The University of Sydney
AUSTRALIA

ASDM

Finite Element Analysis of a Total Knee Replacement

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Company: Australian Surgical Design and Manufacture

Research Goals:

Aim: To understand the mechanics of Total Knee Replacements through the use of Finite Element Analysis (FEA)

Static Analysis

STANCE

→

Quasi-static & Fatigue Analysis

WALKING

-using ISO Gait Curves

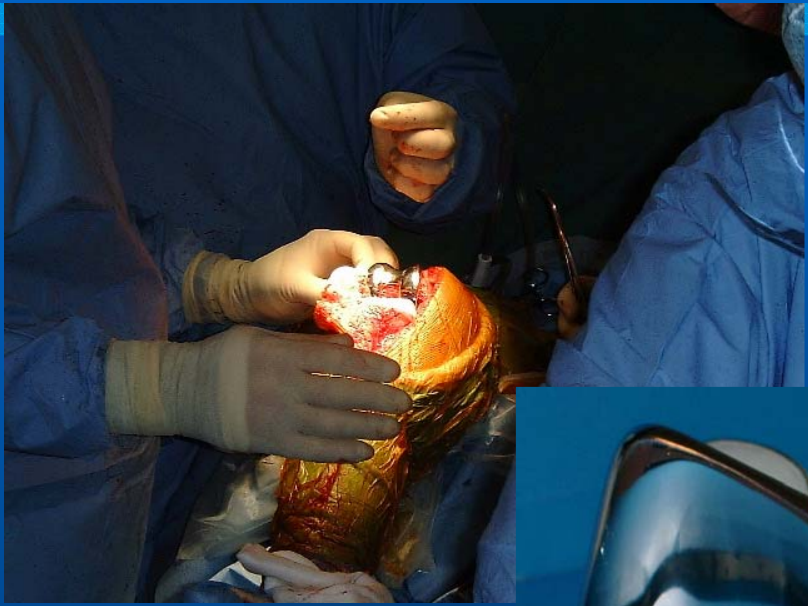
→

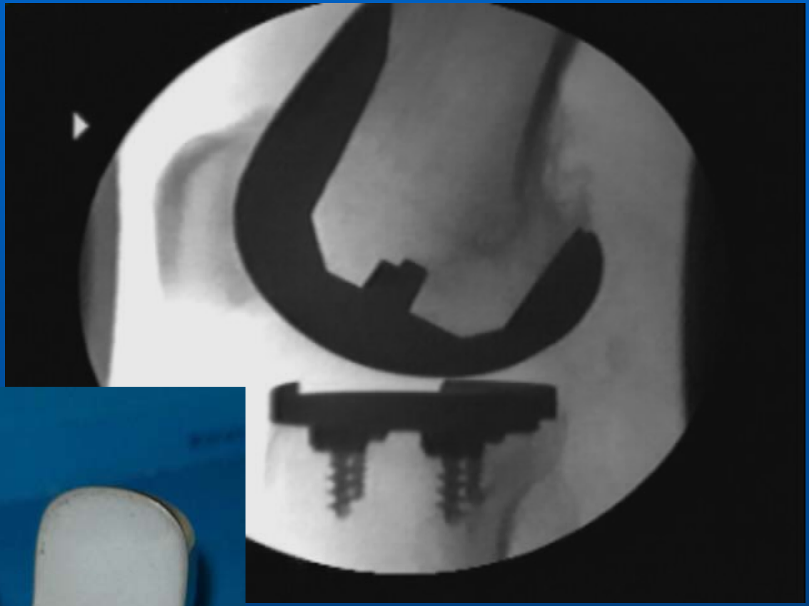
Quasi-static & Fatigue Analysis

STAIR RISE

-using Fluoroscopy Imaging

Total Knee Replacements (TKRs):





Total Knee Replacements:

- **Femoral Component** – CoCrMo, replaces the lower end of the femoral bone (upper leg), designed to closely match the actual geometry of the real knee
- **Meniscal Insert** – UHMWPE, provides a low friction surface for the articulation between the femoral component and tibial component during motion of the knee joint. It is fitted to the tibial plate by an impingement fit, which allows this component to be replaced with out replacing the whole TKR
- **Tibial Plate** – CoCrMo, used to attach meniscal insert to the upper end of the tibial bone (lower leg)

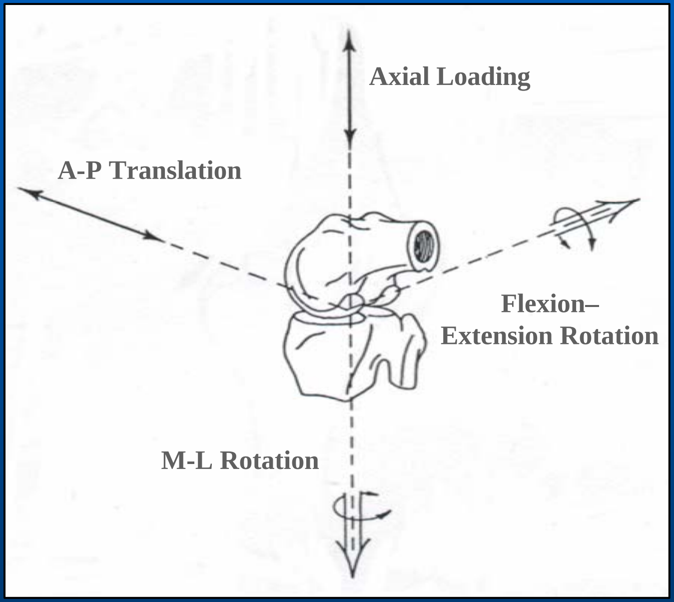
Wear and Fatigue of TKRs:

Most common failure in a TKR is due to the deterioration of the UHMWPE meniscal insert. This is due to geometric deformation, adhesive wear, surface pitting, 3 body abrasive wear, and most destructive - DELAMINATION

Subsurface cracks develop about 1mm below the articulating surface, which propagate forming large subsurface cracks eventuating in sheets of the material delaminating from the surface

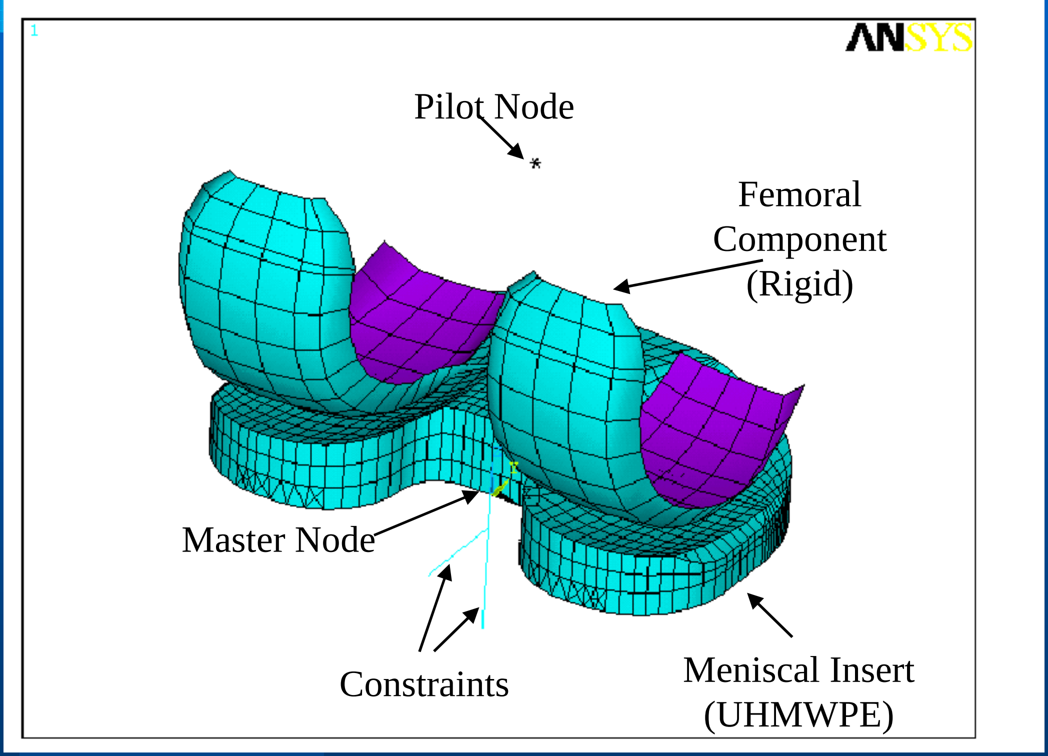
Movement of the Knee Joint:

- Axial Loading – this load is applied by the ground and by the ligaments holding the joint together
- Anterior-Posterior Translation – the motion as the knee moves forwards and backwards, this motion is greatly restricted by the cruciate ligaments



- Medial-Lateral Rotation –the motion as the knee internally or externally rotates, again this motion is restricted by ligaments and geometry of the end of the tibial bone
- Flexion-Extension Rotation – the motion of the knee bending and straightening

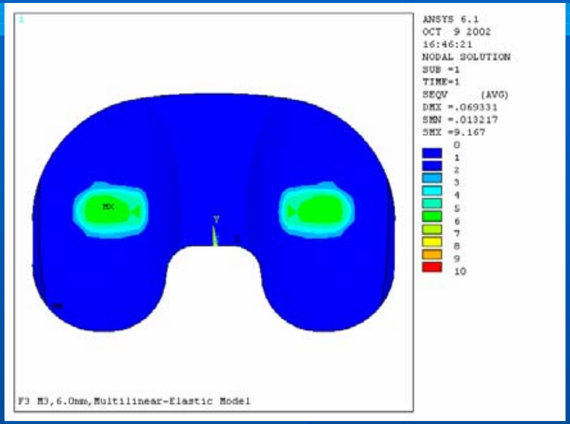
FEA Model Set-Up:



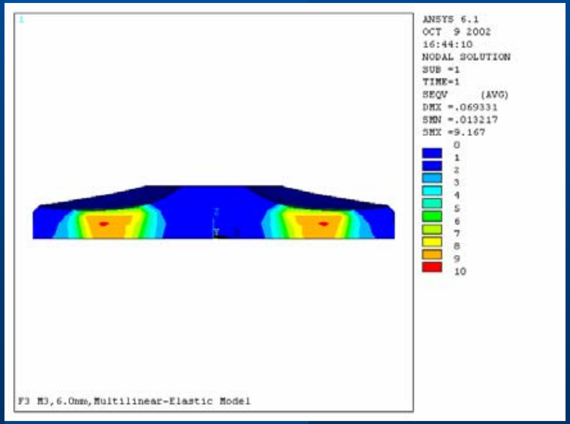
ANSYS software was used for all finite element modelling

- The femoral component is treated as a rigid surface
- The meniscal component was modelled using 3D 20 node hexahedral elements
- A contact pair is used to model the contact between the femoral surface and meniscal articulating surface
- Pilot Node Controls flexion-extension movement of femur
- Master node controls the meniscal insert in the axial, A-P translation and M-L rotation directions
- Springs are used to constrain the A-P displacement and M-L rotation of meniscal insert

Static FEA:



a.



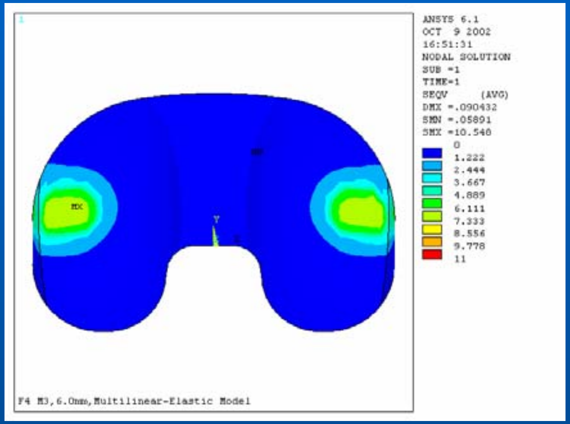
b.

a. Contact Stress on size 3 6mm meniscal insert (M3) when loaded at 3*Body Weight with a size 3 femoral component (F3)

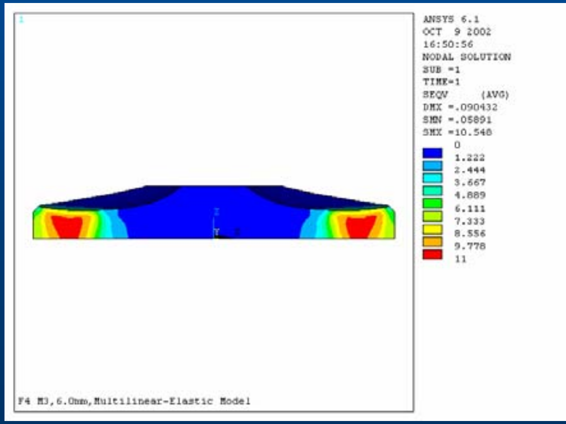
b. Slice through the maximum stress point – this shows the maximum stress situated below the surface

c. Contact stress on an M3 when cross sized with an F4 showing higher contact stresses

d. Slice through maximum stress, again higher stresses below the surface

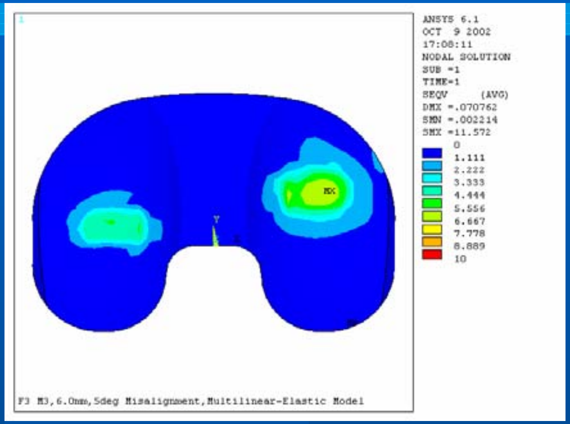


c.

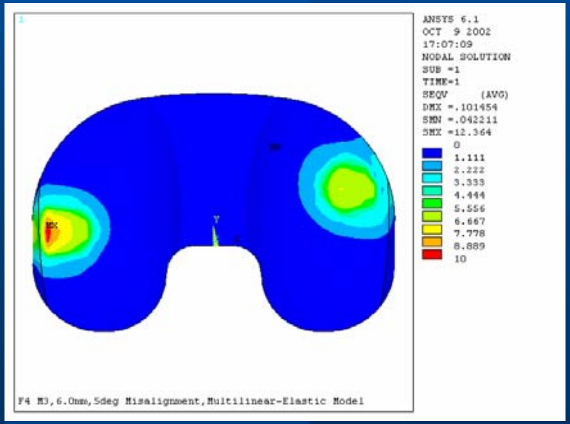


d.

Static FEA:



a.



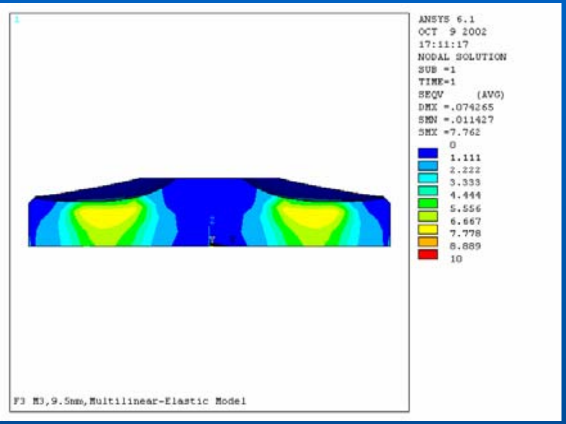
b.

a. Contact Stress on M3 when there has been 5 deg surgical misalignment, loaded with an F3

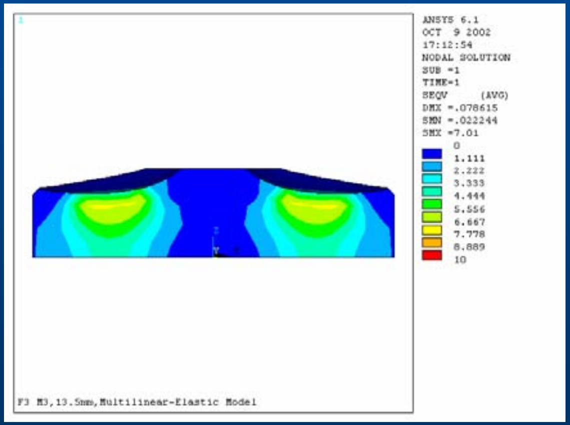
b. Contact Stress on M3 when there has been 5 deg surgical misalignment, loaded with an F4, producing higher stress

c. Slice through maximum stress on an M3 with 9.5mm minimum thickness

d. Slice through maximum stress on an M3 with 13.5mm minimum thickness, stress decreases with an increase in thickness

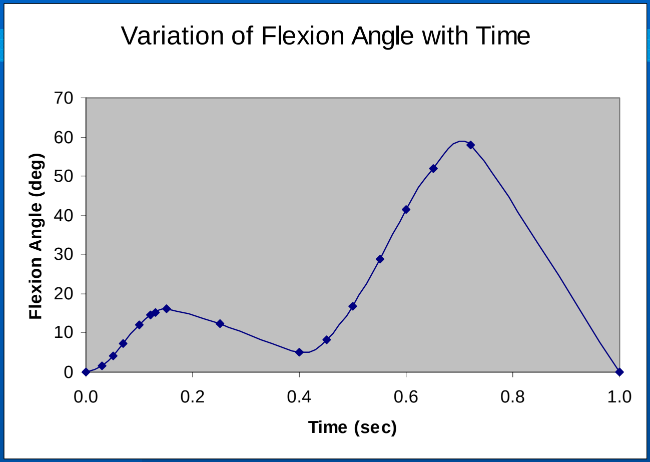


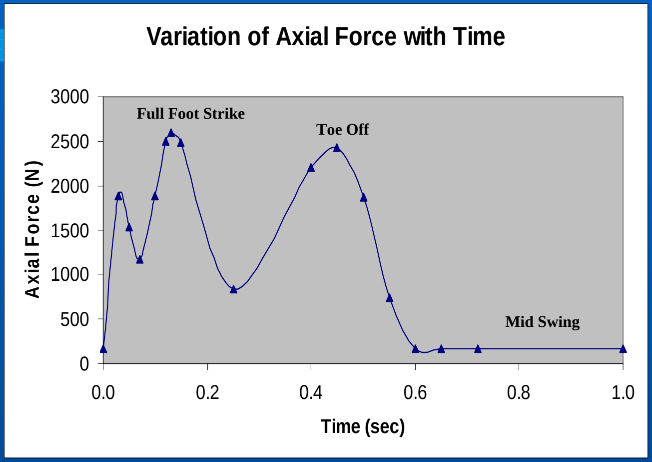
c.

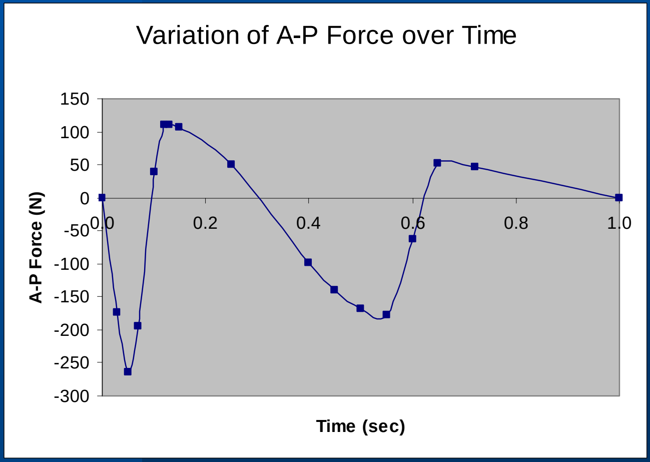


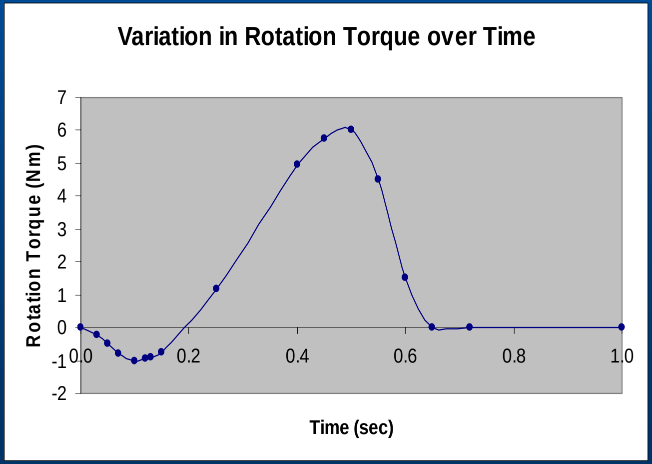
d.

ISO Standard Gait Curves:



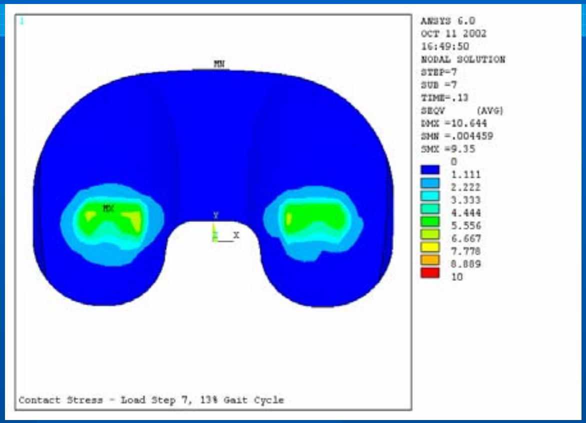




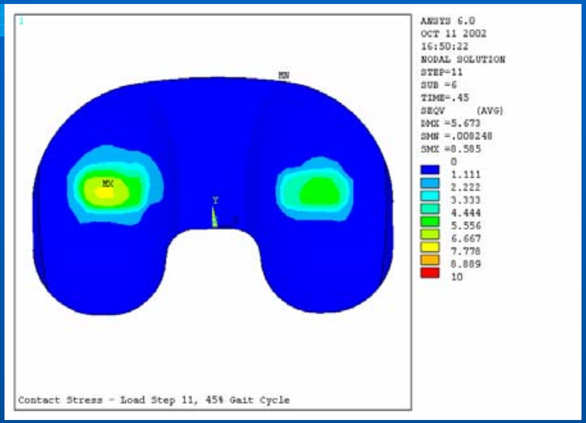


Based on draft ISO standard 14243-1.4: Implants for Surgery – Wear of Total Knee Joint Prostheses

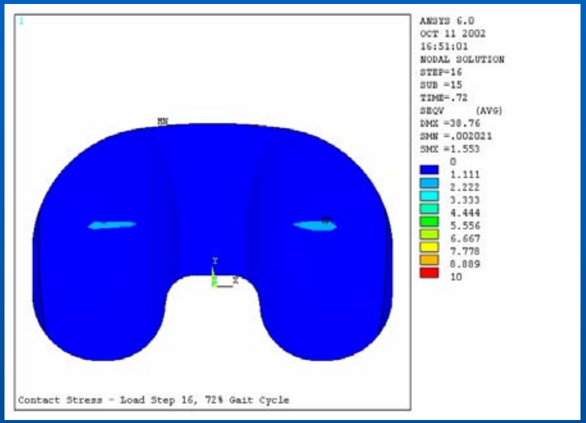
Simulation of a Gait Cycle:



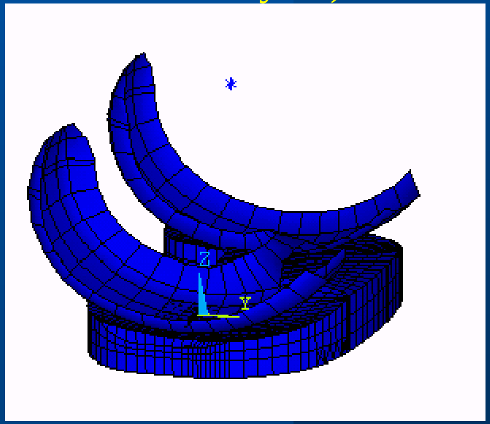
Foot Strike (13% of Gait Cycle)

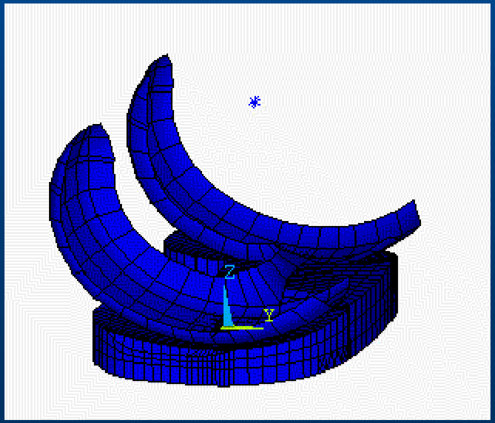


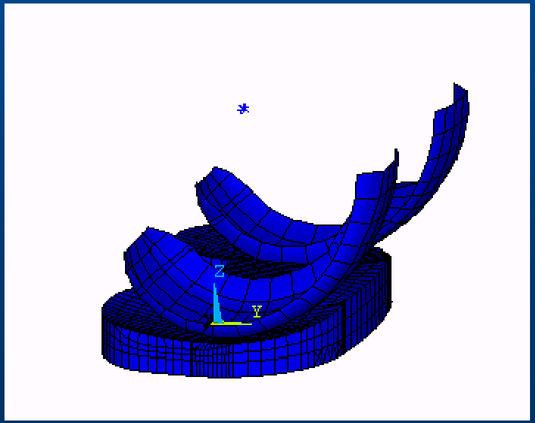
Toe off (45%)



Mid Swing (72%)







Future Research:

Within this research project there are two more main goals to achieve:

• A fatigue model will be developed using the gait cycle model, which will be used to predict lifetime of the TKR

• Real dynamic data from fluoroscopic and force plate patient data will be used in the above model to predict *in vivo* TKR lifetime

Research outcomes will lead to a better understand of the dynamics of TKRs and the development of a useful design tool in TKR R&D