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Short communication

An *ex vivo* experiment to reproduce a forward fall leading to fractured and non-fractured radii

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ABSTRACT

Forward falls represent a risk of injury for the elderly. The risk is increased in elderly persons with bone diseases, such as osteoporosis. However, half of the patients with fracture were not considered at risk based on bone density measurement (current clinical technique). We assume that loading conditions are of high importance and should be considered. Real loading conditions in a fall can reach a loading speed of 2 m/s on average. The current study aimed to apply more realistic loading conditions that simulate a forward fall on the radius *ex vivo*. Thirty radii from elderly donors (79 y.o. ± 12 y.o., 15 males, 15 females) were loaded at 2 m/s using a servo-hydraulic testing machine to mimic impact that corresponds to a fall. Among the 30 radii, 14 had a fracture after the impact, leading to two groups (fractured and non-fractured). Surfacic strain fields were measured using stereovision and allow for visualization of fracture patterns. The average maximum load was 2963 ± 1274 N. These experimental data will be useful for assessing the predictive capability of fracture risk prediction methods such as finite element models.

1. Introduction

Among the different bone fractures, those of the distal section of the radius occur earlier in life than other osteoporotic fractures and can be interpreted as a warning signal for later, more deleterious fractures (Melton et al., 2010). The gold standard method for clinical diagnosis of osteoporosis and evaluation of the risk for fracture is Dual X-ray Absorptiometry (DXA) (World Health Organization, 2004). It has been shown, however, that this measurement presents insufficient sensitivity, and indeed 50% of fractures occur in patients considered as non-osteoporotic (Siris et al., 2004).

Ongoing research has proposed different methods to improve sensitivity. One of these methods is analysis by micro-finite element models (μFEM) based on High Resolution peripheral Quantitative Computed Tomography (HR-pQCT) (Pistoia et al., 2002, Vilayphiou et al., 2011). All validation studies have shown that bone strength is better estimated by μFEM (R^2 between 0.73 and 0.92) than by DXA measurements (R^2 between 0.31 and 0.71) (van Rietbergen and Ito, 2015). Despite this good level of prediction of bone strength using μFEM, retrospective studies have not yet provided clear evidence that the output of μFEM provides better predictors of fracture risk than DXA measurements (van Rietbergen and Ito, 2015).

Currently, the assessment of bone fragility using HR-pQCT implies a finite element analysis under static axial loading (Pistoia et al., 2002; Macneil and Boyd, 2008; Varga et al., 2009; Hosseini et al., 2017). However, only 15% of fall cases are associated with an axial load on the radius (Melton et al., 2010) and asymmetrical body orientation influences loading of the radius (Burkhart et al., 2017). The most common angle between the floor and the arm found in the forward fall is 75° (Greenwald et al., 1998; Chiu and Robinovitch, 1998) and the average velocity when the subject hits the floor can reach 2 m/s (Tan et al., 2006; Troy and Grabiner, 2007). Thus, we assume that this dynamic loading should be considered for *ex vivo* experiments that result in fractured and non-fractured bones. Having these two groups in known loading conditions would be of interest to assess new methodologies to predict bone fracture risk.

Previous studies loaded radii until failure in all cases, with some under quasi-static conditions (Pistoia et al., 2002; Macneil and Boyd, 2008; Varga et al., 2009; Hosseini et al., 2017) and one using fall conditions (Burkhart et al., 2012). In this context, the aim of this study is to propose an *ex vivo* experiment to reproduce a

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forward fall loading condition, leading to fractured and non-fractured radii.

2. Methods

Thirty radii from elderly donors (50–96 y.o., 79 ± 12 y.o., 15 males, 15 females) were considered. The bones were provided by the Departement Universitaire d'Anatomie Rockefeller (Lyon, France) through the French program on voluntary corpse donation to science. First, during the dissection, 2/3 of the distal radius was cut and cleaned of soft tissues. Each radius was wrapped in a saline-moistened gauze and frozen at −20 °C before the experiments.

The day before the experiments, bones were thawed for 16 h at 4 °C and then 6 h at room temperature. The third part of the distal radius was exposed after being potted in a polyurethane resin (reference: 84A&B, Esprit Composite, Paris, France) in a steel cylinder (Fig. 1. Using a positioning laser, radii were potted with an alignment of 75° between the anterior face of the radius and the ground, without any tilt in any other planes. This position reproduces alignment of the radius in the most common forward fall (Chiu and Robinovitch, 1998).

Taking into account that the scaphoid and lunate are both involved in the mechanism of fracture of the distal radius (Jupiter and Fernandez,1997), a rigid polyurethane mold was made to reproduce a simplification of these bones for each radius.

A silicon rubber kept the mold on the radius, but also allowed some displacement (a few millimeters) in perpendicular directions to the impact, as expected in real life.

The pot was placed in a horizontal cylinder bar on a rail system, which was free to slide along the loading axis (Fig. 2). This bar had a weight of 12.5 kg, which was an arbitrary value representing the mass involved in a fall, i.e., a percentage of body weight. This weight was the same for all the tests. The rail system allows one to limit the loading on the radius to avoid having bone fracture in all cases.

The radius was then loaded through the mold at 2 m/s using a hydraulic high-speed testing machine (LF technologies, France).

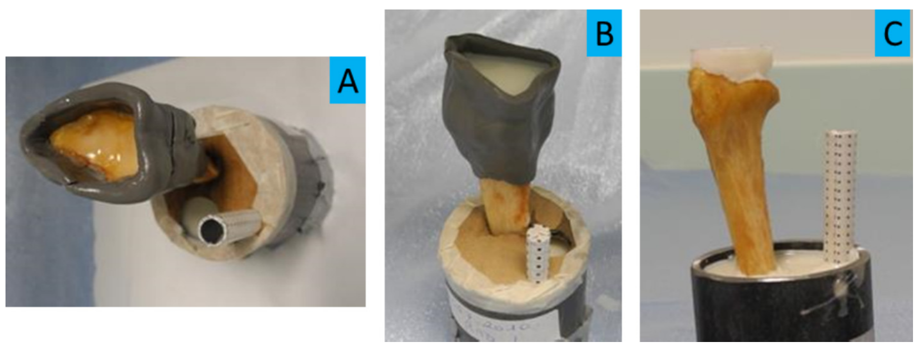

Fig. 1. Construction of the articular mold. (A) Modelling clay shell is put on the distal radius to contain the resin. (B) Polyurethane resin inside the modelling clay shell. (C) After removal of the modelling clay.

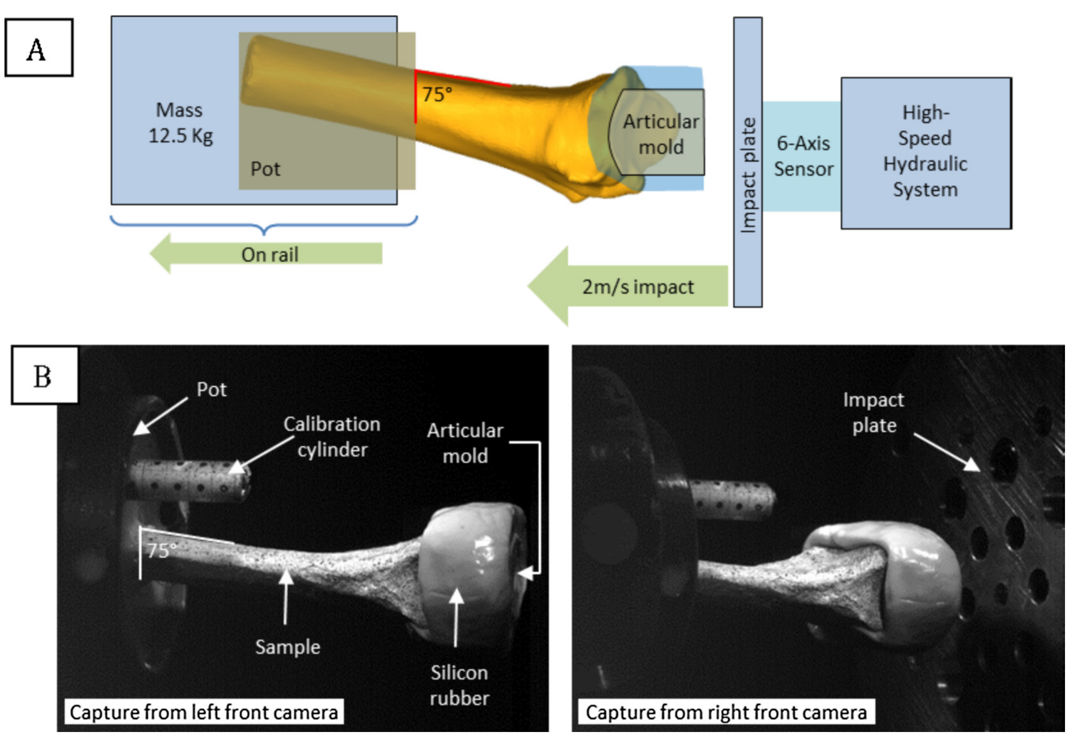

Fig. 2. (A) Diagram of the experiment. This configuration loads the radius at 75° with a velocity of 2 m/s, representing the forward fall case studied. (B) Final setup of the experiment.

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