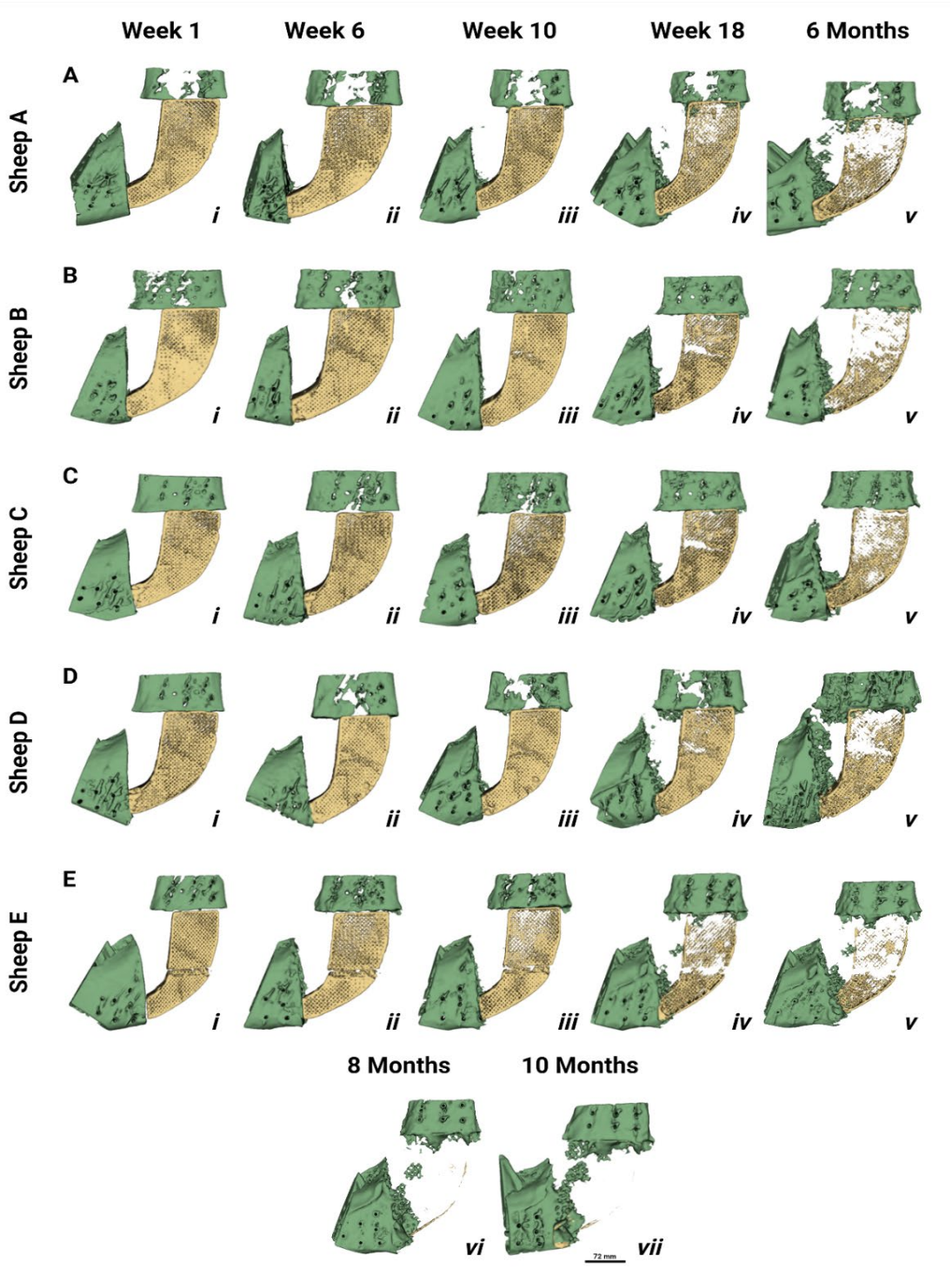
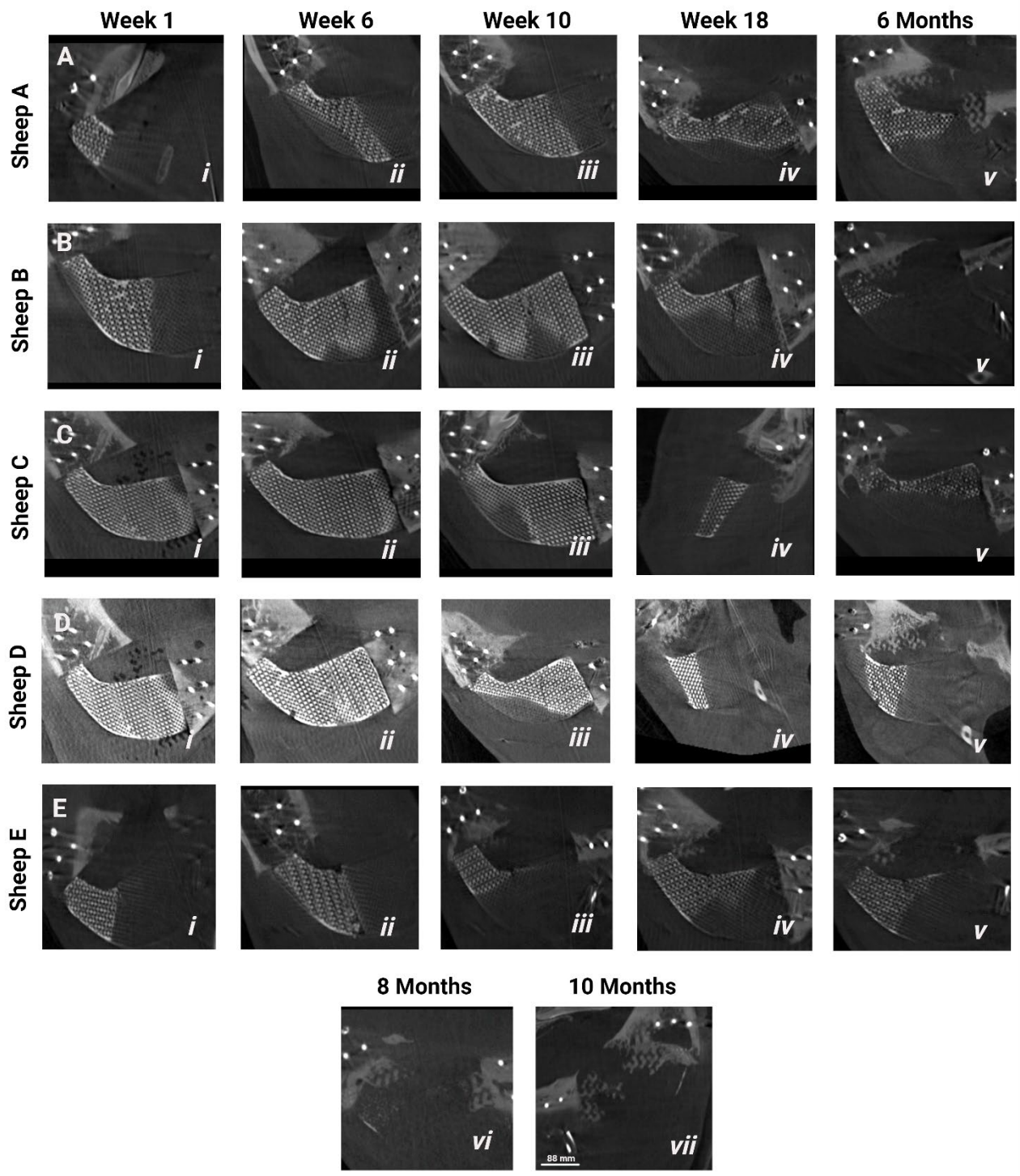
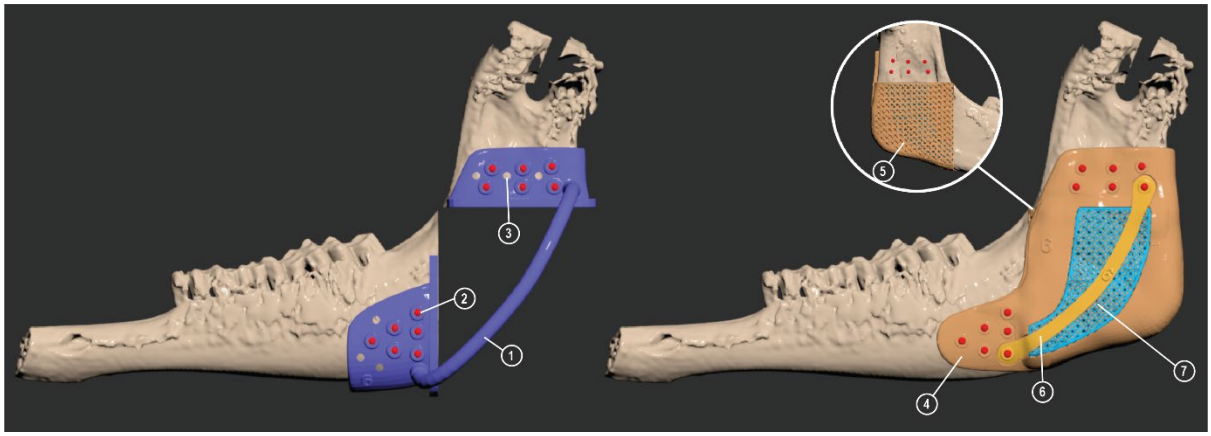


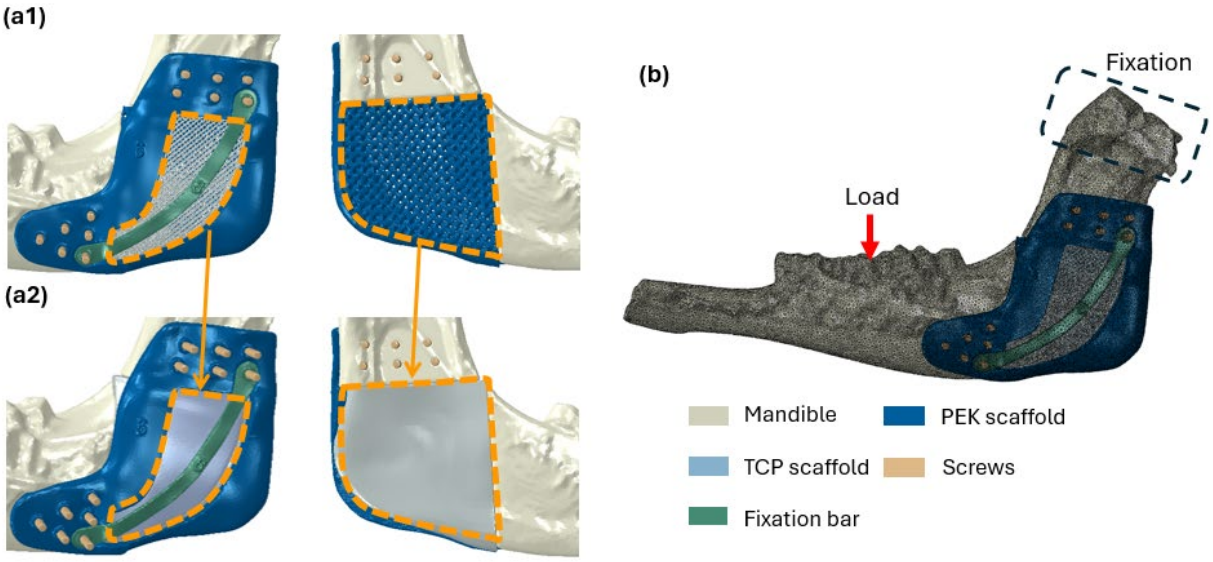
Supplementary Fig. S1: 3D reconstruction of new bone formation within the hybrid artificial bone from CBCT scans taken at various time intervals. This figure shows longitudinal 3D CBCT reconstructions tracking bone formation in segmental mandibular defects of five sheep (Sheep A-E) at various time points post-implantation: Baseline (i), Week 6 (ii), Week 10 (iii), Week 18 (iv), and 6 Months (v). Panels vi and vii display additional scans at 8 and 10 months for Sheep E. Progressive new bone (green) was formed and shown to be interlocking with the SLS-PEK frame (which is radiolucent) in all sheep, however notable osteoconduction bridging the defect was only observed in Sheep A, D, and E. The βTCP lattice within the segmental defect is radio-opaque (yellow). Islands of new bone (green) are seen within the βTCP lattice, which progressive degrades over time but at different rates within each sheep. Scale bar: 72 mm.



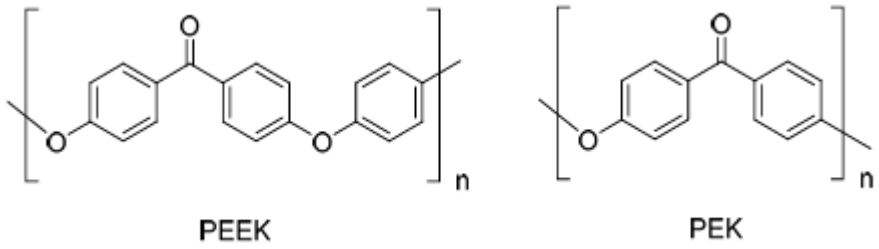
Supplementary Fig. S2: Selected 2D sagittal images of new bone formation within the hybrid artificial bone from CBCT scans taken at various time intervals. CBCT scans display progressive bone formation within the hybrid artificial bone in five individual sheep (A-E) across various post-operative time points: Week 1 (i), Week 6 (ii), Week 10 (iii), Week 18 (iv), and 6 Months (v). Additional time points of 8 Months (vi) and 10 Months (vii) are presented for Sheep E. The 2D images more clearly show new bone filling the voids of the SLS-PEK gyroid scaffold structure than the 3D images; this is evident in all sheep at the bone-implant interface, but can be seen more extensively in sheep A, D, and E.



Supplementary Fig. S3: Virtual surgical planned cutting guide and hybrid artificial bone. (1) SLS nylon 12 surgical guide design (2) Screw hole locations for SLS-PEK frame (3) Screw hole locations for surgical guide (4) SLS-PEK frame (5) TPMS gyroid architecture of the middle component of the SLS-PEK frame (6) SLS-PEK crossbar securing βTCP lattice (7) βTCP lattice inset into SLS-PEK frame.

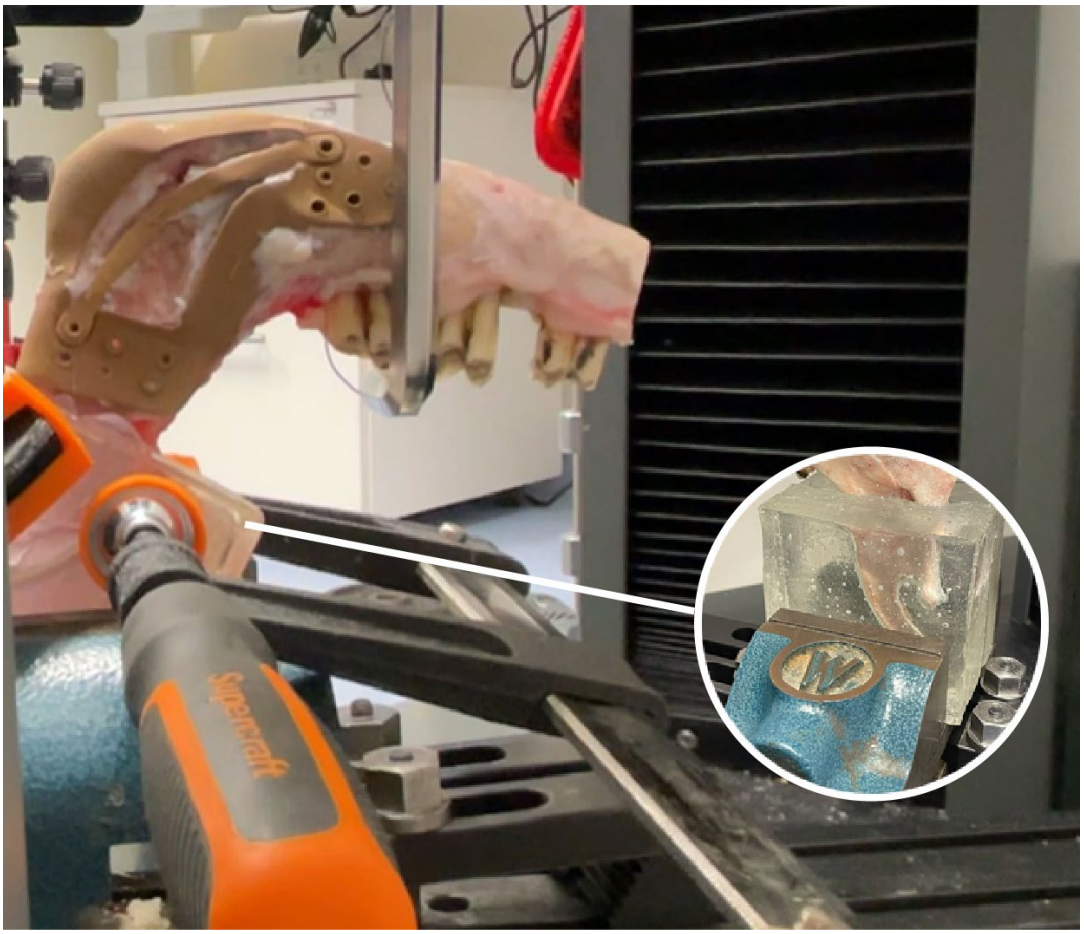


Supplementary Fig. S4: Mechanobiological numerical model of hybrid artificial bone. (**a1**) The βTCP scaffold was positioned on the lateral side of the SLS-PEK frame, while the SLS-PEK TPMS scaffold component of the frame was defined on the medial side. (**a2**) The homogenized solid model of the SLS-PEK and βTCP scaffolds were tailored for the bone growth simulation. (**b**) The mandible was fixed at the condyle, and a compressive load was applied to the teeth for testing.



Supplementary Fig. S5: Chemical structure of PEEK and PEK.

Supplementary Fig. S6: A custom SLS-PEK frame held in the thermal toughening tray.



Supplementary Fig. S7: Mechanical testing setup of the harvested hemimandible with hybrid artificial bone after removal of fixation screws and immobilized using custom resin condyle and coronoid moulds. The molar teeth were loaded until the first sign of mandibular system failure and force-displacement curves generated.

Supplementary Table 1. The parameters for printing PEK using the EOS SLS P800 3D printer system

Layer thickness (mm)	0.12
Temperature set points (℃) Process chamber Building platform Exchangeable frame	 364 336 343
Post-sintering time (s)	12
Beam offset (mm)	0.41
Exposure Parameters Set	Custom
Cool-down cycle	High-Temp Cooldown
Build Volume	350mm x 230mm
Base powder thickness before warmup (mm)	2.5
Base powder thickness after warmup (mm)	6

Supplementary Table 2. The parameters used for the post printing quenching process

Parameter	Value
Heat soak temperature (℃)	300±5
Heat soak time (s)	240
Quench time (s)	50
Quench air temperature (℃)	23±4
Quench air flow rate (m^3/min)	17±10