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Original Article

Anthropometric study of the knee and its correlation with the size of three implants available for arthroplasty☆

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ABSTRACT

Objective: To define the anthropometric profile of the knee in a Brazilian population with gonarthrosis using intraoperative measurements; and to evaluate the compatibility of three implants available for total knee arthroplasty.
Methods: Morphometric data were collected prospectively from 117 subjects with gonarthrosis. Six dimensions in the distal femur and two in the proximal tibia were documented in 118 knees while performing total arthroplasty. These data were compared with the dimensions of three implants available for total knee arthroplasty.
Results: The statistical analysis showed that more than a quarter of the patients presented an unsatisfactory relationship between the knee and prosthesis.
Conclusion: The implants evaluated need to be adjusted to better fit Brazilian patients.
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Estudo antropométrico do joelho e sua correlação com o tamanho de três implantes disponíveis para artroplastia

Palavras-chave:
Artroplastia do joelho
Antropometria
Fêmur
Tíbia

RESUMO

Objetivo: Definir o perfil antropométrico do joelho em população brasileira portadora de gonartrose, com o uso da mensuração intraoperatória, e avaliar a compatibilidade de três implantes disponíveis para artroplastia total do joelho.
Métodos: Foram coletados, de forma prospectiva, os dados morfométricos de 117 pacientes portadores de gonartrose. Documentaram-se seis dimensões no fêmur distal e duas na tíbia

☆ Study conducted at Hospital Santa Teresa de Petrópolis, RJ, Brazil.
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proximal em 118 joelhos, durante a artroplastia total. Esses dados foram comparados com as dimensões dos três implantes disponíveis para artroplastia total do joelho.
Resultados: A análise estatística revelou que mais de um quarto dos pacientes apresentou relação inadequada entre os joelhos e as próteses.
Conclusão: Os implantes avaliados necessitam de ajustes para melhor atender aos pacientes brasileiros.
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Introduction

Osteoarthrosis (OA) is the main cause of musculoskeletal disability in the elderly and the main cause of total knee arthroplasty (TKA).[1] The aging process, the genetic burden, and female gender are non-modifiable factors associated with the origin of the disease.[2] Obesity and activities with load also have a direct participation in this disease. In the Brazilian population above 19 years of age, 5.2% of the individuals have some type of arthrosis (nearly 10 million individuals). This number will probably increase and reach 12.4 million in 2015.[3] OA incidence has a direct relation with age, affecting 85% of the population above 75 years.[4] According to projections of the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística [IBGE]), in 2030 Brazil will probably have the sixth oldest population in the world,[5] a fact that, associated with the increase of obesity rates, will significantly increase the prevalence of this disease.

Even though there are no official statistics for Brazil, it is estimated that 70,000 knee arthroplasties are performed yearly.[6] The increase of the Brazilian mean income has facilitated the access to healthcare services and increased the number of TKA candidates, seeking better quality of life and higher physical capacity.[7]

Prosthesis implantation is a surgery of precision, and the similarity between the implant and the resected bone is essential for a good clinical result and the durability of the replacement.[8] The knee anatomy presents great variability regarding gender,[8–14] ethnicity,[10,15–20] and body type.[21]

After researching the literature in Portuguese and English language, the authors did not retrieve studies defining knee dimensions in the Brazilian population with gonarthrosis. Thus, prostheses developed for Caucasians were introduced in the country without any modification. A possible incompatibility, even if partial, increases the complexity of the surgery and hinders the appropriate matching of the implant with the bone.

This study aimed to define the anthropometric knee profile in the Brazilian population with gonarthrosis using intraoperative mensuration, and to compare the bone dimensions with three available implants for arthroplasties.

Material and methods

After approval of the study by the institution's Research Ethics Committee, under No. CEP 68542, 118 knees of 117 patients who underwent TKA between August 2012 and December 2013 were prospectively studied. The study included all patients who accepted to participate by signing the informed consent form. Cases with history of prior knee fracture or surgery, patients who presented bone losses that needed grafting, and those with varus or valgus deformity greater than 15° were excluded.

Three metal pachymeters were purchased and sent to the National Institute of Metrology, Quality, and Technology (Instituto Nacional de Metrologia, Qualidade e Tecnologia [Inmetro]), which confirmed the precision of the instruments. During the surgical procedure, the lead surgeon conducted six mensurations of the femur: height and width of the lateral and medial condyles, total mediolateral and intercondyle width (Fig. 1A), and two on the tibia: mediolateral and anteroposterior width (Fig. 1B). The dimensions were recorded in millimeters, after two measurements performed by the main investigator, in order to avoid any interobserver alteration. The arithmetic mean was used for analysis.

Prior to the measurements, the distal cut of the femur and the proximal cut of the tibia were performed, and all osteophytes were removed. This maneuver allowed for the identification of the actual dimensions of the bone surfaces that would be in contact with the implant. The mediolateral femoral distance was measured at the level of the surgical transepicondylar axis. The width of each femoral condyle was measured at 8 mm of the posterior articular surface of the lateral condyle and at 10 mm of the posterior articular surface of the medial condyle, simulating the external rotation of the femur. The anteroposterior measurements were performed prior to the cuts, in order to assess whether overstuffing would occur. The anteroposterior width of the tibia was measured from the center of the posterior cruciate ligament (PCL) to the medial third of the patellar tendon. The mediolateral width was the largest perpendicular distance to the first measurement.

The implants were chosen by the similarity with the height of the lateral condyle and its width compared with the total width of the femur after the distal cut. The relative index (RI) between total width and height of the lateral condyle, as described by Hitt et al., was also assessed.[9]

Considering the objective of the study, the following assumptions were made for the calculation of the sample size: significance level of 5% (α), statistical power of 80% ($1-\beta$), and relatively moderate ($r > 0.30$) expected relation between two variables (total width of the femur and lateral condyle height, or mediolateral and anteroposterior width of the tibia). In agreement with Cohen,[22] the minimum number of patients was 96, being 64 women and 32 men.

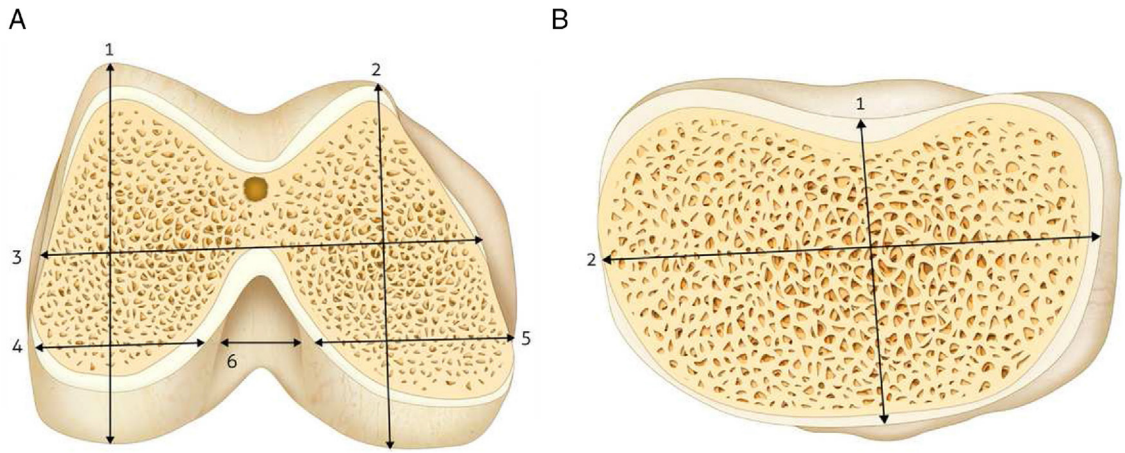

Fig. 1 – Intraoperative measurement (A) right distal femur: 1 – height of the lateral condyle; 2 – height of the medial condyle; 3 – total width of the femur; 4 – width of the lateral condyle; 5 – width of the medial condyle; 6 – intercondylar fossa; (B) right proximal tibia: 1 – anteroposterior width; 2 – mediolateral width.

The descriptive analysis was presented on tables and illustrative charts. The observed data were expressed as mean, standard deviation, median, minimum, and maximum for numerical data, by frequency (*n*) and percentage (%) for categorical data.

The intraclass correlation coefficient (ICC) was used to assess the compatibility of three implants frequently available in Brazil: Scorpio® (Stryker Howmedica Osteonics), NexGen® (Zimmer, Warsaw, Indiana), and Native Knee® (Zimmer, Warsaw, Indiana). The McNemar test was used to compare the three implants brands.

Non-parametric methods were used, as the variables did not present a Gaussian distribution as shown by the rejection of the Shapiro–Wilks normality test. The adopted significance criterion was the level of 5%. Statistical analysis was performed using the statistical software SAS® version 6.1.

Results

The study included 118 knees from 117 patients; 33 patients were male and 84 were female. One female patient underwent bilateral TKA. Table 1 presents the distribution of the sample regarding gender, operated side, and ethnicity.

The analysis of the distal femur data showed significantly greater absolute values for male patients. The RI between total width of the femur and height of the lateral condyle was similar for both genders (Table 2).

Similarly to the distal femur, the tibial measures presented significantly greater values for male patients. The RI between the mediolateral and anteroposterior width was greater for female patients. That suggests that these tibias may be wider. However, this difference was not significant ($p = 0.26$; Table 3).

There was great variation of the relation between the total width of the femur and the height of the lateral condyle, regardless of the size of the femur (patient height).

Figs. 2 and 3 show the relation of the prosthesis with the bone surfaces already prepared to receive the implant.

Table 1 – Sample characterization.

Variable	Number of knees	Percentage
Gender		
Male	33	28.0%
Female	85	72.0%
Side		
Right	60	50.8%
Left	58	49.2%
Ethnicity		
White	105	89.0%
Mixed-race	9	7.6%
Black	4	3.4%

Source: Data from the institution.

The correlation of the femoral implants with the resected bones received greater attention, as these are directly related to appropriate joint balance and normal gait. To assess this relation, the ICC was used, which revealed a significant, albeit moderate, conformity of three implants to the distal femur of the studied sample ($p < 0.0001$, Table 4).

A difference equal to or greater than 3 mm was considered unbearable for implant over- or underhang in the mediolateral sense. This study observed that 29.7% of the patients who used Scorpio®, 28.8% of those who used NexGen®, and 27.9% of those who used Native Knee® presented inadequacies. Underhang was the most frequent problem, present in 20.9% of the patients, and it was twice as common among male patients. Mediolateral overhang was present in 7.9% of the patients and was three times as common among female patients. The distribution of incompatibilities equal to or greater than 3 mm is presented in Table 5.

The comparison between the three implants after the distribution of the incompatibilities was performed with the McNemar test, which indicated that there were no significant differences among the prostheses studied (Table 6).

Table 2 – Distal femur.

Gender	Number of knees	Total width[a]	Height of the lateral condyle[a]	Relative index
Male	33	77.7 (±4.9)	70.3 (±4.7)	111% (±7.1%)
Female	85	67.8 (±4.0)	61.5 (±4.9)	111% (±10.4%)
Total	118	70.6 (±6.1)	64.0 (±6.3)	111% (±9.6%)

Source: Data from the institution.
[a] Measurements in millimeters.

Table 3 – Proximal tibia.

Gender	Number of knees	Mediolateral width[a]	Anteroposterior width[a]	Relative index
Male	33	79.8 (±5.8)	53.9 (±6.1)	150% (±22.1%)
Female	85	69.6 (±4.3)	46.0 (±4.0)	152% (±15.3%)
Total	118	72.4 (±6.6)	48.2 (±5.9)	152% (±17.4%)

Source: Data from the institution.
[a] Measurements in millimeters.

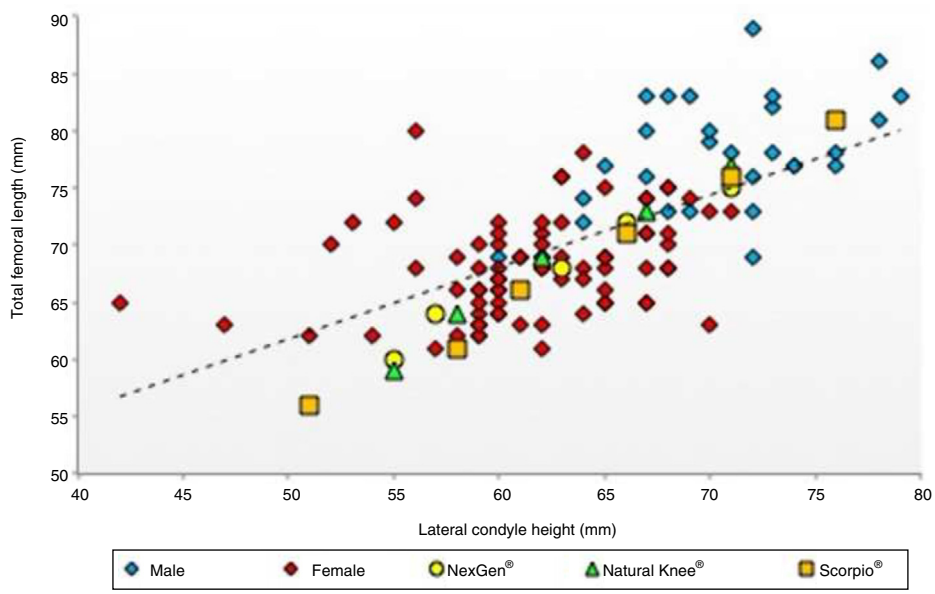

Fig. 2 – Relation between implants and distal femur.
***Source*: Data from the institution.**

Discussion

Brazil has been presenting typical social changes of developing countries, such as population aging[23] and the growth of obesity.[24] These factors are directly connected to the genesis of osteoarthrosis, which allows us to predict that the demand for joint replacements will grow exponentially in the near future.

Following the principles of TKA and implanting the appropriate prosthesis size are fundamental factors for the success of joint replacement surgery. Correct ligament balance and maximum bone coverage by the implant are pursued, in order to reduce the stress on the bone–implant surface.[15] Mismatchings in this relation increase the complexity of the surgery.[19]

Table 4 – Relation between distal femur and implants.

Prosthesis	ICC	95% CI	*p*-value
Scorpio®	0.592	0.462–0.698	<0.0001
Natural Knee®	0.534	0.392–0.651	<0.0001
NexGen®	0.547	0.407–0.661	<0.0001

Source: Data from the institution.
ICC, intraclass correlation coefficient; CI, confidence interval.

Several morphometric studies have been conducted in cadavers,[12,13] using image exams[15,17,18] or surgical navigation systems.[25] The present measurements were done *in vivo*, intraoperatively after the distal cut of the femur and proximal cut of the tibia, what allowed for the evaluation of the actual

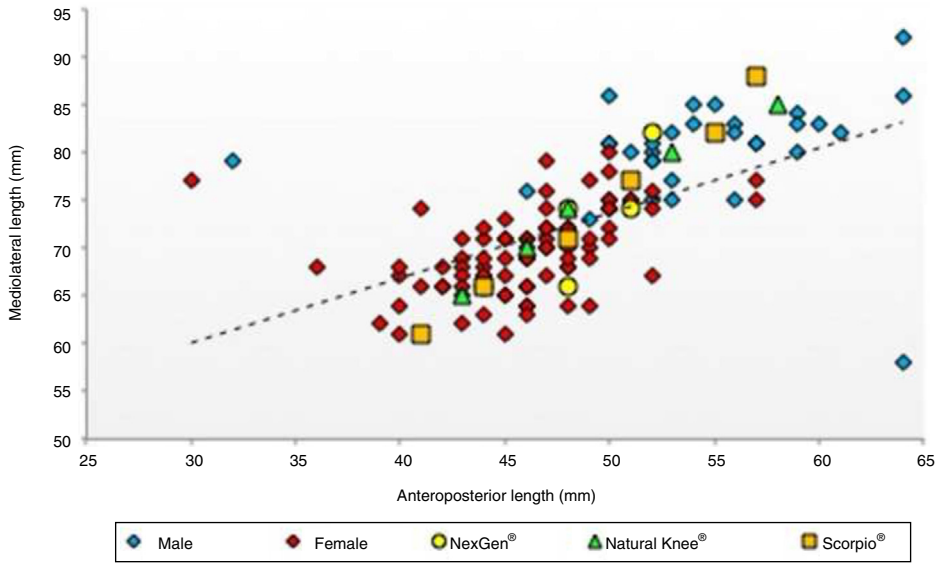

Fig. 3 – Relation between implants and proximal tibia.
***Source*: Data from the institution.**

Table 5 – Distribution of the incompatibilities ≥3 mm.

Gender	Male		Female	
Prosthesis/incompatibility	Underhang[a]	Overhang[a]	Underhang[a]	Overhang[a]
Scorpio®	9	1	18	7
NexGen®	13	1	12	8
Natural Knee®	9	1	13	10
Total	31 (31.3%)	3 (3%)	43 (16.9%)	25 (9.8%)

Source: Data from the institution.
[a] Number of patients.

bone dimensions that would be in contact with the implants. Additionally, every patient of the sample presented the clinical and radiographic diagnosis of knee osteoarthrosis, and therefore presented the typical anatomical changes of this disease. These aspects increased the reliability of the study, since the dimensions of osteoarthritic knees are different from those of normal knees.[8]

The mean RI of the femur among male patients was 111%, ranging from 101% to 124%. Female patients presented the same mean, however with a much wider range, from 90% to 143%. This fact reveals the greater anatomical variability of the distal femur in this gender. This value is in agreement with the dimensions found for Koreans (111%)[19]; however they are larger than those of the Chinese (109%)[10] and smaller than those of the Japanese (129%) populations.[19] The studied implants presented an RI variation between 105% and 112%, indicating that there can be both under- and overhang.

Ha et al.[19] found a tendency of underhang for smaller femurs, and of overhang for larger femurs. This tendency was not observed in the present sample. A great variability of the total width of the femur was observed for the same height of the lateral condyle. The studied implants presented only one width for each height, which appears not to be the ideal format.

Table 6 – Comparison between the implants.

Prosthesis	*p*-value[a]
Scorpio® *vs.* Nex Gen®	0.88
Scorpio® *vs.* Natural Knee®	0.23
NexGen® *vs.* Natural Knee®	0.15

Source: Data from the institution.
[a] *p*-value for 5%.

Perfectly matching the implant to the resected bone can be a problem. In the studied sample, 7.9% of the patients showed mediolateral overhang greater than 3 mm; this finding was three times more common in females than in males. According to Mahoney et al.,[26] overhang doubles the chance of post-operative complications, such as range of movement limitation and pain, and impairs the appropriate ligament balancing. When the implant is too small in the mediolateral direction, there can be underhang. This was the most frequent problem, observed in 20.9% of the patients, twice as often in males, and it can lead to increased blood loss[9] and lead to the development of radiolucent lines around the prosthesis.[13]

Table 7 – Comparison between the femoral measurements.

Authors	Population	Method	LTF	ACL	RI
Mensch et al. (1975)[27]	American	Cadavers and X-rays	69.7 ± 2.7(F) 81.1 ± 3.4(M)	69.9 ± 2.6(F) 67.9 ± 3.3(M)	99% 119%
Vaidya et al. (2000)[18]	Indian	CT		55.58(F) 61.09(M)	
Hitt et al. (2003)[9]	American	Intraoperative	72.4 ± 8.3	64.3 ± 4.7	112%
Ho et al. (2006)[10]	Chinese	Intraoperative	70.2 ± 5.4	63.7 ± 5.1	109%
Lonner et al. (2008)[28]	American	Intraoperative	67.49(F) 76.92(M)	66.79(F) 74.22(M)	101% 104%
Ewe et al. (2009)[20]	Chinese. Malaysian. and Indian	Intraoperative (navigation)	63.83(F) 72.45(M)	59.14(F) 64.55(M)	108% 109%
Chaichankul et al. (2010)[15 a]	Thai	MRI	59.9 ± 3.7(F) 70.1 ± 3.8(M)	43.3 ± 3.6(F) 48.5 ± 3.7(M)	138% 144%
Kwak et al. (2010)[16]	Korean	CT in cadavers	65.9(F) 74.4(M)	41.2(F) 46.2(M)	160% 161%
Chin et al.[29] 2011[b]	Chinese, Malay, Indian, and others	Intraoperative	63.0(F) 73.0(M)	66.5(F) 71.3(M)	95% 102%
Yue et al. (2011)[30]	Chinese and American	CT MRI	72.8 ± 2.6(CF) 76.4 ± 4.0(AF) 82.6 ± 3.6(CM) 86.0 ± 5.6(AM)	58.8 ± 2.5(CF) 59.7 ± 2.6(AF) 65.0 ± 2.8(CM) 67.5 ± 3.6(AM)	124% 128% 127% 128%
Dargel et al. (2011)[12]	German	Cadavers	61.5 ± 3.39(F) 70.5 ± 3.79(M)	63.1 ± 3.82(F) 69.3 ± 2.50(M)	97% 102%
Ha et al. (2012)[19]	Korean	Intraoperative	68.2(F) 74.8(M)	60.8(F) 66.3(M)	112% 113%
Guy et al. (2012)[13]	English	Intraoperative	64.1 ± 2.6(F) 74.9 ± 3.9(M)	65.5 ± 5.32(F) 73.5 ± 4.5(M)	98% 102%
Terzidis et al. (2012)[31]	Caucasian (Greeks)	Cadaves (dry bones)	78.5 ± 3.0(F) 88.6 ± 4.2(M)	55.4 ± 2.1(F) 61.1 ± 3.3(M)	142% 145%
Li et al. (2014)[32]	Chinese and American	MRI	64.4 ± 2.6(CF) 72.7 ± 3.8(CM) 65.4 ± 1.4(AF) 74.6 ± 3.9(AM)	52.8 ± 2.6(CF) 56.5 ± 2.5(CM) 55.4 ± 2.8(AF) 59.6 ± 3.2(AM)	122% 129% 118% 125%
Present study 2012 2013	Brazilian	Intraoperative	67.8 ± 4.0(F) 77.7 ± 4.9(M)	61.5 ± 4.9(F) 70.3 ± 4.7(M)	111% 111%

F, female; M, male; AF, American female; CF, Chinese female; AM, American male; CM, Chinese male.

[a] Chaichankul did not use the same anatomical parameters.

[b] AP measurement after the trochlear cut.

The studied implants were developed based on anthropometric studies in Caucasian populations. The authors' initial hypothesis was that values for knee anthropometry in the Brazilian population would be different from that other population. When the measurements of the present study were compared with other studies that assessed different ethnicities, the mean Brazilian values were similar to those described for Caucasians, which leads to the belief that the incompatibilities are not a consequence of ethnic differences. The conflict between the small number of available implants and the great anatomical variability of the distal femur can be the cause of these incompatibilities. The main assessed anthropometric studies are summarized in Table 7.[9,13,15,17–20,27–32]

The great number of patients who self-declared as white might be a factor. Pena et al.[33] conducted a genetic study of the Brazilian population and demonstrated that the African ancestry in white subjects from the Brazilian Southeast was up to 32%, while the European ancestry in black subjects from that region reached up to 49%. That proves that the relation between skin color and genetic inheritance in Brazil is very weak. After five centuries of racial mixing, the phenotypic manifestation of skin color has little or no value in medical practice.

The incompatibility between implant and bone in the tibia also presents clinical implications, albeit lower than in the femur.[19] Medial or lateral overhang can irritate soft tissues and simulate the osteophytes, while insufficient coverage can favor the early sinking of the prosthesis.[34] Although maximum coverage of the cancellous bone is compulsory, some authors defend that an appropriate rotation of the component is more important.[15,18] A mean RI of 152% was observed for the tibia, a little lower in males (150%) than in females (152%). The studied implants varied between 137% and 157%. Among the implants, one group presented asymmetrical tibial components and two had symmetrical tibial components. Martin et al.,[35] when assessing four types of tibial implants (two symmetrical and two asymmetrical), concluded that, for

higher tibial coverage, the correct rotational alignment occurs more frequently in asymmetrical implant, as the matching between rotation and coverage is easier in this type of prosthesis.

Conclusions

A significant number of patients who undergo TKA in Brazil present differences above the acceptable between the dimensions of the knees and of the studied implants, which may compromise the clinical result and the durability of the surgery results. The study indicates that adjustments need to be made so that the implants can appropriately meet this growing demand.

Conflicts of interest

The authors declare no conflicts of interest.

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