Strain Changes Associated with Pelvic Fracture Healing: A Proof-of-Concept Investigation Using Experimentation and Finite Element Analysis

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Summary

To investigate the possibility of monitoring pelvic fracture healing using the strain change on an instrumented implant, both finite element (FE) analysis and a validation experiment of a composite bone were conducted. In each case, discrete stages of the fracture healing process were represented by removing increasing amounts of bone material along the fracture line. The results demonstrate the feasibility of monitoring the fracture healing by the strain change on the implant and provide basis of the smart implant to monitor the pelvic fracture healing.

Introduction

Pelvic fracture associated with traumatic injury has a mortality up to 23% [1], which is a consequence of its proximity to organs which may be injured by bone fragments leading to severe hemorrhage. Previous research has demonstrated a capability to infer fracture healing based on strain measurements of instrumented fracture plates [2]. This promising approach has the potential to objectively guide rehabilitation protocols, however, this method has never been used in the pelvic fracture. This research aims to determine the strain range on the implant at various stages of fracture healing in both experimental and numerical methods.

Methods

A composite hemipelvis (3409, Sawbones) was tested experimentally under three configurations: intact, partially-cut and fully-cut, which were assumed to represent a healed, healing and fractured bone, respectively. The cut was positioned to create a fracture line for an iliac wing fracture. A customized stainless-steel implant was designed with a thickness of 2.5 mm, 3D-printed then attached to the ilium with non-locking screws. The bone in proximity to pubic symphysis joint (PSJ) and the sacroiliac joint (SJ) were clamped using poly (methyl methacrylate) and attached via fixtures to a testing machine (Instron 8874). The bone was oriented such that a ball-ended loading rod applied force to the acetabulum in the direction of peak hip force measured in a walking cycle from an instrumented hip implant [3]. Three sets of rosette strain gauges were applied to the implant in positions G1, G2 and G3 (**Figure 1a)**. An initial force of 150 N was applied to the loading rod, which was increased at 150 N/s to 850 N. The peak force was held for 5 seconds, over which the maximum and minimum principal strains were computed for each strain gauge.

A FE model was created for the experiment in Abaqus (Dassault Systèmes). The geometry of the hemipelvis was obtained via a CT scan and segmented to create a 3D model using Mimics 21.0 (Materialise). The Young's modulus of trabecular bone, cortical bone and the implant were 170 MPa, 16 GPa and 163 GPa, respectively. The PSJ and SJ were both clamped. The force magnitude and direction of the experiment (from 150 N to 850 N) was applied to the acetabular surface. The simulation was repeated for the three configurations (intact, partially-cut and fully-cut), with tetrahedral elements along the fracture line removed accordingly.

Results and Discussion

The experimental maximum and minimum principal strain measured on the implant decreased from the fully-cut to partial-cut to intact conditions (**Table 1)**. The strain decreases from the fully-cut to the intact condition was over 60%. A linear regression between the experimental and simulated strains indicated good correlation (r^2=0.924), with a slope and intercept of 0.82 and -5.00 με, respectively (**Figure 1b)**.

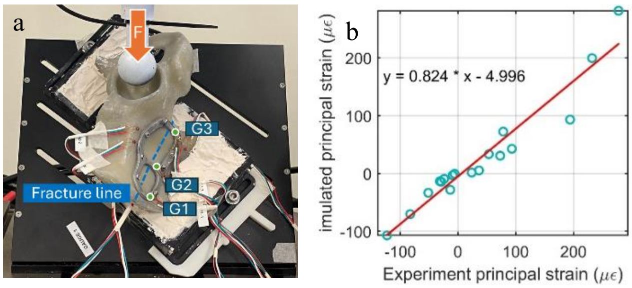

Figure 1: a. Experimental setup (F: force direction, G1 to G3: strain gauge number); b. Comparison of strain between experiments and simulation.

Conclusions

This study supports the feasibility of using an instrumented fracture plate to monitor the iliac fracture healing via the strain change. Good agreement between the experiment and simulation strains confirms the validity of the modelling approach, in particular the boundary conditions. Future work will apply these experimental and computation techniques to cadaveric hemipelvis which will be used in the development of a wireless sensor to monitor the fracture healing process in the pelvic region.

References

[1] Balogh et al. (2007), *J Trauma*, **63(5) p**: 1066-1073.
[2] Cunningham et al. (1987), *J. Med. Eng*, **16(4)**:229-232.
[3] Bergmann et al. (2016), *PloS one*, **11(5)**: e0155612.

Table 1: Max. and Min. principal strain on the implants measured in the experiments.

Stage	Max. and Min. strain of gauge 1 (με)		Max. and Min. strain of gauge 2 (με)		Max. and Min. strain of gauge 3 (με)	
Fully-cut	189.82	-50.20	228.75	-79.54	300.40	-130.20
Partially-cut	35.52	-9.05	92.73	-29.75	85.37	-33.42
Intact	23.67	-6.16	73.33	-24.67	51.96	-32.60