Patellofemoral Contact Area: The NexGen® in Comparison to the Duracon™, the PFC™ and the Natural-Knee™

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Summary: The objective of the study was to compare the patellofemoral contact area characteristics between the *NexGen* Complete Knee Solution prosthesis design and three other knee prosthesis designs comprising modified-dome patellar components: the Duracon Knee, the PFC and the Natural Knee. Two cadveric knee specimens were used for each comparison for a total of six specimens. Using Fuji Film Prescales™, the contact area measurements were taken in each specimen sequentially implanted with the two prosthesis being compared.

Near extension (0° to 30°), during which patello-femoral contact loads are minor, point-contact conditions with low contact areas (2 to 20mm²) were determined similarly in all the prosthesis designs.

In the mid and deep flexion angles (60° to 110°), in association with increased loading demands, increased contact areas (40 to 73mm²) corresponding with partial to full line-contact conditions were determined for the *NexGen*. The Duracon was found to perform similarly to the *NexGen* although the contact geometry differed between the two designs. In both the PFC and the Natural Knee, generally point-contact conditions were determined with reduced contact areas relative to the *NexGen*. In deep-flexion these reductions ranged between 41% and 50% in the PFC, and between 34% to 53% in the Natural Knee.

Introduction

From the point of view of the design of the patellofemoral joint in total knee replacements, reduction of the contact stresses is of primary concern in extending the longevity of the components. Wear and gross deformation of the patellar polyethylene stem from high contact stresses, and both have been shown to occur extensively, especially in dome-type patellas.[1-5] Fatigue wear, amongst the various wear mechanisms, is the one which is the most directly dependent on the contact stresses, and results in pitting, delamination and cracking of the polyethylene. Gross deformation on the other hand, can lead to loosening in the case of all-polyethylene patellar components, or, in the case of metal-backed components, to dissociation between the polyethylene and its backing. As demonstrated by experimental wear and analytical stress-distribution studies,[6,7] a viable manner by which fatigue wear and gross deformation can be minimized is through increased component conformity to effectively increase the contact area and reduce the contact stresses.

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Modified-dome patellas offer the potential for increased conformity over a greater flexion range than thatachievable using a standard dome patella. The flared peripheral surfaces of modified-dome patellas are more suitable to conform to the inner condylar surfaces (flanks) of 'anatomic' femoral components. Generally the conformity is increased in the transverse plane (as seen from a skyline view) with unconforming conditions remaining in the sagittal plane to avoid overly constraining the patella and compromise the fixation. However, depending on the precise geometric details of each modified-dome design and its corresponding femoral component, the degree of conformity, and therefore the contact area, can be expected to vary amongst such designs.[8] The *NexGen®* Complete Knee Solution prosthesis (Zimmer, IN), which comprises a modified-dome patella, has recently been made available. In view of the importance of the contact area, the purpose of the present study was to evaluate its patellofemoral contact characteristics, in comparison to three other common designs comprising modified-dome patellas: the Duracon™ Knee (Howmedica, NJ), the PFC™ Knee (Johnson & Johnson, MA) and the Natural-Knee™ (Intermedics Orthopedics, TX).

Materials and Methods

a) Specimen:

Six cadaveric knee specimens were used. They were obtained fresh-frozen at autopsy and selected according to the A/P dimension of the femoral components. All were inspected to be free of gross abnormalities including moderate to severe arthritic changes. The *NexGen* was compared with each of the other designs, individually, using two specimens per comparison. This approach allowed direct analysis of the measurements without incurring inter-specimen uncertainties.

b) Prosthesis Description:

The manufacturers' specifications and dimensions of the prosthetic components are given in Table 1. All components were re-used in both of the two specimens of each comparison-set such that scaling of the results was not required.

The femoral components were all posterior-cruciate-retaining and dimensionally comparable within each comparison. The femoral components were all generally 'anatomic' in shape. However the femoral groove was notably more extended posteriorly in the distal regions in the *NexGen* than in the PFC and Natural-Knee. The tibial articular surfaces were all of the semi-constrained type and symmetric, except in the Natural-Knee with asymmetric compartments. With regard to the patellar components, in all designs the topographies of the articular surfaces were axisymmetric with raised apexes.The apexes were generally placed centrally with gradual flattening of the surfaces down to the perimeters with the exception of the Duracon. The Duracon patella presented hybrid modified-dome patella features with a hemispherical (dome) apex clearly demarcated on an otherwise flat surface with a medial offset. The frontal shapes were circular in the *NexGen* and Natural-Knee. In the PFC, the frontal shape was that of a regular ellipse with the major axis directed medial/laterally. In the Duracon, corresponding with the offset apex, the frontal shape was that of an eccentric ellipse with the flat peripheral surface around the apex being elongated laterally. The dimensions of the patellar components were matched in the proximal/distal direction since this would normally be the limiting dimension of the resected retropatellar surface. This resulted in increased medial/lateral dimensions in the PFC and Duracon patellar designs in view of their elliptic shapes.

TABLE 1:

PROSTHESIS SPECIFICATIONS

SPEC. #	PROSTHESIS	FEMUR (A/P dimen.)	TIBIAL SURFACE	PATELLA (thickness)
1 & 2	*NexGen*-CR		yellow-9mm	std-35mm (9mm)
	Duracon	med. (59mm)	med.-9mm "standard"	med. 35x39mm (11.3mm)
3 & 4	*NexGen*-CR	Sz.E (61.5mm)	green-9mm	std-35mm (9mm)
	PFC	Sz.3 (61mm)	Sz.3-10mm "curved"	36x41mm (10mm)
5 & 6	*NexGen*-CR	Sz.F (65.5mm)	green-9mm	std-38mm (9.5mm)
	Natural-Knee	Sz.3 (65.5mm)	Sz.B-11mm "congruent"	#3-38mm (7.65mm)

c) Implantation Details:

The femoral components were all externally rotated by 3° and placed equivalently such as to maintain the medial/lateral location of the intercondylar notch and the joint line distally and posteriorly between the design cases. The tibial components were all inserted with a 7° anatomic posterior slope except for the Duracon with a 3° posterior slope as specified by the manufacturer. The tibial components were also equivalently placed centrally up to the posterior margins of the cut proximal tibias. For the patellar components, in all cases the thickness of the intact patella prior to resurfacing was maintained, and medialization performed up to the medial margins of the cut retropatellar surfaces.

In view of the different component thicknesses, box dimensions and slope requirements, specially fabricated shims and wedges were utilized such as to minimize further resection between component fittings.

d) Loading Simulation:

The simulated loading conditions consisted of those of the static lifting manoeuvre at the discrete flexion angles of 0°, 10°, 30°, 60°, 90° and 110°. The static lifting manoeuvre is similar to rising from a deep-knee bend or from a chair, without the aid of an armrest with each leg supporting half-body weight (assumed at 335 N in all specimens). An unconstrained loading simulator was used in order to apply the loads in a physiological manner.[9] Commensurate with the activity, the quadriceps force, the knee flexional moment and the tibial axial force (the latter two being components of the foot-floor reaction) were adjusted at each flexion angle. The quadriceps force, which was applied through the quadriceps tendon, increased approximately linearly with flexion from about 175 N at extension to 960 N at 90°. For the flexion angle of 110°, being outside the theoretical range of the static lifting manoeuvre, the loading conditions used at 90° were adopted.

e) Measurements:

The contact area measurements were taken using low-range Fuji Film Prescale (Fuji Photo Co., Japan) with a threshold of about 1 MPa. The contact area magnitudes were measured from the outlines of the imprints using a digital image analysis system. The measurement inaccuracy was about ±5%. Because of the film threshold, a narrow band of low-pressure zone surrounding the main areas of contact will not have been recorded. This underestimation of the true contact area can nevertheless be assumed to occur approximately evenly between the designs.

Measurements were not taken in the *NexGen* vs. Duracon set in deep-flexion (110°) for specimen #1, and at full extension for spec. #2. Hardware interference prevented deep-flexion in spec. #1, and spec. #2 would only extend to 5° once either prosthesis was implanted.

Results

The area magnitude measurements are shown as a function of flexion angle in Figures 1, 2, and 3 respectively for each comparison-set; i.e., *NexGen* vs. Duracon, *NexGen* vs. PFC and *NexGen* vs. Natural-Knee.

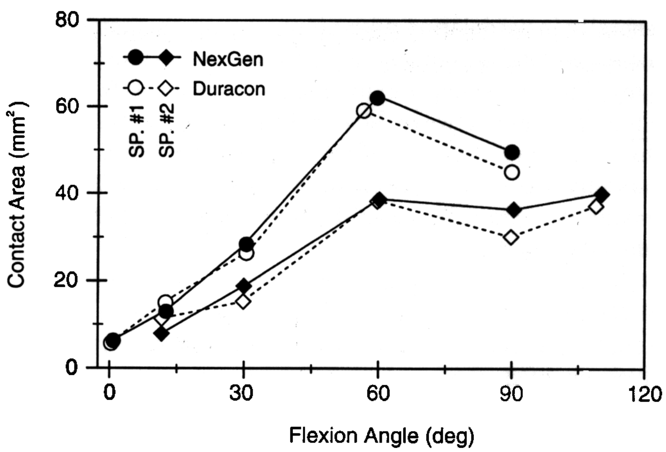

FIGURE 1

NexGen vs. Duracon Comparison of Contact Area

In the *NexGen* vs. Duracon comparison (Fig. 1), the area magnitude results as well their specimen-sensitivity were generally similar between the two designs despite their geometric distinctions. In spec. #1, the magnitudes for both designs increased from around 5mm² at extension to 60mm² at 60° flexion, reducing thereafter to around 50mm² at 90° flexion. In spec. #2, although starting with similar magnitudes at 10° as in the previous specimen, the magnitudes in both cases only reached 40mm² at 60° flexion and stayed approximately constant thereafter into deep-flexion. The greatest difference between the two designs occurred at 90° flexion in both specimens with around 5mm² of increased contact area in the *NexGen*.

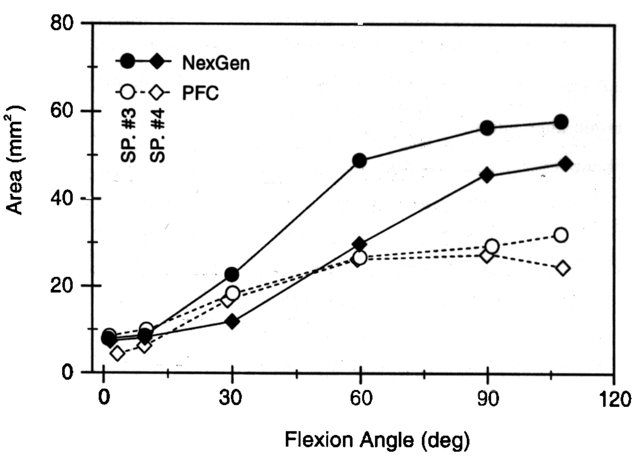

FIGURE 2

NexGen vs. PFC Comparison of Contact Area

In the *NexGen* vs. PFC comparison (Fig. 2), the magnitudes were considerably decreased in the PFC in mid-flexion and especially in deep-flexion. Furthermore, the results were notably less specimen-sensitive in the PFC than in the *NexGen*. In the *NexGen*, with small magnitudes of around 7mm² at extension for both specimens, the area magnitudes increased with flexion up to 57mm² and 48mm² at 110° flexion respectively in specs. #3 and #4. In the PFC, the magnitudes were nearly identical in both specimens with the increases with flexion mostly noted in the first 60° of flexion. Corresponding to the differing characteristics between the two designs, at 30° flexion the magnitudes in the PFC were slightly less or greater than in the *NexGen* (by -5mm² for spec. #3, and by +5mm² for spec. #4). At 60° flexion, the magnitudes in the PFC were less in both specimens although by variable amounts (-23mm² for spec. #3, -4mm² for spec. #4). Thereafter to 90° and 110° flexion, the magnitudes in the PFC were dramatically reduced in both specimens by amounts ranging between -19mm² to -27mm² (41% to 50% reductions).

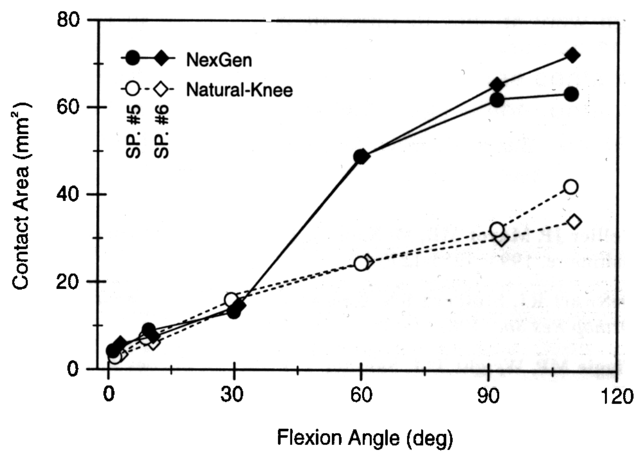

FIGURE 3

NexGen vs. Natural Knee Comparison of Contact Area

In the *NexGen* vs. Natural-Knee comparison (Fig. 3), the magnitudes were greatly reduced after 30° flexion in the Natural-Knee, and appeared generally specimen-insensitive in both designs over the full flexion range. From extension up to 30° flexion, the magnitudes were approximately equal in both designs ranging from 5mm² to 15mm². With increased flexion, while for the *NexGen* the magnitudes increased to between 64mm² and 73mm² at 110° flexion, for the Natural-Knee the magnitudes only attained 42mm² and 34mm² respectively in the two specimens (34% to 53% reductions). Although otherwise specimen-insensitive, after 90° up to 110° flexion themagnitudes in the *NexGen* increased less in spec. #5 than in spec. #6, while conversely in the Natural-Knee they increased more in spec. #5 than in spec. #6.

In order to typify the conformities achieved in each design; i.e., line-contact versus point-contact; sample outlines of the contact areas over the range of those obtained in the 0°-30°, 60°, and 90°-110° flexion ranges are shown in Figures 4, 5 and 6 respectively.

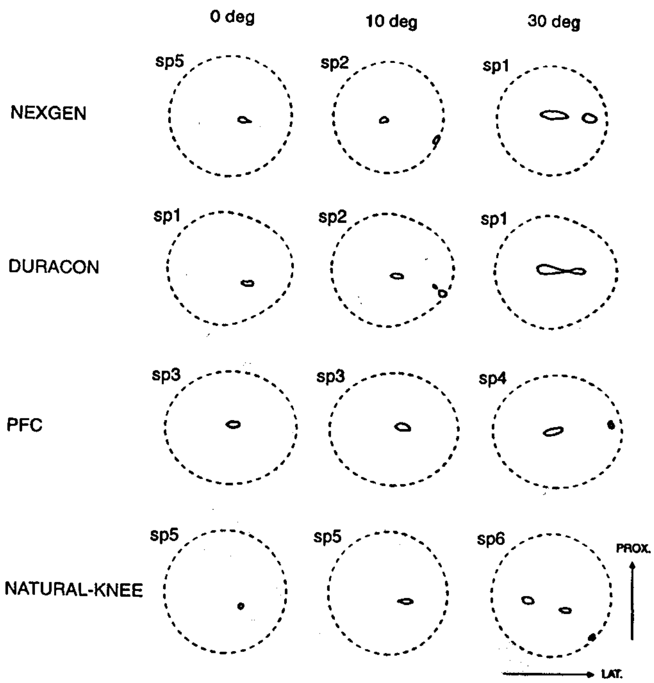

FIGURE 4

Range of Contact Area Outlines; 0 to 30 deg.

In the 0° to 30° flexion ranges (Fig. 4), in all four designs the contact area outlines were generally small circular point-contact zones which increased slightly in size over the flexion ranges. Line-contact features began to occur at 30° with the *NexGen* and Duracon in spec. #1 only.

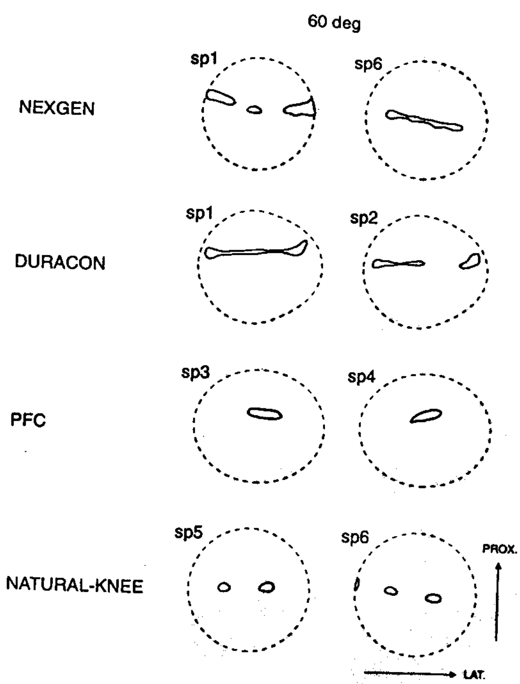

FIGURE 5

Range of Contact Area Outlines; 60 deg.

At 60° flexion (Fig. 5), either full line-contact or combined line- and point-contact zones were achieved in both the *NexGen* and the Duracon. The line-contact zones tended to be slightly more elongated in the Duracon with a lower aspect ratio than in the *NexGen*. For the PFC, only short line-contact zones were achieved in the region of the apex. For the Natural-Knee, point contact zones as noted near extension continued.

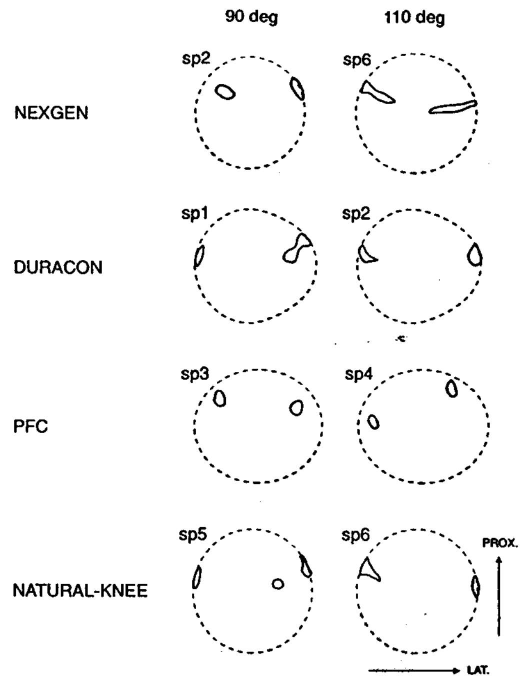

FIGURE 6

Range of Contact Area Outlines; 90 to 110 deg.

In the 90° to 110° flexion range (Fig. 6), for the *NexGen* the character of the outlines noted at 60° flexion for this design, line-contact or combined line- and point-contact, generally continued in all specimens except specs. #1 and #2. The contact zones generally originated at the proximal edges medially and laterally and were typically elongated towards the apex. In spec. #2, point-contact zones were determined in this flexion range as shown in the figure. In spec. #1, the line-contact features denoted at 60° flexion were diminished in this flexion range in that the length of the outlines was notably reduced (not shown). For the Duracon, the conditions noted at 60° flexion were also diminished in this flexion range as in the *NexGen* although the relative location of the contact zones differed somewhat between the two designs. For the PFC, the outlines consistently illustrated point-contact zones in the proximal regions. For the Natural-Knee, point-contact zones at 90°, or combined line- and point-contact zones at 110°, were noted. However the line-contact segments of the Natural-Knee were significantly shorter than in the *NexGen* and restricted to the edge-regions.

Discussion

In the 0° to 30° flexion range, low contact area magnitudes corresponding to small point-contact zones were generally observed in all designs. Although the situation improved slightly as flexion increased up to 30° with line-contact zones beginning to appear in one specimen in the *NexGen* and Duracon, the results nevertheless generally indicated relatively unconforming contact conditions for all designs. Although not ideal, in this flexion range such contact conditions are acceptable as the risks associated with constraining the patellar displacements can be assumed to outweigh those associated with reduced contact areas.[10] On one hand, the designs should be such as to allow the normal medial/lateral shift and tilt components of the patellar tracking pattern which are both significant and dependent on each individual's extensor muscle alignment near extension. On the other hand, the actual loads transmitted through the patellar components are less severe in extension than in flexion. This is because both the fulcrum effect of the patellar force system and the actual extensor moments associated with functional activity are reduced in this flexion range.

In mid- and deep-flexion however, the functional loading sustained by the patella can be more extreme and the importance of maximising the contact area to reduce the contact stresses is of primary concern. In these flexion ranges the degree of conformity and contact areas were generally different between the designs depending on their particular features.

For the *NexGen*, with the exceptions of specs. #1 and #2, the contact areas were generally found to increase significantly with increased flexion in agreement with the realisation of line-contact conditions as noted from the contact area outlines. These results indicated that high conformity was generally achieved in the mid to deep flexion angles considered in the study (60°-110°), with, nominally, full line-contact being attained. However, in spec. #1, after a substantial increase in contact area between 30° and 60° flexion, the area dropped notably thereafter at 90° flexion. In spec. #2 the contact areas were not increased after 60° flexion and remained thereafter significantly lower than in all the other specimens with this design including spec. #1. Point-contact conditions were furthermore noted in this specimen in deep-flexion. It is apparent that in these two specimens, the patella, possibly being low-riding, was already too far advanced into the intercondylar notch at 90° flexion and beyond the support offered by the patellar groove. The results in this instance indicated that the flexion limit beyond which high conformity diminishes can be reduced to below 90° depending on individual specimen characteristics.

In addition, for the *NexGen* overall the results were found to be specimen-sensitive as the magnitudes of contact area and the features of the area outlines (line vs. combined line and point), generally varied amongst all the specimens in the mid to deep flexion angles. This is in general consistent with situations of high contact-conformity. It is understood that the greater the conformity of contact, the greater is the sensitivity of the contact characteristics to the precise geometry of the contacting surfaces.[8] Given the relatively complex geometry of patellar and femoral articular surfaces, and the variable orientations that are possible between the two surfaces as dictated by the extensor mechanism, departures from nominal conditions are therefore expected in designs of high conformity.

For the Duracon, the area magnitude and contact type, as well as the sensitivity of these parameters were generally similar to that of the *NexGen*. Although differences in the contact features were noted, owing to the differing topographies, the effective total contact area magnitudes were not significantly altered between the two designs. In view of the possible sources of error (film threshold and measurement error) and the small sample size (only two specimens), the largest difference of 5mm^2 in the area magnitudes between these two designs is insufficient to conclude differing performance characteristics.

For the PFC, the area magnitudes were reduced in comparison to the *NexGen* in mid-flexion and especially in deep-flexion. The results were furthermore notably less specimen-sensitive in this design. Correspondingly the outlines consistently denoted short line-contact zones at 60° flexion and well-defined point-contact zones in the deeper flexion angles. These results, in contrast to those noted in the *NexGen*, clearly indicate reduced conformity in the PFC in mid-flexion and especially in deep-flexion. This is furthermore strongly supported by the observed opposing specimen-sensitivity characteristics of the results. As to the wider elliptic frontal area of the PFC patella, this does not appear to have been used to any benefit with respect to the contact area.

For the Natural-Knee, the contact areas were greatly reduced in comparison to the *NexGen* in the mid to deep flexion angles. Correspondingly, unlike in the *NexGen*, point-contact zones were generally noted apart from short line-contact segments appearing solely at the maximum flexion angle. These results indicated markedly reduced conformity in the Natural-Knee relative to the *NexGen* especially in mid-flexion. However, unlike in the other comparisons, the results generally appeared specimen-insensitive similarly in the two designs. This, in this instance, neither supports nor contradicts the different conformities between the two designs. Since the *NexGen* results were already shown to be specimen-sensitive, it is apparent that the specimens in this comparison were very similar in terms of extensor characteristics. Therefore the specimen-sensitivity characteristics of the Natural-Knee may not be ascertained from the present results.

The results also illustrated that the contact area outlines extended to closer to the apex in the *NexGen* than in the PFC and Natural-Knee in the deep flexion angles. This would appear to stem directly from the patellar groove in the *NexGen* femoral component being more posteriorly extended in the distal regions. This feature effectively provided increased patellar support and contact area in deep-flexion.

Summary

Near extension, all four designs performed equally with relatively unconforming contact characteristics and reduced contact area magnitudes. This was found however to be acceptable in this flexion range as functional loading is reduced while the necessity to accommodate increased patellar displacements is increased.

With increased flexion however, corresponding to expected increased functional loading, the conformity and contact areas were found to be markedly increased in the *NexGen* design with line-contact conformity generally being attained. For this design, the flexion limit for high conformity was beyond the maximum flexion angle considered in the study (110°) in four out of the six specimens examined, and below 90° flexion in the remaining two specimens. The results for the *NexGen* were found to be generally specimen-sensitive in a manner consistent with high contact conformity. In the comparison to the Duracon, the contact characteristics measured for that design were similar to those of the *NexGen* in terms of contact area magnitudes and line-contact features, as well as in terms of specimen-sensitivity, despite the distinct surface topographies between these two designs. On the other hand, in both the PFC and the Natural-Knee, in comparison to the *NexGen*, notably reduced contact area magnitudes and conformity features were determined generally in association with point-contact characteristics. The reductions in contact area in these two designs relative to the *NexGen* in deep-flexion ranged between 41% to 50% in the PFC, and between 34% to 53% in the Natural-Knee. The results in the PFC were furthermore found to be markedly less specimen-sensitive than in the *NexGen*. The sensitivity characteristics of the Natural-Knee could not be concluded by the results.

In addition, a favourable feature in the *NexGen* relative to the PFC and the Natural-Knee was found to be the extended patellar groove of the *NexGen* femoral component which enabled increased conformity and contact area in deep-flexion.

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