Comparison of Human and Animal Femoral Head Chondral Properties and Geometry
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INTRODUCTION
Recently, research into less invasive treatments to deter the progression of osteoarthritis has gained increasing interest. Investigations into these treatments should consider the tribology of articular cartilage; where, simulations using animal joints are a predominate choice.

It has been proposed that tribology and wear of articular cartilage is directly associated with the intrinsic mechanical properties, which are governed by the extracellular matrix (ECM). The micro-architecture of the ECM is altered by the loads and motions applied to the tissue. Most investigations take cartilage samples from quadrupeds, where the loading and motions are different compared to human (bipeds). However, very few studies have investigated the differences between human and animal cartilage, despite the importance under identical conditions.

This study assessed the differences between human, porcine, ovine and bovine articular cartilage from the femoral head; in terms of anatomical geometry, cartilage thickness, equilibrium elastic modulus and permeability.

METHODS
Femoral heads were taken from six pigs (3-6 months old), sheep (≈4 years old), and cows (18-24 months old). Six human femoral heads were also obtained via hip surgery undertaken as a result of femoral neck fracture. Diameters of each femoral head in the anterior/posterior and superior/inferior directions were measured using a Vernier caliper. Osteochondral plugs (Ø = 9 mm) were taken from the centre of the superior region (due to being the primary weight bearing region of the human femoral head).

Creep indentation was performed on each cartilage plug on a custom made indentation rig. The rig allowed a constant load of 0.8 N to be applied through a hemispherical rigid indenter (Ø = 3 mm) for a period of one hour to the cartilage surface. Deformation was recorded with the use of a linear variable differential transducer (RDP D5-200H; 2 mV/V/0.001” sensitivity). The plugs were submerged in saline solution throughout the test to maintain hydration.

Thickness of cartilage was measured using an Instron 3365 material testing machine (Instron, Bucks, U.K.). A needle, placed < 1 mm above the cartilage surface was set to transverse the cartilage and bone at a constant feed rate of 4.5 mm/min whilst measuring the resistive load. Two step increases in load were observed when the needle touched: 1) the surface of the cartilage and 2) the bone. The distance the needle traveled between these points was taken as cartilage thickness. This was performed four times on each plug and a mean calculated.

The results from the creep indentation and thickness tests were both used to derive the intrinsic material properties: equilibrium elastic modulus and permeability. An axisymmetric poroelastic biphasic finite element model (ABAQUS, version 6.9-1) was used to do this [1].

Single factor ANOVA (P<0.05) was used to test for significant differences throughout the study.

RESULTS
Significant differences in average femoral head diameter were observed between all animals, where bovine showed the largest femoral head with an average diameter of 64.4±4.0 mm, which was significantly larger than human (46.8±5.7 mm). However, human femoral head exhibited significantly larger femoral heads than porcine (35.6±6.0 mm) and ovine (23.2±1.4 mm).

Roundness of isphericity of the femoral head was determined by calculating the percentage difference between the two diameters. Human exhibited the roundest femoral head with average difference of 1.16%, where as ovine was the least round with average difference of 15.29%.

Human cartilage was found to be 1.82±0.18 mm thick, which was significantly thicker than cartilage from all quadrupedal hips (Figure 1). Bovine cartilage (1.32±0.13 mm) was thicker than porcine cartilage (1.22±0.05 mm), yet this was not found to be significant. Ovine cartilage was 0.52±0.10 mm thick, which was significantly thinner than all the other species.

DISCUSSION
Human cartilage was significantly thicker than all other species, comparing well with previous studies. A positive correlation was found between femoral head diameter and cartilage thickness when comparing between species of animal, which was not observed in previous studies [2]. Human cartilage was also found to have the largest equilibrium elastic modulus compared to the quadrupeds (4.89±0.76MPa) (Figure 2). This was significant when compared with porcine (1.18±0.17MPa) and bovine (1.86±0.44MPa). However, due to the large variation in ovine cartilage equilibrium elastic modulus (3.94±2.52MPa), no significant difference was observed when compared to human.

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