Use of High-Speed X-Ray to Document Bone-Implant Motion and Fracture During a Post-Mortem Human Subject Fall Impact

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I. INTRODUCTION

Hip fracture is a devastating injury that causes staggering morbidity and mortality rates, particularly in elderly populations. This injury most often occurs during a sideways fall from standing height [1]. In experimental biomechanics, high-speed x-ray has been used to capture internal skeletal phenomena such as distal radius fracture in a fall [2] and impact of the mandible [3]. This high-speed x-ray technique was applied to fresh frozen post-mortem human subject (PMHS) pelvis-femora implanted with an orthopaedic fracture fixation system and subjected to a sideways fall. The implantation of orthopaedic hardware for fracture fixation or to augment skeletal strength is common, and there is a paucity of data regarding the relative bone-implant motion that occurs during traumatic injury. This work presents a method and preliminary results for the capture and quantification of bone-implant motion and subsequent fracture in a PMHS during a simulated sideways fall impact.

II. METHODS

A custom high-speed x-ray system was added to a previously developed pendulum impactor that guides PMHS pelvis-femora encased in a subject-specific soft tissue surrogate in an inertia-driven fall. The biplanar x-ray system used in this study consists of two x-ray sources and corresponding image intensifiers with high-speed video cameras mounted to them (see Fig. 1). Protocol details related to the PMHS preparation and fall experiment can be found in the work of [4]. Before soft tissue moulding, a fellowship-trained orthopaedic surgeon (PG) implanted the impacting (left) femur of each PMHS with a titanium intramedullary nail and lag screw. After the fall impact, PG inspected each PMHS and classified fracture severity.

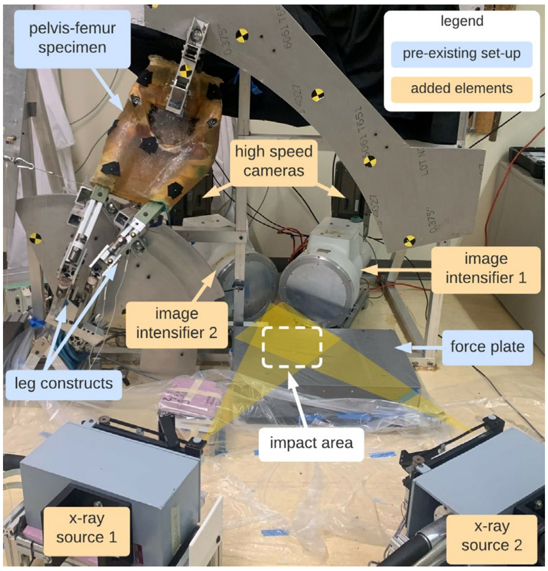

Fig. 1 Experimental set-up with previously existing [4] and newly introduced protocol elements indicated.

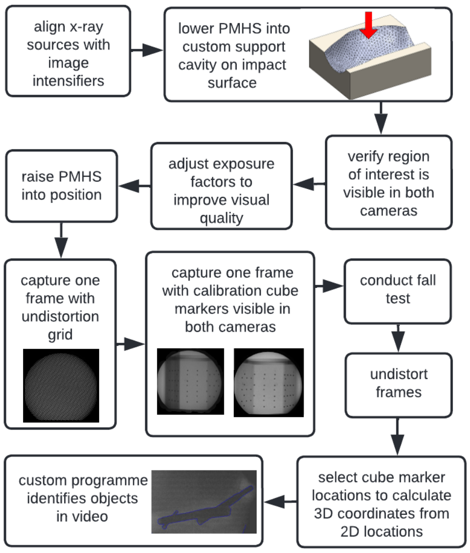

Fig. 2 Current workflow for capturing and processing x-ray data.

The procedure used to prepare, collect, and process x-ray data is described in Fig. 2. Emitted voltage (kV) and current (mA) of the x-ray system are adjusted with a microprocessor-based control panel set in fluoroscopy mode. The exposure of the video cameras is set in the corresponding camera software and the high-speed

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cameras were set at a frame rate of 8,500 fps. X-ray video frames are synchronised with force plate data via an electrical contact trigger activated during the descent of the falling PMHS construct. XMALab software [5] is used for video undistortion and calibration steps, and a custom programme uses edge detection algorithms to identify objects in the video like orthopaedic implants or bony features.

III. INITIAL FINDINGS

Preliminary results include two PMHSs tested and evaluated using the described method (Table I.)

TABLE I.
DESCRIPTION OF PMHSS

PMHS	Sex	Age (years)	Fracture outcome
1	Male	81	Left pelvic ramus and ischium
2	Female	63	No sign of fracture

The pelvic fracture in PMHS 1 was observable on the collected x-ray videos, initiating at 2 ms after the peak force of 3996 N (Fig. 3A), during the rebound phase occurring after initial impact. Although no sign of fracture was present in PMHS 2, movement of the distal tip of the nail in the shaft of the impacting femur was observed (Fig. 4). The relative distance between the implant and medial cortex varied by up to 1.35 mm over the span of less than 1 ms and was visually reminiscent of a wobbling motion.

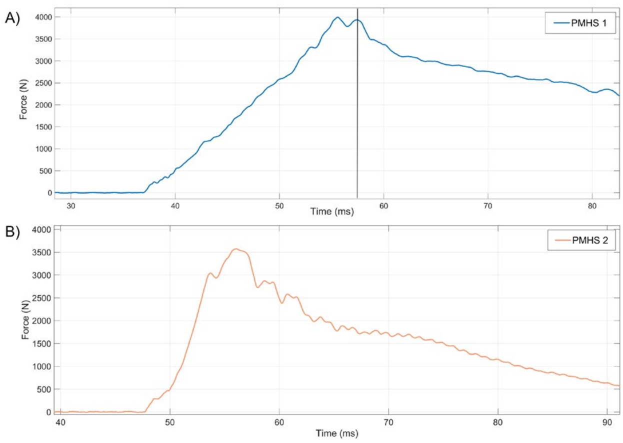

Fig. 3 Force-time curve for A) PMHS 1 and B) PMHS 2. The vertical black line on A) shows the frame where fracture became visible on x-ray.

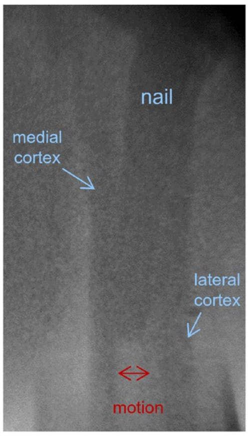

Fig. 4 Diagram showing location of nail tip motion recorded within the intramedullary space.

IV. DISCUSSION

These preliminary results demonstrate the ability to capture skeletal fracture and quantify relative bone-implant motion during a sideways fall impact. Collecting these data during an impact expands on how such positional information is typically acquired from pre- and post-impact scans alone. It could be speculated that this implant motion may correlate to features of the impact force-time curve (Fig. 3B); however, the underlying mechanics of this phenomenon merit further examination. Future work in this study will increase the number of PMHSs tested and improve x-ray video quality through exposure factor and post-processing modifications.

To the authors knowledge, documenting the relative motion of implants and bone during traumatic injury at high speeds is a relatively unexplored field in biomechanics. The presented method offers the novel opportunity to document fracture phenomena together with implant behaviour during a common impact scenario. Such information could be key to better understand and ultimately prevent catastrophic injuries like hip fracture.

V. REFERENCES

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