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ORIGINAL STUDY

Principal component analysis as a tool for determining optimal tibial baseplate geometry in modern TKA design

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Optimal tibial component fixation in total knee arthroplasty (TKA) requires maximal tibial bone coverage, optimized mediolateral cortical fit as well as component rotation. Failure to achieve an optimal fit may result in component subsidence and loosening in case of undersizing, or overhang with subsequent soft tissue impingement in case of overhang.

To date there is no consensus on optimal tibial component shape, and significant variability exists among different design manufacturers. In this study "principal component analysis" was used as a statistical tool in order to determine the ideal tibia baseplate shape, based upon anthropometric CT-scan data defining an average proximal tibial shape and variations. Gender specificity was evaluated and differences in geometry depending on anatomic constitution (varus, neutral, valgus) were analyzed.

The results from our study indicate that in the arthritic knee differences in proximal tibial morphology at the resection level were mainly attributed to size and not shape. This is true for both Caucasian men and women, and is independent from the anatomical constitution.

Keywords: principal component analysis ; tibial shape ; tibial component ; overhang.

INTRODUCTION

To date there is no consensus on optimal tibial component design in TKA, and significant variability exists among different manufacturers.

In order to determine the optimal prosthetic design, a thorough understanding of bony anatomy is mandatory. Recent advances in imaging and analysis techniques allow us today to determine the "best shape" more accurately than ever before.

The majority of currently available TKA systems have a symmetric tibial baseplate design, although some of the more recent TKA systems now start to offer asymmetric baseplates. Advocates of the use of asymmetric tibial baseplates claim superior bone coverage without increase in component overhang or compromised rotational alignment *(6)*. Not all studies however confirm this, suggesting that the

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actual shape of the tibial tray and the number of accommodating sizes determine tibial coverage, rather than the asymmetric or symmetric aspect *(3,4,9)*.

The current knowledge on geometry of the proximal tibia is mainly derived from cadaveric studies or analysis of resection specimens after TKA. These studies have already provided great insight, although with the advent of more modern imaging techniques and software processing methods, a much more detailed analysis can be performed.

Our study combines CT-scan data with advanced "principal component analysis (PCA) " software algorithms and analytical data processing, resulting in mathematical models defining average proximal tibial geometry and its variability. PCA is a statistical technique used for emphasizing strong patterns (the principal components) and their variation in complex datasets *(1)*. Using this technique, an optimal baseplate shape can be determined for a certain population. In addition, anteroposterior (AP) and mediolateral (ML) dimensions can be studied independently for the medial and lateral compartment, and morphological differences between gender or differences related to the anatomical constitution (varus, neutral, valgus) can be explored.

MATERIALS AND METHODS

After ethical committee approval was obtained for this retrospective CT-scan based study, the proximal tibial geometry of 299 knees (134 men, 165 women) requiring total knee replacements for advanced osteoarthritis was evaluated.

Principal component analysis was performed on tibia plateau contours from the anthropometric CT-scan derived data, defining the average proximal tibia and the main shape variations. Anteroposterior and mediolateral dimensions, as well as plateau boxiness and symmetry were determined separately for the medial, lateral and overall tibial plateau. Gender specificity was evaluated and differences in geometry depending on the anatomical axis (varus, neutral, valgus) were explored using statistical testing.

The mean age of the included patients was 67.59 (69.53 year in women, 65.19 year in men). All patients were Caucasian. Patients received a primary total knee replacement (Genesis II – Smith & Nephew) between January 2009 and May 2011. Axial slices through the proximal tibia were reconstructed with an interval of 2.5 mm. The axial slice immediately inferior to the slice through the metal of the tibial tray was chosen for data collection. This represents the tibial resection level and therefore correlates with the tibial shape during surgery (Figure 1).

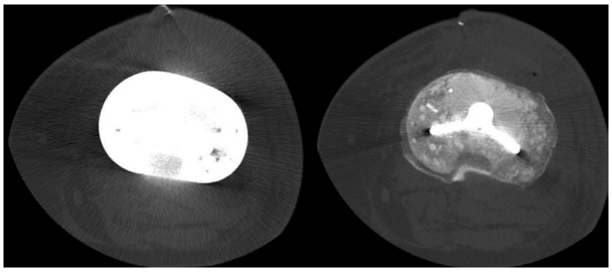

Fig. 1. — left: axial CT-section through the tibial baseplate; right: section immediately inferior for data collection

The tibial contour was manually segmented from the DICOM images using visualization software (Avizo® - VSG, FEI™). The outer contour of each tibia was extracted from the segmented images using OpenCV (opencv.org). All contours were then placed in a reference pose by alignment on the fin of

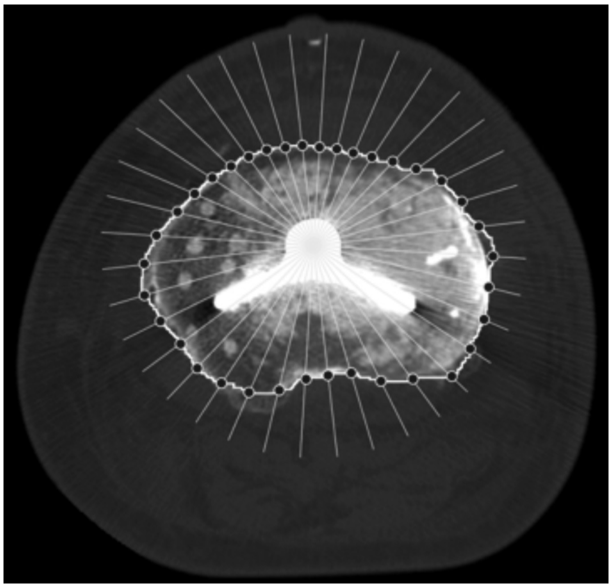

Fig. 2. — Each contour was intersected with 360 equidistant rays emanating from the center of the fin, resulting in a set of 360 corresponding 2D points for each tibial contour

the tibial trays. Finally, each contour was intersected with 360 equidistant rays emanating from the center of the fin, resulting in a set of 360 corresponding 2D points for each tibia contour (Figure 2). By doing so, the population of 299 tibial contours can be represented by a single 299 by 720 matrix allowing further statistical analyses to investigate the shape of the tibial contour.

Morphometric measurements

Morphometric measurements of the tibia contours in the reference pose were obtained using customized automated software (SSMTK, Vision Lab, University of Antwerp) as described by Dai et al. *(2)*.

First, the vertical axis was determined as the axis of symmetry of the tibial baseplate and keel. Next, the horizontal axis was defined as perpendicular to the vertical axis and going through the midpoint of the intersection of the vertical axis with the tibial plateau. Combined, these axes defined the origin of the coordinate system.

The vertical axis was used for dividing the plateau in a medial and a lateral part. The surface plateau area (Area) was calculated as well as the surface area of the lateral (Lateral_Area) and medial (Medial_Area) plateau. Bounding boxes, aligned with the coordinate axes, were calculated for the whole plateau, the medial and the lateral part. Areas were calculated for the overall bounding box (BBox_Area), the medial (Medial_BBox_Area) and lateral (Lateral_BBox_Area) bounding box.

The mediolateral distance (ML) of the plateau was measured as the length of intersection of the horizontal axis with the plateau. The medial and lateral anteroposterior dimension (Medial_AP and Lateral_AP) were measured as the length of the intersection of the plateau with the vertical midline of, respectively, the medial and lateral bounding box.

The medial radius (Medial_Radius) and lateral radius (Lateral_Radius) were calculated through circle fitting. Fitting was perfromed respectively to the anterior 50% - most medial 25% and the anterior 50% - most lateral 25% of the contour.

The aspect ratios (Plateau_Aspect, Lateral_Aspect, and Medial_Aspect) of the plateau bounding boxes were also calculated as the ratio of bounding box's minimum and maximum dimension. Plateau boxiness parameters (Boxiness, Lateral_Boxiness, and Medial_Boxiness) were calculated as the ratio of the respective plateau areas and bounding box areas.

The asymmetry of the tibia plateau was quantified as the ratio of medial and lateral AP dimensions (AP_assymetry) and the ratio of medial and lateral boxiness (Boxiness_Assymetry).

The anteroposterior distance ratio's of the medial and lateral tibial plateau were plotted against the distance from the periphery, yielding in a continuous graphic representation of anteroposterior distance.

Figure 3 shows an individual tibial contour with its estimated axes, boxes, and radii that were used to describe these different morphometric parameters.

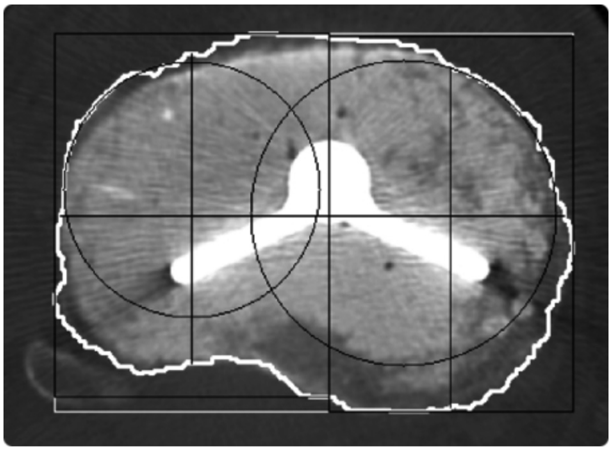

Fig. 3. — Individual tibial contour with its estimated axes, boxes, and radii that were used for the different morphometric parameters

Statistical shape model

In order to explore the shape variations of the tibia contour within the population, a statistical shape model was constructed. Such a model is obtained by principal component analysis of the population matrix containing the points of the contours in the reference position. This results in an average contour and an ordered set of shape modes, where the first few modes capture the most prominent variations in contour shape, such as global size and aspect ratio differences, while the next components capture more local shape variations.

Statistical comparison of mean contour shape

For each of the investigated groups, a mean contour shape was calculated and a comparison

Table I. — distribution of tibial data sets with respect to gender, operated side and anatomical axis

	Left	Right	Total	Neutral	Varus	Valgus	Total
Male	68	66	134	25	78	31	134
Female	63	102	165	41	75	49	165
Total	131	168	299	66	153	80	299

between the groups was made through statistical testing in the following manner: The comparison between two groups, e.g. male and female, was executed for each point on the contour separately, effectively resulting in 360 statistical tests. Each of these tests is an unpaired student-t test (Welch's t-test) and evaluates whether the location of the mean contour point, along the radial ray emanating from the tray fin center, is different for the two groups. The results were visualized on the mean contour of the combined group through a color map that reveals the p-value of the test result in each point along the contour. Points for which the means were not significantly different ($p > 0.05$) were drawn in black, while points for which the means were significantly different ($p <= 0.05$) were drawn in yellow ($p = 0.05$) to red ($p = 0.00$). In this way, a graphic visualization is obtained that reveals the parts of the tibial contours that were significantly different between the two groups.

RESULTS

Images of 299 patients were included in this study (134 males, 165 females). Left knees were involved in 131 cases, right knees in 168 cases. Analysis of the anatomical axis revealed a neutral axis in 66 cases, varus alignment in 153 cases and valgus alignment in 80 cases. Distribution of the tibial data sets with respect to gender and axis is summarized in table I. The numbers are not entirely balanced, there is a difference between the

Table II a,b,c. — Morphometric data of 299 knees analysed separately according to gender, operated side and anatomical axis

Table II a.

	Morphometric measurements											
	MALE											
	ALL		L		R		Normal		Varus		Valgus	
	mean	std	mean	std	mean	std	mean	std	mean	std	mean	std
ML (mm)	85.36	3.84	85.77	3.69	84.95	3.98	84.67	3.90	85.56	3.65	85.35	4.19
Medial_AP (mm)	55.40	3.52	55.45	3.12	55.27	3.85	55.84	3.98	54.93	3.38	56.16	3.41
Lateral_AP (mm)	55.28	3.61	55.54	3.19	55.08	4.01	55.43	3.50	54.53	3.27	57.29	3.89
Area (mm^2)	4360.03	385.31	4374.46	321.07	4345.12	441.24	4347.63	382.68	4317.93	358.44	4475.76	427.00
Medial_Area (mm^2)	2041.83	186.94	2026.14	160.65	2047.82	210.07	2025.75	185.83	2036.16	180.07	2046.98	203.88
Lateral_Area (mm^2)	2318.20	245.10	2348.32	207.03	2297.30	276.76	2321.87	251.86	2281.77	220.49	2428.78	264.91
BBox_Area (mm^2)	5570.50	510.97	5605.37	439.76	5531.37	570.92	5517.41	515.20	5537.50	478.19	5701.04	571.63
Medial_BBox_Area (mm^2)	2573.70	231.27	2568.23	205.95	2569.84	252.92	2553.70	227.84	2572.78	225.19	2572.12	246.76
Lateral_BBox_Area (mm^2)	2854.55	322.81	2889.63	272.36	2826.46	360.83	2836.90	333.00	2819.44	297.01	2977.43	343.23
Medial_Radius (mm)	39.77	11.39	40.67	12.86	38.66	8.91	40.21	9.42	38.58	11.69	42.21	10.44
Lateral_Radius (mm)	26.39	9.55	26.72	8.15	26.50	13.87	25.70	5.41	26.03	8.71	27.96	14.24
Plateau_Aspect	0.73	0.03	0.74	0.04	0.73	0.03	0.74	0.02	0.73	0.03	0.75	0.04
Medial_Aspect	0.66	0.03	0.65	0.03	0.66	0.03	0.64	0.03	0.67	0.03	0.64	0.03
Lateral_Aspect	0.74	0.04	0.75	0.05	0.74	0.04	0.75	0.04	0.75	0.05	0.73	0.04
Boxiness	0.78	0.02	0.78	0.02	0.79	0.02	0.79	0.02	0.78	0.02	0.79	0.02
Medial_Boxiness	0.79	0.02	0.79	0.02	0.80	0.02	0.79	0.02	0.79	0.02	0.80	0.02
Lateral_Boxiness	0.81	0.03	0.81	0.03	0.81	0.03	0.82	0.02	0.81	0.03	0.82	0.03
AP_asymmetry	1.00	0.07	1.00	0.07	1.01	0.07	1.01	0.06	1.01	0.07	0.98	0.07
Boxiness_Asymmetry	0.98	0.04	0.97	0.04	0.98	0.04	0.97	0.04	0.98	0.05	0.98	0.04
Count	134		68		66		25		78		31	

Table II b.

	Morphometric measurements											
	FEMALE											
	ALL		L		R		Normal		Varus		Valgus	
	mean	std	mean	std	mean	std	mean	std	mean	std	mean	std
ML (mm)	74.79	3.61	75.49	3.76	74.35	3.44	74.29	3.95	74.96	3.38	74.93	3.61
Medial_AP (mm)	49.13	2.74	49.40	2.73	48.96	2.74	48.96	2.69	49.37	2.95	48.90	2.40
Lateral_AP (mm)	47.85	3.23	48.86	3.01	47.22	3.20	48.08	3.11	47.69	3.26	47.89	3.26
Area (mm^2)	3355.83	299.64	3426.73	316.20	3312.04	280.11	3346.55	318.27	3363.67	298.60	3351.59	284.45
Medial_Area (mm^2)	1619.22	143.25	1641.13	152.67	1605.70	135.36	1607.86	141.48	1641.69	142.48	1594.35	140.66
Lateral_Area (mm^2)	1736.60	186.54	1785.60	188.73	1706.34	178.58	1738.69	199.45	1721.98	184.70	1757.24	175.82
BBox_Area (mm^2)	4260.39	394.94	4326.36	414.76	4219.64	376.46	4235.66	415.48	4269.93	387.47	4266.47	387.70
Medial_BBox_Area (mm^2)	2012.94	175.72	2034.25	188.59	1999.78	165.91	1993.71	180.41	2039.98	171.11	1987.64	172.79
Lateral_BBox_Area (mm^2)	2143.41	238.82	2197.21	245.74	2110.19	228.19	2132.84	243.47	2122.79	232.62	2183.82	239.29
Medial_Radius (mm)	32.84	8.11	32.70	8.11	32.93	8.11	31.07	7.23	33.40	8.11	33.47	8.58
Lateral_Radius (mm)	21.25	6.07	22.88	7.17	20.24	5.01	21.99	7.12	20.96	4.93	21.07	6.61
Plateau_Aspect	0.73	0.03	0.73	0.03	0.73	0.03	0.73	0.03	0.73	0.04	0.73	0.03
Medial_Aspect	0.67	0.03	0.67	0.03	0.67	0.03	0.67	0.03	0.67	0.03	0.66	0.03
Lateral_Aspect	0.73	0.04	0.73	0.04	0.74	0.04	0.73	0.04	0.73	0.04	0.74	0.04
Boxiness	0.79	0.02	0.79	0.02	0.79	0.02	0.79	0.02	0.79	0.02	0.79	0.02
Medial_Boxiness	0.80	0.02	0.81	0.02	0.80	0.02	0.81	0.02	0.80	0.02	0.80	0.02
Lateral_Boxiness	0.81	0.03	0.81	0.03	0.81	0.03	0.82	0.03	0.81	0.03	0.81	0.03
AP_asymmetry	1.03	0.06	1.01	0.05	1.04	0.06	1.02	0.05	1.04	0.06	1.02	0.07
Boxiness_Asymmetry	0.99	0.04	0.99	0.04	0.99	0.04	0.99	0.04	0.99	0.04	1.00	0.04
Count	165		63		102		41		75		49	

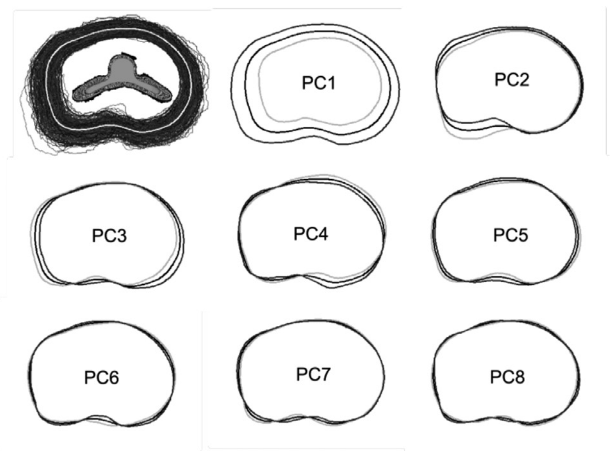

Fig. 4. — Top-left: visualization of the different contours in the reference position for the combined male-female population. Each of the 299 contours is drawn as a thin line, each in a different color. The thick white line represents the mean contour of the population. The thick red lines represent the extreme contours (= two standard deviations of the mean contour in both directions along the radial rays). Top-middle to bottom-right: first eight principal components or shape modes of the population denoted PC1-PC8. For each shape mode, the average contour is shown in black, the negative offset of two standard deviations from the mean contour is shown in green and the positive offset is shown in red

variety of men, women, side and anatomical axis. There is Morphometric data were summarized in table 2a/b/c. Table 3 gives an overview of the p-values of difference in mean test of morphometric measurements usinWilcoxon's signed rank test for gender, side and constitution. Measurements were performed for men and women separately. All length and area dimensions were significantly larger in man than in woman ($p < 0.05$). Some shape parameters were also significantly different, except for Plateau aspect and Lateral Boxiness, but the actual differences were marginal. The significant differences in size (not shape) between left and right knees observed in our population were due to a larger amount of right female knees in our data. The lateral compartiment is larger in men and significantly larger in women (Lateral_AP 48.86mm left vs 47.22mm right, Lateral_area 1785.60 mm² left vs 1706.34 mm² right, Lateral_BBox_Area 2197.21 left vs 2110.19 right). The female right knee is also more asymmetric (AP_ Asymmetry, 1.01 left vs 1.04 right). On the level of constitution, only a few measurements were significantly different but the absolute differences were clinically irrelevant.

Table II c.

	Morphometric measurements									
	ALL									
	L		R		Normal		Varus		Valgus	
	mean	std	mean	std	mean	std	mean	std	mean	std
ML (mm)	80.81	6.35	78.51	6.34	78.23	6.38	80.35	6.37	78.98	6.35
Medial_AP (mm)	52.51	4.25	51.41	4.45	51.58	4.65	52.21	4.23	51.70	4.52
Lateral_AP (mm)	52.33	4.56	50.27	5.23	50.86	4.83	51.19	4.69	51.50	5.81
Area (mm^2)	3918.65	570.85	3717.86	615.40	3725.77	595.14	3850.15	580.31	3787.36	648.08
Medial_Area (mm^2)	1838.74	249.99	1776.48	275.88	1763.44	259.76	1840.49	257.43	1766.82	278.98
Lateral_Area (mm^2)	2079.91	342.36	1941.37	362.59	1962.33	357.17	2009.66	344.28	2020.55	389.27
BBox_Area (mm^2)	4991.17	768.67	4733.23	791.77	4721.18	770.25	4917.33	768.40	4826.35	837.91
Medial_BBox_Area (mm^2)	2310.19	333.24	2220.27	348.06	2203.60	338.87	2309.14	335.18	2212.11	352.32
Lateral_BBox_Area (mm^2)	2557.94	431.33	2393.17	452.10	2401.12	441.32	2480.05	437.51	2494.93	476.56
Medial_Radius (mm)	36.87	11.48	35.26	8.94	34.61	9.21	36.16	10.41	36.94	10.41
Lateral_Radius (mm)	24.79	7.65	22.63	10.00	23.47	7.15	23.49	7.55	23.86	10.91
Plateau_Aspect	0.73	0.04	0.73	0.03	0.74	0.03	0.73	0.03	0.74	0.03
Medial_Aspect	0.66	0.03	0.66	0.03	0.66	0.03	0.67	0.03	0.65	0.03
Lateral_Aspect	0.74	0.05	0.74	0.04	0.74	0.04	0.74	0.05	0.74	0.04
Boxiness	0.79	0.02	0.79	0.02	0.79	0.02	0.78	0.02	0.79	0.02
Medial_Boxiness	0.80	0.02	0.80	0.02	0.80	0.02	0.80	0.02	0.80	0.02
Lateral_Boxiness	0.81	0.03	0.81	0.03	0.82	0.03	0.81	0.03	0.81	0.03
AP_asymmetry	1.01	0.06	1.03	0.07	1.02	0.06	1.02	0.07	1.01	0.07
Boxiness_Asymmetry	0.98	0.04	0.99	0.04	0.98	0.04	0.98	0.05	0.99	0.04
Count	131		168		66		153		80	

Statistical shape modeling using principal component analysis resulted in an average tibial plateau geometry as represented in Figure 4.

The extreme contours as defined by 2 standard deviations of the mean shape, is represented in the same figure. Principal components shape modes of significance were size (PC1), rotation around the tibial keel as central axis (PC2), and mediolateral translation to the vertical axis (PC3).

When corrected for size, proximal tibial geometry at the resection level was not significantly influenced by gender or varus/valgus constitution. (Fig. 5 and 6)

DISCUSSION

This is the first study that analysis the tibial shape at the resection level of the tibial cut as commonly performed in today's total knee arthroplasty. The unique aspect of analysing CT- images at the level of the tibial cut, allow us to precisely judge the tibial plateau's shape at the level where it matters, that is at the level where the actual implantation of the tibial baseplate occurs.

The obtained CT-scan data were processed using "principal component analysis (PCA) " software algorithms, resulting in a mathematical model defining average proximal tibial geometry and its variability. As such, the optimal baseplate shape could be determined for patients undergoing TKA.

Previous cadaver derived data have demonstrated that the shape and dimension of the proximal tibia is asymmetric, with the medial tibial plateau being larger than the lateral plateau. This difference increases as one moves away from the periphery of the tibial plateau toward the center. A study on resection specimens after total knee replacement demonstrated that the lateral plateau is on average 92%, 87% and 82% of the medial plateau at 10%, 20% and 30% from the periphery, respectively *(8)*. Some authors have reported gender and ethnic

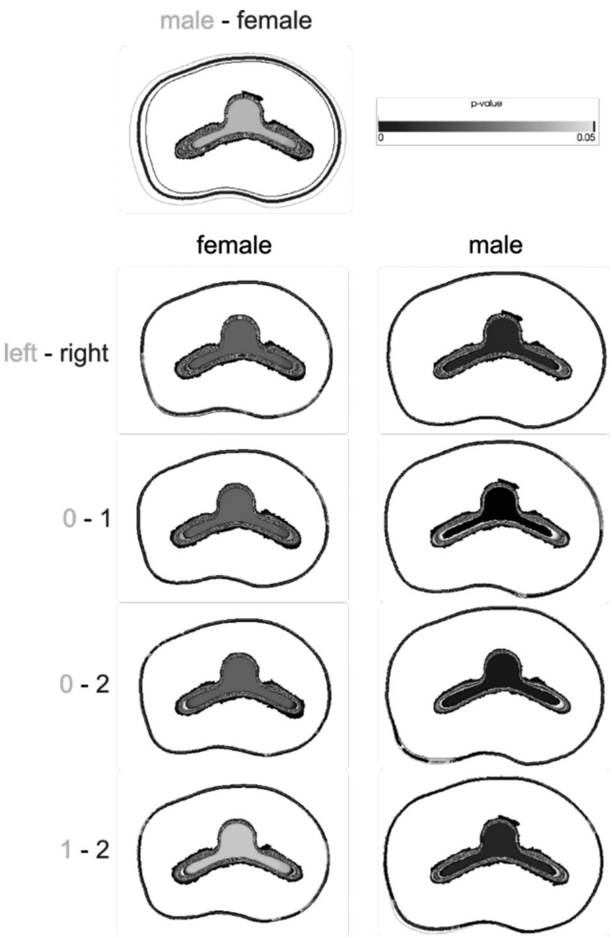

Fig. 5. — Visualization of the results for gender group testing in mean contour shape. For each combination of two groups, the mean contour of both groups were shown in thin in green and blue and the global mean contour is shown in thick using a color map. Black parts were not significantly different, while yellow and red parts were significantly different (p<=0.05). (0:neurtral, 1:varus, 2: valgus)

differences. In a study on 1000 normal adult knees (80 African American, 80 East Asian, 860 Caucasian) African American males had larger mediolateral and anteroposterior dimensions, as well as larger lateral anteroposterior height and smaller medial anteroposterior height compared to Asian males. Asian males and Asian females had smaller anteroposterior and mediolateral dimensions than Caucasian males and Caucasian females *(5)*. In the Chinese population the mediolateral/ anteroposterior ratio was shown to be higher in men than in women, which yields in a more oval shaped tibial plateau in men compared to a more spherical

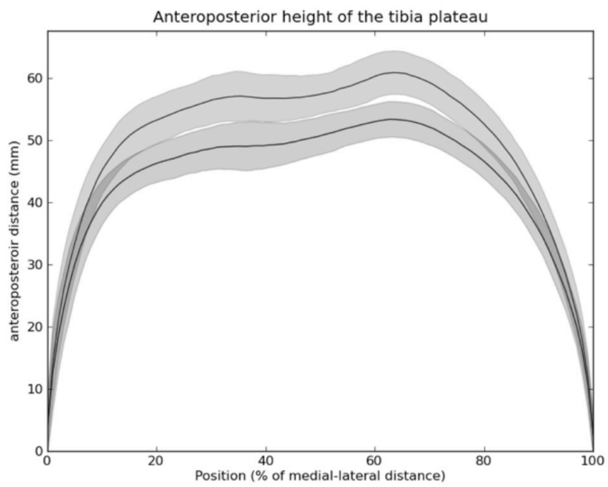

Fig. 6. — Gender specific anteroposterior height of the tibia plateau along the mediolateral axis. Male and female average and positive/negative offset of one standard deviation shown in red and blue respectively

plateau in women. Furthermore, for a given AP dimension the ML/AP aspect ratio was higher in men and lower in women, which suggests that for a given dimension this risies the potential for the component to be undersized in men and oversized in women *(10)*. Literature demonstrates a correlation between patient height and overall tibial plateau anteroposterior and mediolateral dimensions *(7)*.

In our study we analyzed morphology of the proximal tibia at the resection level for total knee replacement in Caucasian men and women with advanced osteoarthritis requiring surgery. Our results confirm the difference in shape between the medial and lateral tibial plateau. This is true for both men and women, and is independent from the constitutional axis of the knee. Our results also indicate that in the arthritic knee differences in proximal tibial morphology at the resection level were mainly attributed to size and not shape. This is true for both Caucasian men and women, and is independent from the anatomical constitution.

Our study has some limitations. The axial CT-section chosen for shape analysis of the proximal tibia is based on the surgical resection level. Theoretically this level may differ from the ideal resection level, given the fact that the surgical resection level is based on the surgeon's visual estimate and measurement. We feel however that the senior experience level of the surgeons and the

Table III. — p-values of difference in mean test of morphometric measurements using Wilcoxon's signed rank test

	Wilcoxon signed rank test -- difference in means												
	ALL					MALE				FEMALE			
	M-F	L-R	N-VR	N-VL	VR-VL	L-R	N-VR	N-VL	VR-VL	L-R	N-VR	N-VL	VR-VL
ML	0.00	0.00	0.02	0.39	0.10	0.14	0.41	0.56	0.94	0.04	0.16	0.18	0.95
Medial_AP	0.00	0.01	0.20	0.84	0.21	0.64	0.19	0.82	0.06	0.25	0.48	0.98	0.48
Lateral_AP	0.00	0.00	0.53	0.58	0.99	0.47	0.30	0.09	0.00	0.00	0.53	0.98	0.59
Area	0.00	0.00	0.15	0.68	0.30	0.53	0.58	0.39	0.08	0.03	0.80	0.89	0.86
Medial_Area	0.00	0.02	0.04	0.98	0.02	0.63	0.89	0.88	0.83	0.17	0.18	0.75	0.05
Lateral_Area	0.00	0.00	0.34	0.48	0.92	0.13	0.41	0.21	0.01	0.01	0.53	0.68	0.24
BBox_Area	0.00	0.00	0.08	0.52	0.27	0.27	0.94	0.37	0.19	0.10	0.63	0.55	0.99
Medial_BBox_Area	0.00	0.01	0.03	0.94	0.03	0.84	0.85	0.87	0.86	0.24	0.14	0.95	0.09
lateral_BBox_Area	0.00	0.00	0.21	0.25	1.00	0.14	0.66	0.26	0.04	0.03	0.78	0.30	0.10
Medial_Radius	0.00	0.35	0.26	0.13	0.54	0.92	0.35	0.29	0.03	0.79	0.13	0.15	0.74
Lateral_Radius	0.00	0.00	0.94	0.63	0.51	0.32	0.85	0.53	0.37	0.00	0.62	0.27	0.56
Plateau_Aspect	0.49	0.60	0.19	0.51	0.05	0.58	0.15	0.30	0.01	0.95	0.57	0.99	0.60
Medial_Aspect	0.00	0.53	0.01	0.66	0.00	0.16	0.00	0.96	0.00	0.34	0.17	0.70	0.08
Lateral_Aspect	0.05	0.87	0.84	0.40	0.57	0.58	0.89	0.22	0.25	0.31	0.61	0.69	0.83
Boxiness	0.02	0.71	0.03	0.20	0.39	0.13	0.06	0.91	0.21	0.01	0.31	0.19	0.58
Medial_Boxiness	0.00	0.24	0.28	0.36	0.91	0.03	0.78	0.90	0.60	0.16	0.57	0.29	0.54
Lateral_Boxiness	0.37	0.61	0.10	0.10	0.93	0.69	0.12	0.99	0.23	0.28	0.47	0.07	0.22
AP_asymmetry	0.00	0.01	0.42	0.71	0.22	0.67	0.89	0.22	0.14	0.01	0.09	0.50	0.48
Boxiness_Asymmetry	0.00	0.15	0.45	0.25	0.92	0.30	0.35	0.51	0.64	0.79	0.64	0.40	0.76

number of patients included in the study make great errors unlikely.

Secondly, the mathematical averaging of the different plateaus was performed by superimposing the fin of the tibial tray. Hence the rotation of the tibial component, as defined intra-operative by the surgeon, has an influence on the final average shape analysis. Analogous to the surgical resection level the authors feel that these theoretical errors were unlikely to result in great variations in de final data processing. In fact, using the surgical resection level and component rotation may also be considered a strength of this study, rather than a weakness, as these variables truly reflect the in-vivo clinical setting during total knee replacement surgery.

As conclusion, our study demonstrates that tibial plateau size is the principal attribute responsible for differences in tibial morphology at the resection level, independent from gender or axis. Our data therefore suggest that gender specific or constitution specific tibial baspelate designs were not necessary for optimal tibial coverage

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