

Required fidelity of forefoot geometry representation for practical and accurate prediction of plantar pressures using finite element analysis: SUPPLEMENTARY MATERIALS

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1. Model designs

1.1 Measurements

All simplified models are based on the measurements named in Table 1.

Table 1: Bone measurements for simple models. X means dimension is required to produce model

Measurement	SM1	SM2	SM3
1. Plantar soft tissue thickness (each MTH)	X	X	X
2. MTH width (each MTH)	X	X	X
3. MTH sagittal radius (MTH 2-5)		X	X
4. MTH distal/proximal displacement (MTH 2, 4,5, medial/lateral sesamoids)	X	X	X
5. MTH mediolateral displacement (MTH 2, 4,5, medial/lateral sesamoids)	X	X	X
6. Metatarsal length (all metatarsals)	X	X	X
7. Sagittal plane metatarsal angle	X	X	X
8. Coronal plane metatarsal angle		X	X
9. Sesamoid width (both)		X	X
10. Sesamoid length (both)		X	X

MTH: metatarsal head

1.2 Measurement definitions

Definitions of the measurements taken are provided in this section. Figure numbers refer to those given in Table 1.

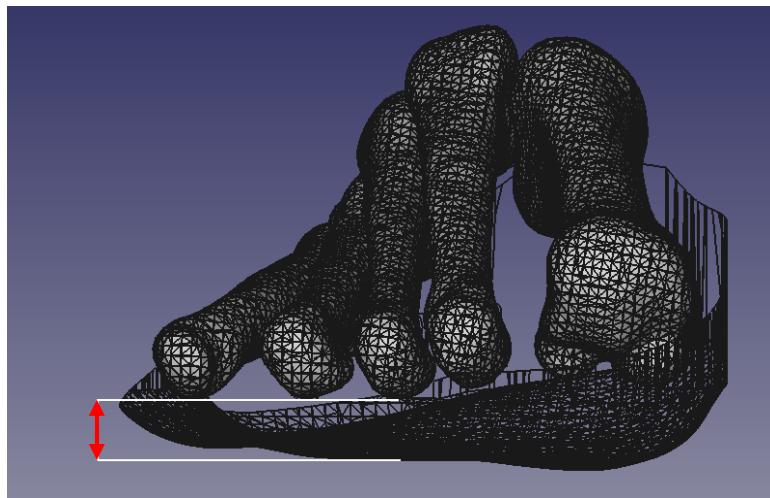


Figure 1 - Plantar soft tissue thickness

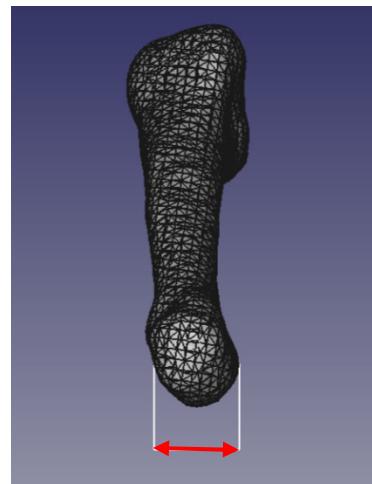


Figure 2 - MTH width

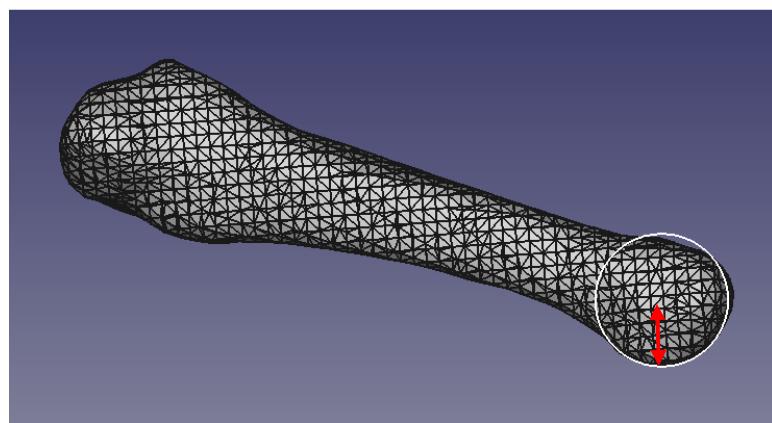


Figure 3 - MTH sagittal radius

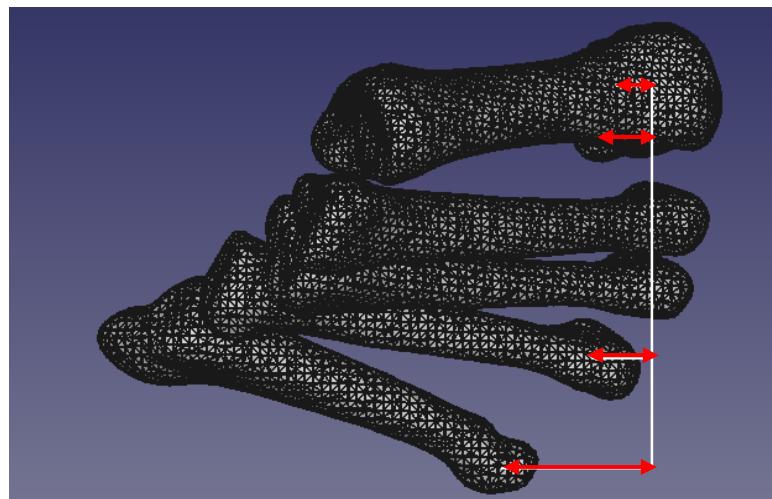


Figure 4 – MTH distal/proximal displacement (from MTH3)

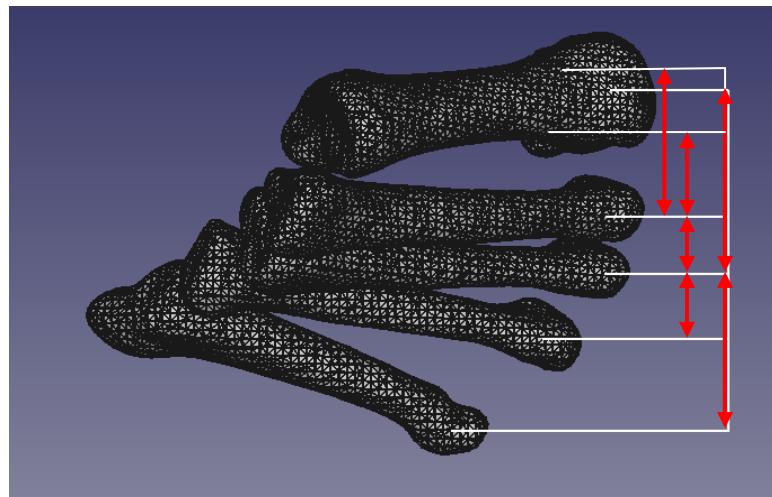


Figure 5 – MTH mediolateral displacement (from MTH3)

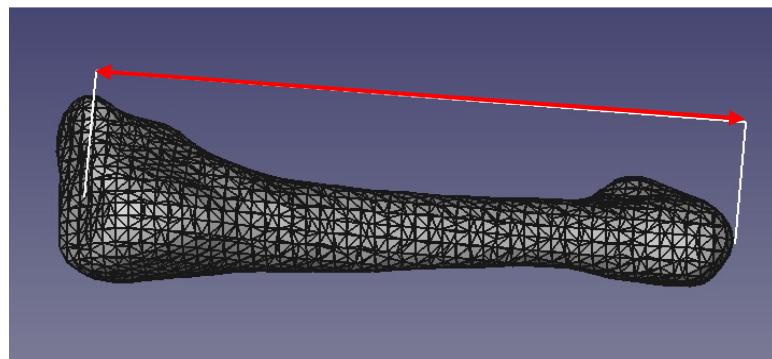


Figure 6 – Metatarsal bone length

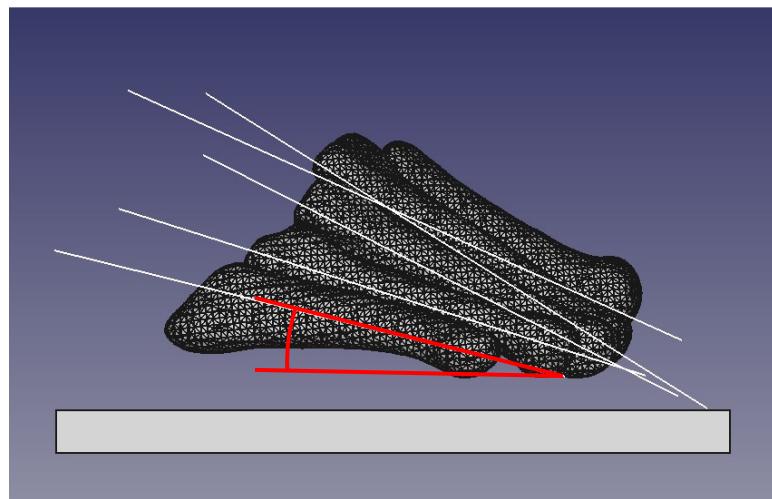


Figure 7 - Sagittal plane metatarsal angle($^{\circ}$)

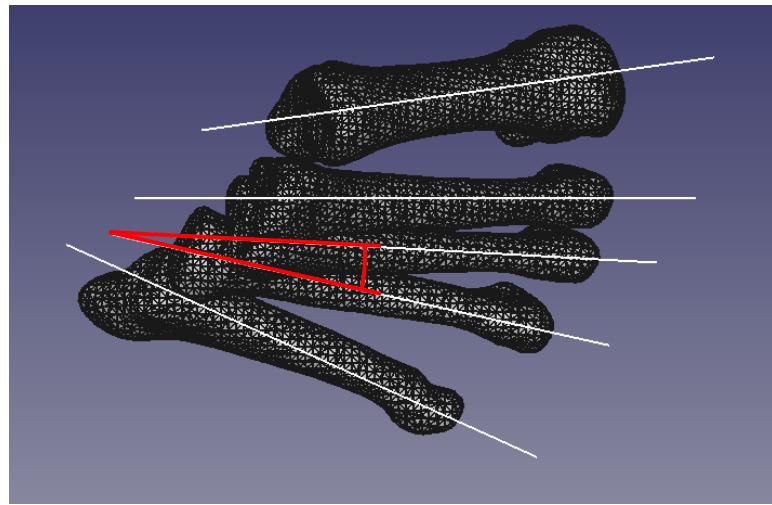


Figure 8 - Coronal plane metatarsal angle($^{\circ}$) taken relative to MT3

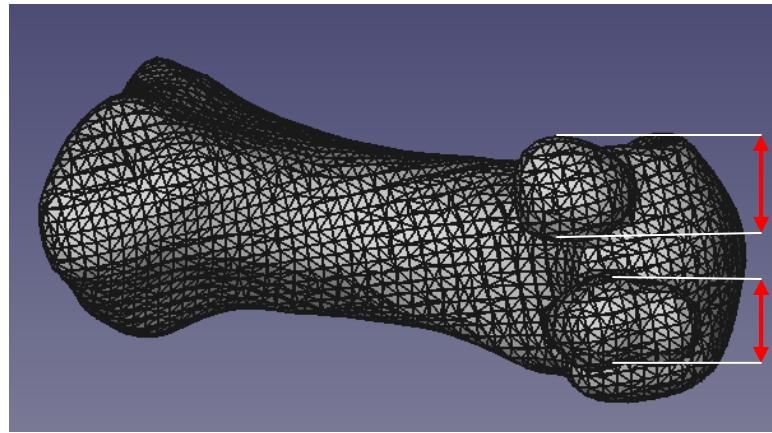


Figure 9 – Sesamoid width

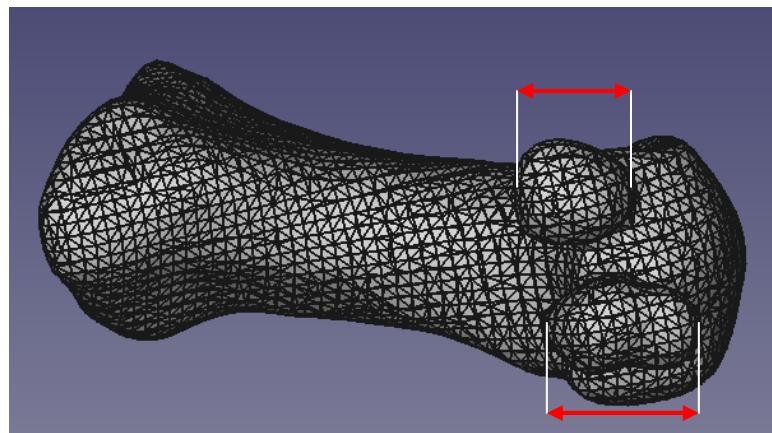


Figure 10 – Sesamoid length

1.3 Model design

1.3.1 Simplified Model 1

The design of SM1 is described in detail in Spirka et al. (J Biomech 2014;47:2948-55). In brief, each metatarsal is formed by a sphere (MTH) defined by the relevant *MTH width* measurement, and a cylinder with diameter 80% of the *MTH width* measurement and length equal to the *Metatarsal length* measurement minus half the *MTH width* measurement. The sphere and cylinder are merged (Figure 11) and rotated to match the *Sagittal plane metatarsal angle* and *Coronal plane metatarsal angle*, then translated to match the *MTH distal/proximal displacement* and *MTH mediolateral displacement*.

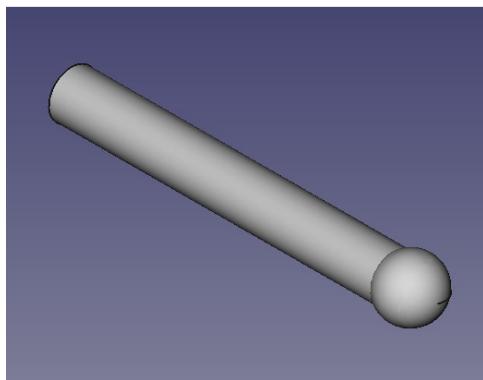


Figure 11 – SM1 metatarsal

The soft tissue block is formed from a cuboid that has its width defined by the measured width of the forefoot (taken from the medial side of MTH1 to the lateral side of MTH5 on the surface scan), length 10mm beyond MTH2 plus the 3rd *metatarsal length*, and the height adjusted such that the bones are embedded fully within the block. Boolean subtraction operations are then performed to remove the upper part of the tissue block such that only the plantar surface of the metatarsals are embedded. A further Boolean subtraction is made at the lateral corner of the block, based on the angle in the coronal plane between MTH3 and MTH5. To accommodate the presence of the metatarsal bones, Boolean subtraction is used to remove a volume in the shape of the CAD metatarsals from the remainder of the tissue block (Figure 12). An ellipsoid object is then produced with height equal to the measured arch height and diameter equal to the distance from the navicular to the terminal point of the medial arch (all measured from foot surface scan) This is then Boolean subtracted from the tissue block to represent the arch in the model.



Figure 12 – SM1 model

1.3.2 Simplified Model 2

For SM2, the MTHs 2-5 are formed by a cylinder on its edge with the radius defined as the measured *MTH sagittal radius* and the height defined as the measured *MTH width* multiplied by 0.8. A fillet radius equal to 30% of the measured *MTH width* is added to both edges of the cylinder (Figure 13).

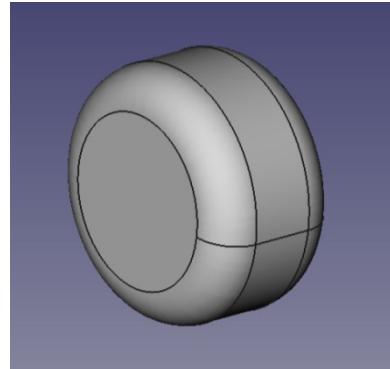


Figure 13 – Metatarsal head in SM2 and SM3

For MTH1, each sesamoid is represented as two spheres (diameter equal to the measured *sesamoid width*) positioned such that their most distal relative points are equal to the measured *sesamoid length*. A cylinder is then placed between the two spheres and all three objects are Boolean joined. Following this, an extrusion, based on the outline of the joined spheres and cylinder and internally offset by 0.5mm is added to join the sesamoids to the main part of the metatarsal. The main part of metatarsal 1 is produced as described for SM1. The shaft cylinder is designed as described previously for the M1 model, and the individual CAD bones are rotated and translated as described previously (Figure 14).

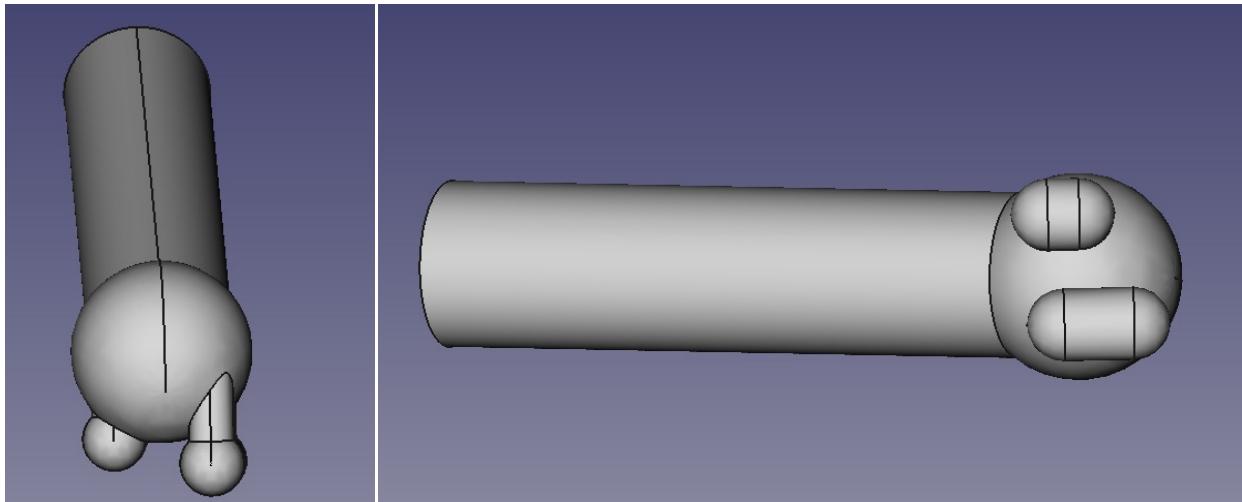


Figure 14 – 1st metatarsal in SM2

The soft tissue block for SM2 is produced in the same manner as described for SM1, with the addition of two further Boolean subtractions on the lateral and medial sides of the block, matching the coronal plane angle of metatarsals 5 and 1 respectively (Figure 15). A 20mm fillet is also applied to the lower medial edge of the block.

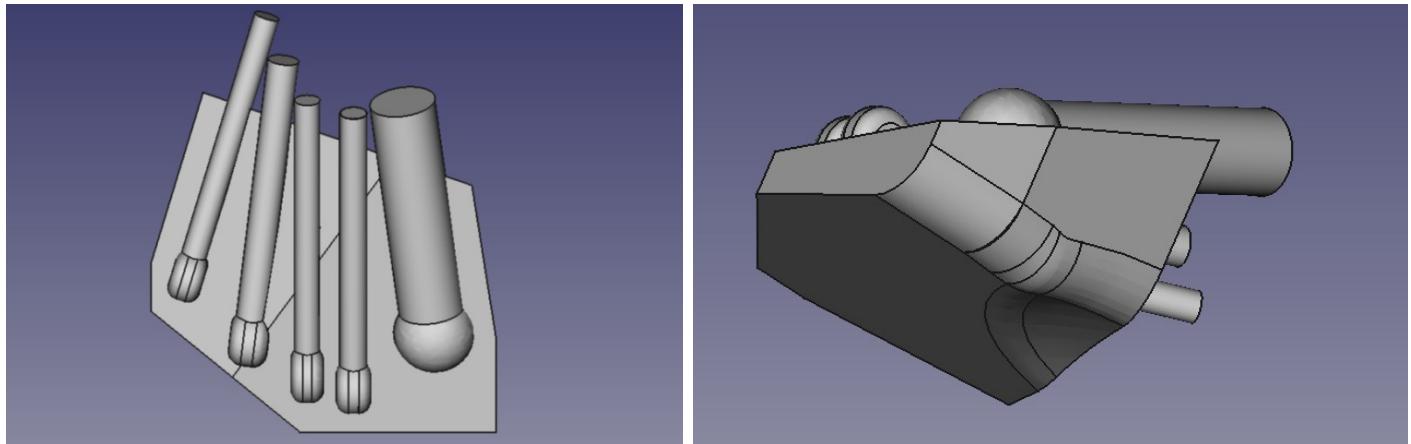


Figure 15 – Coronal view of SM2 (left) and view showing 20mm fillet

1.3.3 Simplified Model 3

For SM3, the metatarsals are designed in the same manner as described for SM2, with the vertical positions adjusted, where necessary, for the contours of the forefoot to ensure the correct tissue thickness below each MTH.

The soft tissue block is produced from the surface scan of the foot. As with the geometric representations of the tissue, Boolean subtractions are performed to trim the scan to the correct size and to remove the upper part of the tissue block such that only the plantar surface of the metatarsals are embedded. Subtractions are performed at the distal end of the metatarsals (perpendicular to metatarsal 3), the lateral corner (angle based on coronal plane angle between MTH3 and MTH5), and the proximal end of the metatarsal (angle based on the coronal angle between the distal ends of metatarsals 1 and 5).

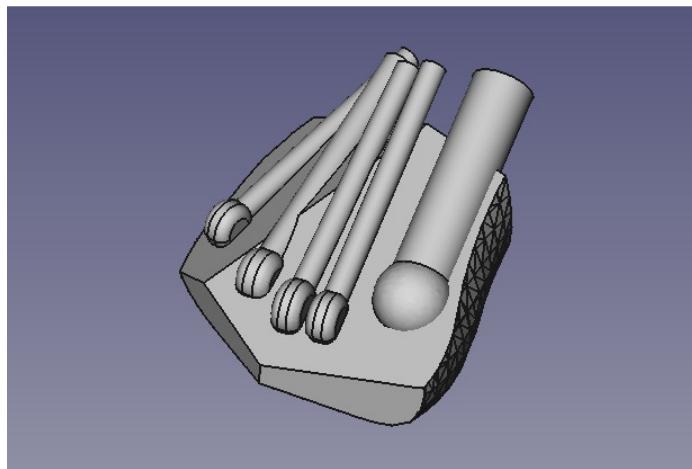
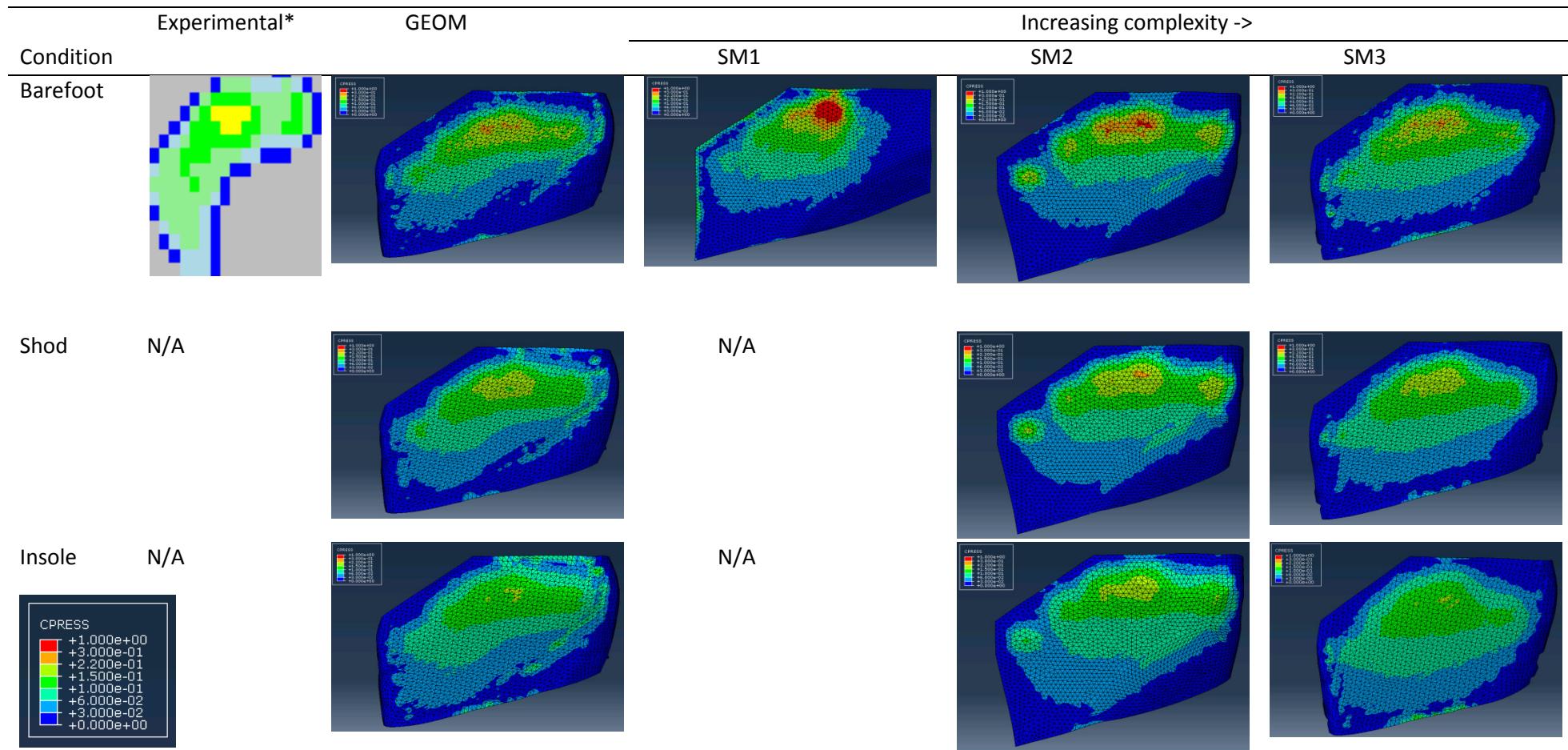


Figure 16 – SM3 model

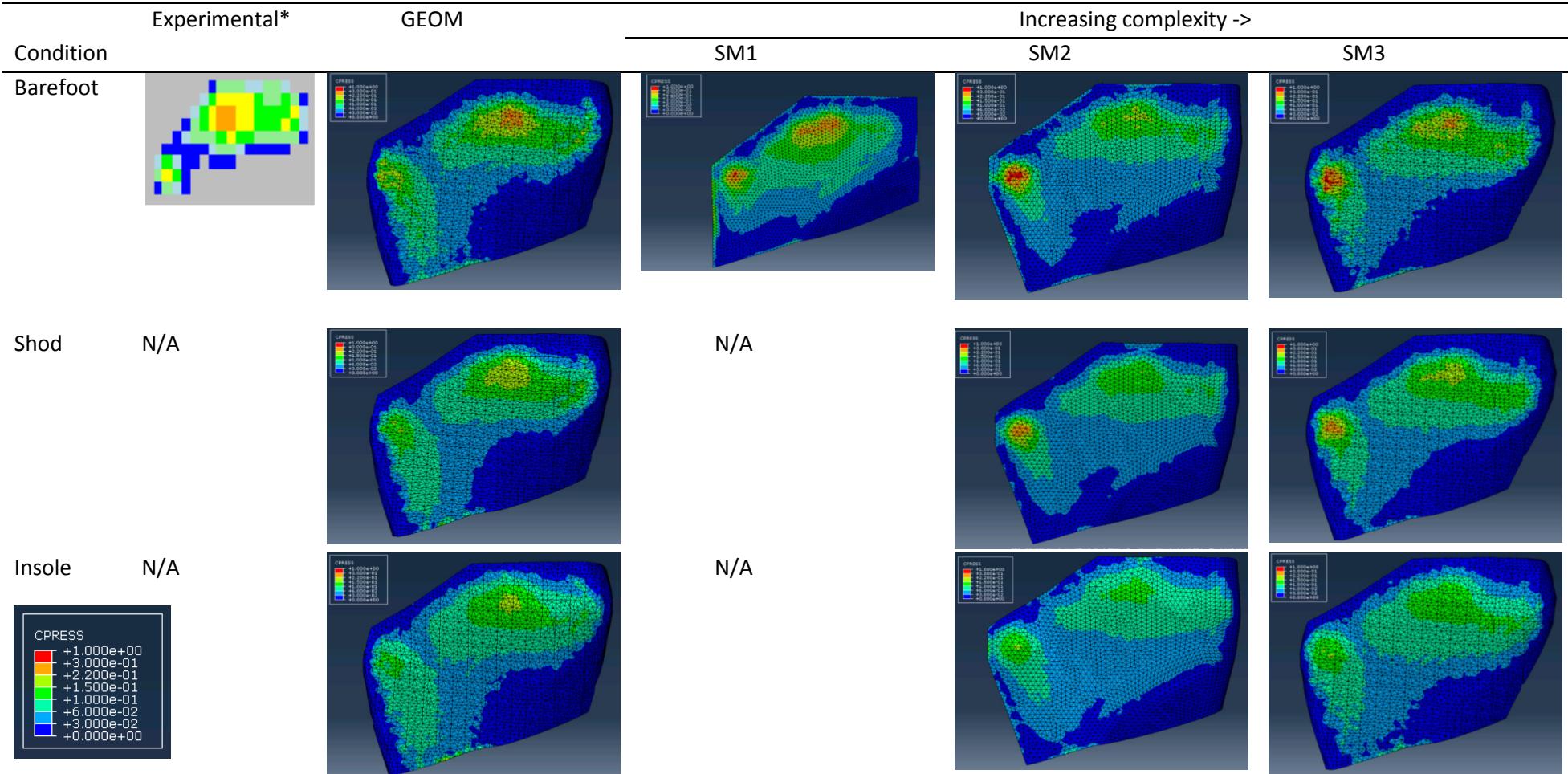
2. Results

2.1 Participant 1 (training set)



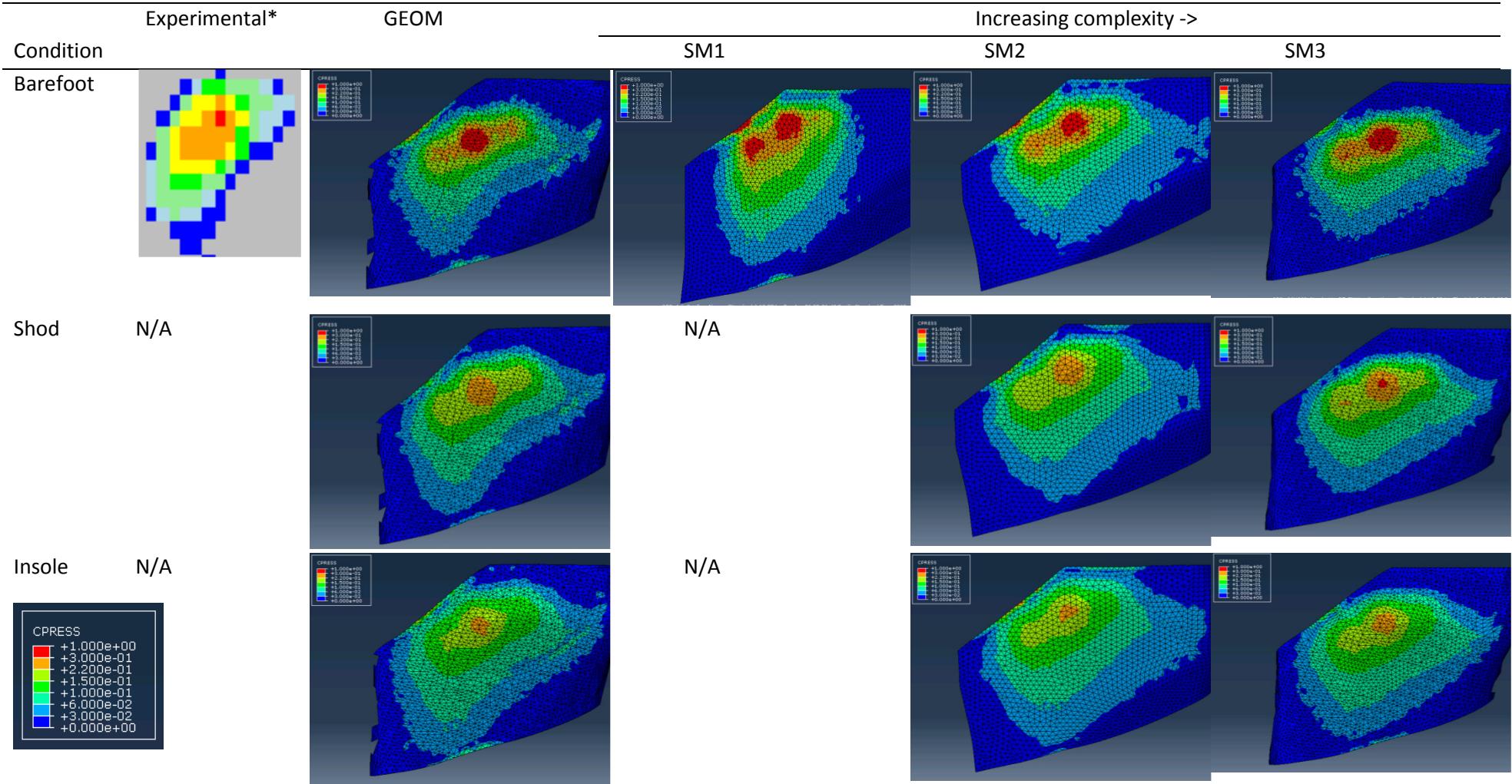
*Note that representative image from one trial used, data used for models is mean of several trials. Data is in MPa

2.2 Participant 2 (training set)



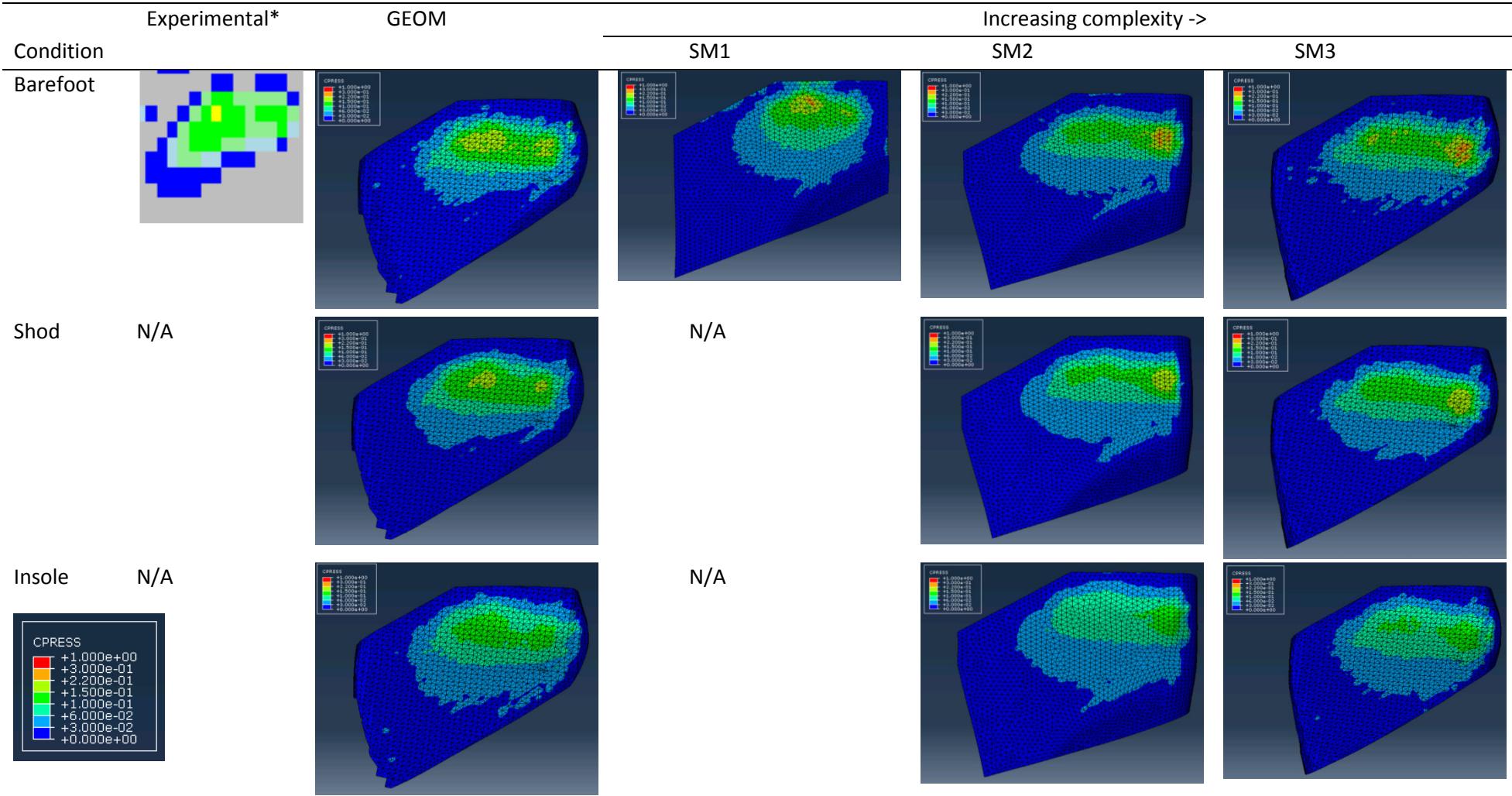
*Note that representative image from one trial used, data used for models is mean of several trials. Data is in MPa

2.3 Participant 3 (training set)



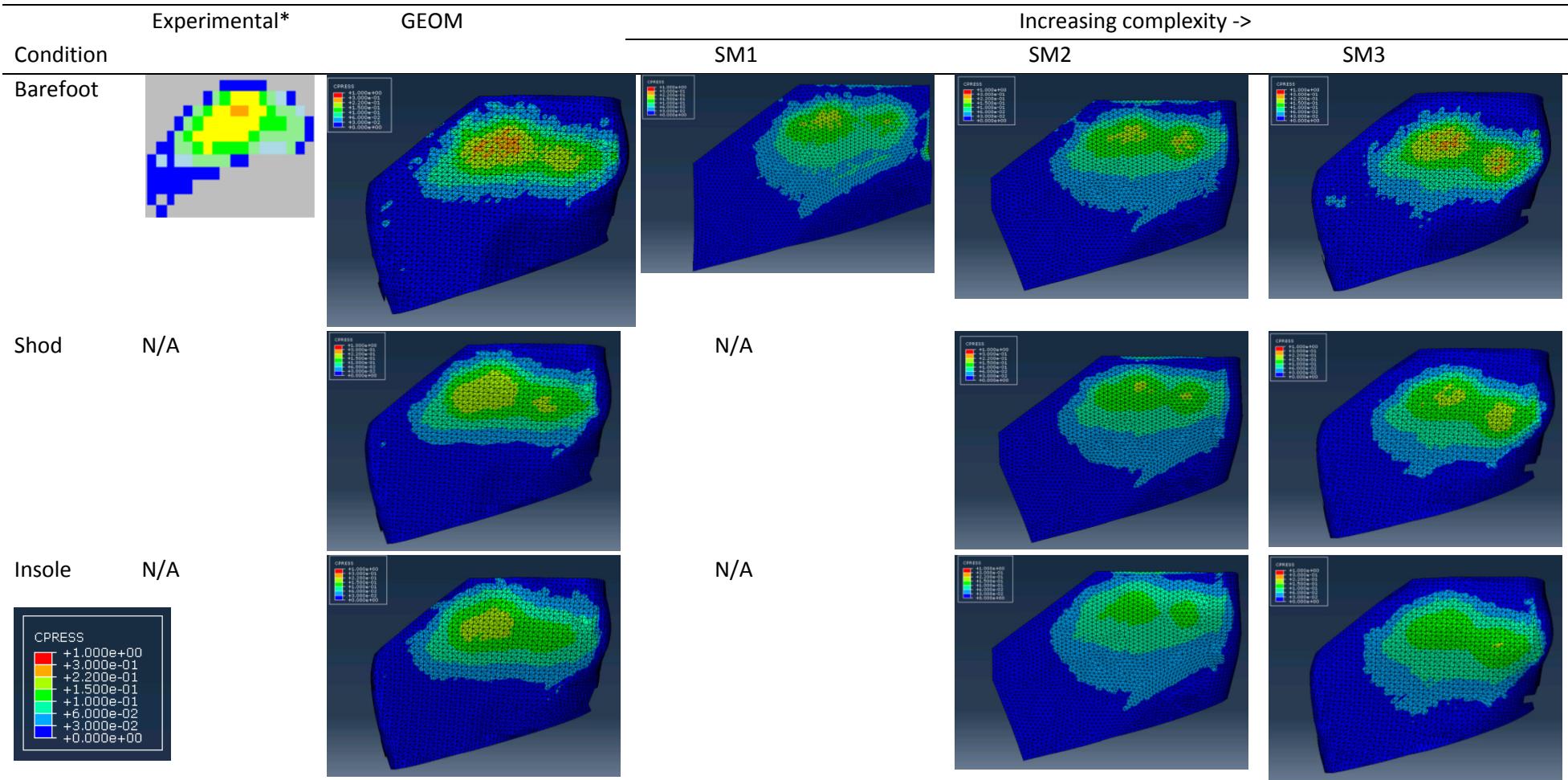
*Note that representative image from one trial used, data used for models is mean of several trials. Data is in MPa

2.4 Participant 4 (training set)



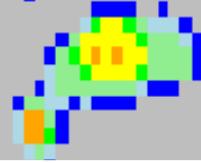
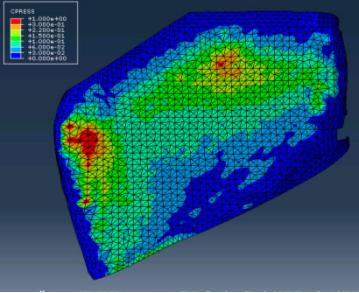
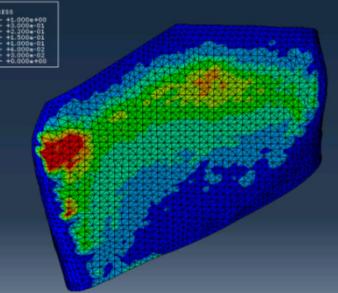
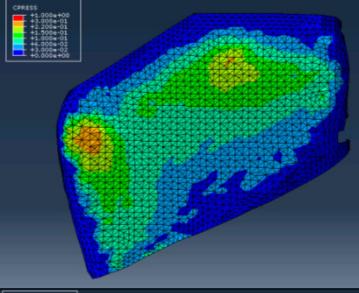
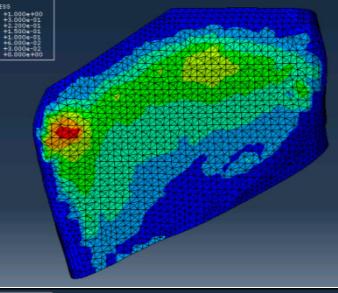
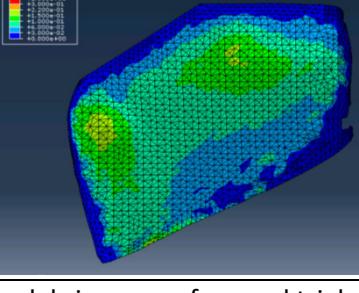
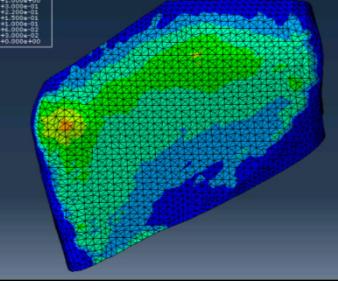
*Note that representative image from one trial used, data used for models is mean of several trials. Data is in MPa

2.5 Participant 5 (training set)



* Note that representative image from one trial used, data used for models is mean of several trials. Data is in MPa

Participant 6 (validation set)

Condition	Experimental*	GEOM	SM3
Barefoot			
Shod	N/A		
Insole	N/A		

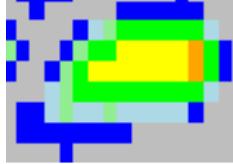
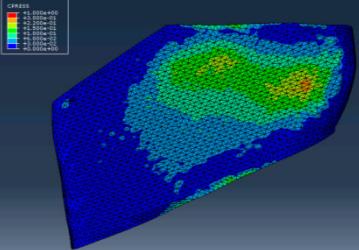
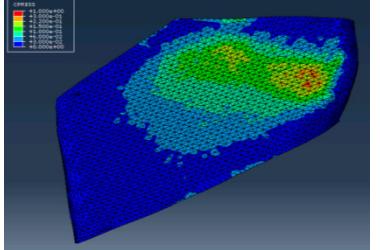
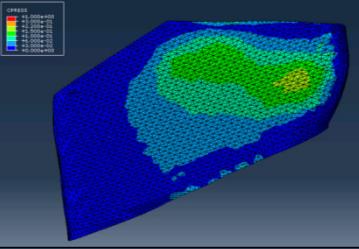
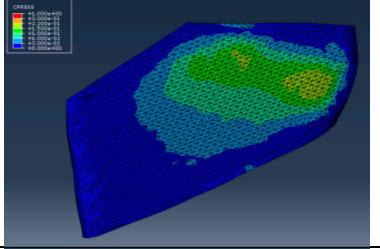
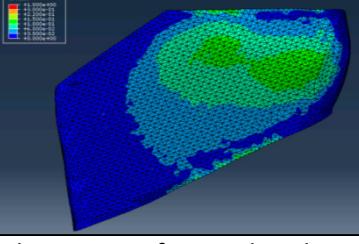
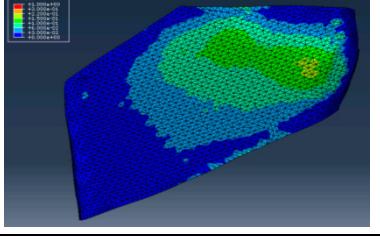
*Note that representative image from one trial used, data used for models is mean of several trials. Data is in MPa

Participant 7 (validation set)

Condition	Experimental*	GEOM	SM3
Barefoot		 CPRESS +1.000e+00 +3.000e-01 +2.200e-01 +1.500e-01 +1.000e-01 +6.000e-02 +3.000e-02 +0.000e+00	 CPRESS +1.000e+00 +3.000e-01 +2.200e-01 +1.500e-01 +1.000e-01 +6.000e-02 +3.000e-02 +0.000e+00
Shod	N/A	 CPRESS +1.000e+00 +3.000e-01 +2.200e-01 +1.500e-01 +1.000e-01 +6.000e-02 +3.000e-02 +0.000e+00	 CPRESS +1.000e+00 +3.000e-01 +2.200e-01 +1.500e-01 +1.000e-01 +6.000e-02 +3.000e-02 +0.000e+00
Insole	N/A	 CPRESS +1.000e+00 +3.000e-01 +2.200e-01 +1.500e-01 +1.000e-01 +6.000e-02 +3.000e-02 +0.000e+00	 CPRESS +1.000e+00 +3.000e-01 +2.200e-01 +1.500e-01 +1.000e-01 +6.000e-02 +3.000e-02 +0.000e+00

*Note that representative image from one trial used, data used for models is mean of several trials. Data is in MPa

Participation 8 (validation set)

Condition	Experimental*	GEOM	SM3
Barefoot			
Shod	N/A		
Insole	N/A		

*Note that representative image from one trial used, data used for models is mean of several trials. Data is in MPa

