The use of an ultrasonic tool to cut human bone: cutting forces of orthopaedic surgeons

Irene Yang[1], Russell Buchanan[3], Nisreen Al-Namnam[1], Xuan Li[4], Margaret Lucas[4], A. Hamish Simpson[1,2]
[1]Department of Orthopaedics and Trauma, University of Edinburgh, [2]Royal Infirmary of Edinburgh, [3]School of Informatics, University of Edinburgh, Scotland, United Kingdom, [4]James Watt School of Engineering, University of Glasgow
iyang@ed.ac.uk

Disclosures: Irene Yang (N), Russell Buchanan (N), Nisreen Al-Namnam (N), Xuan Li (N), Margaret Lucas (N), Hamish Simpson (N)

INTRODUCTION: Ultrasonic cutting of bone boasts many advantages over alternatively powered surgical instruments, including but not limited to: elimination of swarf, reduced reaction forces, increased precision in cutting and reduced adjacent soft tissue damage, reduced post-operative complications such as bleeding and bone fracture, reduced healing time, reduced intra-operative noise and ease of handling. Despite ultrasonic cutting devices being well established in oral and maxillofacial surgery, applications in orthopaedic surgery are more niche and are not as well understood. The aim of this study was to investigate the cutting speed (mm/s) and cutting forces (N) of orthopaedic surgeons using a custom-designed state of the art ultrasonic cutting tool to cut fresh human bone samples.

METHODS: A setup based on the Robot Operating System (ROS) and AprilTag (Figure 1) was designed to track and to record the real time position of the ultrasonic cutting tool in space. Time synchronised load cell axial force readings of three separate orthopaedic surgeons during ultrasonic cutting were recorded using a 6-wire single point load cell (maximum 1000 N load capacity) (Model: SP-1040, PCM, UK). Each surgeon was asked to find a comfortable position that reflects as close as possible their clinical handling of a cutting instrument used in surgery, and to perform two cuts in each of three samples of human cortical bone mounted onto a custom designed test clamp, 3D printed in Polylactic Acid (PLA). Bone samples were obtained following ethical approval from an institutional review board (ethics approval number: SR1342) and prior informed consent was obtained from all patients. Bone samples were extracted from the femoral neck region of three hip osteoarthritis patients. During cutting, surgeons were allowed a total cutting time of one minute and cutting was conducted using an ultrasonic tool with frequency of a 35kHz (35.7 µm peak to peak displacement amplitude) under constant irrigation using a MINIPULS® 3 Peristaltic pump (38 revolutions per minute) using Phosphate-Buffered Saline (PBS) at 25°C. From the recorded data, the average and maximum cutting force was identified.

RESULTS SECTION: Variation in the applied cutting force was observed (Table 1). The average axial cutting force across all surgeons 1.91N, which is far below the reported surgeon cutting forces during orthopaedic surgery using conventional cutting tools (up to 210N [1]).

DISCUSSION: In this study, all surgeons cut using a back-and-forth cutting motion, with variation in the applied cutting force, which may ultimately inform which clinical applications in orthopaedic engineering are most suitable for this technology. Applying too much force caused overloading of the ultrasound transducer, which is a limitation with the current cutting tool. The results from this study may facilitate the eventual uptake of ultrasonic cutting tools for application in orthopaedic surgery, particularly for use in robotics, minimally invasive or remote surgical procedures where lower forces are required.

SIGNIFICANCE/CLINICAL RELEVANCE: Despite ultrasonic cutting devices being well established in oral and maxillofacial surgery, their application in orthopaedic surgery, particularly its use in robotic, minimally invasive or remotely controlled procedures may be more applicable for its comparatively smaller forces however, these applications are generally not well understood. The results from this study report the amount of force required to cut human cortical bone using an ultrasonic tool, which may facilitate the eventual uptake of ultrasonic cutting tools for application in orthopaedic surgery, particularly for use in robotics, minimally invasive or remote surgical procedures where lower forces are required.

REFERENCES: 1. Golahmadi, A.K., et al., *Tool-tissue forces in surgery: A systematic review.* (2049-0801 (Print)).

ACKNOWLEDGEMENTS: The authors thank Mark Mason, Imogen Heard, Iain Gold, Stephanie Collishaw, Christine Beadle, Pauline Irvine, Louise Robiati and Joe Esland for their assistance with this study. This study is funded by an Engineering and Physical Sciences Research Council (EPSRC) Programme grant: Ultrasurge – Surgery enabled by Ultrasonics (EP/R045291/1).

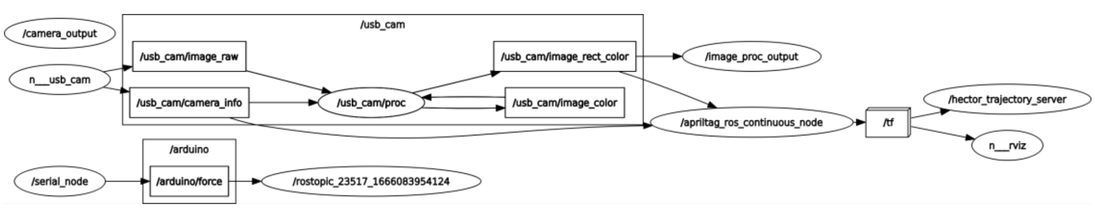

Figure 1. A plot demonstrating the ROS system (nodes and topics) used in this study.

Table 1. Surgeon vertical cutting speed (mm/s), cutting force (N) and cutting depth (mm).

		Experiment force (no irrigation) (N)					Cut depth (mm)				
		S1	S2	S3	AVG	TOTAL AVG	S1	S2	S3	AVG	TOTAL AVG
Sample 1	Cut 1	0.30	2.02	1.85	1.39	1.40	0.46	0.53	0.63	0.54	0.63
	Cut 2	0.50	1.82	1.89	1.40		0.30	0.90	0.96	0.72	
S1 AVG		0.40	1.92	1.87			0.38	0.71	0.79		
Sample 2	Cut 1	0.92	3.38	2.70	2.33	2.45	0.72	0.88	1.10	0.90	0.75
	Cut 2	1.01	4.27	2.42	2.57		0.56	0.70	0.55	0.60	
S2 AVG		0.96	3.82	2.56			0.64	0.79	0.83		
Sample 3	Cut 1	0.51	4.09	1.99	2.20	1.87	0.59	0.75	0.81	0.72	0.82
	Cut 2	0.70	1.90	2.03	1.54		0.72	0.75	1.29	0.92	
S3 AVG		0.60	3.00	2.01			0.65	0.75	1.05		
AVG ACROSS ALL SAMPLES		0.65	2.92	2.15			0.56	0.75	0.89		
AVG ACROSS ALL SAMPLES & SURGEONS		1.91					0.73				