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A PRELIMINARY STUDY OF CONTRALATERAL KNEE STRUCTURE AND FUNCTION ASSOCIATIONS IN PERSONS WITH UNILATERAL KNEE OSTEOARTHRITIS

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Purpose: Persons with unilateral knee osteoarthritis (OA) are at risk for developing bilateral OA. Because of joint pain and dysfunction, some individuals will adopt compensatory gait mechanisms that shift the load distribution from the affected to the healthy contralateral limb during weight-bearing activities. The resultant change in load history is speculated to contribute to bilateral disease onset. The purpose of this preliminary study was to evaluate structure-function associations in persons with unilateral knee OA in order to identify risk factors for contralateral OA onset. We hypothesized that gross morphological and microstructural OA indicators are associated with greater contralateral limb loading during stair descent.

Methods: Subjects: Four radiographically-diagnosed unilateral OA (age=56.2±11.7), and four sex- and age-matched healthy controls (age=57.5±11.3) were recruited. The "affected" limb of controls was assigned based on the side of the injured knee of their matching OA subject. Tibiofemoral gross morphology: Bilateral 3T knee magnetic resonance (MR) images were obtained using fast-spin echo and steady state free precession image sequences (GE, USA). Two musculoskeletal radiologists, who were blinded as to the treatment group, graded knee morphology using the established MOAKS grading construct. Contralateral tibiofemoral bone marrow lesion (BML) and cartilage lesion size subscale scores were summed and used to quantify morphological differences between OA and control knees, as these measures were hypothesized to be sensitive to load changes. Microstructural OA indicators: T2 relaxometry sequences were captured using a multislice Carr-Purcell Meiboom-Gill sequence. For each medial and lateral tibiofemoral compartment, a single mid-compartment sagittal MR image was selected, and the tibiofemoral cartilages were segmented manually. For each mid-compartment slice, cartilage T2 relaxation was calculated on a pixel-by-pixel basis, and the T2 relaxation variance of all identified cartilage pixels determined. T2 variance was chosen as a microstructural OA indicator as this measure has been previously associated with OA-like changes in high-risk populations enrolled in the Osteoarthritis Initiative study. Loading asymmetry: A custom-built staircase was instrumented with a force plate (Kistler Instruments, CH), and vertical ground reaction force data (vGRF) were collected at 1200Hz as subjects stepped down onto and over the plate three times for each limb. Force data were low-pass filtered at a cut-off frequency of 5Hz, and mean peak vGRF calculated for affected and contralateral limbs. All force data were normalized to body weight (%BW). Statistics: Significant between-group differences in contralateral knee measures were tested using a Mann-Whitney test (gross morphology), or one-tailed t-tests (contralateral limb loading). Associations between contralateral limb vGRF and cartilage T2 relaxation variance were tested using Pearson correlation tests.

Results: Affected tibiofemoral MOAKS BML and cartilage lesion size grades were consistent with OA, whereas only minor abnormalities were noted in healthy control knees. Summed contralateral tibiofemoral scores were greater in OA subjects (4.5±4) than controls (0.25±0.5), but did not reach significance (p=0.06). Contralateral limb vGRF was not greater than affected limb vGRF in OA (-1.2±17.6 %BW) or control (9.2±8.2 %BW) subjects, nor was there a between-group effect (p=0.22). Tibiofemoral cartilage T2 relaxation variance was not associated with increased contralateral limb vGRF forces (r^2=-0.4-0.7; p=0.07-0.8). Medial femoral condyle T2 relaxation variance and contralateral vGRF approached significance only because the contralateral limb was loaded less compared to the "affected" limb in the control group.

Conclusions: The preliminary study results do not support the hypothesis; however, work is ongoing to increase sample size, and to map cartilage T2 relaxation variance across multiple MR image slices. Inclusion of additional MOAKS construct subscales may increase the sensitivity to detect significant contralateral differences between OA and control groups by capturing more joint damage features. Additional knowledge of relative tibiofemoral surface interactions and joint moments in this patient population may reveal biomechanical factors that contribute to OA pathogenesis not reflected by the current outcome measures. Identifying and quantifying risk factors for bilateral OA onset are central to implementing effective intervention strategies early on in the disease trajectory.

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BIOMECHANICAL AND MORPHOLOGICAL CHANGES OF SUBCHONDRAL BONE IN ANTERIOR CRUCIATE LIGAMENT TRANSECTION – INDUCED RAT MODEL OF KNEE OSTEOARTHRITIS

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Purpose: To observe the biomechanical and morphological changes of subchondral bone in aratmodelof knee osteoarthritis (OA).

Methods: Sprague-Dawley (SD) rats (6 weeks old, n=30) were selected to establish OA model usingAnterior Cruciate Ligament Transection (ACLT) method in the right knee joint. After six weeks, the knee joints were dissected and scanned by micro-computed tomography (μCT) to measure morphological parameters of bone mineral content (BMC). In Micview software, subchondral bone (including epiphysis and trabecular bone) was divided into medial and lateral regions of interest (ROI) by tibialtuberosity. The three-dimensional micro-finite element model of knee OA was established through Mimics software. The model was then imported into Hypermesh and ABAQUS to analyses mechanical properties of medial and lateral ROI quantitatively, including Von Mises (VM) and displacement (DIS). In this process, the compressive load of 5 N from femur, equal to the weight of rat, was applied. The stiffness of subchondral bone was calculated as VM/DIS. Statistical analyses were performed within-animal, between left and right knee, then between medial and lateral ROI.

Results: Compared with the left healthy knee, BMC was lower(6.035±0.688vs 6.675±0.492, p=0.037), while stiffness of subchondral bone higher(11206.73±3434.75 vs 7365.45±1060.55, p=0.034) significantly inthe right OA knee. Medial BMC was lower in medial compartment than in lateral compartment(6.035±0.688 vs 7.065±1.135, p=0.33). Subchondral bonestiffness in medial compartment was also higher than that in lateral compartment (7872.565±2467.827 vs 11206.726±3434.751, p= 0.031).

Conclusions: While subchondral BMC is lower,subchondral bone stiffness is higher in osteoarthritic than in healthy joints, and in medial than lateral compartment, suggesting that biomechanical and morphological changes of subchondral bone may play roles in knee OA development.

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DEVELOPMENT OF ASIAN HIP STEM 2 – COMPUTATIONAL ANALYSIS USING 3D FINITE ELEMENT METHOD

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Purpose: Finite element analysis (FEA) is a useful tool for preclinical testing of newly designed implants and can be used to predict early and medium term results. FEA helps the researcher to produce better designs before the fabrication stage by enhancing their understanding the stress distribution and micromotion that occurs within the medullary canal.

Methods: The implant model was designed using computer aided design (CAD) software. As the ultimate goal was to achieve optimal fit and fill, the stem was designed according to a prior anthropometric. The stem was then imported to finite element software in geometric data file format (.igs) to convert the triangle node mesh into the tetrahedral node mesh and to produce better mesh by repairing the edges. The model input file (.inp) was then converted into stereo lithographic (.stl) format. The osteotomy level was set to 20 mm above the center of the lesser trochanter. A perfect contact fit between stem and medullary canal was assumed by creating a 'virtual surgery femur' from the surface mesh of the correct position of the cementless stem during the surgery in a manner similar to Boolean operation in MAGICS. An average of 13 200 elements with 4200 nodes was found to be optimal for the cementless femoral stem, and the 'virtual surgery femora' consisted of 7900 nodes and 41 900 elements. The finite element model was completely restrained distally. Two static physiological loads were simulated; normal walking and stair climbing. The micromotion algorithm

used in this study was validated experimentally in house and the algorithm was written using Compaq Visual Fortran software as the subroutine. The result focused on equivalent von Mises stress and micromotion.

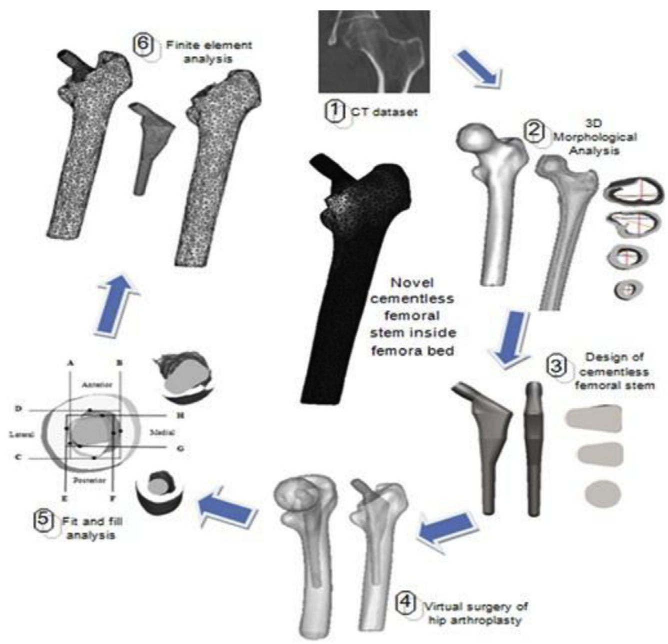
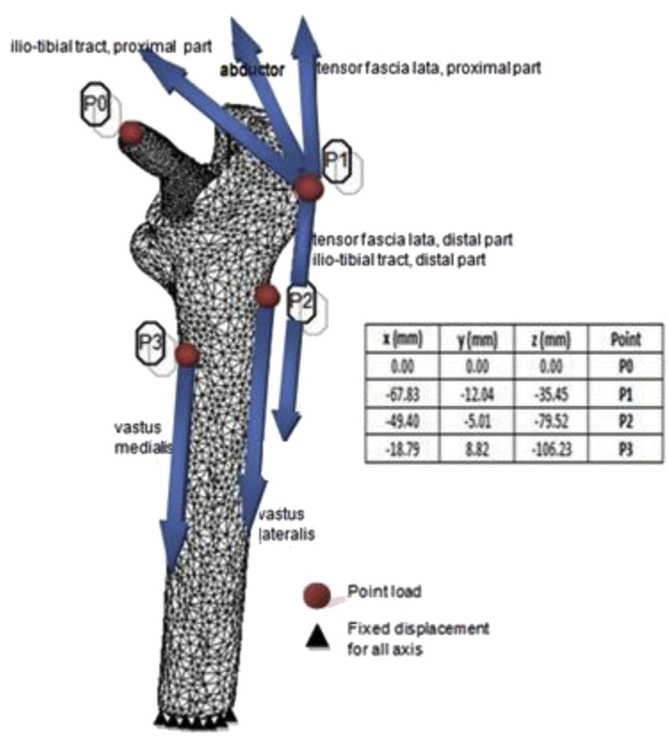


Figure 1. Design process of hip stem for Asian.



x (mm)	y (mm)	z (mm)	Point
0.00	0.00	0.00	P0
-67.83	-12.04	-35.45	P1
-49.40	-5.01	-79.52	P2
-18.79	8.82	-106.23	P3

Figure 2. Physiological loading condition.

Results: This study used both types of physiological loading: normal walking and stair climbing. However, the result did not reveal significant differences between these types of loads. The maximum stress observed was 65.38 MPa at the proximal region and minimum stress was 1.28 x 10-12 MPa at distal region. When the limit was scaled to 600 000 Pa, we found that the stress was normally distributed at metaphyseal region, which is essential for primary stability fixation and preventing stress shielding at the proximal level. The safety factor for this new stem design was computed as 2.45. The micromotion and displacement were closely related to the promotion of bone osseointegration, we found that the maximum value for micromotion was 4.76 μm with a displacement of 1.34 μm. This ensured that osseointegration occurred in the bone - stem interface and fibrous tissue formation was prevented, which reflected the implant's fixation stability.

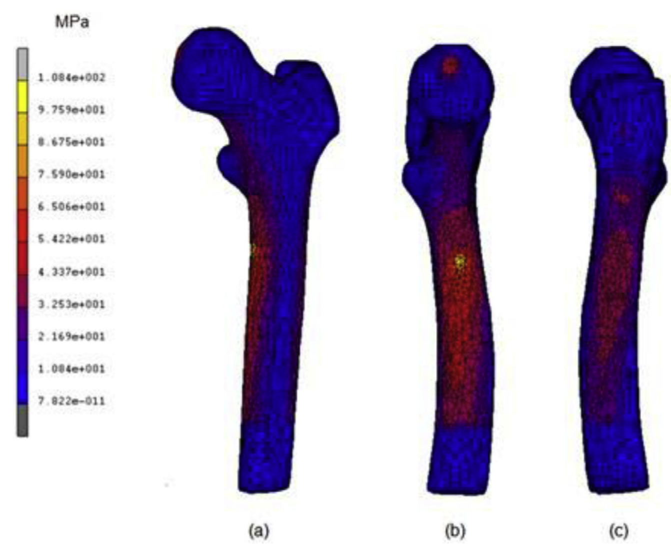


Figure 3. Strain distribution of intact femur.

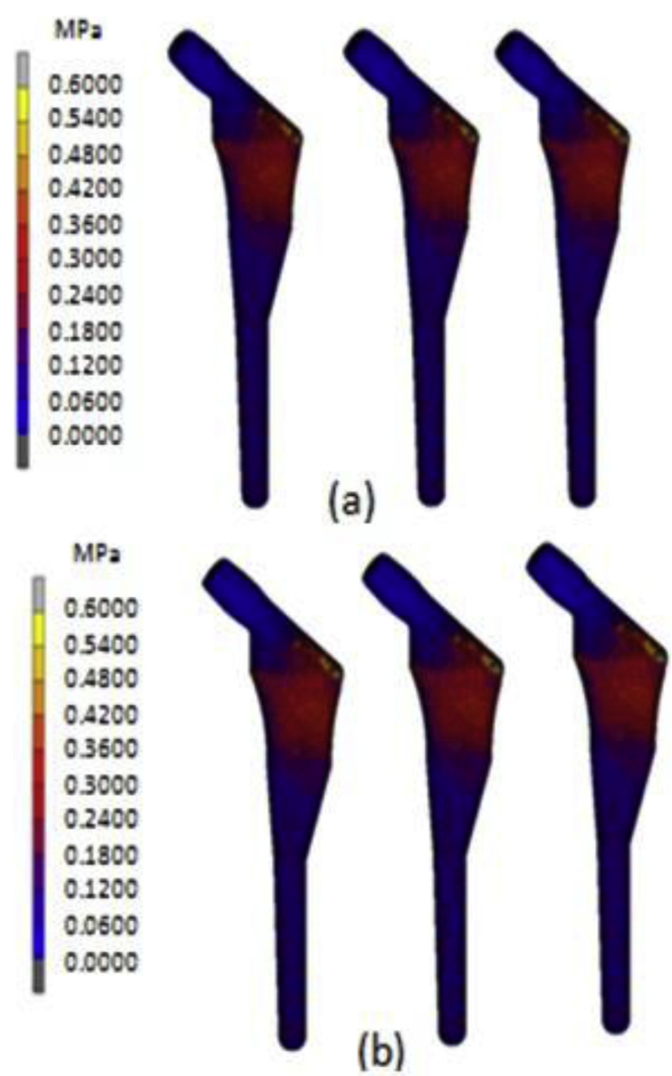


Figure 4. Strain distribution of stem.

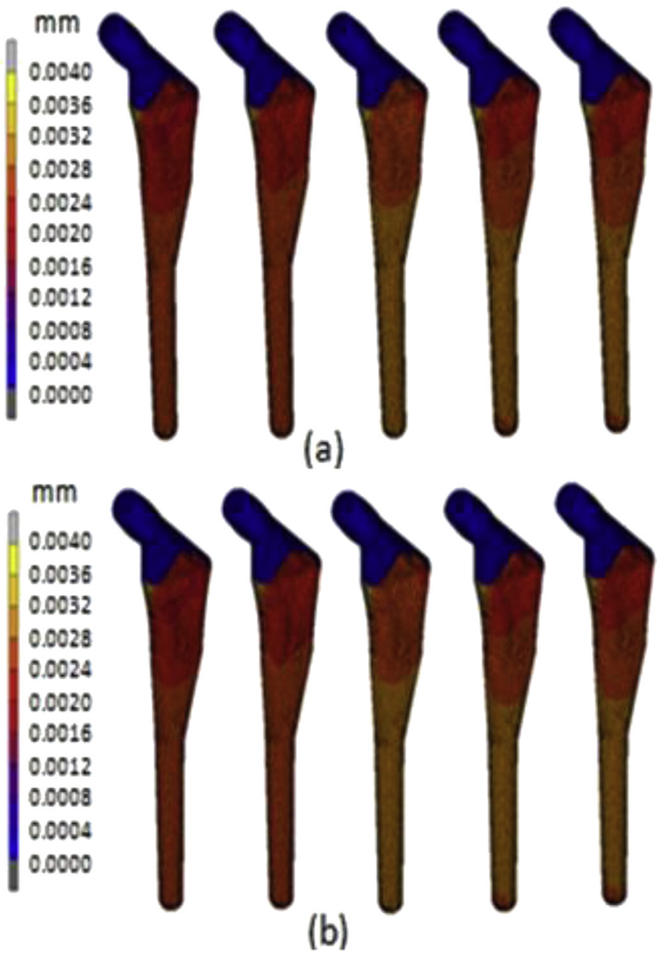


Figure 5. Micromotion of stem.

Conclusions: In conclusion, we would like to stress the importance of stem design based on femur morphology, especially in Asians. The cementless stem design was crucial especially at the metaphyseal region which provided initial fixation stability. In addition, a universal stem of variable size is not the only option available to the peculiar morphology of the Asian population. We hope that this new design process framework will shorten the design cycle, and help researchers to design better femoral stems by identifying the major steps which must be taken and providing anthropometric datasets that could be used as guidelines. The use of accurate three dimensional models obtained from morphological analysis and finite element analysis could be used as preclinical assessment tools to mimic the actual optimal conditions, of stem geometry, and to rectify any problems prior to fabrication.

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DEVELOPMENT OF ASIAN HIP STEM 3 – FABRICATION USING INVESTMENT CASTING TECHNIQUE

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Purpose: The cutting edge technology used in three dimensional reverse engineering helps to produce an accurate implant which is well suited to the actual morphology of the bone. In this study, a cementless femoral stem was fabricated that not only optimally fits and fills the medullary canal, but also reduces the cost of the implant itself. The performance of nonlinear finite element analysis was used to predict the outcome and to rectify design flaws, allowing for the development of a prototype cementless stem and the fabrication of this stem using investment casting techniques.

Methods: The cementless femoral stem was designed to optimally fit and fill the endosteal canal. A nonlinear finite element analysis was conducted to predict the outcome of the early stage after the surgery according to the standard protocol of virtual implantation. After designing the stem based on the morphology analysis, we performed finite element analysis using Marc.Mentat software. The material properties of the cementless femoral stem were assigned as 316L stainless steel with a Young's Modulus of 200 GPa and a Poisson's ratio of 0.3. We proposed a new investment casting technique that may decrease the existing cost and time consumed during the fabrication process of the cementless femoral stem. The implant's prototype was converted from three dimensional stereo lithographic formats into slices 0.085 mm thick using a rapid prototype machine. The silicone rubber compounds for high - low temperature potting, encapsulating and sealing were used as the mould. The investment casting process commenced by injecting the melted wax into the silicone rubber compound mould producing the implant's casting which are called patterns. These patterns were then attached (wax welded) to another three parts; (1) pouring cup, (2) sprue and (3) riser. The more general method which uses the central sprue to produce the wax patterns was not utilized, resulting in reducing the amount of molten 316L stainless steel to be used later and decreasing the fabrication cost. The pattern is invested into the ceramic slurry, a mixture of 25% colloidal silica and zirconia sand. Using coarser aluminum silicate sand, a six layer shell is formed before it is finally dipped into the ceramic slurry to seal it. The 316L stainless steel is heated in an induction furnace at 1600°C. The molten metal is poured through the pouring cup into the shell by using the standard gravity and pouring method. After two hours cooling, the shell is knocked out and other parts are removed using a metal saw blade. The prototype is subsequently sand blasted using 2.0 bar, 180 μm silicon carbide mesh using a blasting machine. The prototype surface roughness is measured using hybrid surface contour machine.

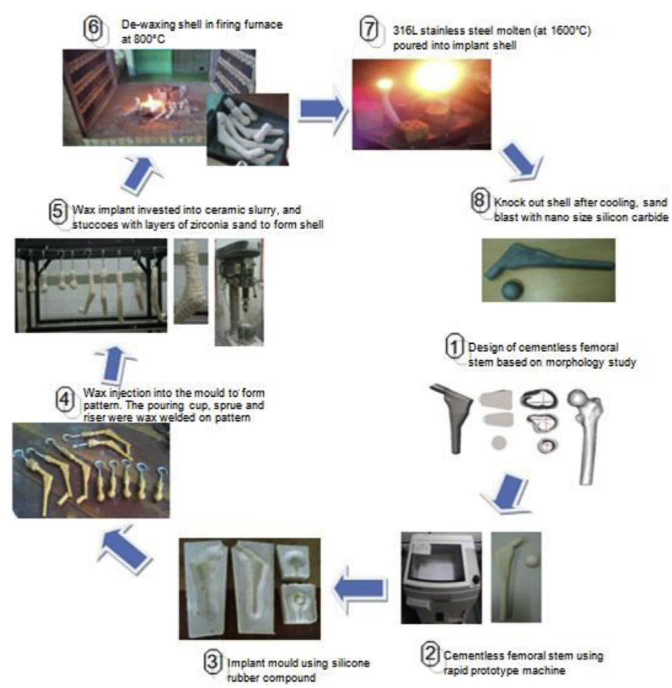

Figure 1. Fabrication process of hip implant using investment casting technique.

Results: We found that the maximum stress was 66.88 MPa at the proximal region and minimum stress was 7.75 x 10-12 Pa at distal region. In addition, the maximum value for micromotion was 4.73 μm, and displacement of 6.47 μm. The surface roughness of the cementless femoral stem was shown to be 7.287 μm proximally, and 1.613 μm distally.