AN ALTERNATIVE APPROACH FOR THE INTERPRETATION OF DATA FROM THREE POINT BENDING OF LONG BONES

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1. General

Bending tests (either three- or four-point) are often employed in biomechanical studies for the determination of the mechanical response of bones (especially long ones) due to the relatively simple experimental procedure which permits short exposure time of the specimens. The bending fracture stress (together with the modulus of elasticity and the energy absorbed up to fracture) are considered the most represenative quantities for the description of the mechanical behaviour of the specific tissue. Unfortunately the determination of the fracture stress is not a trivial task since it strongly depends (among others) on the way the area of the bone's cross section is distributed with respect to the axis of rotation, quantified by the second moment of area, I_{ij}. Moreover it depends on the orientation of the load with respect to the principal centroidal axes, ω_p, which in turn depends on bone's tiny anatomic details (dictating the placement of the bone on the supports), on the exact position of the critical point and finally on the possible distance of the loading axis from the centroid of the cross section. In many applications the above problems are confronted by simulating the bone's section either as a circular or an elliptic ring [1]. In this study an alternative approach is described indicating that ignoring the actual shape of the cross section may lead to erroneous results for the tissue strength.

2. The experimental protocol and the procedure to determine the actual geometric features

A long series of three point bending tests was implemented using an MTS INSIGHT 10 kN loading frame equipped with an MTS 569329-04 cell. Both right and left femurs of ten-month-old female Wistar rats were tested (Fig.1a), harvested according to Greek legislation in compliance to the EEC 609/1986 directive.

The rats were euthanized with an overdose of ketamine hydrochloride and dexdomitor. Both femurs were dislocated from the tibia and pelvis and the surrounding muscles were removed until the bone was left clear of tissues. All experiments were carried out under displacement-control conditions at a rate equal to 1 mm/min. The deflection of the central section was measured using a Limess video-extensometer (Fig.1b). A force-deflection curve for a characteristic experiment is shown in Fig.1c.

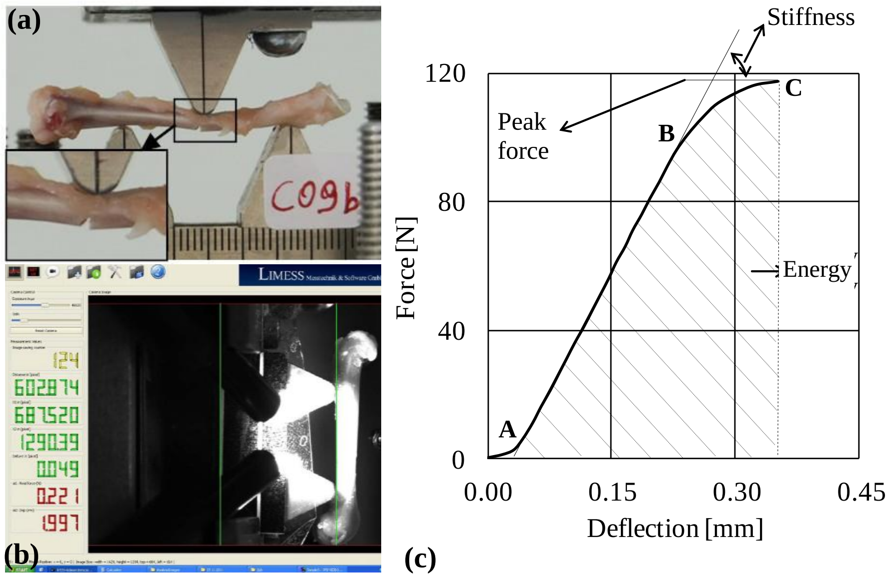

Fig. 1: (a) Typical specimen while loaded. (b) A photo from the software used to determine deflection. (c) Typical force-deflection curve.

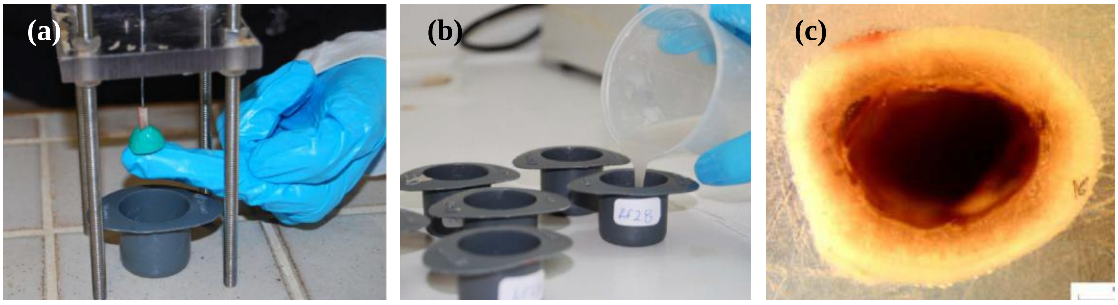

Fig. 2: (a) Placing the fractured bone in the cup in vertical position. (b) Pouring molten resin in the cup. (c) The surface of the resin-bone complex after polishing.

After each test the fractured bone was placed vertical in a small cup (using a specially designed structure, Fig.2a), which was then filled with molten resin (Fig.2b). After curing the resin-bone complex was removed from the cup and its upper surface was smoothed by abrasion removing the minimum possible material from the fractured surface until a plane area was obtained. Using a stereoscope and a digitizer both the outer and inner boundaries of the bone fractured section were obtained (Fig.2c). With the aid of commercially available software the geometrical features of the fractured cross-section were determined, including (i) the coordinates of the centroid with respect to an arbitrary system, (ii) the principal axes and (iii) the principal second moments of area (Fig.3). Taking advantage of these data it was possible to determine the fracture stress:

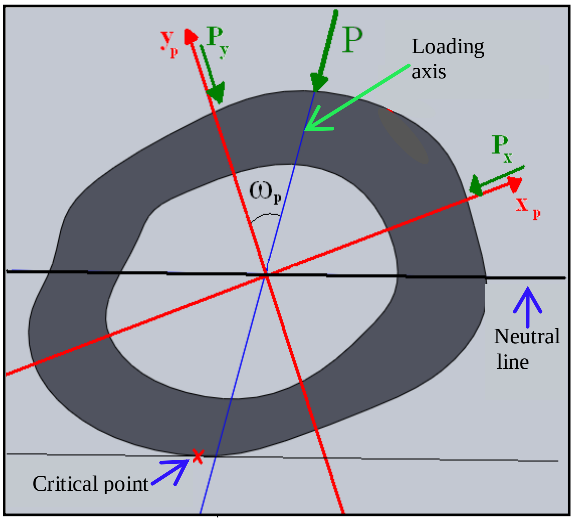

Fig. 3: The quantities required for the determination of bending strength.

(1) $$\sigma_{zz,\text{fracture}} = \pm P_{\text{Peak}} \cos|\omega_p| Ly_c / 4I_{z_p z_p} \mp P_{\text{Peak}} \sin|\omega_p| Lz_c / 4I_{y_p y_p}$$

P_{peak} is the maximum force, L is the span and (y_c, z_c) are the coordinates of the point most distanced from the neutral line. In addition the shear stress developed due to eccentricities was also calculated.

3. Results and conclusions

The fracture stress was compared against the respective one obtained by considering the cross section either as a circular ring of constant outer diameter and thickness or as an elliptic ring the outer and inner boundaries of which were determined using a best fitting procedure (Table 1).

Present approach	Circular ring	Elliptic ring	*Parasitic shear stress*
170.3	160.5	187.4	*10.6*

Table 1. Bending fracture stress and the respective parasitic shear stress in MPa.

It is concluded that ignoring the actual geometric details of the cross section results to differences for the fracture stress varying between about 5% and 13%. This could be crucial in case, for example, comparative studies are implemented for the assessment of various pharmaceutical treatments [2]. Moreover shear stresses of the order of 6% of the respective normal ones are by no means ignorable.

4. References

[1] K.P. Saffar, N. JamilPour and S.M. Rajaai (2009). *American Journal of Applied Sciences*, **6(3)**, 463-470.

[2] S.K. Kourkoulis, Ch.H. Andriakopoulou and A. Kouvaka (2012). *Proc. 5th Int. Conf. of the Hellenic Society on Biomechanics*, Thessaloniki, Greece, Paper Code: O-24 (In Greek).