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# Contact mechanics of the natural knee following Autologous chondrocyte implantation (ACI) – the clinical significance for rehabilitation programmes

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# Modelling assumptions

- The models are of the patella-femoral joint.
- Units SI
- The dimensions of the knee are from Nuno et al (2003) and life size model by Adam, Rouilly.

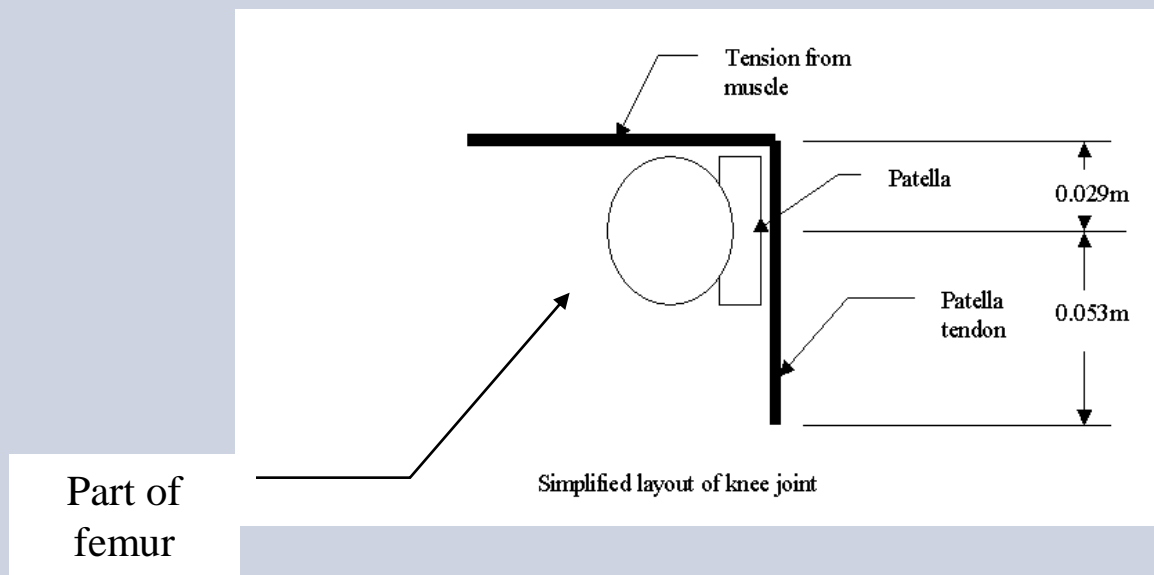


# The knee joint

- The knee joint is one of the most complex in the human body
- The forces acting are very high
- The cartilage between the mating parts acts as a bearing surface with low friction and long life

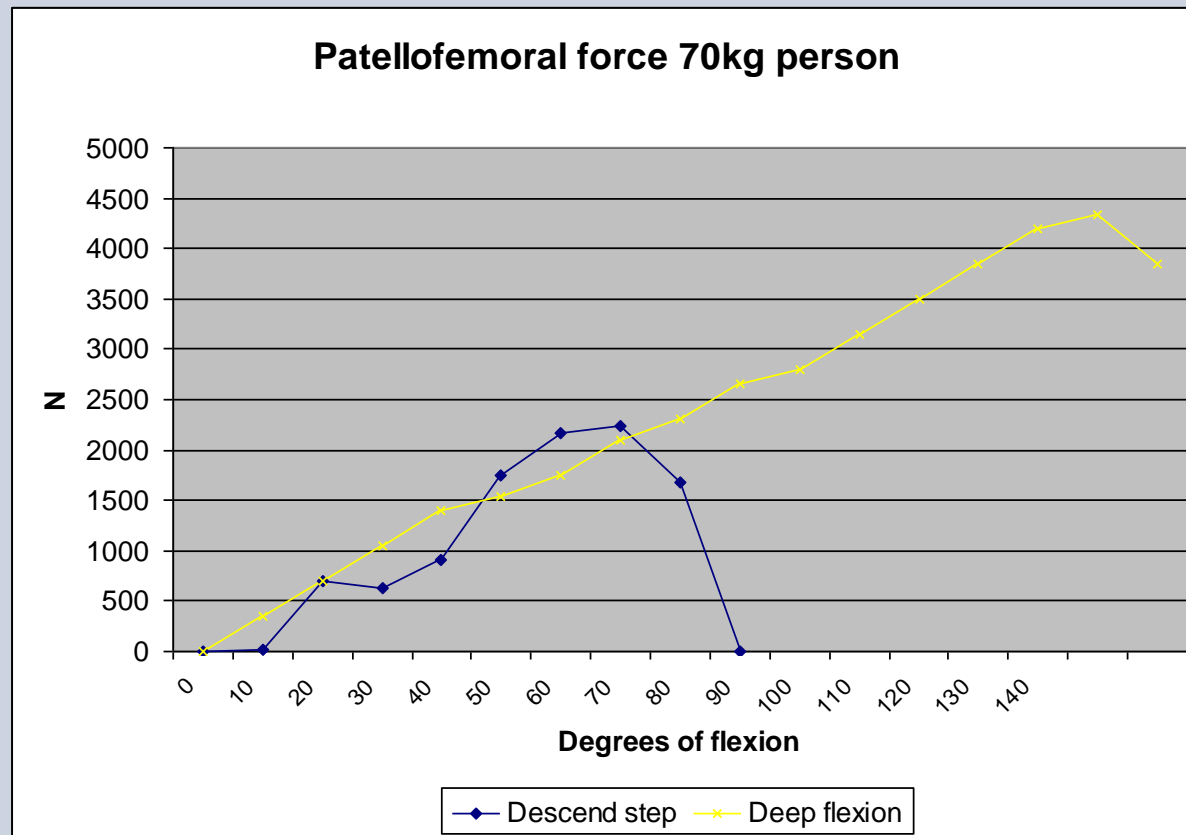


## Simplified knee joint





The graph is based on a young fit 70kg



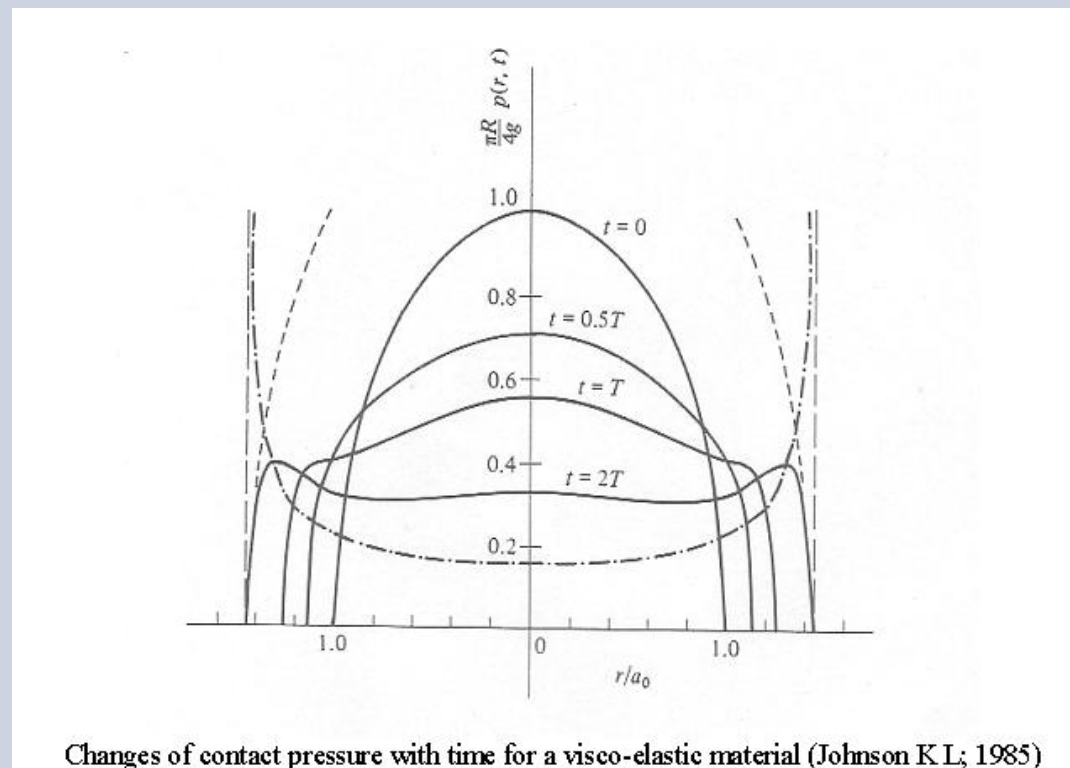


# Cartilage

- Cartilage is a complex structure and consists of:-
- Synovial fluid, which is a non-Newtonian i.e. viscosity decreases as velocity of applied load is increased.
- Organic matrix of collagen fibres.
- Chondrocytes that maintain the matrix.



# Contact pressure with respect to time for visco-elastic material

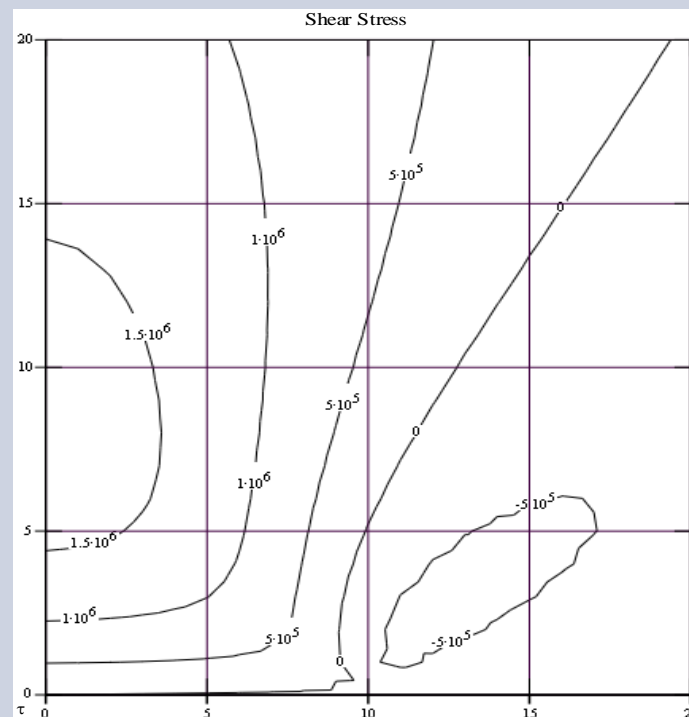




## Plot of shear stress in cartilage

Force 2200N, Young's modulus 100MPa, Poisson's ratio 0.047, coefficient of friction 0.01

Cartilage depth mm



Distance from centre of contact mm





# Cartilage cont.

- The fibres control the flow of the synovial fluid as the load is applied
- This results in the low friction
- The fibre alignment is critical to the ability of the cartilage to carry the stress



# Cartilage damage

- If cartilage and the chondrocytes are killed the cartilage will not regenerate.
- If this happens then there will be contact with the subchondral bone, which will result in a painful stiff joint
- Cartilage can be damaged by repeatedly applying a shear stress in excess of 5.6MPa (Clements et al, 2001)



## Autologous chondrocyte implantation (ACI)

- ACI is a new treatment to regenerate damaged cartilage
- It consists of taking a sample of cartilage from the damaged knee
- Growing a culture of chondrocytes in a laboratory
- The surgeon then opens the knee, trims the damaged cartilage and implants the chondrocyte culture



## Problems with ACI

- The success rate for ACI is very good on the femur at 90%
- However, implants on the patella only have a success rate of 65%
- The hypothesis is that the contact stress is a factor in the above difference
- Computer modelling is used to determine the detail of the contact stress in the patello-femoral joint



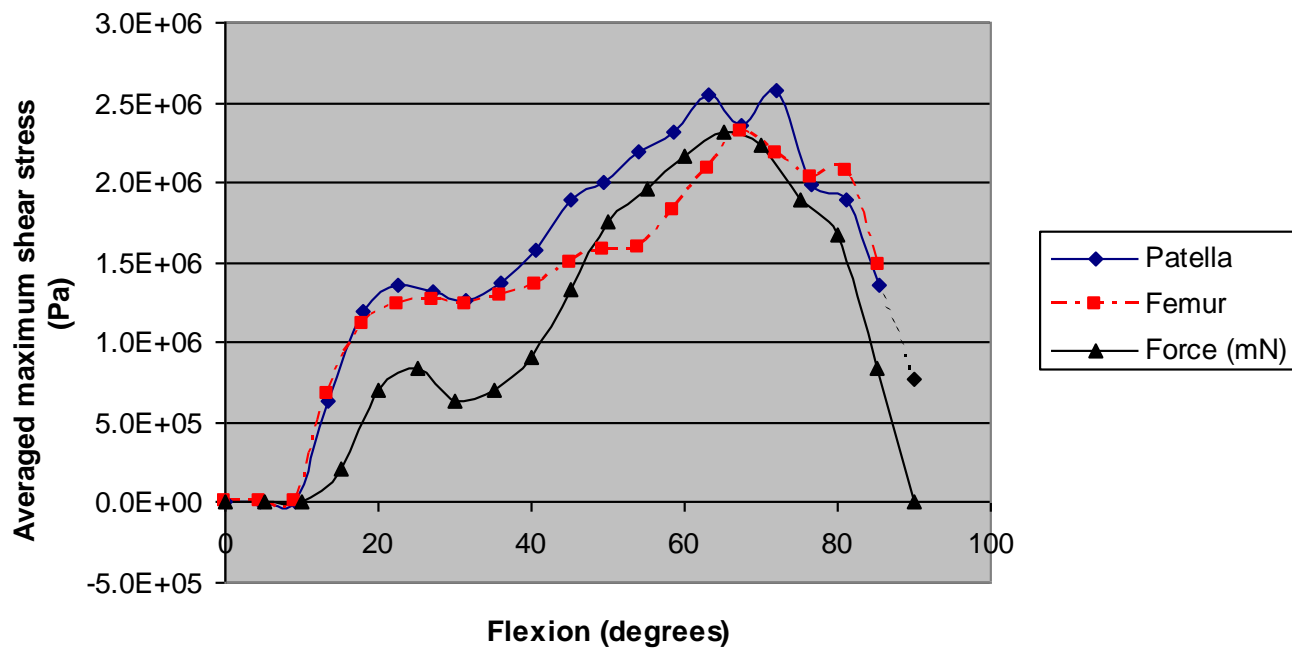
## Stress limit

- Clements et al (2001) reported that tests on bovine patella cartilage show signs of damage and cell death when loaded with a cyclic load well below the pressure when cartilage would be expected to fail.
- The implied limit to prevent damage is therefore 5.6MPa.
- Maximum shear stress is used as this is the stress that is most likely to cause damage in contact problems (Johnson 1985).
- This would explain the delamination of ACI as reported by Paterson (2000)



# Contact shear stress

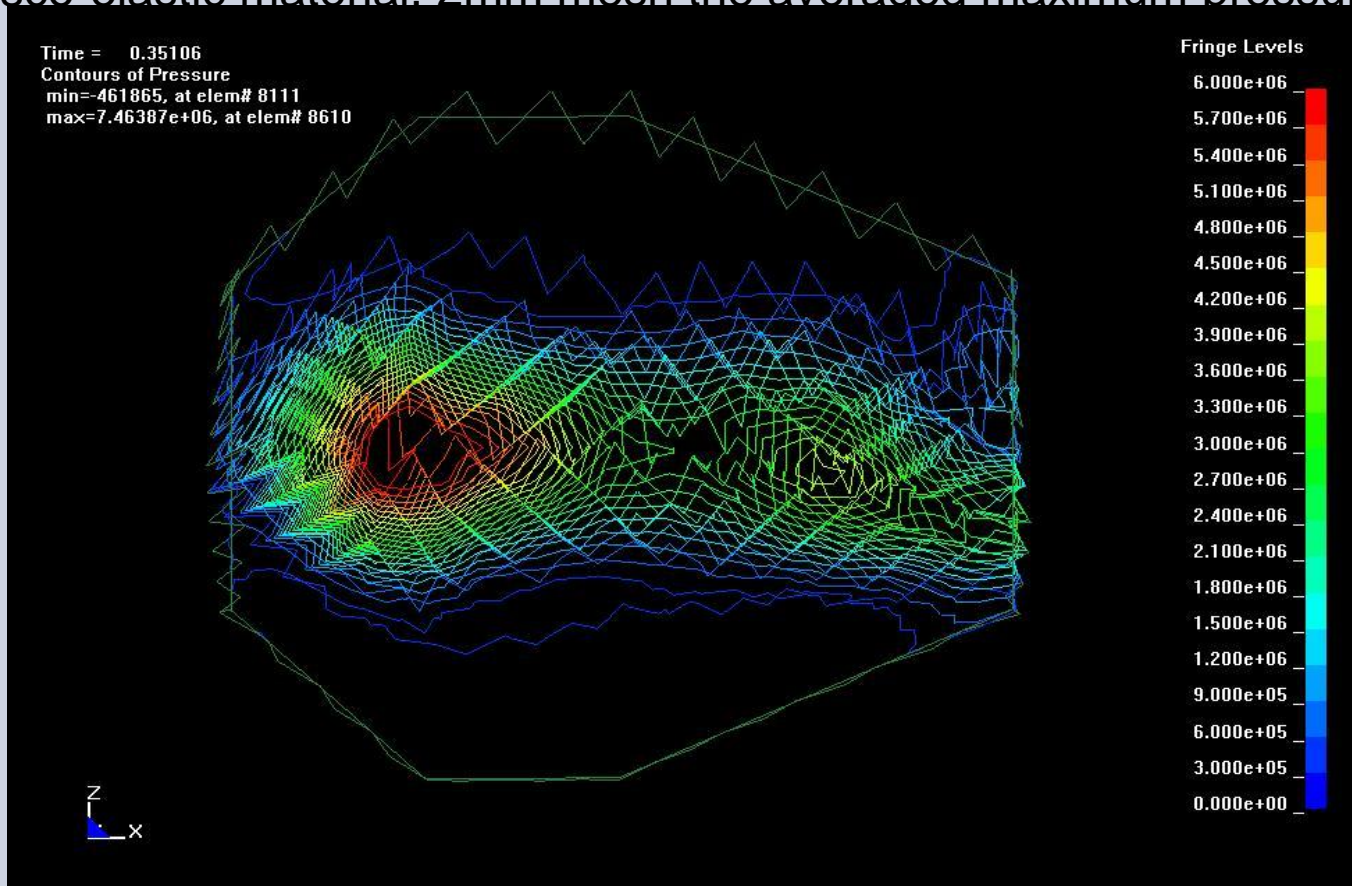
Contact shear stress in a healthy knee of a 70 kg person descending a 200mm step (2mm mesh)





# Contours of pressure in the patella cartilage

Descending a 200mm step, load 2170N, flexion 60° cartilage modelled as a visco-elastic material. 2mm mesh the averaged maximum pressure





# ACI treatment

- The following slides demonstrate the affect of treatment by ACI on the contact stress.
- The treatment is 35mm wide and 25mm high across the face of the patella.
- It is assumed that the material properties of the ACI is Young's modulus of 10% of healthy cartilage and the defect is half filled with ACI
- The cartilage is modelled as a visco-elastic material
- Mesh 2mm



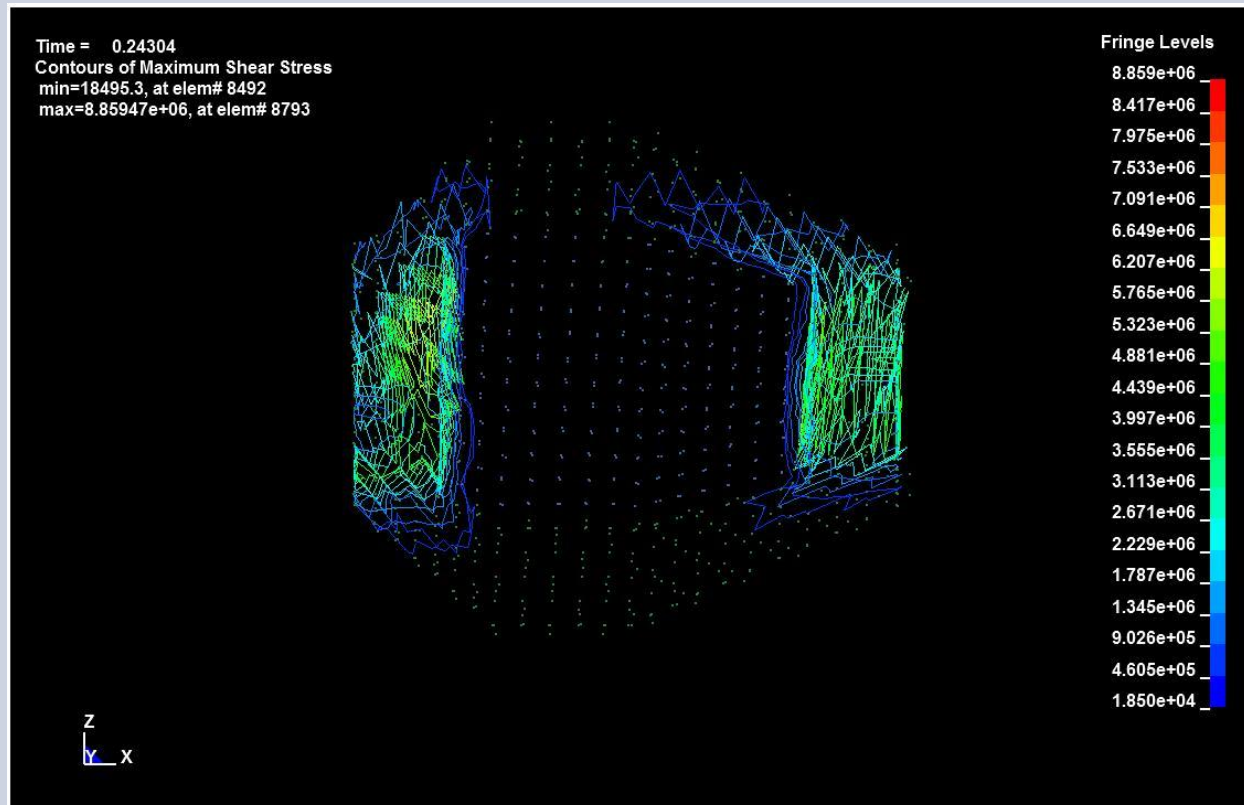


## Patient A

- Weight 76kg
- Height 1.78m
- Right knee
- **Defect:-** A single defect on the cartilage face of the patella. The post debridement size was 35mm wide by 15mm high, across the entire face of the patella.

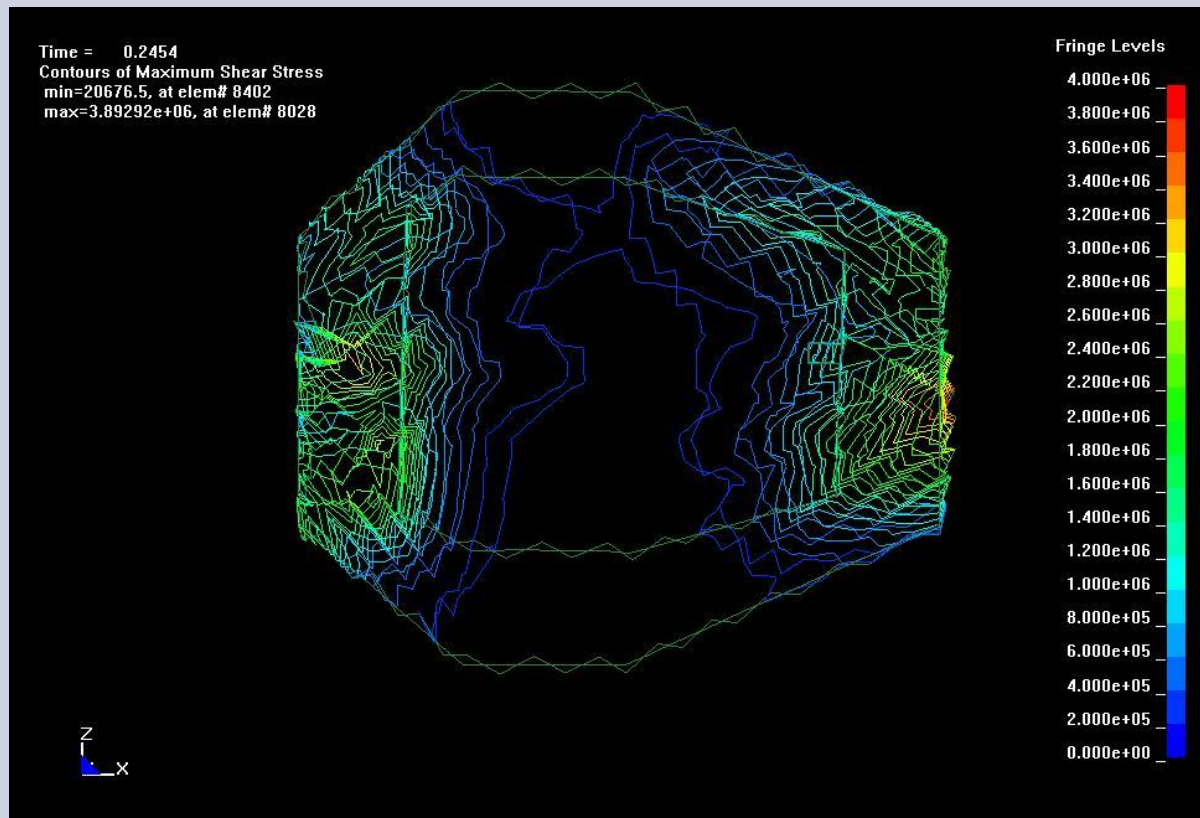


# Shear stress load 700N, flexion 35° immediately following the operation



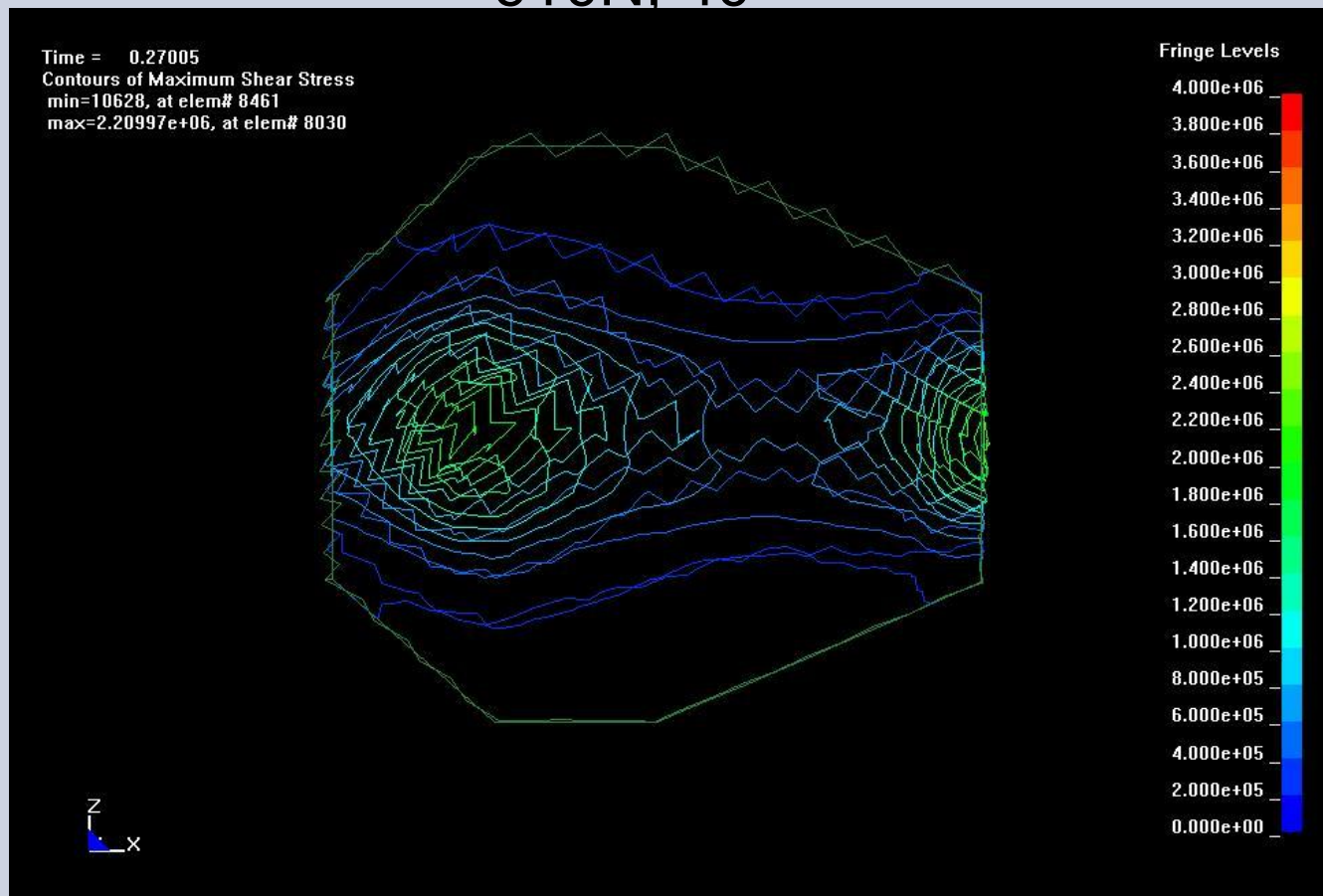


Patient A 97.5% recovery maximum shear stress in  
parent and ACI cartilage 2mm mesh 910N, 40°





# Maximum shear stress in healthy cartilage 2mm mesh 910N, 40°





# Validation

- Alternative calculations have been carried out by Hertzian mechanics.
- The results agree within the areas unaffected by stress concentrations.



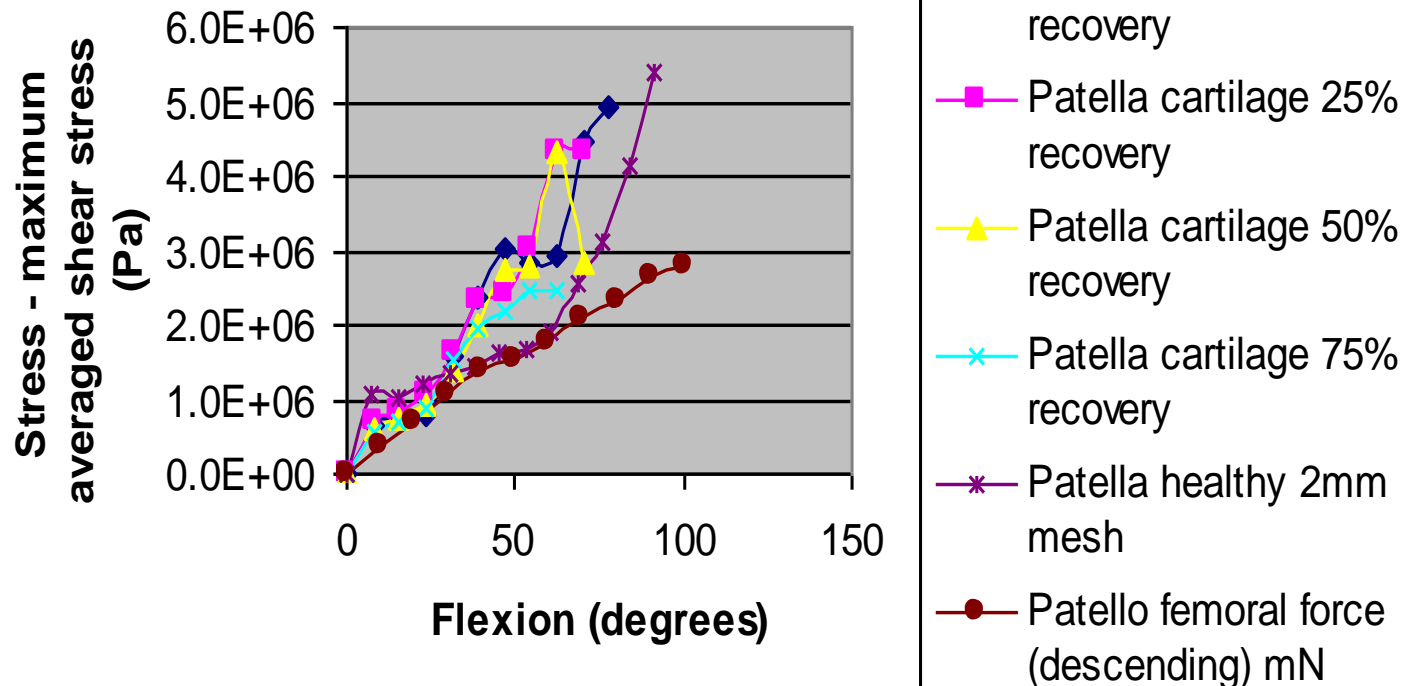
## Deep flexion

- The patellofemoral force in deep flexion can be extremely high and if taken to extreme can result in damage to the implant.
- It is most unlikely that a person will attempt to go into a squat soon after an operation but until the cartilage is fully developed applying that level of force could be foolhardy.
- Exercise should initially be unloaded and then by cycling on an exercise bicycle where the force on the patella can be more carefully controlled.



# Patient A deep flexion

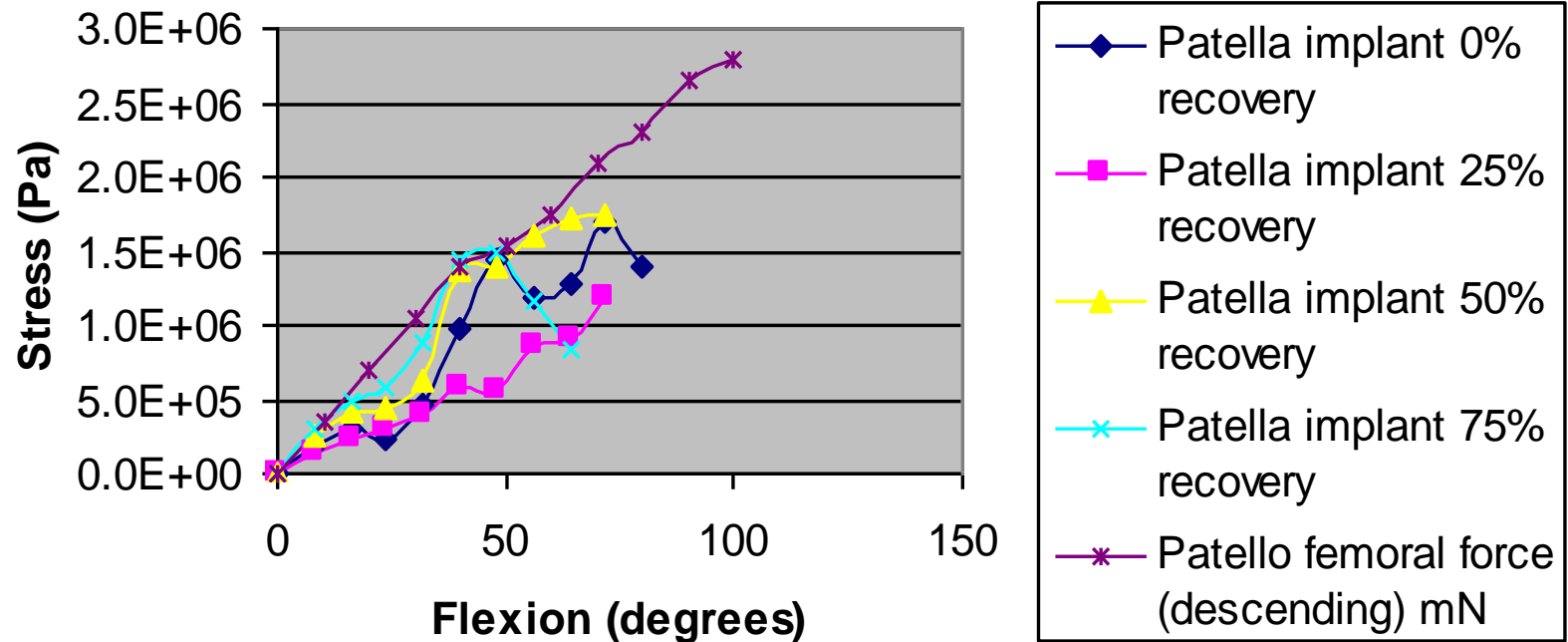
Patient A deep flexion patella cartilage shear stress  
4mm mesh





# Patient A in deep flexion

**Patient A deep flexion patella implant shear stress  
4mm mesh**







## Patients in deep flexion

- The shear stress on the lateral facet of the patella where it bonds to the bone of the patella is a concern.
- At only  $30^{\circ}$  flexion the stress is approaching what must be considered the safe limit for exercise during recovery (5.6MPa).
- For safe high flexion exercise during the recovery period a correctly set-up exercise bicycle should be considered.



# Conclusions

- Exercise by walking on the flat, descending and ascending stairs is useful
- Deep flexion should be discouraged
- A correctly set-up exercise bicycle is good as it is independent of body weight



# Further research

- Study more patients with different implant positions and sizes
- Effect on gait
- Possible damage to the other knee
- More studies on the regeneration of the implant in the knee



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