28 June 2021

Socket Sense

Progress Report – Week 8: FEA of Transfemoral Amputee with donning and standing load

Finite Element Analysis (FEA) – considering the stresses due to donning and the load experienced on standing while wearing the prosthetic.

1. Geometry

The FEA of donning process in Week 5 resulted in a deformed geometry of the transfemoral amputee *i.e.,* the femur, the stump and the socket. This deformed geometry resulted in errors while meshing; thus, instead the geometry constructed in Week 2 is used for the FEA of standing load.

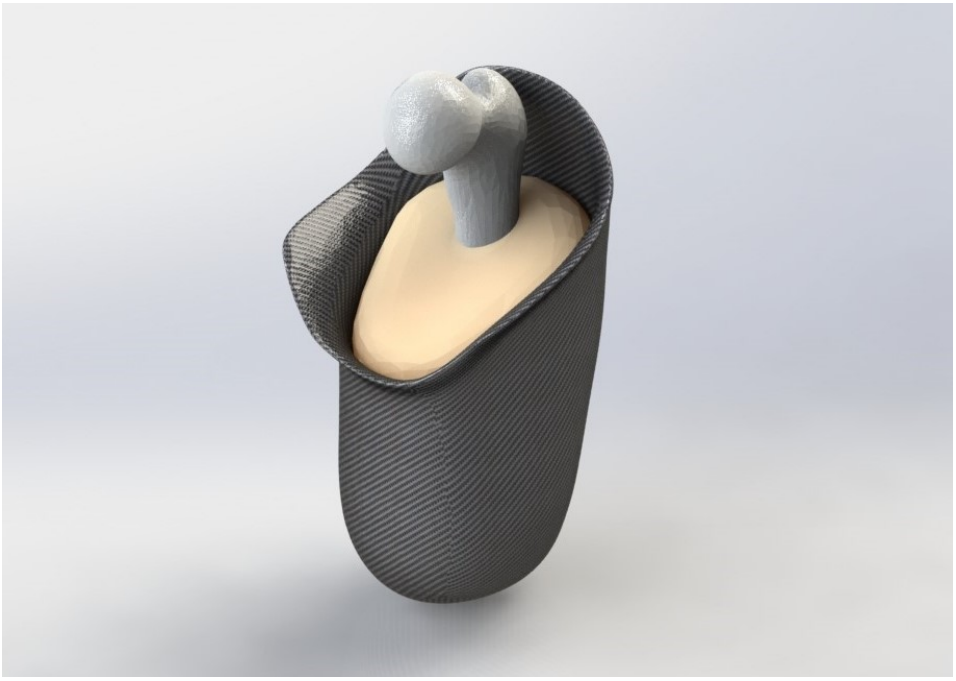

Fig 1. Geometry of transfemoral amputee

2. Material Properties

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

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

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

3. Contacts

3.1 Between Femur and Stump

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

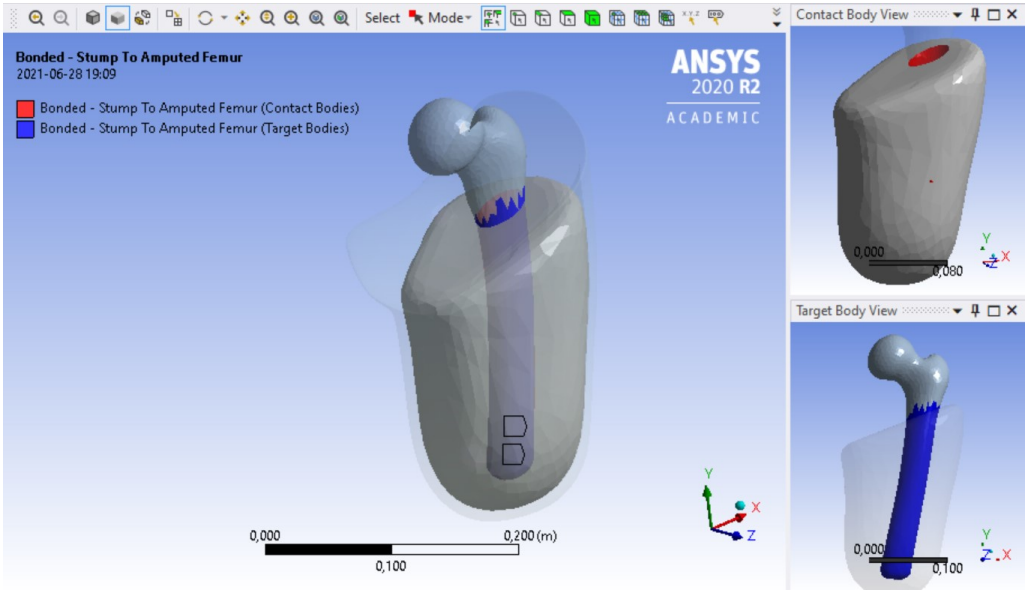

Fig 2. Bonded contact

3.2 Between Stump and Socket

Frictional contact between the stump and socket as shown in Figure 3.

- Friction coefficient: μ = 0.23 [1]
- Behaviour: Asymmetric
- Formulation: Augmented Lagrange
- Detection Method: Nodal-Projected Normal from Contact
- Interface Treatment: Adjust to Touch

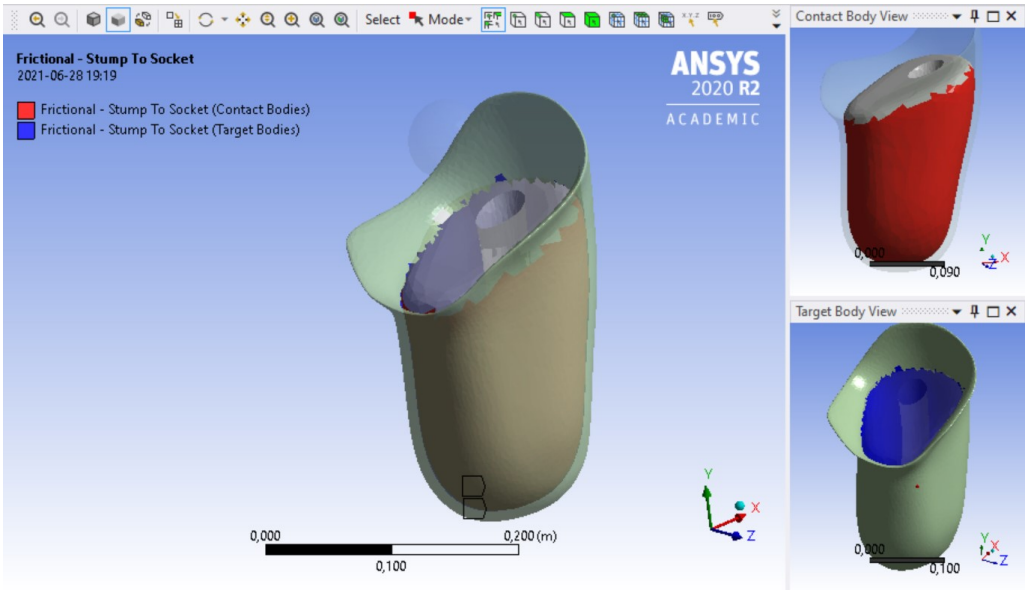

Fig 3. Frictional contact

4. Mesh

4.1 Defaults

- Physical Preference: Mechanical
- Element Order: Linear
- Element Size – Body Sizing (Femur, Stump and Socket) – Element Size: 0.01 m

4.2 Sizing

- Transition: Fast
- Span Angle Center: Coarse

4.3 Quality

- Error Limits: Aggressive Mechanical
- Smoothing: Medium

4.4 Statistics

- Nodes: 31417
- Elements: 120346

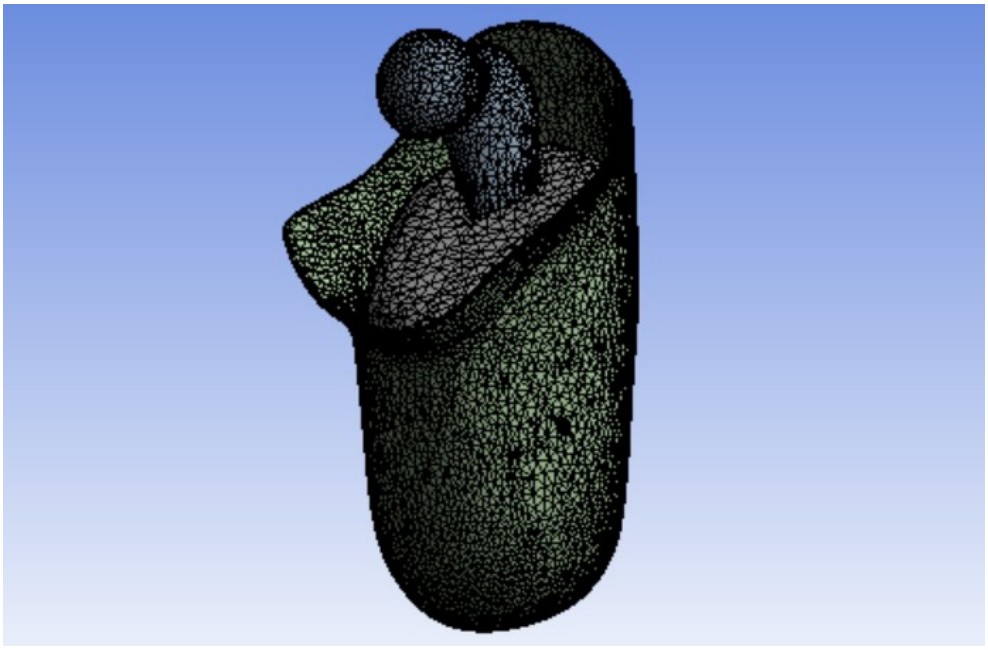

Fig 4. Mesh

5. Static Structural

5.1 Analysis Setting

- Number of Steps: 26
- Auto Time Stepping: On
    - Define by: Substeps
    - Initial Substeps: 30
    - Minimum Substeps: 10
    - Maximum Substeps: 500
- Large Deflection: On

5.2 Donning Load

A load of 50 N [2] is applied at the top face of the Stump as shown in Table 1.

5.3 Standing Load

A load of 600 N is applied on the bottom faces of the Socket as shown in Table 2.

Steps	Time [s]	Y [N]
1	0	0
1	1	-25
2	2	-50
3	3	-50
4	4	-50
5	5	-50
6	6	-50
7	7	-50
8	8	-50
9	9	-50
10	10	-50
11	11	-50
12	12	-50
13	13	-50
14	14	-50
15	15	-50
16	16	-50
17	17	-50
18	18	-50
19	19	-50
20	20	-50
21	21	-50
22	22	-50
23	23	-50
24	24	-50
25	25	-50
26	26	-50

Table 1. Donning Load applied in 2 step

Steps	Time [s]	Y [N]
1	0	0
1	1	0
2	2	0
3	3	25
4	4	50
5	5	75
6	6	100
7	7	125
8	8	150
9	9	175
10	10	200
11	11	225
12	12	250
13	13	275
14	14	300
15	15	325
16	16	350
17	17	375
18	18	400
19	19	425
20	20	450
21	21	475
22	22	500
23	23	525
24	24	550
25	25	575
26	26	600

Table 2. Standing Load applied in 24 steps

5.4 Fixed Support

A fixed support boundary condition is applied on the head of femur as shown in Figure 5.

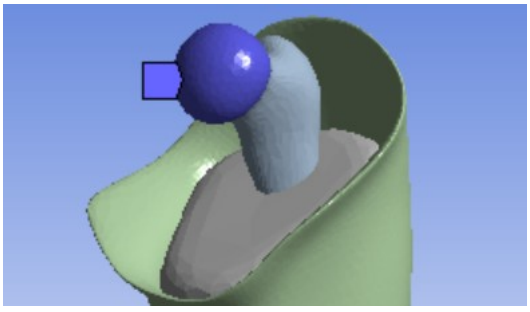

Fig 5. Fixed Support

6. Solution

6.1 Solution Information – Force Convergence

The runtime of ANSYS Solver is 1 hour 37 mins, using AMD Ryzen Threadripper 2950X 16-Core Processor 3.50 GHz and 64 GB RAM, Windows 10 Education 64 bits OS.

The Force Convergence graphs are shown in Figure 6 and Figure 7.

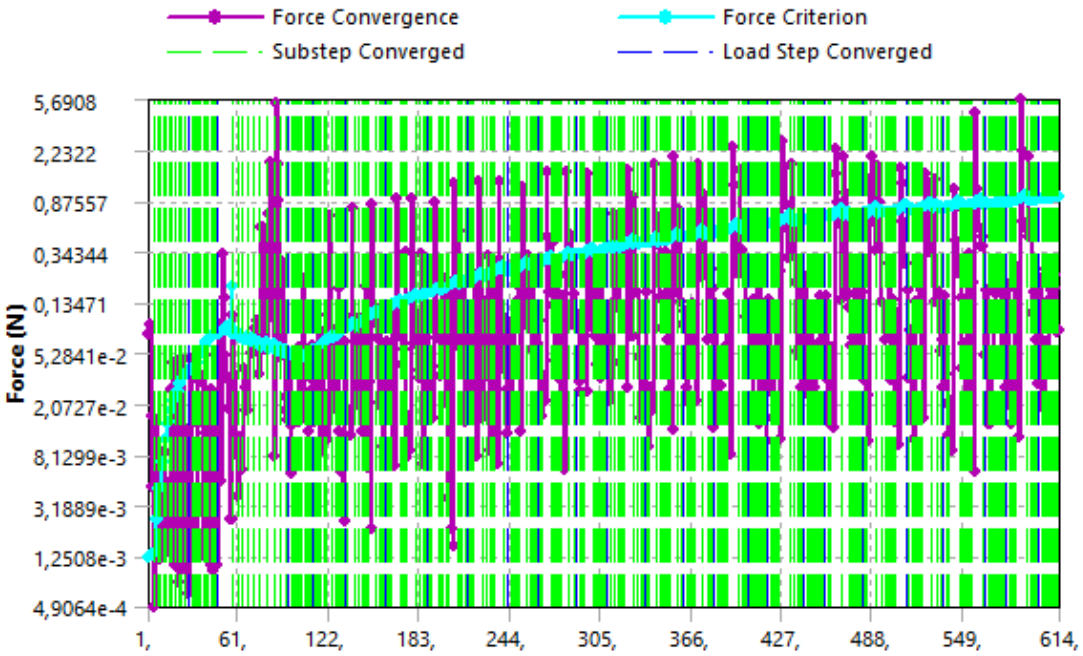

Fig 6. Force Convergence plot

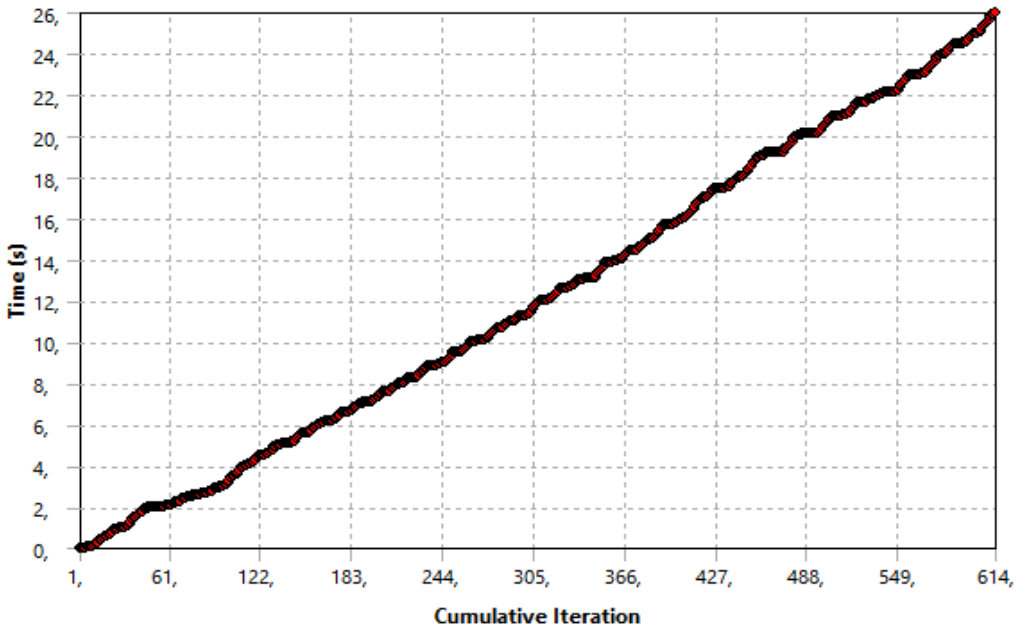

Fig 7. Cumulative iteration vs time plot

6.2 Total Deformation

The resultant Total Deformation from FEA is shown in Figure 8.

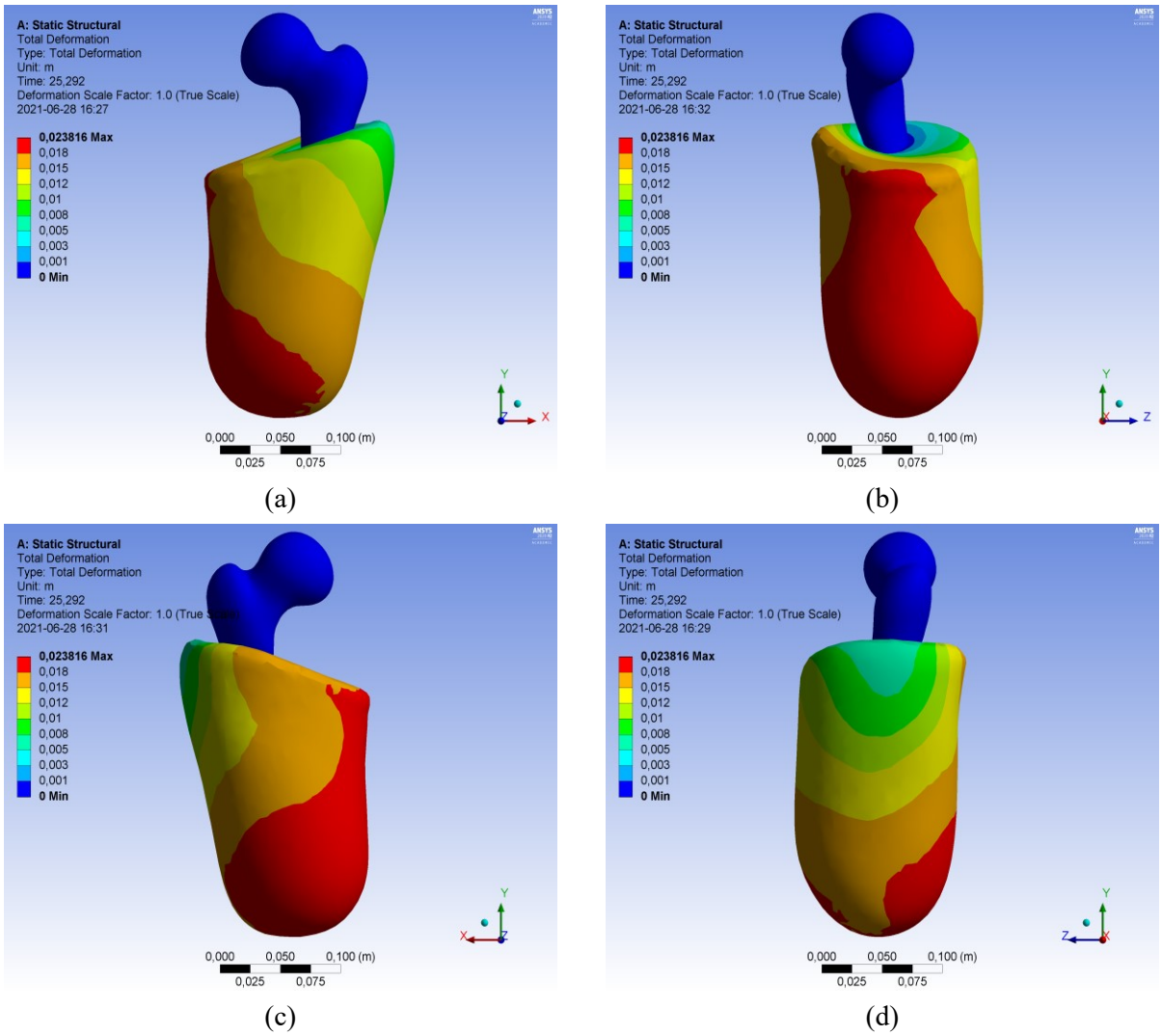

Fig 8. (a) Anterior view of Total Deformation, (b) Medial view of Total Deformation, (c) Posterior view of Total Deformation, and (d) Lateral view of Total Deformation

6.3 Equivalent Stress

The resultant Equivalent Stress from FEA is shown in Figure 9.

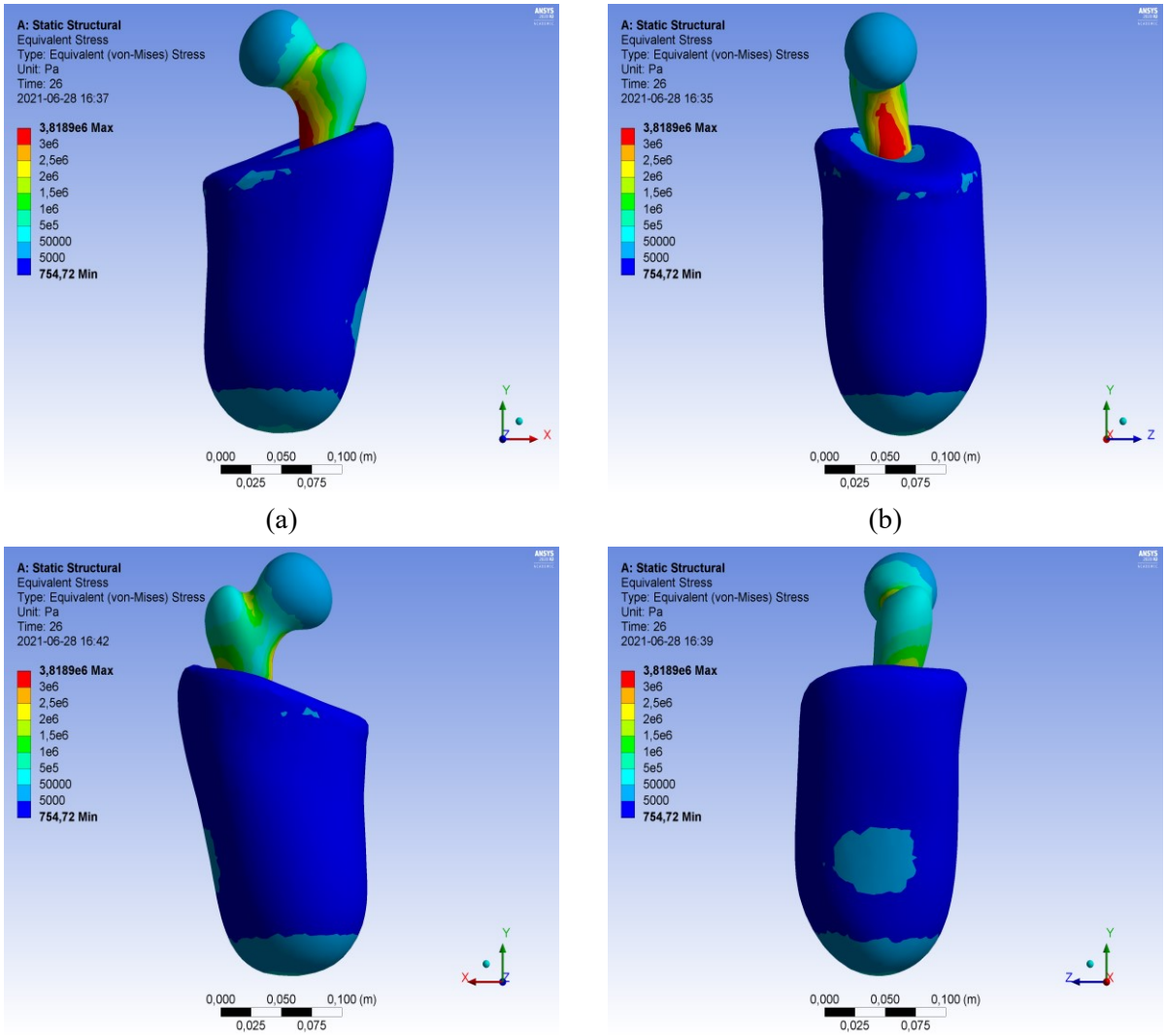

Fig 9. (a) Anterior view of Equivalent Stress, (b) Medial view of Equivalent Stress, (c) Posterior view of Equivalent Stress, and (d) Lateral view of Equivalent Stress

6.4 Equivalent Elastic Strain

The resultant Equivalent Elastic Strain from FEA is shown in Figure 10.

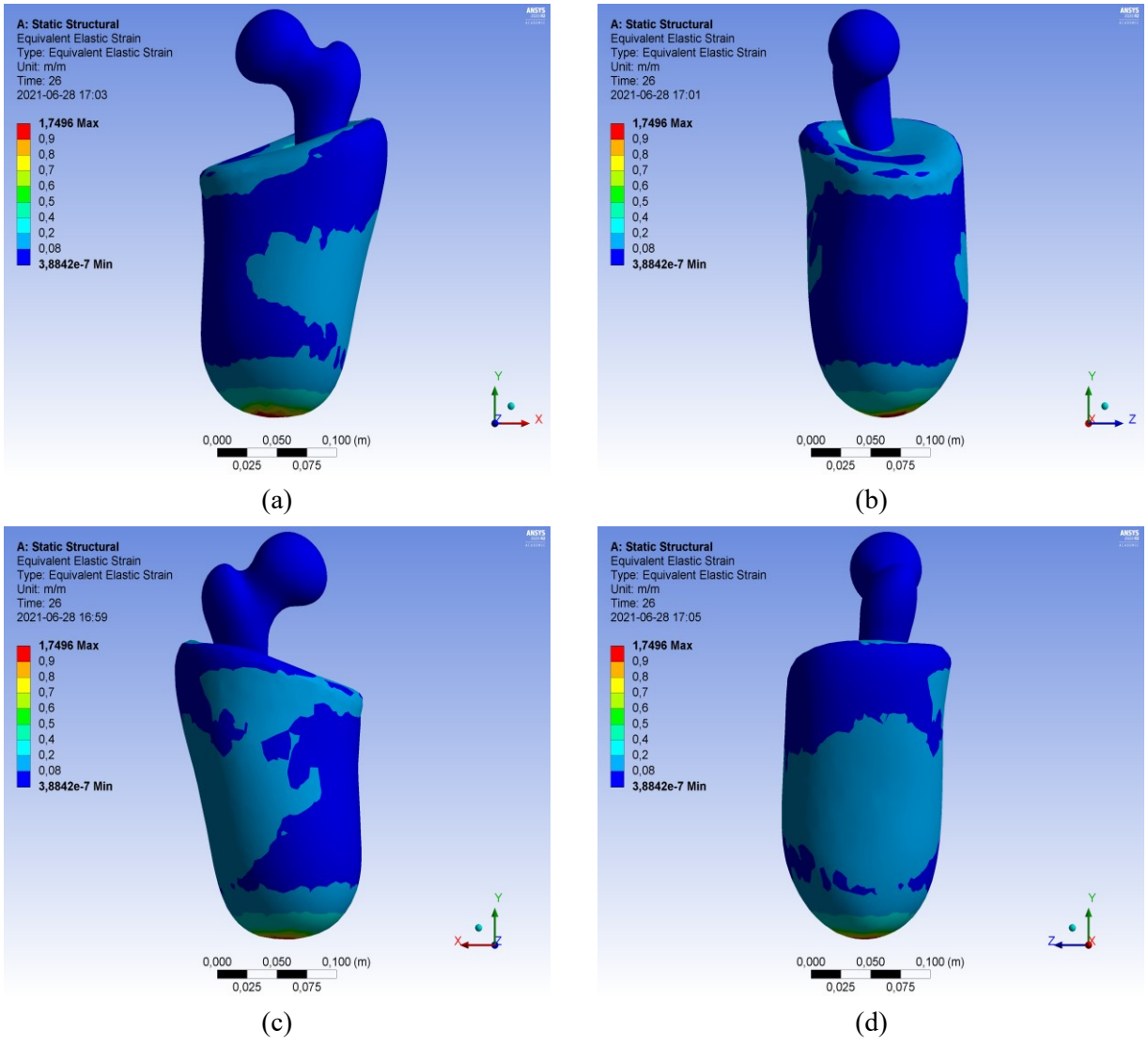

Fig 10. (a) Anterior view of Equivalent Elastic Strain, (b) Medial view of Equivalent Elastic Strain, (c) Posterior view of Equivalent Elastic Strain, and (d) Lateral view of Equivalent Elastic Strain

6.5 Pressure

The resultant Pressure from FEA is shown in Figure 11.

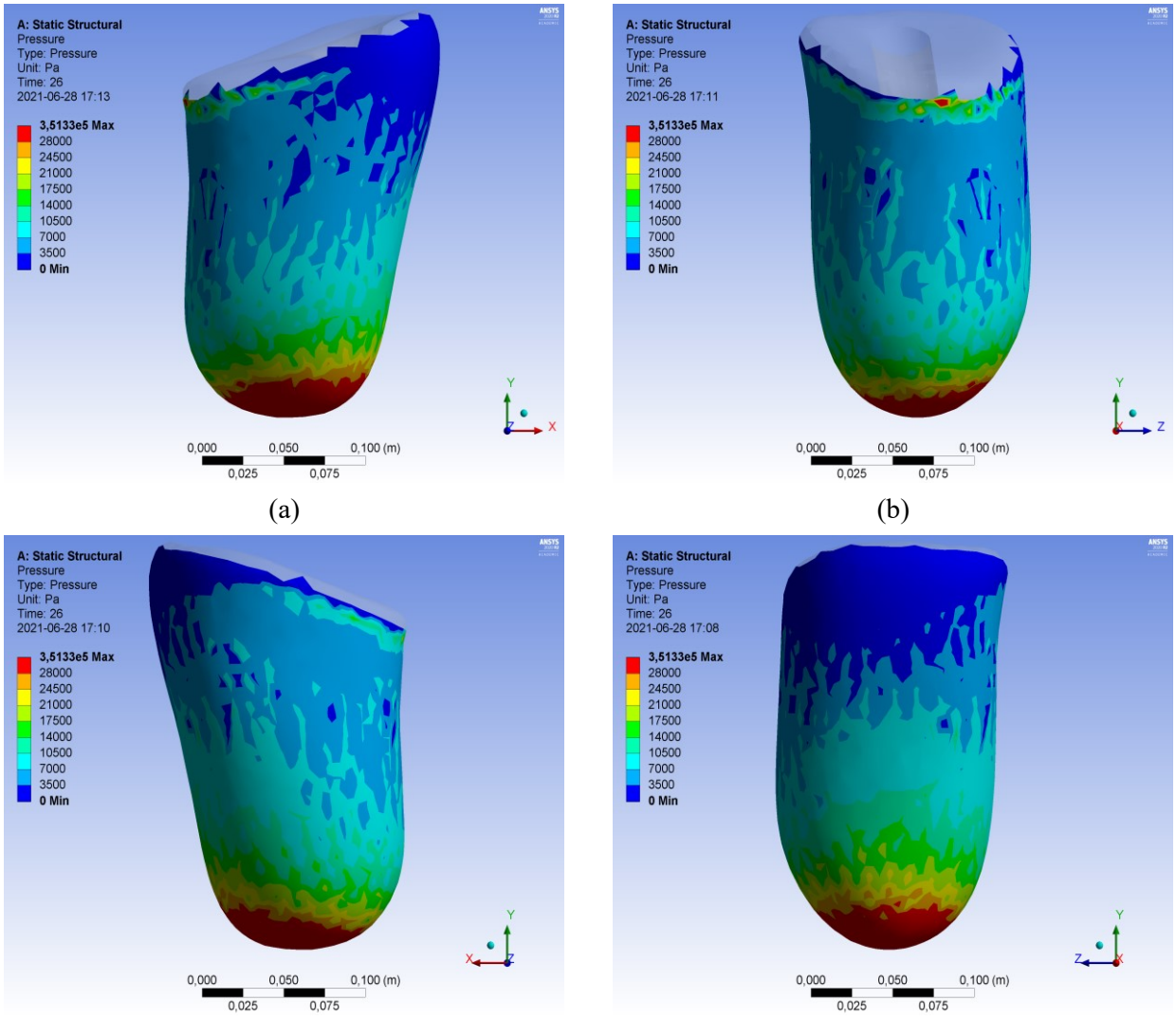

Fig 11. (a) Anterior view of Pressure, (b) Medial view of Pressure, (c) Posterior view of Pressure, and (d) Lateral view of Pressure

6.6 Frictional Stress

The resultant Pressure from FEA is shown in Figure 12.

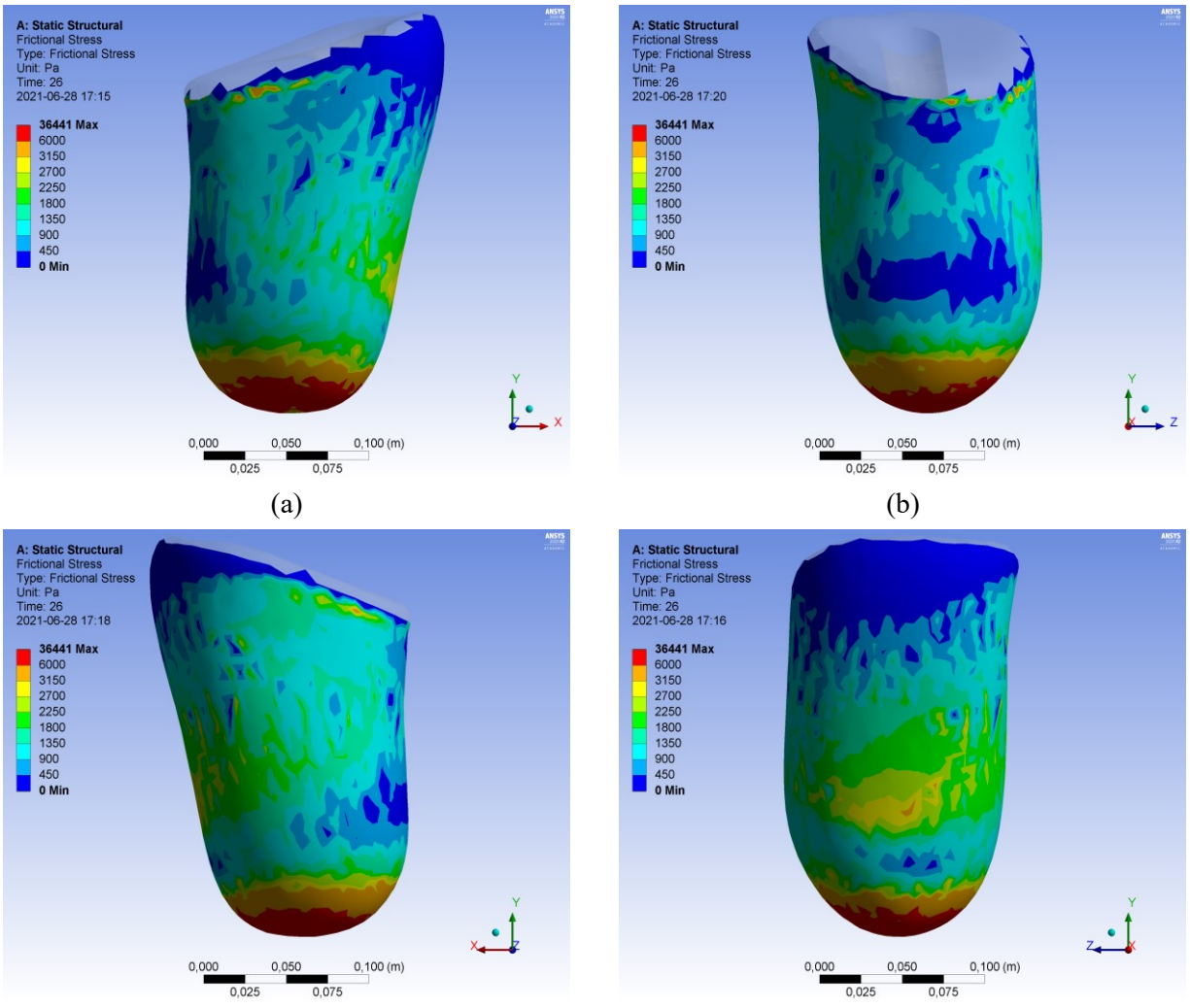

Fig 12. (a) Anterior view of Frictional Stress, (b) Medial view of Frictional Stress, (c) Posterior view of Frictional Stress, and (d) Lateral view of Frictional Stress

7. Conclusion

The results of FEA are fairly in agreement with the results of study conducted by Zheng *et al*, as shown in Table 3.

Zhang et al. (2013)	Examination of interfacial residuum and socket stresses	TF	3D Bone and ST geometry from CT scan Unrectified socket made from residuum external contours	1	Donning: 50N axial load Loading: 3 stance phases, heel strike, mid-stance and toe-off taken from Lee et al. (2004)	E = 15 GPa ν = 0.3	Hyperelastic, 2-paramenter Mooney-Rivlin C10 = 85.5 kPa C01 = 21.4 kPa ν = 0.459	N/A	E = 1.5 GPa ν = 0.3	Bone-soft tissue, tied Residuum-socket, μ = 0.5	Outcome: 3 stance phase loading simulation Peak pressure: 119.3 kPa, at socket brim Peak shear: 25.7 kPa longitudinal, 103.6 kPa circumferential, at socket brim

Table 3. Summary of results

References

1. S. C. Henao, C. Orozco, and J. Ramírez, "Influence of Gait Cycle Loads on Stress Distribution at The Residual Limb/Socket Interface of Transfemoral Amputees: A Finite Element Analysis," *Scientific Reports*, vol. 10, no. 1, Mar. 2020, doi: 10.1038/s41598-020-61915-1.

2. Linlin Zhang, Ming Zhu, Ling Shen, and Feng Zheng, "Finite element analysis of the contact interface between trans-femoral stump and prosthetic socket," *2013 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, Jul. 2013, doi: 10.1109/embc.2013.6609739.