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Original article

Biomechanical investigation into the torsional failure of immature long bone

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ABSTRACT

Approximately 50% of infant and toddler long bone fractures are attributed to non-accidental trauma; however, differentiating from benign mechanisms is subjective, due to an absence of evidence-based diagnostic tools. Previous studies investigated small ranges of rotational velocities in animal long bone models, although did not report the variation in the spiral fracture angle. This study considered the fracture angle as a potential clinical measure, correlating this data with a wider range of rotational velocities. The spiral fracture angle was measured relative to the long axis, whilst noting the narrowest diaphysial diameter, location of the fracture, and the extent of comminution and periosteal disruption. Twenty-six bones failed in spiral fracture, with the potting material failing in the remaining tests. All spiral fractures centred on the narrowest diaphysial diameter. Slower rotational velocities caused fracture angles approaching 45°, whereas fractures at greater velocities caused fracture angles nearer 30°. A relatively strong trend ($R^2 = 0.78$) is reported when the normalised fracture angle (against the narrowest diaphysial dimension) was plotted against the rotational rate. A relationship has been identified between the angle of spiral fracture and the rotational velocity using the immature bovine metatarsal model. This trend forms a scientific foundation from which to explore developing a diagnostic, evidence-based tool that may ultimately serve to assist differentiating between accidental and non-accidental injury.

1. Introduction

Approximately one half of long bone fractures presented by infants and toddlers are attributed to non-accidental trauma.[1–6] Whilst guidelines exist to assist clinicians differentiating between accidental and non-accidental injury, the difficulty of achieving a correct diagnosis should not be underestimated. Spiral fractures, for example, are typically attributed to non-accidental injury; however, these fractures may also result from benign trauma.[7]

Very few studies have investigated the biomechanics of failure in immature bone. Cadaveric studies have reported a difference in biomechanical properties between immature and mature bone, with the former having a lower modulus of

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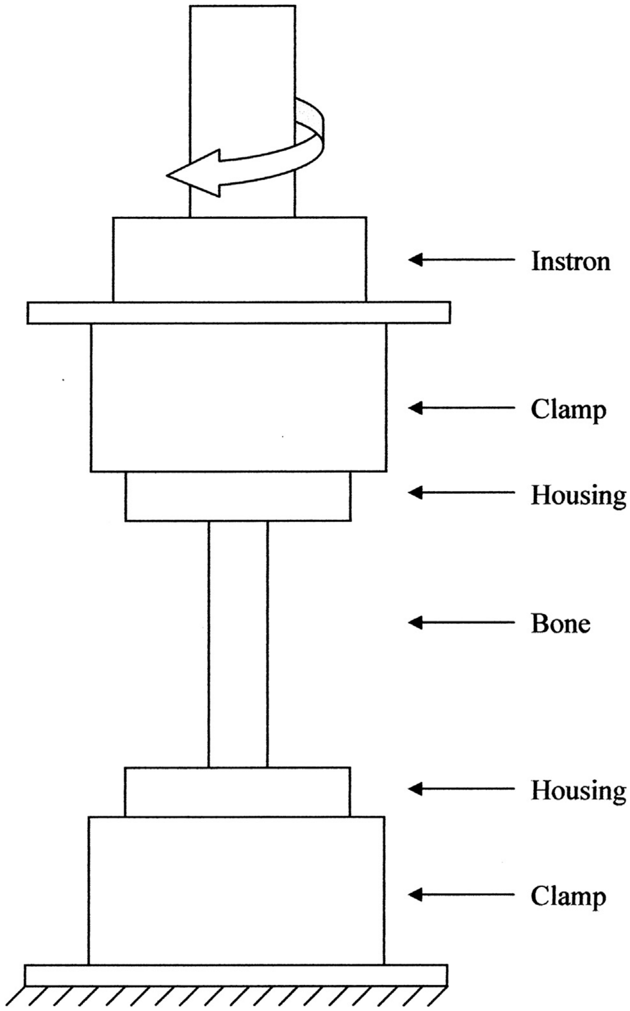

Fig. 1 – A schematic representation of the experimental setup to apply a torque to the immature bovine long bone.

elasticity, bending strength and mineralisation (i.e. ash content).[8,9] Pierce et al (2004) has previously explored the validity of the immature porcine femur as a model of a paediatric long bone; however, frequent epiphyseal plate failures meant that spiral fractures were produced in only two of the seven bones.[10]

This study investigates whether the appearance of a spiral fracture can be related to the causal mechanism. This hypothesis forms a scientific foundation from which to explore developing a diagnostic, evidence-based tool that may ultimately serve to assist differentiating between accidental and non-accidental injury.

2. Methods

Bovine metacarpal bones ($n = 32$) were harvested from skeletally immature, 7-day-old calves; these bones were freely available as a by-product of the food industry. Sharp dissection was used to remove the overlying soft tissues, whilst ensuring the periosteum remained intact. Each bone was then macroscopically examined for any damage or previous fracture. The narrowest diaphysial diameter was recorded and the bones divided in to 8 groups for testing different applied rotational velocities to failure.

The bones were subjected to a torsional load using a servohydraulic testing machine (MTS 858 Mini Bionix testing machine; Cirencester, UK); this is schematically represented in Fig. 1. The centroidal axis of each bone was identified using a custom-made extra-medullary jig, enabling alignment with the rotational axis of the machine and thereby minimising out-of-plane loading (e.g. bending). An 8 mm hole was drilled at each epiphysial centre of rotation to centralise the bones in the cylindrical housings, before a potting material (Building Adhesives Limited, Stoke-on-Trent, UK) was used to embed the epiphyses and epiphysial growth plates. Each group of potted bones was tested at a specific applied rotational velocity (0.5, 1, 15, 30, 45, 60, 75, 90° s^{-1}) to failure.

After testing, each fractured bone was manually reduced and then imaged in two perpendicular planes, allowing the spiral fracture angle to be measured at its mid-point relative to the long axis.[11] This data is ultimately presented following normalisation against the narrowest diaphysial diameter, to account for the variation in bone geometry throughout the tested cohort. Outcomes were also collected describing the fracture location and the extent of both periosteal disruption and comminution.

3. Results

All 32 bones failed with a spiral fracture; however, 6 tests were excluded due to concurrent potting material failure

Table 1 – Minimum diameter and fracture angle of each bone tested at 8 different rotational velocities.

	Bone 1	Bone 2	Bone 3	Bone 4	Mean
			0.5° s^{-1}		
Minimum diameter/mm	18	17	–	16	17
Fracture angle/degrees	47	43	–	39	43
			1° s^{-1}		
Minimum diameter/mm	16	18	19	–	18
Fracture angle/degrees	42	42	40	–	41
			15° s^{-1}		
Minimum diameter/mm	19	18	20	22	20
Fracture angle/degrees	45	44	41	26	39
			30° s^{-1}		
Minimum diameter/mm	23	21	–	21	22
Fracture angle/degrees	42	42	–	37	40
			45° s^{-1}		
Minimum diameter/mm	21	19	20	–	20
Fracture angle/degrees	39	37	36	–	37
			60° s^{-1}		
Minimum diameter/mm	19	18	–	21	19
Fracture angle/degrees	41	39	–	32	37
			75° s^{-1}		
Minimum diameter/mm	19	20	22	–	20
Fracture angle/degrees	37	35	32	–	35
			90° s^{-1}		
Minimum diameter/mm	19	18	19	21	19
Fracture angle/degrees	34	34	30	26	31