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Short communication

In vitro hip testing in the International Society of Biomechanics coordinate system

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ABSTRACT

Many innovative experiments are designed to answer research questions about hip biomechanics, however many fail to define a coordinate system. This makes comparisons between studies unreliable and is an unnecessary hurdle in extrapolating experimental results to clinical reality. The aim of this study was to present a specimen mounting protocol which aligns and registers hip specimens in the International Society of Biomechanics (ISB) coordinate system, which is defined by bony landmarks that are identified by palpation of the patient's body. This would enable direct comparison between experimental testing and clinical gait analysis or radiographic studies. To represent the intact hip, four intact synthetic full-pelves with 8 full-length articulating femora were assembled and digitised to define the ISB coordinate system. Using our proposed protocol, pelvis specimens were bisected into left and right hemi-pelves and femora transected at the mid-shaft, and then mounted in bone pots to represent a typical experimental setup. Anatomical landmarks were re-digitised relative to mechanical features of the bone pots and the misalignment was calculated. The mean misalignment was found to be less than 1.5° flexion/extension, ab/adduction and internal/external rotation for both the pelves and femora; this equates to less than 2.5% of a normal range of hip motion. The proposed specimen mounting protocol provides a simple method to align in vitro hip specimens in the ISB coordinate system which enables improved comparison between laboratory testing and clinical studies. Engineering drawings are provided to allow others to replicate the simple fixtures used in the protocol.

1. Introduction

In the past 10 years, many research labs have developed new methods to study hip joint biomechanics including: digital image correlation (Dickinson et al., 2012, 2011), roentgen stereophotogrammetric analysis (Dy et al., 2008; Myers et al., 2011), digital variable resistance transducers (Safran et al., 2011; Smith et al., 2011), real-time contact-pressure measurement (Lee et al., 2015; Rudert et al., 2014), fluid infusion devices (Cadet et al., 2012; Dwyer et al., 2014), optical tracking motion analysis (Lopomo et al., 2010; Signorelli et al., 2013), 3D digital reconstructions combining CT scans and motion tracking (Dwyer et al., 2014; Incavo et al., 2011), combined use of in-vitro and finite element modelling (Anderson et al., 2008; Dickinson et al., 2011; Elkins et al., 2011), custom built rigs in servo-hydraulic actuators/materials testing machines (Dickinson et al., 2012; Elkins et al., 2011; Ito et al., 2009; Song et al., 2012; van Arkel et al., 2015a, 2015b) and six-degrees-of-freedom robotic load/torque actuators (Colbrunn et al., 2013; Smith et al., 2014). Such variation in testing methodology not only allows new hypotheses to be tested but also prevents systematic bias that could result from using the same methodology with the same limitations. However, to compare experiments, results need to be reported in a well-defined coordinate system, and to compare to the clinical scenario, it could be advantageous that testing is performed in a clinically adopted coordinate system. Many research studies, including many of those mentioned above, fail to report or reference a full coordinate system; most commonly, the body reference frames for the pelvis and/or femur are under-defined. This is not a recent problem: two decades ago, an extensive critical review of in-vitro testing methods for studying hip prosthesis found that 95% of studies did not fully define a reference frame for the femur (Cristofolini, 1997).

The ISB have published a well-defined hip coordinate system based on the hip centre of rotation, anterior and posterior superior iliac spines (ASIS and PSIS) and femoral epicondyles (Wu et al., 2002). These landmarks are easy to identify non-invasively and consequently have been widely adopted in gait analysis and related musculoskeletal modelling research. Whilst the coordinate systems would be equally beneficial when testing in-vitro, they can be challenging to implement and are rarely used. For example,

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identifying the femoral head centre is challenging in-vitro and a full pelvis/femur (to identify the ACIS/PSIS and femoral epicondyles) is commonly too large for the available working volume of test rigs or materials-testing-machines. Indeed, most authors test with only hemi-pelves or proximal femora preventing use of the ISB or equivalent system (Anderson et al., 2008; Colbrunn et al., 2013; Crawford et al., 2007; Dickinson et al., 2012, 2011; Dwyer et al., 2014; Dy et al., 2008; Elkins et al., 2011; Ito et al., 2009; Lee et al., 2015; Myers et al., 2011; Rudert et al., 2014; Smith et al., 2014, 2011; Song et al., 2012). These authors use pots to fix the bones with varying shapes into engineered testing rigs. The specimens are typically secured into the pot with putty/cement and/or bolts/screws whilst the pots have regular/machined features to attach them in a repeatable manner to the testing rig. Whilst standardising testing rigs would unnecessarily limit experimental methodology, a standardised method to orientate bones into pots whilst maintaining the ISB body reference frames would be beneficial.

Thus, the aim of this study is to provide a method to register the ISB body reference frames to bones before bisecting the pelvis and transecting the femur, and then restore the same coordinate system when the specimen is installed in the experimental fixtures. This would enable in vitro testing to be performed in the same coordinate system as clinical studies and allow greater comparison between in vitro and in vivo work.

2. Materials and method

8 solid foam femora and 4 solid foam pelves, 2 each of male/female left/right hemipelvis/femora (Sawbone AB, Sweden, model numbers: #1120, #1120-20, #1129, #1129-21, #1301, #1302) were used in the study. Each pelvis was assembled with two femora and both hip joints were covered with an artificial hip capsule (a paper sleeve covering and encasing the femoral head and neck) to prevent direct visualisation of the femoral head. For each bone model, Ø3.5 × 10 mm screws were inserted into anatomical landmarks as detailed in Table 1. The crossheads of these screws provide a repeatable point for a Polaris optical tracking system's (Northern Digital Inc., Ontario, Canada) digital probe. The screw positions allowed for the ISB body reference frames for the pelvis/femur to be digitised as well as providing seven repeatable points that would be available for re-calculating the pose of the bones after potting them. Whilst three repeatable points per bone would be needed mathematically for subsequent pose estimation calculations, seven were used with as larger spatial distribution as possible to improve accuracy (Challis, 1995). All screws were digitised using the optical tracking system three times. Between repeats the bones were re-orientated in the field of view of the optical tracking system to prevent systematic point registration errors.

The hips were prepared with the drilling guides, with the head centre estimated by manual palpation through the artificial capsule (Figs. 1 and 2 and Supplementary material) before bisecting the pelves and transecting the femora at the mid-shaft. The artificial capsule was removed and the prepared bones were orientated and fixed into the bone pots using the holes drilled in the bones (Fig. 3).

Table 1
Anatomical locations for screw placement.

Body	For ISB Reference Frame	Repeatable landmarks (for comparing intact and potted)
Pelvis	Left anterior superior iliac spine	Anterior superior iliac spine
	Right anterior superior iliac spine	Anterior inferior iliac spine
	Left posterior superior iliac spine	Pubic tubercle
	Right posterior superior iliac spine	Ischial tuberosity
		Posterior acetabular rim
		Superior iliac spine
		Acetabulum centre[a]
Femur	Medial femoral epicondyle	Insertion of ligamentum teres
	Lateral femoral epicondyle	Superior tip of greater trochanter
	Femoral head centre[a]	Lateral base of greater trochanter
		Lesser trochanter
		Medial mid-shaft
		Lateral mid-shaft
		Femoral head centre[a]

[a] These centre points were not pinpointed with screws but were found from a least-squares sphere-fit of > 100 digitised points on the surface of the acetabulum/femoral head.

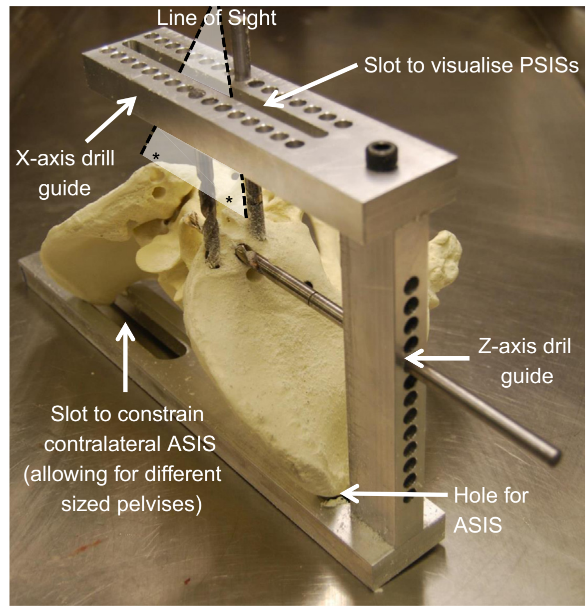

Fig. 1. Pelvis drilling guide (femora not shown for clarity). The anterior superior iliac spines (ASISs) are first located in the bottom hole and slot. The pelvis is then rotated until the posterior superior iliac spines (PSISs) can be visualised through the top slot. Holes representing the ISB X and Z axes can then be drilled into the pelvis using the guide.

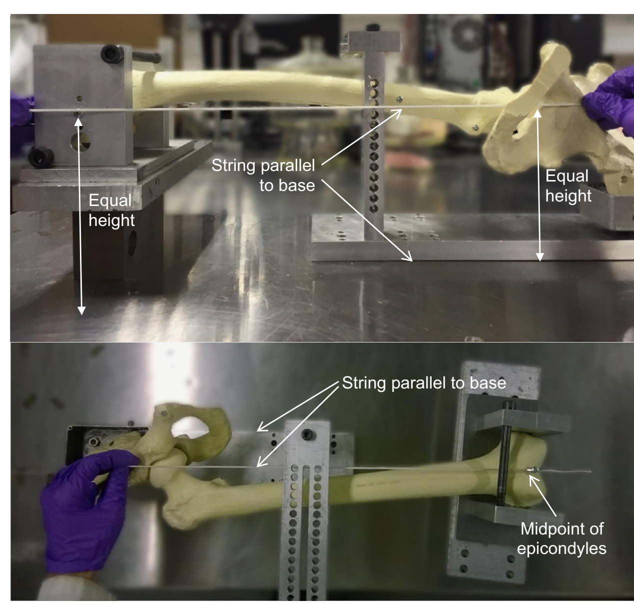

Fig. 2. Femoral drilling guide (the artificial capsule has been removed for clarity). The epicondyles are clamped in the middle of two equal sized plates to set neutral rotation when placed on a horizontal surface. The epicondyles are then moved in first the sagittal plane in a movement akin to flexion/extension (top), then in the coronal plane in a movement akin to ab/adduction (bottom) until the femoral y-axis aligns with the length of the drilling jig in both planes. Holes representing the ISB x and z axes can then be drilled into the femoral shaft. The femur can be supported by using a potted hemipelvis, as shown, or in the absence of the pelvis by supporting the femoral head directly.