STRESS ANALYSIS OF THE ALL POLYETHYLENE TIBIAL TRAY

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Introduction:
All polyethylene tibial (APT) components for total knee joint replacement have been recently reintroduced due to their past success and cost savings in comparison to knee designs with a metal backed tibial trays (MBT) (1,2). However, isolated cases of collapse of the medial bone in APT designs have been observed clinically by the authors prompting this investigation. The objective of this study was to investigate the stress/strain distribution within the cancellous bone for APT and MBT systems, particularly looking at the effects of coverage of the tray over the proximal tibia in each design.

Clinical Background:
Collapse of cancellous bone was observed in 2 cases following the total knee arthroplasty of 22 patients. The 2 failed cases both had osteoarthritis with a valgus deformity. Arthroplasty was performed via a lateral para-patellar arthroscopy and the Depuy PFC sigma all polyethylene tray was implanted (lateralized) in both cases. The radiograph on the right in Figure 1 shows one patient 17 months post-operation. On the medial side cancellous bone collapse was observed and the tibial tray had subsided into the cancellous bone. Similar characteristics were observed in both failed knees.

Materials and Methods:
A three-dimensional finite element model of the proximal tibia implanted with a tibia tray was generated. An elliptical cylindrical tibia tray with a peg was modeled as being perfectly bonded to a PMMA layer on the superior surface of the cancellous and cortical bone. The effect of tibial tray coverage (lateralization of the tibial tray) was investigated by introducing a mediolateral gap on the superior face of the tibia between the medial edge of the tibial tray and the cortical bone. Load was applied on the superior surface of the tibial insert on the medial side. Two lift-off loading cases were used, with either a low load of 800 N (1 body weight) or a high load of 3200 N (4 x BW), applied centrally to the medial condyle. Permanent plastic deformation and collapse was allowed only in the cancellous bone, while all other materials were modeled elastically.

Results:
Under low load conditions within the elastic limit of the cancellous bone, introducing a mediolateral gap between the medial edge of the tray and the cortical bone, to simulate a lateralized tibial tray, produced a stress/strain intensity in the cancellous bone beneath the outer edge of the tray. The strain in the cancellous bone with the APT design was generally 3 times greater than the MBT design, however, peak strain values were similar at the edge of the tray. Whilst the strain increased with the introduction of a gap the resulting strain was not sensitive to the gap size for both designs.

Discussion:
The results of the study are not a function of the specific geometry of the tibial tray but rather the material in which the tibial tray is manufactured (metal backed or all-poly). The authors propose that two factors were primarily responsible for the failures observed clinically. Firstly, the tibia tray was lateralized on the tibia which introduced a gap between medial edge of the tray and cortical bone. The gap, as shown by the FE model results, transmitted greater strain to the cancellous bone in the APT design than the equivalent MBT design.

The results of the study under high load conditions were highly sensitive to the mechanical properties of the cancellous bone. Poorer quality bone with reduced properties caused greater increases in the resulting strain and collapse observed. The second factor of importance may be that in the pre-operative x-rays reduced bone density was observed in the medial side of both the distal femur and proximal tibia. The combination, therefore, of increased volumes of highly strained bone characteristic of the lateralized APT design, combined with reduced bone quality may have lead to the plastic deformation and collapse of the cancellous bone observed clinically.

Conclusion:
The results of the study showed that under the conditions when the tibial insert is lateralized and medial bone quality is poor an all-polyethylene tibial insert produces greater volumes of highly strained cancellous bone compared to the equivalent metal backed design. Tibial plateau coverage may, therefore, be a more important parameter in all-polyethylene tibial tray designs than in metal backed tibial tray designs.

References:
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