Biomechanical Study Reveals Stress Redistribution and Energy Absorption after Tripod Technique Reconstruction in Metastatic Periacetabular Lesions

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INTRODUCTION:

The "Tripod Technique", a minimally invasive percutaneous screw reconstruction method, has shown promising clinical results in treating metastatic periacetabular lesions. However, the biomechanical alterations post-Tripod reconstruction remain unclear. We aim to delineate the biomechanical characteristics of pre-and post-Tripod surgery across varied periacetabular defects induced by metastatic cancers.

METHODS:

We utilized pre- and post-Tripod surgery pelvic CT scans from four representative patients to simulate four distinct types of periacetabular defects based on the Metastatic Acetabular Classification system. Three postural configurations—sitting, standing, and walking—were modeled to mimic human physiology. Each model underwent finite element analysis under an axial compression of 500 N applied to the interface of the sacrum while constraining the bilateral femur heads.

RESULTS:

In all four types of bone defect and across three daily living scenarios (sitting, walking, and standing), the Tripod screw reconstruction exhibited notably higher energy absorption compared to the corresponding pre-operative conditions. Prior to surgery, stress was concentrated around the bone defect, yet post-reconstruction, it was substantially mitigated and redistributed across a broader area of normal bone. Post-operatively, the maximal stress was observed at the interface between the cortical bone and the screw, indicating a shift in stress distribution following the Tripod reconstruction.

DISCUSSION AND CONCLUSION:

The findings corroborate the hypothesis that the Tripod Technique effectively stabilizes and shields the acetabulum from various extensive metastatic cancer-induced bone losses or fractures in the acetabular region. Additionally, these results are consistent with observed clinical improvements, including symptom alleviation in patients after surgery.

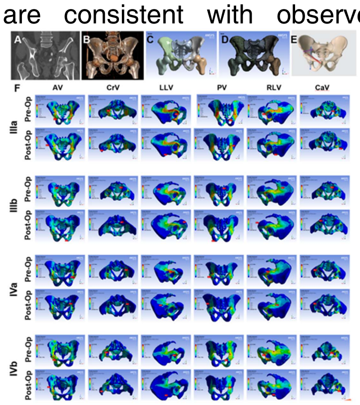

Figure 1. Model establishment and Stress distribution of four types of periacetabular bone defects （IIIa, IIIb, Iva, IVb based on MAC classification） before and after Tripod surgery. (A) Representative CT of a patient with IIIb periacetabular osteolytic lesion and CT reconstructed image (B). Finite element analysis 3D model establishment (C-D), and illustration of Tripod reconstruction. (F) The pre-and post-operative von Mises stress distribution of IIIa, IIIb, IVa, and IVb lesions in standing (shown), walking, and sitting (not shown) positions, respectively. As demonstrated, the highest stress was concentrated around the bone defect before Tripod surgery. Reconstruction with Tripod screws was shown to redistribute stress across the pelvis, roughly recreating the load distribution in the normal pelvis and load transfer from the hip joint to the sacroiliac joint.

AV: Anterior view, CrV: Cranial view, LLV: Left lateral view, PV: Posterior view, RLV: LLV: Right lateral view, CaV: Caudal view.

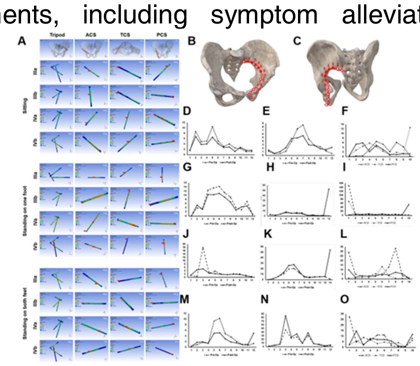

Figure 2. Stress distribution and von Mises concentration within the internal fixation system and the pelvic anterior and posterior ring. (A) Stress distribution of Tripod screws in four types of periacetabular bone defects （IIIa, IIIb, Iva, IV） in sitting, standing, and walking position. (B-C) In order to better analyze the stress changes after the Tripod reconstruction, twelve continuous linear regions around the bone defect in line with either the pelvic anterior or posterior ring were compared. The von Mises concentration in IIIa (D-F), IIIb (G-I), IVa (J-L), and IVb (M-O) type of lesions of the pelvic anterior ring (D,G,J,M), pelvic posterior ring (E,H,K,N) and Tripod internal fixation system (F,I,L,O). As shown, in all four types of bone defects, Tripod reconstruction significantly redistributes stress across the pelvis and relieves the stress concentrated around the bone defect.

ACS: Anterior Column Screw, PCS: Posterior Column Screw, TCS: Transverse Column Screw.