94	0.88	3.7	6.6
AreaTibMedExMen (in cm ²)	5.0	1.32	1.74	2.5	9.0	4.1	0.79	0.63	2.9	5.7
AreaTibMed (in cm ²)	11.4	1.70	2.88	7.5	14.9	9.1	1.41	1.99	6.6	11.6
AreaMenLat/AreaTibLat (in %)	71.4	5.4	0.3	59.2	83.9	69.7	5.2	0.3	59.0	78.0
AreaMenMed/AreaTibMed (in %)	56.2	8.1	0.7	30.2	72.2	55.3	5.2	0.3	40.3	63.0

medial sides, we divided body weight by the general tibial weight-bearing surface of both knees and calculated the weight pressure on a square centimetre of tibial plateau. The pressure on a square centimetre of tibial plateau for an "average" male (173 cm high) from our study ("normal" weight was considered to be 80 kg) could be as follows: weight (80 kg), divided by AreaTibLat (8.7 cm²) plus AreaTibMed (11.4 cm²), when multiplied by 2 (right and left knee) was equal to 1.99 kg/cm² [80 kg: (8.7 cm² + 11.4 cm²) × 2 = 1.99 kg/cm²]. The general structure of the body, the specific construction and biomechanics of the knee allow hypothesizing that the weight pressure on a square unit of tibial plateau should be the same in different parts of the knee. As the lateral and medial parts of the tibia weight-bearing surface are different in size (medial part bigger than lateral), weight distribution on the medial and lateral sides of tibial plateau could be expected to be different. Part of weight on the medial side of tibial plateau could be calculated by multiplying the pressure on square cm of tibial plateau (1.99 kg/cm²) by AreaTibMed (11.4 cm²) and to equal 22.7 kg [1.99 kg/cm² × 11.4 cm² = 22.7 kg]. Knowing the weight coming on the medial part, we can calculate the weight pressure on a square centimetre of the medial side after removing the medial meniscus; the weight coming on the medial side (22.7 kg) should be divided by the surface area of the medial side of tibial plateau excluding the medial meniscus area (AreaTibMedExMen = 5.0 cm²) and equals 4.5 kg/cm² [22.7 kg : 5.0 cm² = 4.5 kg/cm²]. Analogously we can calculate the weight pressure on a square unit of the lateral side after lateral meniscectomy. Consequently, additional 40 kilograms of weight pressure on a square unit of tibia increases the load 1.5 times (up to 2.98 kg/cm²). Total medial meniscectomy changes the pressure on a square unit of the medial side of tibia about 2.3 times (up to 4.5 kg/cm²), while after total lateral meniscectomy the load increases 3.5 times (up to 6.9 kg/cm²).

DISCUSSION

Degenerative changes are known to follow meniscectomy, but the incidence assessed by radiographic examination more than 10 years following surgery has varied from 46% (3.15) to 89% (19), and the frequency of symptoms in the same studies varied from 7% to 53%. In a comparative study of open meniscal resection and total meniscectomy (20), degenerative changes were present in 30% after partial meniscectomy and in 60% after total meniscectomy less than 6 years after surgery. Odgaard et al. (18), using CT scans, found that not only total but also, to a lesser extent, partial medial meniscectomy was followed by density changes in the proximal tibia within the first 5 years after surgery. Only a few authors have analyzed the factors stimulating the

degenerative changes in the knee after meniscectomy. Alien et al. (15) found that above age 40, abnormal leg alignment and localization of the tear influenced the results, but only the age factor appeared to be of statistical significance.

In animal studies, postmeniscectomy changes have been found to be proportional to the size of the resected meniscus (16, 17). The clinical condition of arthritis is the most common cause of disability in older age groups, involving cartilage disruption and ultimately joint destruction (21). One of multiple reasons why osteoarthritis develops is the abnormal loads that can develop because of meniscus resection or overweight. Most studies concentrate on osteoarthritic changes in the knee after meniscectomy or injury, but it is not obvious that overweight is a real reason for degenerative osteoarthritis. Our study shows that total meniscectomy changes the pressure on a square unit more significantly and might be a greater reason for degenerative changes in the knee, while mild overweight should not be the main reason of osteoarthritis in a healthy knee. The hypothesis that the same overweight increases the pressure on the weight-bearing surface of tibial plateau more significantly for short persons and those with a more gracile skeleton as compared to tall and robust skeletons could be raised up from this study: the measurements of the skeleton are interrelated and have a strong correlation with height; hence, the higher the person, the bigger and more robust long bones are, also a larger weight-bearing surface in the knee could be expected. It means that the same overweight could be distributed on a large area and consequently the pressure could be lower in comparison with the same load distribution on a smaller weight-bearing surface of a short individual.

CONCLUSIONS

1. The medial meniscus occupies 55–56% of the medial weight-bearing surface of tibial plateau (no sex differences).
2. The lateral meniscus occupies 70–71% of lateral weight-bearing surface of tibial plateau (no sex differences).
3. The pressure on a square unit of tibial plateau after total medial meniscectomy increases 2.3 times on the medial side and after total lateral meniscectomy 3.5 times on the lateral side.

ACKNOWLEDGEMENT

We are greatly thankful to Dr. A. Barkus (Department of Anatomy, Histology and Anthropology, Vilnius University) for contribution to the statistical analysis of the data and for valuable suggestions.

Received 15 November 2004

Accepted 27 December 2004

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KŪNO SUDEJIMO POVEIKIS KELIO SĀNARIO ATRAMINIAM PAVIRĐIUI

Santrauka

Šio darbo tikslas – išmatuoti kelio sąnario atraminio paviršiaus matmenis, nustatyti santykiną meniskų dydį blauzdikaulio atraminio paviršiaus atžvilgiu, apskaičiuoti, kaip kinta spaudimas á blauzdikaulio atraminio paviršiaus plotą paūalinus meniskus bei priaugus svorio. Buvo ištyti 40 vyrų – kosios lyties ir 28 moteriškosios lyties lavonų 136 kelio sąnariai (68 dešiniai ir 68 kairieji), išmatuotas ūgis bei dešiniojo ir kairiojo kelio sąnario meniskų matmenys, blauzdikaulio atraminio sąnarinio paviršiaus dydis ir plotas. Duomenys apdoroti panaudojus standartinius statistinius programų paketus (SPSS, EXCEL). Rezultatai rodo, kad vyrų dešiniojo kelio sąnario vidinio menisko plotas – 6,4 cm², kairiojo – 6,5 cm², išorinio menisko plotas dešiniajame kelio sąnaryje – 6,1 cm², kairiame sąnaryje – 6,2 cm². Moterų vidinio menisko plotas dešiniajame kelio sąnaryje – 5,0 cm², kairiame sąnaryje – 5,1 cm². Išorinio menisko plotas tiek dešiniajame, tiek kairiajame kelio sąnaryje – 4,5 cm². Vyrų dešiniajame kelio sąnaryje vidinis meniskas užima 55,7% blauzdikaulio vidinio atraminio paviršiaus ploto, išorinis meniskas užima 71,0% blauzdikaulio išorinio atraminio paviršiaus ploto. Kairiajame kelio sąnaryje vidinis meniskas užima 56,8% blauzdikaulio vidinio atraminio paviršiaus ploto, o išorinis meniskas – 71,8% išorinio atraminio paviršiaus ploto. Moterų dešiniajame kelio sąnaryje vidinis meniskas sudaro 55,9% blauzdikaulio vidinio atraminio paviršiaus ploto, o išorinis meniskas – 68,9% blauzdikaulio išorinio atraminio paviršiaus ploto. Moterų kairiajame kelio sąnaryje vidinis meniskas sudaro 68,9%, o išorinis meniskas – 70,5% vidinio ar išorinio blauzdikaulio atraminio paviršiaus ploto atitinkamai. Vyrų kosios lyties 173 cm ūgio asmens, sveriančio 80 kilogramų, masė slepia blauzdikaulio sąnarinio paviršiaus plotą 1,99 kg/cm² jėga. Jei tokio ūgio asmens svoris būtų 40 kg didesnis, spaudimas á blauzdikaulio atraminio paviršiaus ploto vienetą padidėtų 1,5 kartų ir slėgtų 2,98 kg/cm². Paūalinus visą vidinį meniską, spaudimas á ploto vienetą vidinėje sąnario pusėje padidėtų iki 2,3 kartų ir slėgtų 4,5 kg/cm². Paūalinus išorinį meniską spaudimas išorinėje sąnario pusėje padidėtų 3,5 karto ir slėgtų 6,9 kg/cm².

Išvados. Vidinis meniskas užima 55–56% blauzdikaulio vidinio atraminio paviršiaus ploto (skirtumo tarp lyčių nenustatyta), išorinis meniskas – 70–71% blauzdikaulio išorinio atraminio paviršiaus ploto (skirtumo tarp lyčių nenustatyta). Meniskų paūalinimas gerokai padidina spaudimą á sąnario atraminio paviršiaus plotą ir neabejotinai didina osteoartrozės riziką, tačiau nedidelis atsvaris neturėtų sukelti ryškesnių degeneracinių pakitimų sąnario kremzlėje.