Dimensions of the knee

Radiographic and autopsy study of sizes required for a knee prosthesis

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Increasing interest is developing in the design of a knee prosthesis (British Orthopaedic Association, 1970). Some prostheses have used the principle of a hinge (Walldius, 1957; Shiers, 1960). Others have tried a prosthesis of a closer geometry to that of the natural joint (Platt and Pepler, 1969). The prosthesis developed in Leeds (Fig. 1) has two components: a metallic shell that has almost the same geometry as the natural femoral condyles, and a plastic disc with a slot

at the back which is cemented to the tibial plateau. This prosthesis allows the preservation of the cruciate ligaments.

The present investigation was undertaken to determine how many sizes of prosthesis are required to meet the needs of patients. If there was a dimensional relationship within the knee, a convenient dimension could be chosen to designate the knee size. If, however, no such relationship existed, the knee size would have to be defined by a group of dimensions. The problem would then become complex and the required number of sizes would multiply. The present study describes the results of an attempt to determine from cadaveric knees and radiographs of the knees of living subjects whether such a dimensional relationship exists.

Materials and methods

A number of measurements were made in cadavers and radiographs of knees of subjects whose ages ranged from 20 to 68 years. Measurements were limited to those dimensions accessible in the opened joint (with ligaments intact), and clearly defined on the x-ray negatives. These dimensions are illustrated in Fig. 2 (opposite).

- 'a' maximum width of femoral condyles from lateral to medial sides
- 'd' width of lateral condyle
- 'e' width of intracondylar notch
- 'f' width of medial condyle
- 'b and c' maximum dimensions of lateral and medial condyles in antero-posterior direction
- 'g' maximum width of tibial condyles at articular surfaces

These dimensions were measured on x rays from tunnel and lateral views of the knees of 101 subjects (49 men and 52 women). Measurements were also taken from twenty cadaveric knees (12 male and 8 female).

The distance of the source from the films was standardized and noted in order to be able to calculate the true dimensions of the knees from the radiographs. The true dimension 'a' or 'g' was equal to that measured from the x-ray negative, multiplied by Y/Y_0 . Y and Y_0 , illustrated

FIG. 1 *Design of the knee prosthesis*

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FIG. 2 Dimensions accessible for direct measurement and clearly defined on radiographs

in Fig. 3a, were the distances of the x-ray source from the plane of measurement and the film respectively. Y/Y_0 was found to be 0.93 approximately.

In order to calculate the true dimension 'b' of the lateral femoral condyle, the thickness of the cartilage must be considered. The latter was assumed to be approximately the same on the anterior and posterior aspects of the condyles. The lateral joint space (from the tunnel view), S_L , was added to the dimension of the lateral condyle (from the lateral view), b_L , and the true dimension of the lateral condyle b would be $Y/Y_0 (b_L + S_L)$. Y/Y_0 for the lateral condyle was between 0.970 and 0.975.

The same applies in calculating the true dimension of the medial condyle. This dimension was inclined by 20° approximately to the film (Fig. 3b). Taking this into consideration, the true dimension of the medial condyle would be

$$C = (C_m + S_m) \frac{(Y_0 - d - e - f/2)}{Y_0 \cos 20^\circ} \text{ approximately.}$$

C_m = dimension of the medial condyle measured from the x ray, not considering the cartilage
 S_m = medial joint space.

This method was first applied on a cadaveric knee where it was possible to compare direct measurements with the predicted ones. The results showed that they compared satisfactorily.

Results

The reproducibility of measurement was determined on randomly selected radiographs. The dimensions a to g were determined ten times by two observers without knowledge of the identity of the film or of the previous results. Satisfactory reproducibility for each dimension was obtained, the coefficients of variation for 'a' being 0.4 per cent., 'b' 1.1 per cent., 'c' 0.6 per cent., 'd' 2.3 per cent., 'f' 1.8 per cent., and 'g' 0.6 per cent.

DIMENSIONAL RELATIONSHIPS

A dimensional relationship was found in the knee joint. Each one of the dimensions 'b' to 'g' was a definite fraction of the dimension 'a', with a low standard deviation. These results are summarized in Tables I to VI. The relations between the dimension 'b' to 'g' and the dimension 'a' are shown in Fig. 4a-f (overleaf).

There was a high correlation coefficient between these dimensions and the dimension 'a' (Table VII, overleaf), with the exception of the width of the intracondylar notch 'e'.

Table I Dimensional relations in the knee joint, all cadaveric knees

Ratio	b/a	c/a	d/a	e/a	f/a
Mean	0.870	0.860	0.373	0.262	0.362
Standard deviation	0.040	0.043	0.021	0.024	0.024
Standard error of the mean	0.009	0.010	0.005	0.008	0.005

FIG. 3 Schematic diagrams defining the dimensions Y and Y_0 when the knee is x-rayed. (a) lateral view, (b) tunnel view

FIG. 4 a-f Relation between (a) the width of the femoral condyles and the rest of the knee dimensions illustrated in Fig. 2

Table II Dimensional relations in male cadaveric knees

Ratio	b/a	c/a	d/a	e/a	f/a
Mean	0.863	0.848	0.369	0.273	0.355
Standard deviation	0.040	0.040	0.021	0.029	0.022
Standard error of the mean	0.010	0.002	0.007	0.009	0.007

KNEE SIZES

The existence of a dimensional relationship in the knee led to the choice of the lateral medial width 'a' to define the knee size. The distribution of 'a' for the population sample is shown in Fig. 5 (opposite). This

Table III Dimensional relations in female cadaveric knees

Ratio	b/a	c/a	d/a	e/a	f/a
Mean	0.878	0.874	0.381	0.239	0.179
Standard deviation	0.040	0.040	0.017	0.032	0.022
Standard error of the mean	0.015	0.015	0.006	0.011	0.008

differs from a normal (Gaussian) distribution, because of the inclusion of both sexes.

Fig. 6 (opposite) shows the distribution of the female and male population samples. The mean values of 'a' and the standard deviations are shown in Tables VIII and IX (opposite).

Table IV Dimensional relations in the knee joint, seen on x-ray negatives. Mixed sample

Ratio	b/a	c/a	d/a	e/a	f/a	g/a
Mean	0.887	0.880	0.369	0.266	0.363	0.984
Standard deviation	0.038	0.044	0.023	0.036	0.020	0.018
Standard error of the mean	0.004	0.003	0.002	0.002	0.002	0.0018

Table V Dimensional relations in the knee joint, seen on x-ray negatives. Males

Ratio	b/a	c/a	d/a	e/a	f/a	g/a
Mean	0.867	0.852	0.377	0.252	0.364	0.983
Standard deviation	0.052	0.050	0.026	0.035	0.020	0.017
Standard error of the mean	0.008	0.007	0.003	0.005	0.003	0.003

Table VI Dimensional relations in the knee joint, seen on x-ray negatives. Females

Ratio	b/a	c/a	d/a	e/a	f/a	g/a
Mean	0.904	0.880	0.361	0.277	0.361	0.984
Standard deviation	0.046	0.040	0.020	0.033	0.020	0.184
Standard error of the mean	0.007	0.006	0.003	0.005	0.003	0.003

Table VII Correlation coefficients for all x rays

b/a	c/a	d/a	e/a	f/a	g/a
0.73	0.72	0.84	0.48	0.83	0.97

FIG. 5 Distribution of knee sizes for the population sample **FIG. 6** Distribution of knee sizes for males and females in the population sample**Table VIII** Knee sizes measured from cadaveric knees

Knee sizes	Total	Men	Women
Number	20	12	8
Average value of 'a' (mm.)	77.2	80.0	74.0
Standard deviation	5.4	4.8	4.0
Standard error of the mean	1.24	1.50	1.40

Table IX Knee sizes measured from x-ray negatives

Knee sizes	Total	Men	Women
Number	101	49	52
Average value of 'a' (mm.)	82.4	86.0	75.0
Standard deviation	7.18	5.3	3.8
Standard error of the mean	0.71	0.78	0.53

No relationship could be found between the height of the subject and the knee size.

REQUIRED SIZES OF PROSTHESES

A number of experiments on cadaveric knees showed that the prosthesis should have the dimensions represented by 'a' $\pm$ 3 mm. approximately. With the smaller knees this tolerance was lower; with the larger knees it was higher. The number of sizes required to meet the need of the whole population is therefore four, the values of the dimension 'a' being 70, 76, 84, and 94 mm. approximately. The first three sizes would meet the need of 90 per cent. of the population.

Discussion

These results show that there is a definite relationship between the various dimensions of the knee, the width

of the intracondylar notch having the poorest correlation coefficient. However, from the point of view of a prosthesis, this is not of any significance. The antero-posterior widths of the tibial condyles were not assessed, since these cannot be readily measured on x rays, not being clearly defined on the films, and on cadaveric joints it was necessary to leave them relatively intact for experiments with the prosthesis. In practice this omission did not prove serious, since careful matching of the tibial component with the femoral component produced a suitable endoprosthesis.

The lateral-medial width 'a' measured directly from a flexed opened joint, or determined from a tunnel view radiographically, is therefore a good representation of the size of the joint. Female knees were smaller than male knees. Interestingly, there was no correlation between knee size and the height of the subject.

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Summary

A study of twenty cadaveric knees and radiographs of 101 subjects has demonstrated a close correlation between the dimensions of the knee joint. The mean values (and standard deviations) of the various relations calculated from the radiographs are almost identical to those obtained for direct measurements taken from cadaveric knees. The lateral-medial width of the femoral condyles gives an adequate representation of the knee size. Three sizes of prosthesis, 70, 76, and 84 mm., would meet the needs of 90 per cent. of patients, and a further size (94 mm.) would suffice for the rest.

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