Bone & Joint Research

Supplementary Material

10.1302/2046-3758.1310.BJR-2023-0362.R2

Model validation

To validate the finite element models, it is essential to compare them with biomechanical experiments.[1] In this study, biomechanical experiments were performed using a synthetic femur (Model 2200; Synbone, Switzerland) and compared with the results of the finite element analysis (FEA) (Figure b). The femur model was fitted with a posterior stabilizing prosthesis that was encapsulated and fixed 242 mm from the distal end. A vertical load of 1,000 N was applied to the femoral condyle. To simulate a 3:2 load distribution between the medial and lateral condyles in the knee joint,[2] two springs of different stiffnesses (k1 = 40 kg/mm, k2 = 60 kg/mm) were used to apply the load. Eight strain gauges were placed on the medial and lateral sides of the femur. The static strain test analysis system (TST3822EW; Test Electron, China) was used to obtain strain data. The FEA was performed using the same uniaxial load conditions, and strain data were obtained at the above positions. Given the discrepancies between the material properties of synthetic bone and those in our finite element model, it is necessary to scale the material properties to achieve overall consistency, thus rendering the results comparable. We obtained the difference in overall stiffness values between the finite element model and the synthetic bone through compression testing, which represents the overall disparity in material properties. Since the analysis for validating the finite element model is linear, scaling material properties has the exact same effect as scaling the magnitude of applied forces. Therefore, for simplicity, we scaled the magnitude of the applied forces based on the stiffness value differences between the finite element model and the synthetic bone. Finally, differences between the experimental and FEA groups were analyzed using an independent-samples *t*-test.

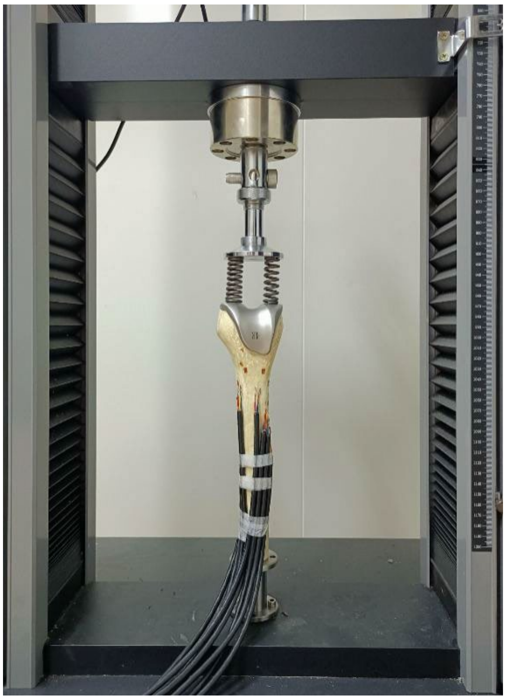


Fig a. Stain test of the synthetic femur under compressive load.

Strain results at eight positions on the femur are presented in Figure b. While there were some discrepancies between the experimental and FEA results at individual measurement points, the overall trend was similar. To further validate the FEA results, independent-samples *t*-tests were conducted using both the biomechanical experimental results and the FEA results. The results showed no significant difference between them ($p = 0.757$), indicating the validity of the FEA findings.

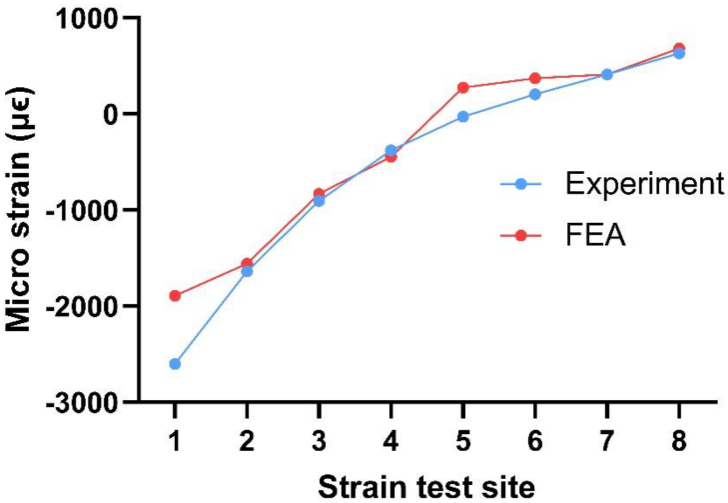


Fig b. Comparison of mechanical test and finite element analysis (FEA) results.

Mesh sensitivity analysis

Figure c shows the results of the mesh sensitivity analysis. When the element sizes of the femur were 1.0 mm, 0.75 mm, 0.5 mm, and 0.25 mm, the maximum stresses at the notch were 21.9 MPa, 25.3 MPa, 31.6 MPa, and 32.3 MPa, and the maximum micromotions at the anterior flange were 14.5 μm, 14.9 μm, 14.1 μm, and 14.2 μm, respectively. The difference in stress between the 0.5 mm and 0.25 mm element sizes was 2.2% (< 5%), and the difference in micromotion was 0.7% (< 5%). The element size of 0.5 mm was sufficient to ensure accurate analysis.

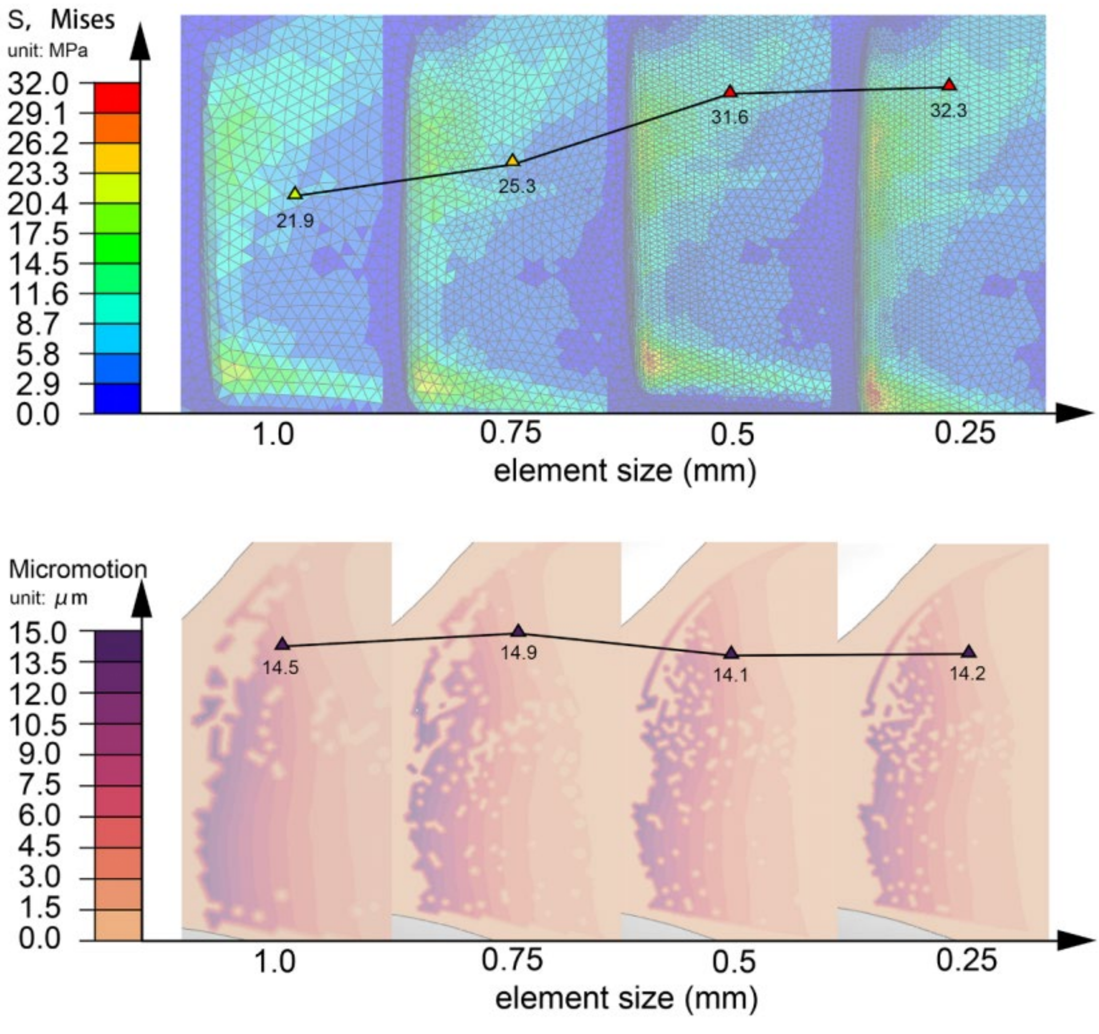
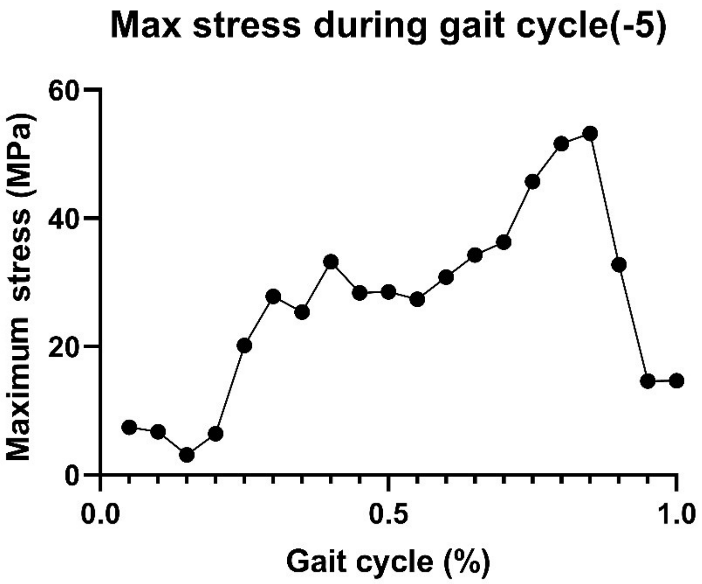
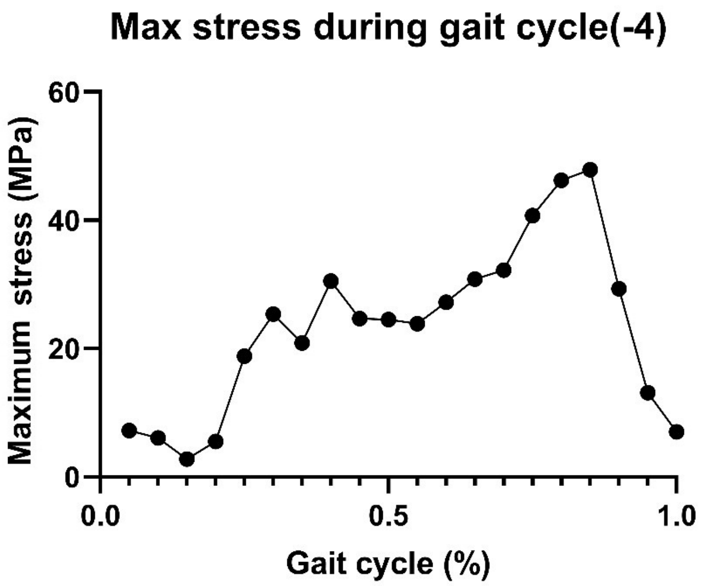
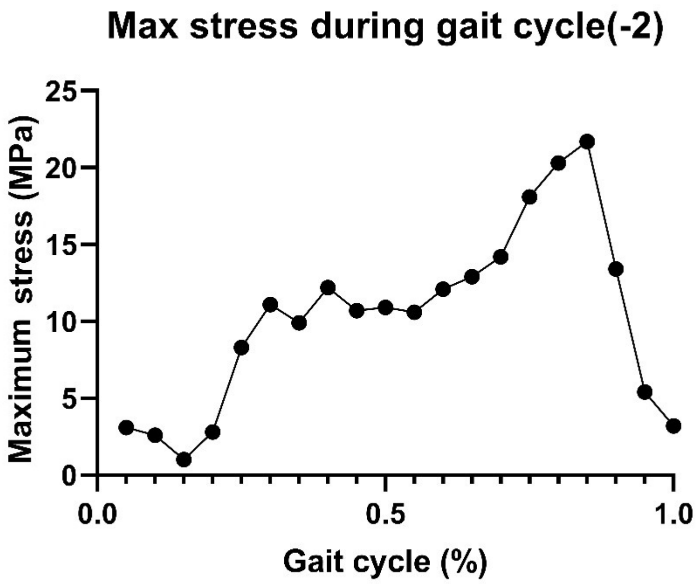


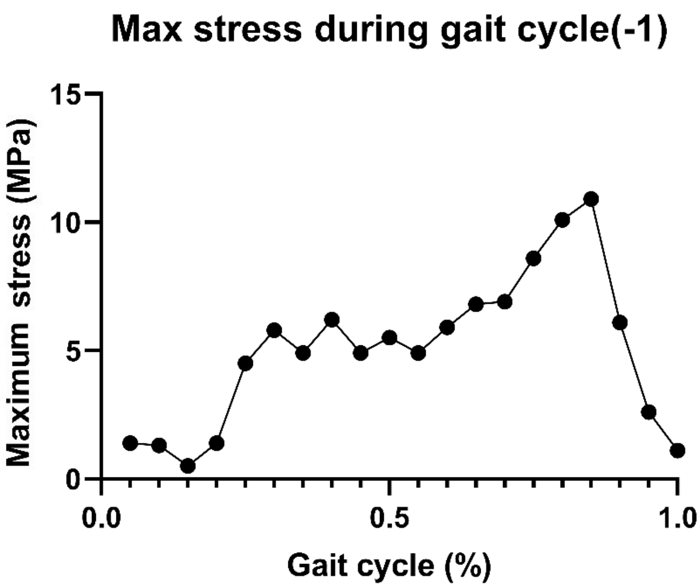
Fig c. Stresses, micromotion, and maximum at anterior notch for different mesh sizes; 0.5 mm mesh was sufficient to ensure accuracy.

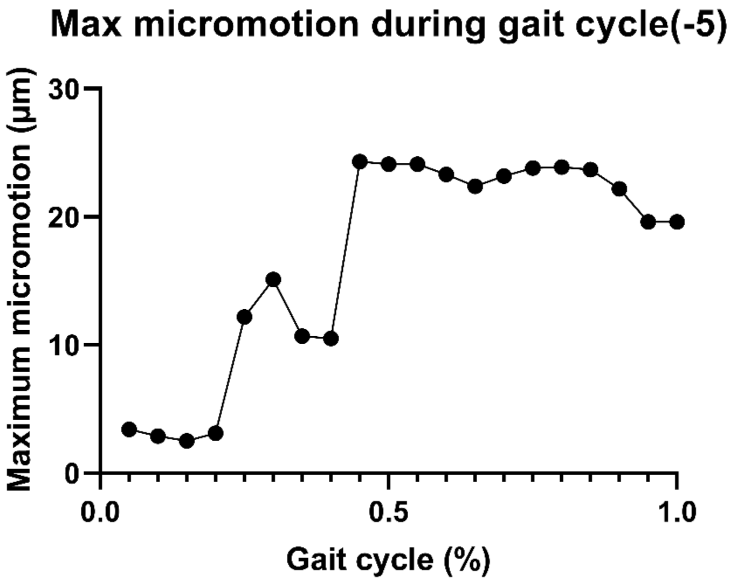
The maximum Von Mises stress at the notch and the maximum micromotion at contact interface during the gait process for all conditions besides -3 mm sagittal position, the results for which are in the main text

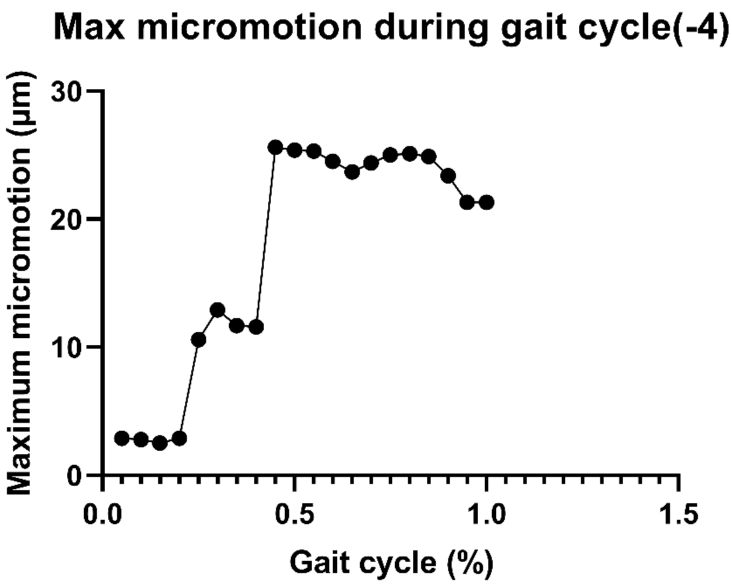


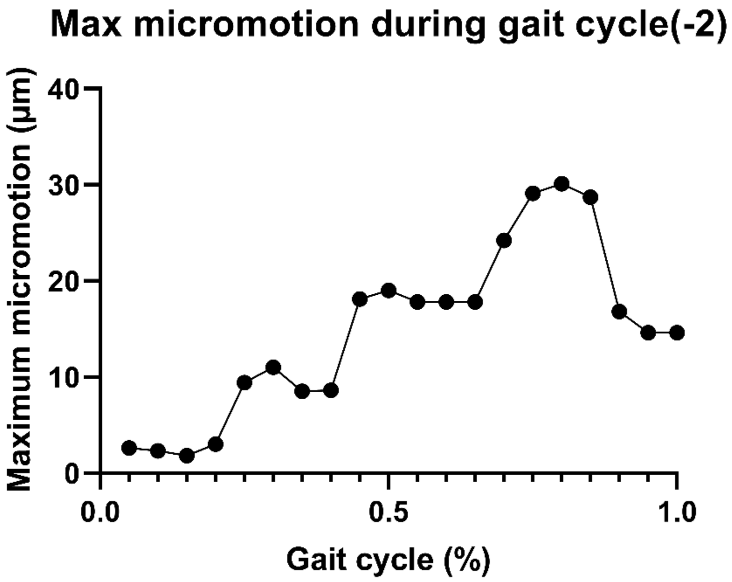


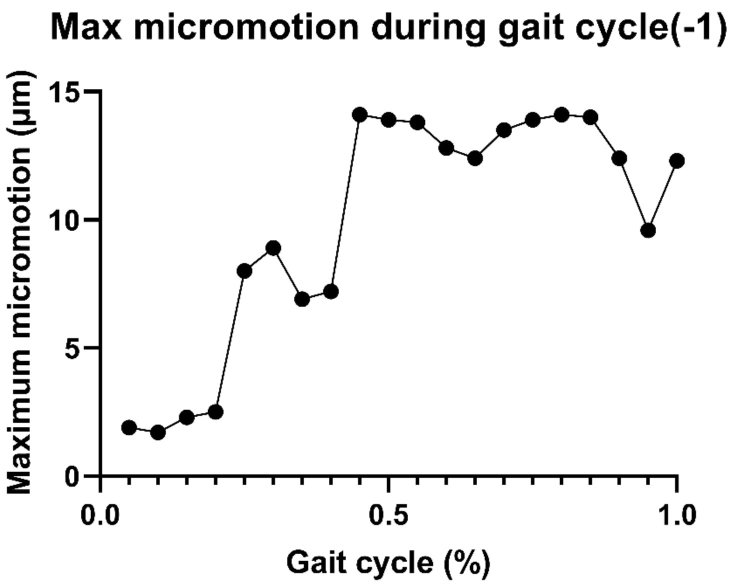

Max stress during gait cycle(-2)
Maximum stress (MPa)
Gait cycle (%)
25
20
15
10
5
0
0.0
0.5
1.0

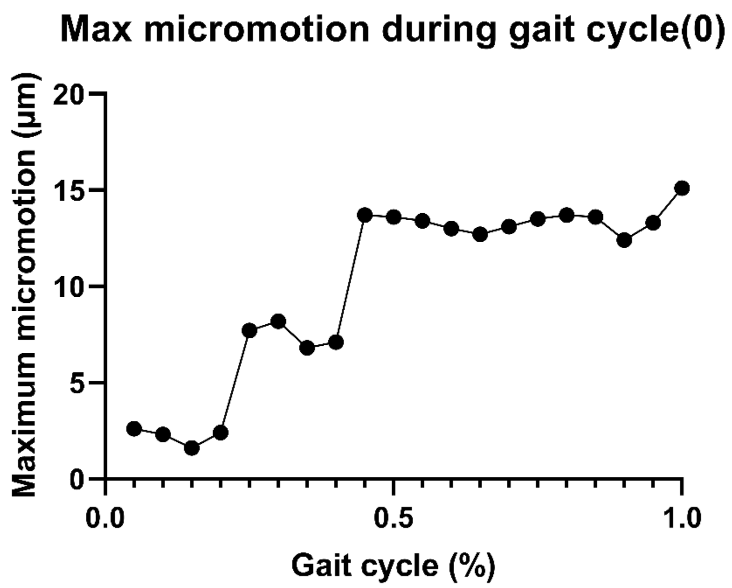

Max stress during gait cycle(-1)
Maximum stress (MPa)
Gait cycle (%)
15
10
5
0
0.0
0.5
1.0

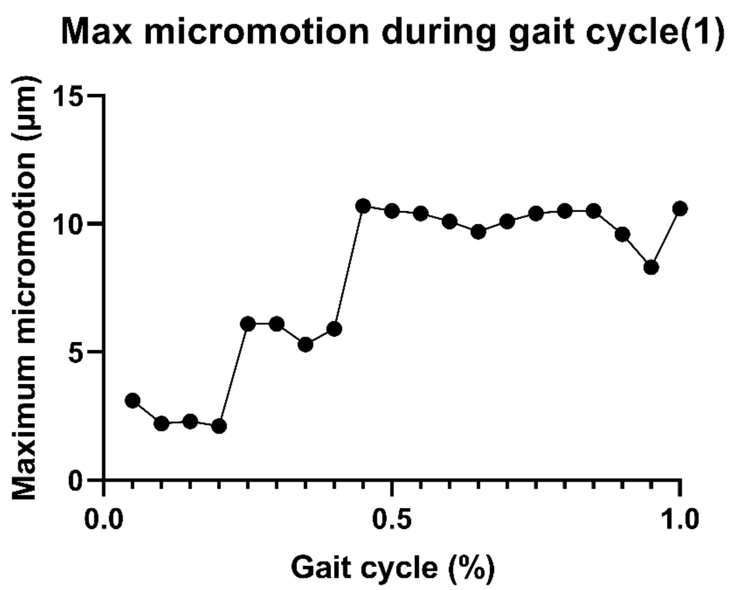

Max micromotion during gait cycle(-5)
Maximum micromotion (μm)
30
20
10
0
0.0
0.5
1.0
Gait cycle (%)

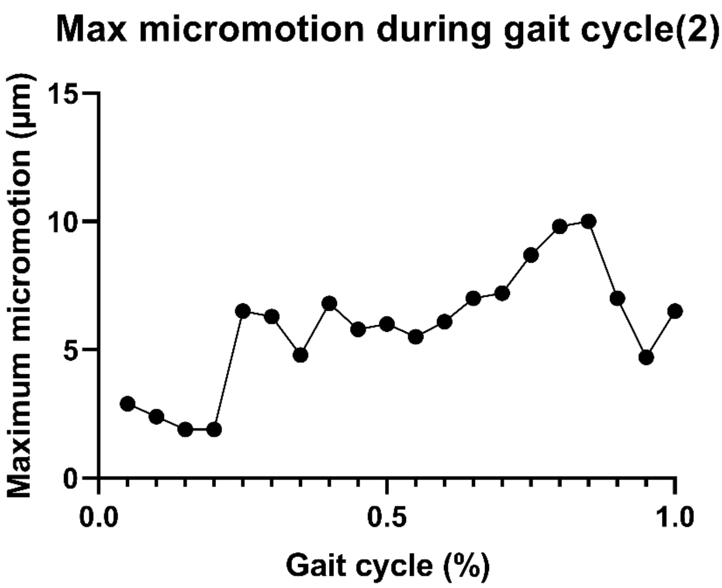

Max micromotion during gait cycle(-4)
Maximum micromotion (μm)
30
20
10
0
0.0
0.5
1.0
1.5
Gait cycle (%)

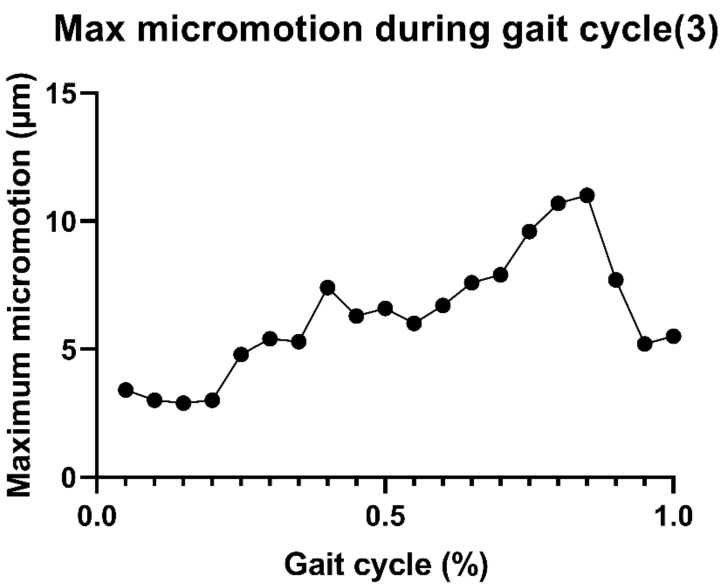

Max micromotion during gait cycle(-2)
Maximum micromotion (μm)
40
30
20
10
0
0.0
0.5
1.0
Gait cycle (%)

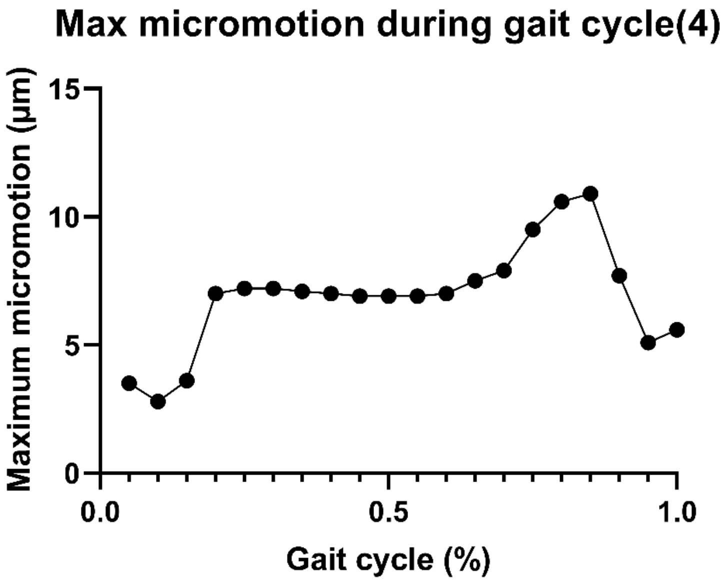

Max micromotion during gait cycle(-1)
Maximum micromotion (μm)
15
10
5
0
0.0
0.5
1.0
Gait cycle (%)


Max micromotion during gait cycle(0)
Maximum micromotion (μm)
Gait cycle (%)
0
5
10
15
20
0.0
0.5
1.0


Max micromotion during gait cycle(1)
Maximum micromotion (μm)
Gait cycle (%)
0
5
10
15
0.0
0.5
1.0


Max micromotion during gait cycle(2)
Maximum micromotion (μm)
15
10
5
0
0.0
0.5
1.0
Gait cycle (%)


Max micromotion during gait cycle(3)
Maximum micromotion (μm)
15
10
5
0
0.0
0.5
1.0
Gait cycle (%)



Max micromotion during gait cycle(4)
Maximum micromotion (μm)
15
10
5
0
0.0
0.5
1.0
Gait cycle (%)

Von Mises stress and maximum principal stress plots for each subgroup

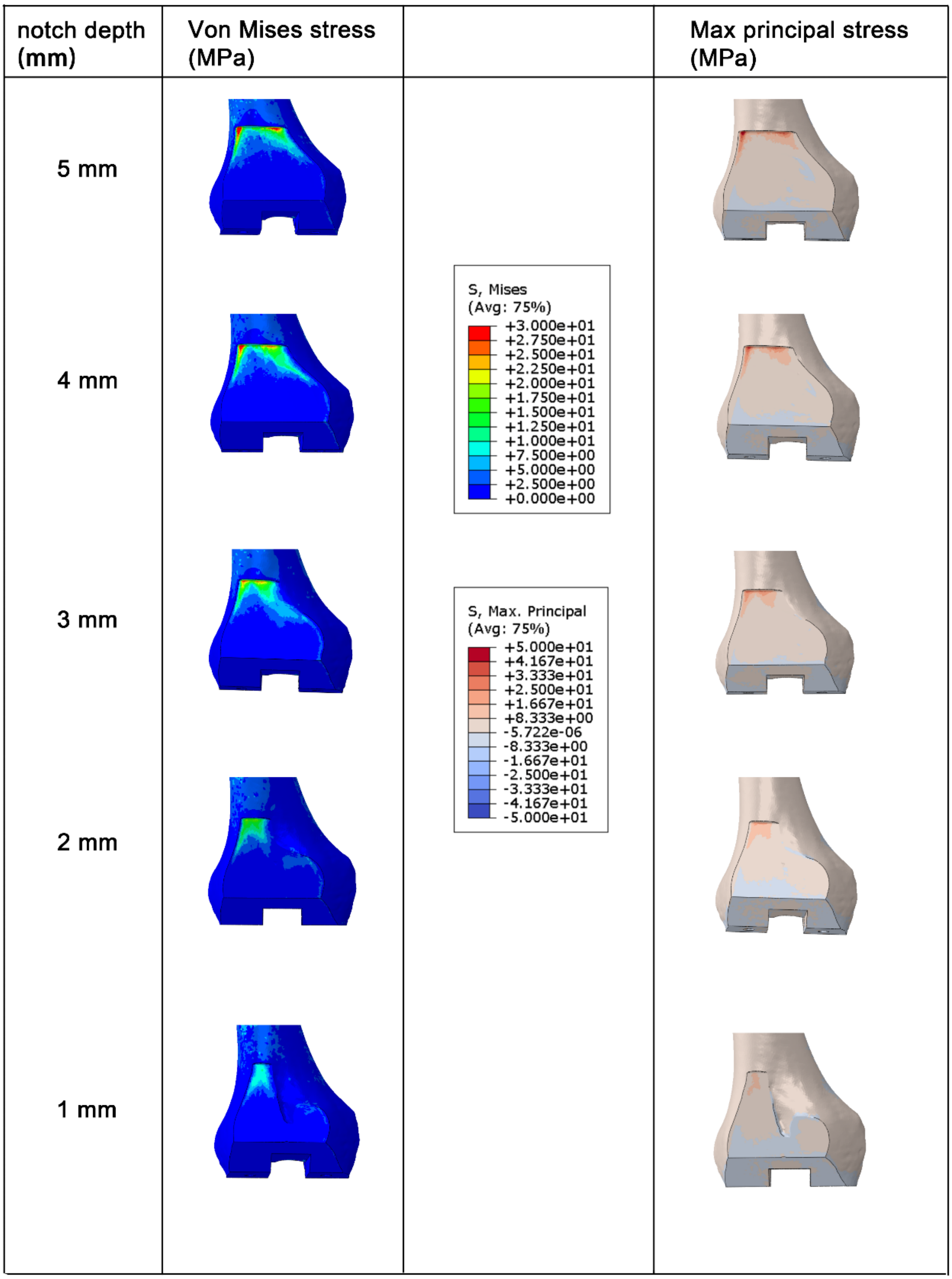


Fig d. Von Mises stress and maximum principal stress plots for each subgroup at gait loading condition.

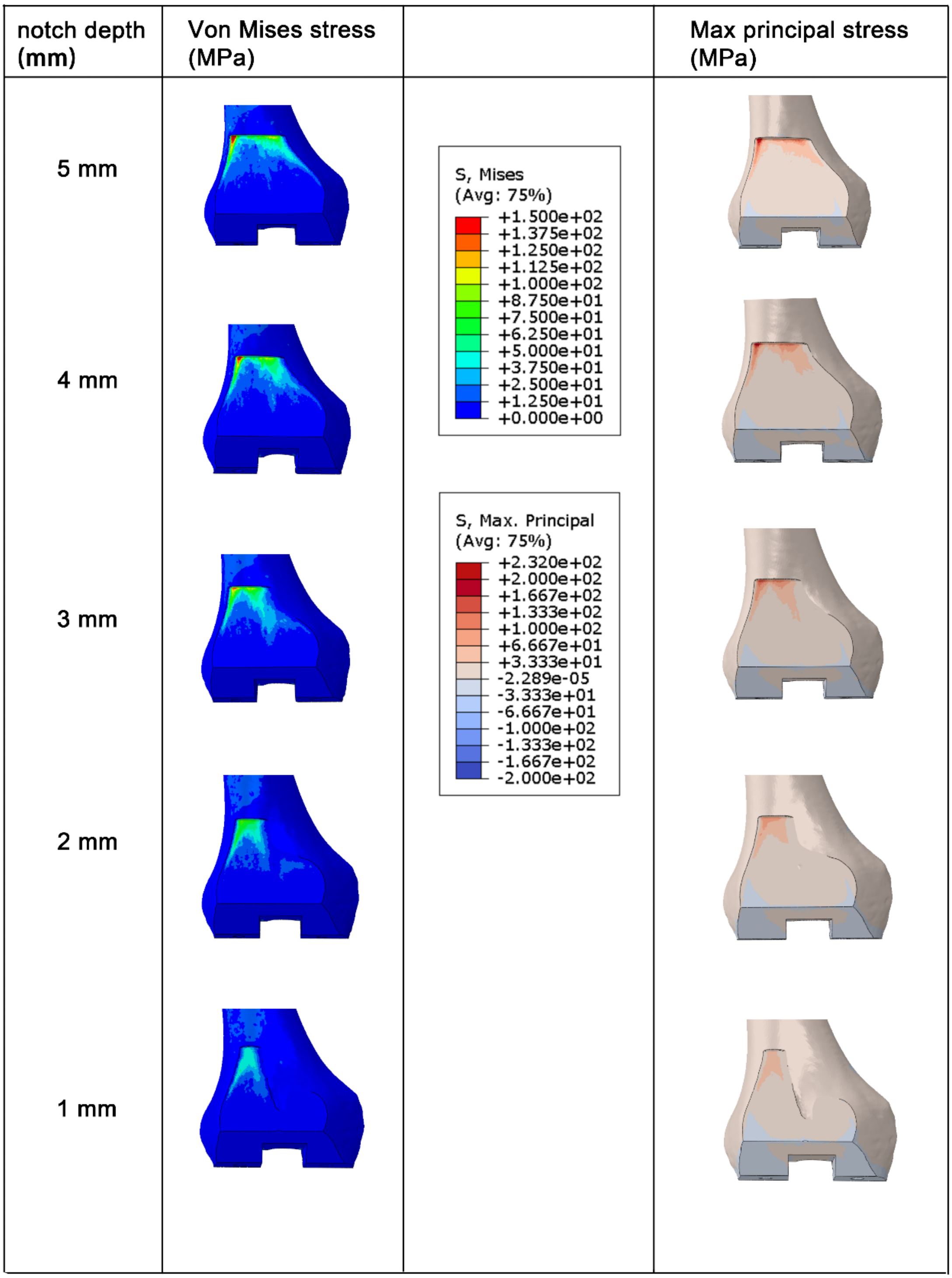


Fig e. Von Mises stress and maximum principal stress plots for each subgroup at deep knee bend loading condition.

References

1. **Gómez FS, Lorza RL, Bobadilla MC, García RE.** Improving the process of adjusting the parameters of finite element models of healthy human intervertebral discs by the multi-response surface method. *Materials (Basel)*. 2017;10(10):1116. doi: 10.3390/ma10101116.
2. **Liu Y, Zhang A, Wang C, et al.** Biomechanical comparison between metal block and cement-screw techniques for the treatment of tibial bone defects in total knee arthroplasty based on finite element analysis. *Comput Biol Med*. 2020;125:104006. doi: 10.1016/j.compbiomed.2020.104006.