Experimental Characterisation of Coefficient of Friction at Bone-implant Interface

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INTRODUCTION: Oxford Unicompartmental Knee Replacement (OUKR), which is a treatment for end-stage knee osteoarthritis, is the most commonly used unicompartmental knee replacement implant in the UK [1]. Primary fixation of the cementless OUKR tibial component is achieved through interference fit at the keel, which is the vertical protrusion at the bottom of the tibial tray. Successful primary fixation is a prerequisite for long-term implant stability. After press-fit implantation, the component is held in place by periprosthetic stress and resulting friction force at the bone-implant contact interface. Finite element (FE) analysis is a widely used tool in orthopaedics when assessing the primary fixation of implants. However, the input value of coefficient of friction (COF) at the bone-implant contact interface has a significant influence on the results [2-4]. Previous FE studies used values ranging from 0.5 to 0.95 to simulate contact between bone and porous implants [5, 6], and some other studies conducted sensitivity analyses on COF as the exact value was unknown [3, 4]. Thus, to better characterise the frictional behaviour at the bone-implant contact interface, an experiment was designed and conducted. This study aimed to find the COF between implants and plastic trabecular bone analogue, animal trabecular bone and human trabecular bone. Specimens representing smooth and porous implant surfaces were tested. The results can potentially improve the accuracy and efficiency of computational simulations of cementless implantation.

METHODS: Testing was conducted on a smooth 3D-printed titanium keel (Cp-Ti Grade 2, AP&C) and the porous keel of the cementless OUKR tibial component. Trabecular bone samples of 5x15x15 mm^3 were resected from fresh porcine, defrosted bovine and defrosted cadaveric human tibiae. Ethical approval (16NW0859) was obtained. Samples were retrieved from the proximal tibia along the long axis of the tibia, the direction in which the keel slot is made during operation, to replicate the contact between the keel of the OUKR tibial component and bone. Samples of the same dimension were cut from a plastic bone block (Sawbones Solid Rigid Polyurethane Foam, PCF20) which acted as an analogue to human trabecular bone. The tested fixation component was initially clamped between two pieces of bone samples under a vertical load (F_N) applied by a DARTEC HC-10 servohydraulic material testing machine (ZwickRoell Ltd) and FSB-01 S-beam load cell (Force Logic) (Fig.1). Then a 2 kg mass (W) was connected to the tested component via a pulley to apply a horizontal force (Fig.2). The load from the loadcell was then gradually decreased until the tested component moved and became free of the clamp indicating that the friction forces at the contact surfaces under this vertical load F_N were not large enough to resist the weight of the hung mass. The vertical force at which the tested component became free of the clamp was recorded and the COF was derived as $COF = \frac{W}{2F_N}$.

RESULTS: Table 1 lists the COFs at the interface between each bone-implant pair. The mean COF value was larger at the contact face with the porous implant for all specimen types. COF values were similar at the contact interfaces between cementless tibial component and plastic, porcine and cadaveric bone. For bovine samples, large variability was shown among the three different tibias with mean values ranging from 0.2 to 1.0.

DISCUSSION: This study proposed an experimental method of measuring COF between bone and implant with one load cell. Similar COFs between human trabecular bone and porous implants were found as reported in a previous study using multiaxial load cells [7]. Large variability in COF at the bovine bone-OUKR tibial component interface was shown among bovine samples. During the preparation of bone samples, it was noticed that bovine tibia 3 was noticeably qualitatively different to the other two bovine tibiae. This might explain why the COFs measured with bovine tibia 3 were smaller than those measured using tibia 1 and 2. One limitation of this study is that no statistical analysis was performed due to the limited number of samples that could be retrieved from each tibia. Despite the limited number of repeats, the COFs found in this experimental study can be applied to computational modelling to better characterise frictional contact between bone and implant while improving the analysis efficiency by eliminating the need for a sensitivity study.

SIGNIFICANCE: This experimental study proposed a method of measuring COF at bone-implant interfaces using one load cell only. The COF values found provided a better understanding of the frictional behaviour at the bone-implant interfaces and will potentially improve the reliability of the computational simulations of cementless implantation. Experimental characterisation of the COF also eliminates the additional effort required to conduct sensitivity analysis.

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Table 1: Coefficients of friction values.

			Coefficient of friction	
Bone sample	**Implant**	**n**	**Mean**	**Standard deviation**
Sawbones	Smooth keel	6	0.27	0.03
Sawbones	Porous keel	6	0.99	0.09
Porcine	Smooth keel	4	0.54	0.06
Porcine	Porous keel	7	0.93	0.18
Bovine Tibia 1	Smooth keel	2	0.46	0.02
Bovine Tibia 1	Porous keel	3	1.00	0.03
Bovine Tibia 2	Porous keel	3	0.68	0.09
Bovine Tibia 3	Porous keel	3	0.20	0.01
Cadaveric	Smooth keel	3	0.41	0.08
Cadaveric	Porous keel	5	0.99	0.14

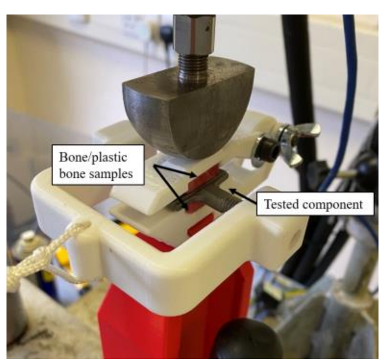

Figure 1: Equipment setup. The tested implant was clamped between two pieces of bone samples through the vertical load applied by the load cell. The implant was connected to the 2kg mass via a piece of string and a pulley.

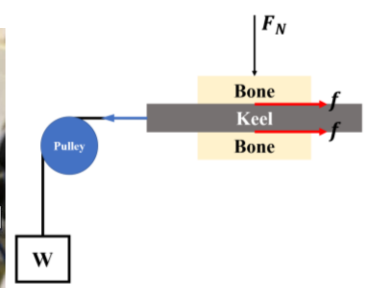

Figure 2: Schematic of experimental setup. F_N: vertical load; f: friction force