7 June 2021

Socket Sense
Progress Report – Week 5: FEA of Donning

Finite Element Analysis (FEA) of donning process in transfemoral amputees is required to take into account the pre-stresses generated at the socket-stump interface. Considering the pre-stresses before simulating the standing or gait of the amputee reduce the gap between the FEA results and reality.

1. Geometry

The geometry for FEA of donning process is constructed to prevent any initial contact between the stump and the socket. It is achieved in SOLIDWROKS by displacing the socket by 181 mm along -Y direction as shown in Figure 1.

Fig 1. Geometry for FEA of donning

2. Material Properties

2.1 Femur [1]
Young's modulus =15 GPa Poisson's ratio = 0.3 Density = 2000 kg/m^3

2.2 Stump [1]
Neo-Hookean Hyperelastic model
C_{10} = 11.6 kPa and D_1 = 11.9 MPa^{-1}

2.3 Socket [1]
Young's modulus = 1.5 GPa Poisson's ratio = 0.3 Density = 800 kg/m^3

3. Contacts

3.1 Between Femur and Stump

Bonded contact between the femur and the stump as shown in Figure 2.

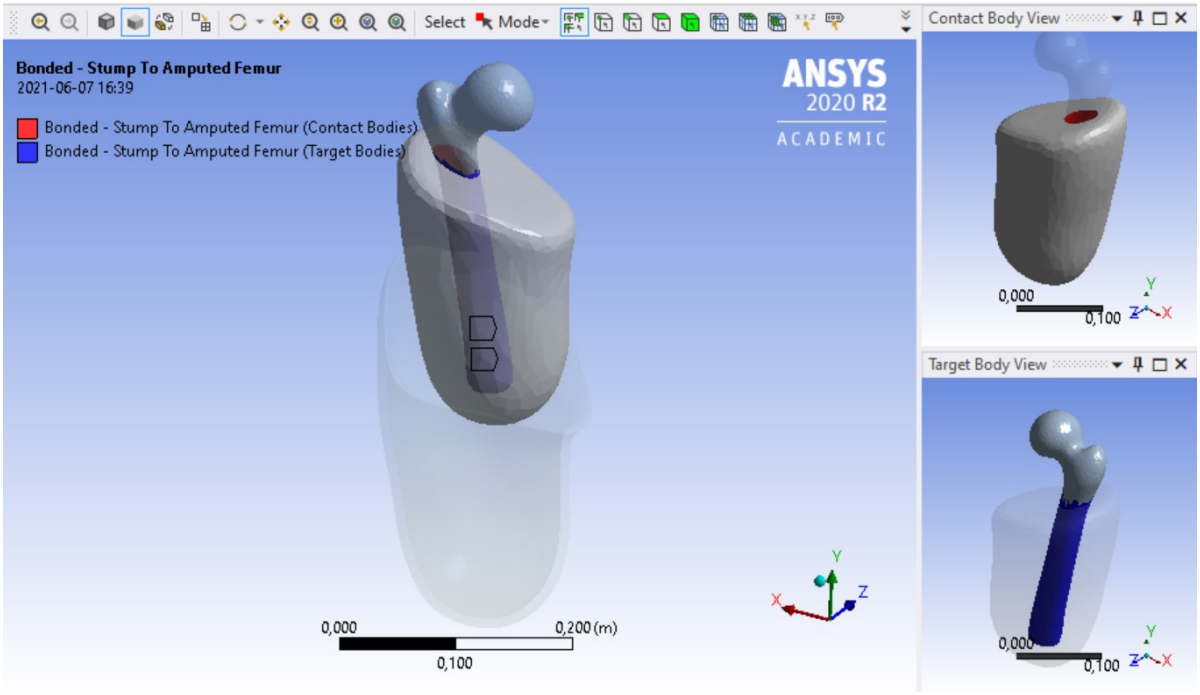

Fig 2. Bonded contact

3.2 Between Stump and Socket

The frictional contact between the stump and socket has a coefficient of friction [3], $\mu = 0.37$.

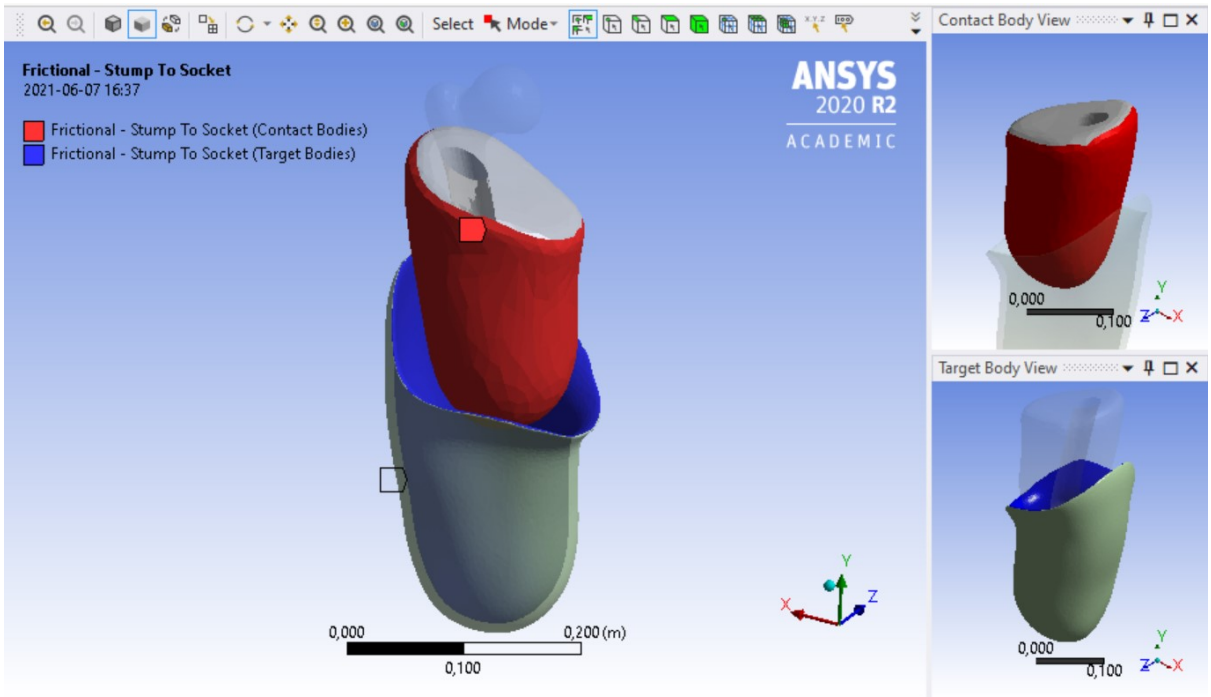

Fig 3. Frictional contact

4. Displacement

A displacement of 181 mm is applied on a singular face at the bottom of the socket to simulate the donning process i.e., the wearing of socket by the patient.

5. Boundary Conditions

A fixed support is applied on the head of femur in contact with acetabulum at the hip joint.

6. Results of Static Structural analysis in ANSYS Mechanical

6.1 Force Convergence

The runtime of ANSYS Solver is 1 hours 24 mins, using AMD Ryzen Threadripper 2950X 16-Core Processor 3.50 GHz and 64 GB RAM, Windows 10 Education 64 bits OS.

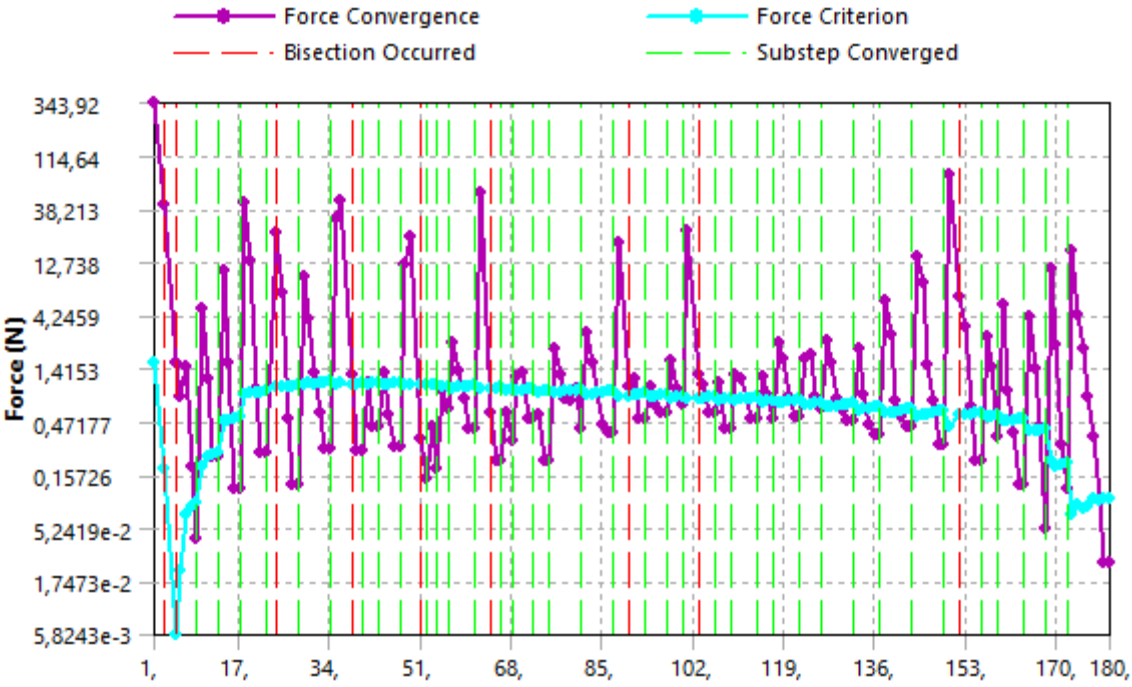

Fig 4. Force Convergence plot

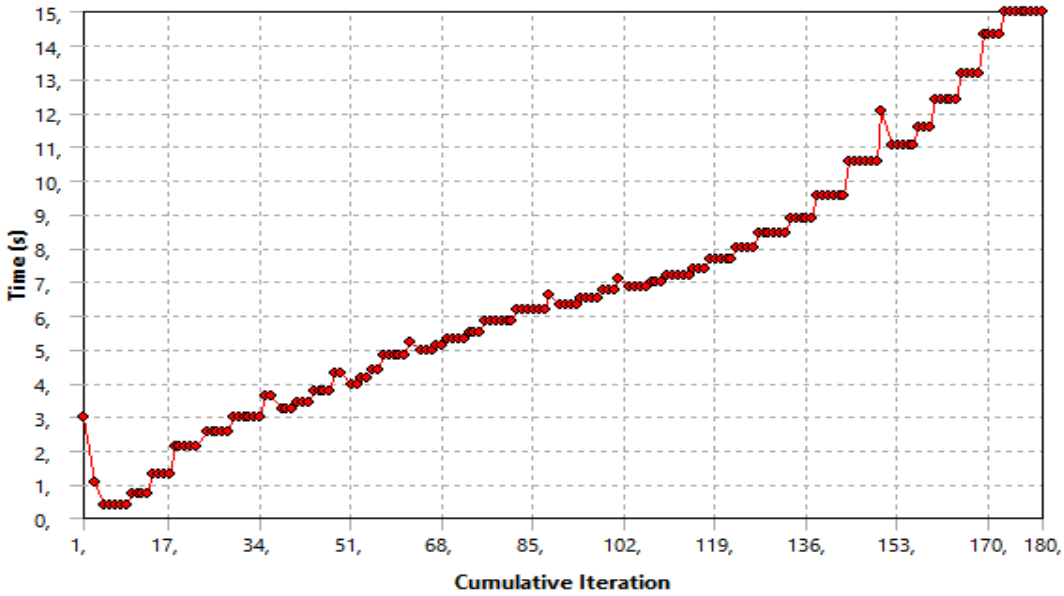

Fig 5. Cumulative iteration vs time plot

6.2 Total Deformation

The deformation at the end of donning is shown in Figure 6. (Please refer to the animation)

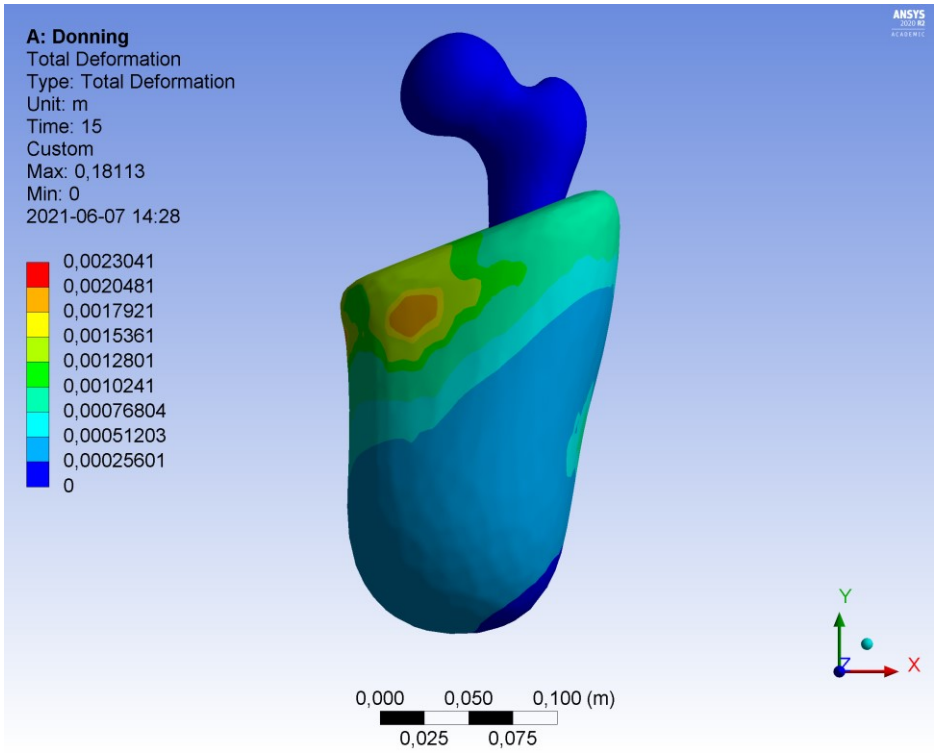

Fig 6. Total Deformation of the stump

6.3 Equivalent stress

The equivalent stress is shown in Figure 7. (Please refer to the animation)

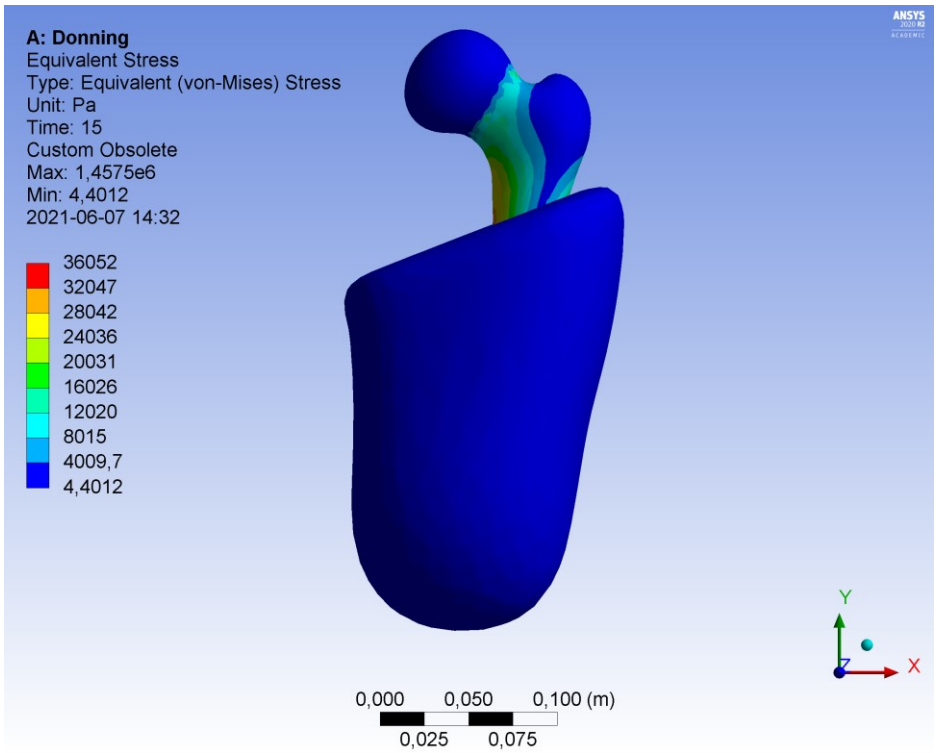

Fig 7. Equivalent Stress

6.4 Equivalent strain

The equivalent stress is shown in Figure 8. (Please refer to the animation)

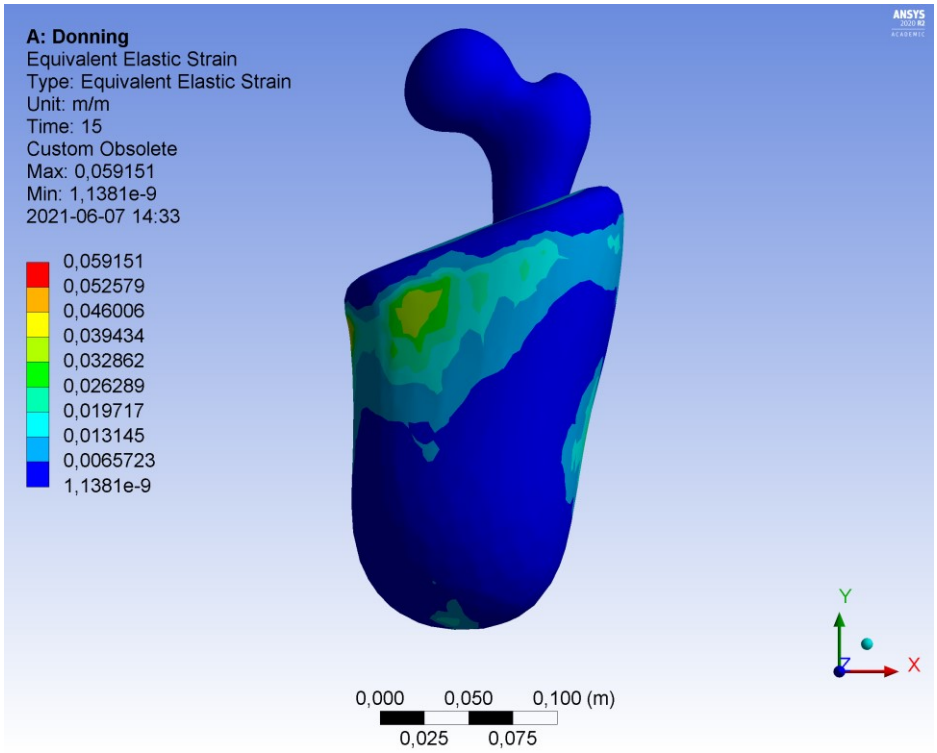

Fig 8. Equivalent Strain

6.5 Pressure at contact of socket and stump

Pressure at contact of Socket and Stump is shown in Figure 9. (Please refer to the animation)

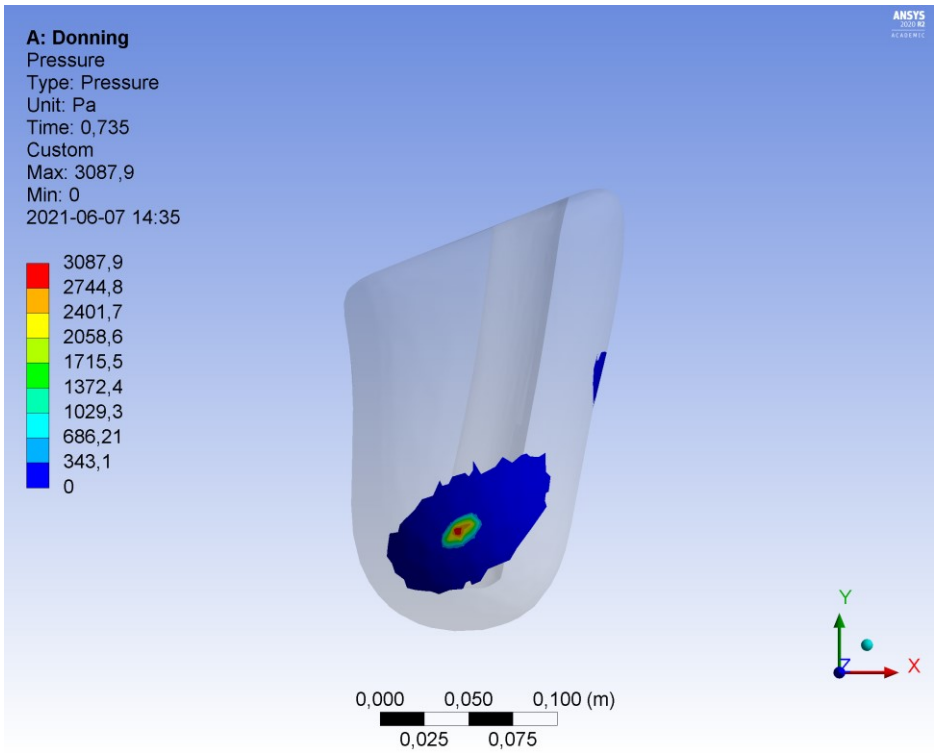

Fig 9. Pressure at contact

6.6 Frictional Stress at contact of socket and stump

Frictional stress at contact of Socket and Stump is shown in Figure 10. (Please refer to the animation)

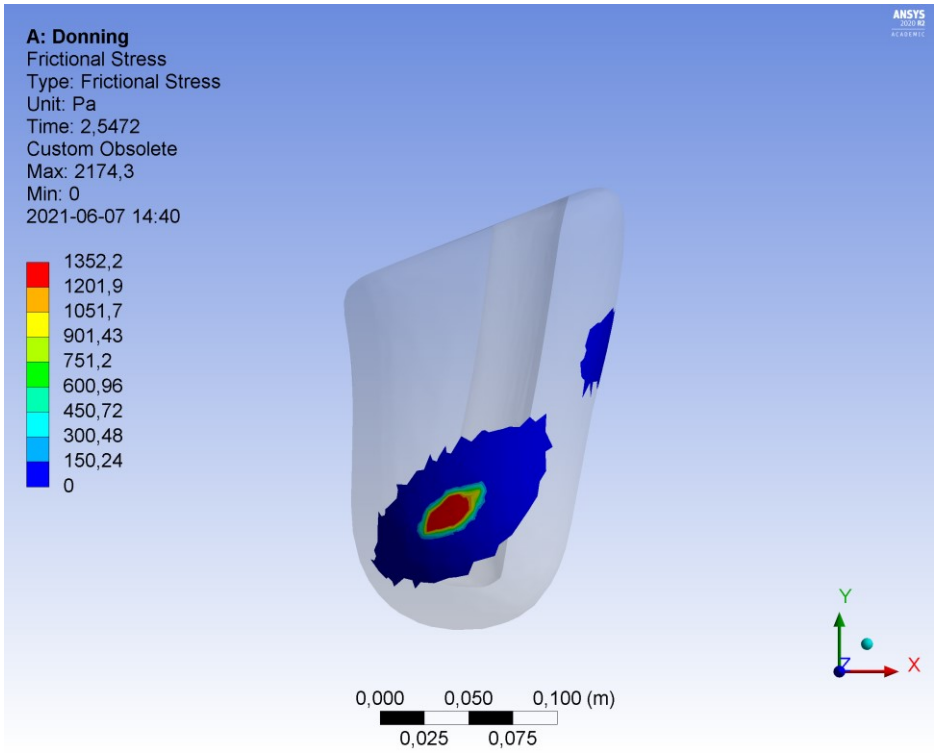

Fig 10. Frictional Stress at contact

7. Conclusions

The peak pressure results are in agreement with the work of Lacroix and Patino [2] *i.e.,* FEA of donning in transfemoral amputee. Lacroix and Patino's FEA study of the donning process involved the displacement of socket in absence of loads, similar to this report.

Lacroix and Patino (2011)	Examination of explicit donning process simulation	TF	3D Bone and ST geometry from CT scan Socket geometry from external scan of residuum	5	Donning: soft tissue deformed from axial socket donning Loading: N/A	$E = 15$ GPa $\nu = 0.3$	Hyperelastic, 3-parameter Mooney-Rivlin C10 = 4.25 kPa C11 = 0 kPa D01 = 2.36 MPa-1	N/A	$E = 1.5$ GPa $\nu = 0.3$	Bone-soft tissue, tied Residuum-socket, $\mu = 0.415$	Outcome: Implemented an accurate method of simulating the donning process Peak pressure: 1.54 – 5.61 kPa Peak shear: 0.23 – 0.93 circumferential, 0.57 – 2.00 longitudinal

References:

1. Henao, S.C., Orozco, C., Ramírez, J., 2020. Influence of Gait Cycle Loads on Stress Distribution at The Residual Limb/Socket Interface of Transfemoral Amputees: A Finite Element Analysis. Sci Rep 10, 4985. https://doi.org/10.1038/s41598-020-61915-1

2. Lacroix, D. and Ramírez Patiño, J.F. (2011). Finite Element Analysis of Donning Procedure of a Prosthetic Transfemoral Socket. *Annals of Biomedical Engineering*, [online] 39(12), pp.2972–2983. Available at: https://pubmed.ncbi.nlm.nih.gov/21887588/ [Accessed 7 Jun. 2021].