

Surface flatness after bone cutting

A cadaver study of tibial condyles

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A methodologic study with which the cut surface could be quantified was performed on cadaveric tibial bone prepared for endoprosthetic components. Using sterilized, dental-imprint material and measuring with a Zeiss UMC 850, the characteristics of the cut surface were defined. A clinically flat surface was found to be uneven, with a maximum roughness between the uppermost and lowermost

points of 1.0 and 2.4 mm for the bone surface and between 1.2 and 2.3 mm for the imprint. The flatness, defined as the standard deviation of the measuring points, was between 0.15 and 0.40 mm for the bone and 0.20 and 0.42 mm for the imprint. This lack of flatness creates gaps between the prosthesis and the bone.

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The concept of biological fixation by bony ingrowth into porous surfaces of orthopedic implants is supported by reports of successful short-term clinical results with noncemented knee systems (Hungerford et al. 1986, Stulberg and Stulberg 1986). However, bony ingrowth into the porous surface of the tibial component can be variable and unreliable (Haddad et al. 1987, Sumner et al. 1989). Stereophotogrammetric analyses of noncemented tibial components (Ryd 1986, Ryd et al. 1990) have shown inducible displacements up to 1.3 mm, which are incompatible with bony ingrowth.

The gap between bone and implant should not exceed 0.3-0.5 mm (Sandborn et al. 1987, Carlsson et al. 1988). Uneven prosthetic beds may create gaps between the prosthesis and bone large enough to prevent bony ingrowth.

We have developed a method with which the flatness of the cut bone surface can be quantified for use in vivo during knee arthroplasty.

Methods

Operations were performed on eight cadaver knees using a 3M Maxi Driver™ Blade L122 oscillating saw blade (Orthopedic Products Division 3M, St Paul, U.S.A.), and the P.C.A.™ Universal Total Knee Instrument System (Howmedica, Rutherford NJ, U.S.A.). The cut surfaces of the tibia thus obtained were trimmed to a point where they would have been accepted for noncemented fixations of endoprostheses in a clinical situation.

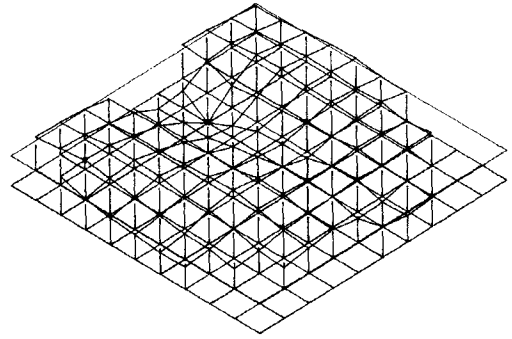
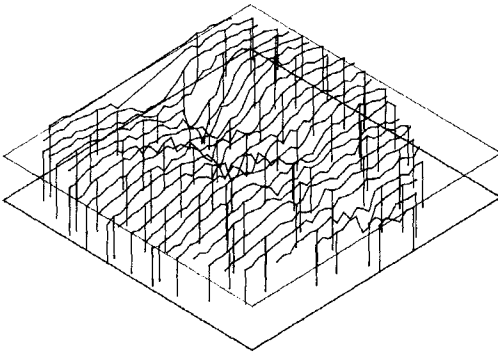
To obtain a negative imprint, an ethylene-sterilized alginate impression material (Alginoplast®, Bayer Dental, D-5090 Leverkusen, FRG) was used.

The negative was reinforced with a metal form with the same configuration as the metal backing of the tibial component to make the imprint stable. After curing, positive imprints were made from a dental plaster cast to obtain a stable and storage imprint. For a comparison, the upper tibia was excised and frozen for subsequent direct measurements.

Measurements of the surface flatness were made with a Zeiss Universal Measuring Centres UMC 850 using a software program (Umess 300 Universal Software, Carl Zeiss, Industrielle Messtechnik, D-7082 Oberkochen, FRG). The accuracy of the Zeiss UMC 850 is about 2 µm, and the software can handle maximally 1,000 measuring points. The tibial plateau was scanned along lines 1.75 mm apart at points with 1.75-mm intervals. The outermost 2-mm rim was not included in the measured area to avoid influencing marginal osteophytes and soft tissues. Thus, only the area covered by the prosthesis was measured.

The data are presented in two plots (Figure 1), with one showing the real configuration of the measuring line and the other with the data interpolated to a standard-mesh diagram of 10 × 10 points. Figures were also obtained denoting the maximum difference between the lowest and the highest points, the maximum roughness, and the standard deviation of the measuring points, the flatness.

Measurements were made on the frozen pieces of bone and on the corresponding plaster-cast model to assess the reproducibility of the method. In three



The actual measuring points on each measuring line for a proximal tibial bone cut.

The same data interpolated to a 10 × 10 standard mesh diagram.

Figure 1. Measurements of surface flatness.

knees, double-negative imprints were made; on each of these imprints, double plaster casts' positive imprints were made to assess the reproducibility of each step and of the entire procedure. On three occasions, measurements were made twice on the same surface randomly with a new set up to estimate the technical accuracy of this application. The same points on one plaster cast were measured with four different probe-tip diameters (3, 5, 8, and 50 mm) to evaluate the influence of different sizes of the probe. Two, porous-coated (PCA) tibial prostheses with pegs were measured with the 5-mm probe to assess the prosthetic flatness.

The accumulated percentage of points within each 0.3-mm interval was plotted against the distance from the lowermost point on the surface (Figure 2).

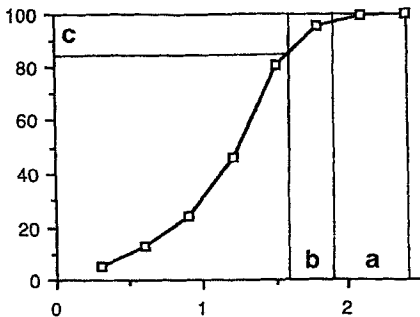


Figure 2. The accumulated percentage of measuring points in increments of 0.3 mm for a random surface.
 a. 0.5-mm subsidence during the first week.
 b. 0.3-mm gap.
 c. Bone area as a percentage within 0.3 mm of the prosthesis after a subsidence of 0.5 mm.

Results

The maximum roughness on the bone blocks was 1.05–2.39 mm. The corresponding results for the imprints were 1.22–2.30 mm. The flatness was 0.15–0.40 mm for the bone blocks and 0.20–0.42 mm for the imprints (Table 1).

The total accuracy (SD), as obtained from a comparison of measurements by the impression method and on the corresponding bone blocks directly, was 0.41 mm (maximum roughness) and for the flatness 0.02 mm.

Table 1. Measurements on corresponding bone and plaster cast

Results (mm)	Maximum roughness	Flatness
B1	2.07	0.28
P1	1.56	0.26
B2	1.66	0.23
P2	1.22	0.23
B3	1.96	0.40
P3	2.30	0.42
B4	1.55	0.31
P4	1.90	0.33
B5	1.05	0.15
P5	1.58	0.20
B6	2.39	0.30
P6	1.74	0.29
B7	1.20	0.25
P7	1.31	0.23
B8	1.60	0.30
P8	1.89	0.31

B bone. P plaster cast.

Measurements on the double-positive, plaster-cast specimens, made from double alginate imprints, showed the total accuracy (SD) of the method to be 0.37 mm or 0.74 mm at the 95 percent confidence limit as regards the maximum roughness. The corresponding value as regards the flatness was 0.02 mm, i.e., 0.04 mm at the 95 percent confidence limit. The SD of measurements of the double plaster specimens alone was 0.13 mm (maximum roughness and 0.04 mm (flatness), showing that the alginate impression process accounted for about two thirds of the variations in the system as regards maximum roughness. As regards the flatness, the plaster-impression process caused the variation (Table 2).

Double measurements on the same plaster specimen showed an SD of 0.11 mm (maximum roughness) and 0.00 (flatness), which represent the total technical accuracy of the system, including mounting and calibration.

The maximum roughness could be reduced from 1.32 to 1.12 mm and the flatness from 0.24 to 0.20 mm, with an increased diameter of the tip from 3 mm to 50 mm.

There was a consistent lack of flatness in the central region in front of the posterior cruciate attachment (Figure 1).

Measurements of the two prostheses showed immediately a maximum roughness of about 0.6 mm and a corresponding flatness of 0.11 mm.

The plots showed a rather consistent shape, with a small number of high and low points (Figure 2). The distances from the highest point to the point where 5 percent of the highest points were compressed ranged, however, from 0.10 to 0.75 mm.

Discussion

Our method had a reasonable reproducibility, with an overall resolution of 0.41 mm when using direct computation for the maximum roughness (SD) or 0.37 mm using the stepwise computation. As regards the flatness, the accuracy was high, with a SD of 0.02 mm. This indicates that measurements of the maximum roughness show a variation that probably depends on the difficulty of defining high and low points.

Measurements with different sizes of probe-tip diameters showed that sizes > 5 mm gave approximately the same results, whereas the 3-mm tip showed a tendency to cut into intertrabecular voids, and thus exaggerate the results. The 50-mm probe tip diminished the area that could be measured because of an exaggerated lift-off tendency at the

Table 2. Measurements on double-positive plaster imprints

Results	Maximum roughness		Flatness	
411	1.97	1.99	0.34	0.32
412	2.01		0.30	
421	1.75	1.90	0.31	0.33
422	1.88	1.82	0.36	0.33
511	1.77	1.82	0.19	0.20
512	1.88		0.22	
521	1.23	1.58	0.21	0.20
522	1.46	1.34	0.19	0.20
811	2.17	2.09	0.35	0.33
812	2.01		0.30	
821	1.75	1.89	0.31	0.31
822	1.62	1.69	0.29	0.30

margin of the impressions' specimens. For this reason, the 5-mm tip was chosen for the measurements.

The flatness described by the software is not, however, equal to the one occupied by the prosthesis, which instead will ride on a few weight-bearing points. To assess the flatness from a biological point of view, the results were arranged according to the data on the significant gap size, i.e., 0.3 (Carlsson et al. 1988). Thus, all the points except the ones within the first 0.3-mm interval will be outside this critical gap, i.e., no ingrowth will occur. By determining the accumulated percentage of points in increments of 0.3 mm, the percentage of the surface available for ingrowth can be determined. After insertion, the primary weight-bearing points will be first crushed; and subsequently even larger areas of high points will be remodeled, causing the prosthesis to subside. Indeed, noncemented prostheses have been reported to consistently subside between 0.5 and 1.0 mm (Ryd et al. 1988, 1990). About half of this subsidence occurred during the first week, thus introducing a larger portion of the surface into the acceptable distance from the prosthesis. Under physiologic conditions, especially when a clinical implant is allowed full weight bearing soon after insertion, the critical gap may well be even smaller than those reported by Carlsson et al. (1988). Sandborn et al. (1987) showed that there was a difference in the response of the cortical and cancellous bone, with a poorer conductive bony ingrowth for cancellous bone. This may emphasize the importance of close press fit in the tibial region. In the cases of our study, the prosthesis will rest on 1-2 percent of the surface before subsidence. A 0.5-mm subsidence will cause 7-75 percent of the bone bed to be within 0.3 mm of the prosthesis (Figure 2).

From a technical point of view, we found a considerable lack of flatness despite the use of guide instruments with the surfaces acceptable for noncemented insertion.

Histologic studies of bone-prosthetic interfaces have indicated very irregular and minor bony ingrowth. Sumner et al. (1989) reported an average area of ingrowth of 25 percent predominantly at the center of each condyle adjacent to the fixation pegs. This area corresponds to the most even areas in this study, whereas the consistently depressed area in the intercondylar region showed little bony ingrowth.

Our measurements indicated that the bone-prosthetic gap in substantial areas can be large enough to prevent direct bone anchorage. Indeed, the surfaces of the prostheses themselves were slightly uneven to a degree that in itself could create a critical gap according to the data of Carlsson et al. (1988). This could be an additional explanation for the small amount of bony ingrowth found in retrieval studies (Cook et al. 1988, Sumner et al. 1989).

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