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IMPACT VELOCITY INFLUENCE ON THE FRACTURE BEHAVIOUR OF PORCINE FEMURS UNDER DYNAMIC LOADING

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1. Introduction

Bone is a complex tissue composed of inorganic, organic, and cellular components. Far from being inert, it is a metabolically active, dynamic structure that undergoes continuous remodeling throughout life. Most high-resolution imaging techniques are currently limited to ex vivo research due to radiation exposure, sample size restrictions, and long acquisition times. High-resolution computed tomography (HR-CT) and magnetic resonance imaging (HR-MR) can be performed in vivo, but have been used primarily for validating diagnostic methods and evaluating osteoporosis treatments.

A significant challenge in bone research lies in accurately classifying bone quality. Biomechanical studies on cadaveric material are needed to correlate clinically accessible parameters such as bone mineral density (BMD) with more precise histological and three-dimensional high-resolution imaging data.

This study presents experimental results on post-mortem porcine femurs, aiming to compare the mechanical response of bone under different impact velocities. The working hypothesis is that loading rate influences fracture mechanics: at lower velocities, fractures are expected to be ductile, while higher velocities are expected to produce brittle or even comminuted fractures.

2. Materials and Methods

Dynamic impact tests were conducted at the Structural Mechanics Laboratory, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, using an INSTRON Drop Tower 9450 (capacity: 222 kN). Adjustable test parameters included impact velocity (1–24 m/s), drop height (0.5–40 m), striker mass (up to 70 kg), impact energy (up to 1800 J), and striker geometry (wedge, spherical, or flat). For this study, impact energy was kept constant across tests (360 J), while impact velocity was varied. Two test series were performed: one at an impact velocity of 5 m/s and another at 10 m/s. Each series included four healthy femurs, resulting in a total of eight specimens tested.

Force–time data were recorded at up to 4 MHz and processed to determine absorbed energy, displacement, and velocity during impact. The fracture mechanism was assessed using the ductility index, calculated from the ratio of post-peak to peak absorbed energy. A ductility index below 30% indicates purely brittle fracture, while values above 60% correspond to purely ductile fracture:

$$Ductility\ index\ [\%] = \frac{(Energy\ at\ Total)-(Energy\ at\ Peak)}{Energy\ at\ Peak}. \quad (1)$$

Characteristic Ponits are shown in Fig 1.

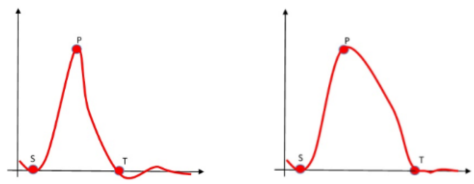

Fig. 1. Characteristic force–time diagram for a) ductile fracture, b) brittle fracture.

Fresh porcine femurs were obtained from animals of similar size, age, and sex, with comparable living conditions. Weight, volume, and length were measured for each specimen. Bones were tested fresh, within 48 hours post-mortem, to avoid dehydration.

3. Results

Bar charts compare the average values obtained from the two test series. It is evident that both the maximum impact force and the fracture force are higher for impacts conducted at higher velocities (Figs. 2 and 3).

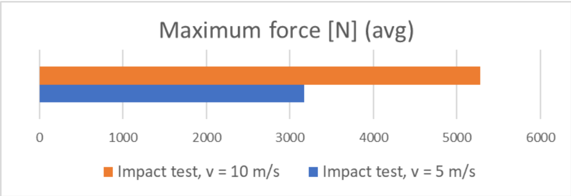

Fig. 2. Maximum (average) force.

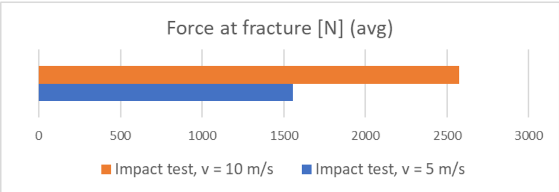

Fig. 3. (Average) force at fracture.

Conversely, displacements at maximum force and at fracture are greater for the lower-velocity impacts (Fig 4).

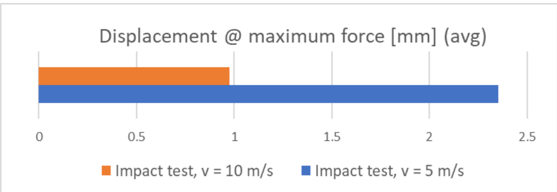

Fig. 4. (Average) displacement at fracture.

In Figs. 5 and 6 femur bones after impact tests are shown.

Fig. 5. Femur after dynamic testing at an impact velocity of 5 m/s

Fig. 6. Femur after dynamic testing at an impact velocity of 10 m/s

Of particular interest is the comparison of total absorbed energy during impact. The absorbed energy at lower impact velocity was clearly higher than that recorded at higher velocity, Fig. 7. This can be attributed to the fact that, at lower velocity, the bone had more time to undergo gradual plastic deformation and dissipate energy progressively, which supports the hypothesis that lower-velocity impacts promote more ductile fracture behavior. In contrast, higher-velocity impacts are predominantly characterized by brittle fracture mechanisms.

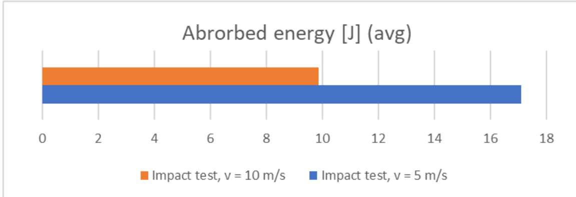

Fig. 7. (Average) absorbed energy during impact.

This study demonstrates that the fracture behavior of porcine femurs under dynamic loading is strongly dependent on impact velocity, Fig. 8.

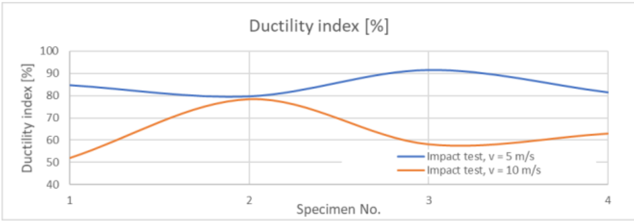

Fig.8. Comparison of ductility indices for fractures resulting from impacts at 5 m/s and 10 m/s.

4. Conclusions

Lower velocities favor ductile fracture mechanisms with higher energy absorption, while higher velocities promote brittle or comminuted fractures with reduced ductility. These findings support the hypothesis that loading rate is a critical factor in bone failure mechanics. The results provide a biomechanical basis for understanding fracture patterns in high-energy trauma and may assist in refining computational bone models and improving the design of orthopedic fixation devices.

References

[1] Donnelly E. Methods for assessing bone quality: a review. Clin Orthop Relat Res. 2010;469(8):2128–38.

[2] Hernandez CJ, Keaveny TM. A biomechanical perspective on bone quality. Bone. 2006;39:1173–81.

[3] [43] Kulić M, Bagavac P, Bekić M, Krstulović-Opara L. Ex Vivo Biomechanical Bone Testing of Pig Femur as an Experimental Model. Bioengineering. 2024; 11(6):572. https://doi.org/10.3390/bioengineering11060572.