Tool bracing for performance improvement in simulated femoral head-neck osteochondroplasty

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Introduction: Bracing is a strategy employed by humans and robotic devices to improve performance in a variety of tasks such as writing and automated grinding [1]. It can be more generally described as a parallel mechanical link between the actor, the environment, and/or the workpiece that alters the mechanical impedance between the tool and workpiece in order to improve task performance.

As an extension of recent 1 degree-of-freedom (DoF) work in our lab, we recently investigated the potential value of bracing in the context of the surgically relevant 3DoF task of bone milling with a spherical burr. More specifically, we simulated the milling of cam-type femoroacetabular impingement (FAI) lesions, as described by [2]. This procedure was chosen due to the growing recognition of FAI as a mechanism for the development of early osteoarthritis [2].

To meet a rising demand for procedures, surgeons are reluctant to embrace technologies that require increased procedure time. We hypothesize that bracing can enhance precision in simulated femoral head-neck osteochondroplasty without extending procedure time. The goal of this study was to evaluate whether a proposed bracing technique could enable a user to perform a resection on a femoral model more accurately and quickly than a currently employed arthroscopic technique [3].

Methods: A mold of a commercially available proximal adult femur (Sawbones Inc.) was made using silicone
rubber and reproduced using white urethane plastic (OOMOO® 30, Smooth Cast® 300, Smooth-On, Inc. Easton PA). Each proximal femur model was scanned with a Vivid 9I 3D laser scanner (Konica Minolta Sensing Americas, Inc. Ramsey NJ) at 30 intervals to obtain ground-truth surface information. A scan–rescan repeatability analysis found that the upper 95% error bound on RMS error was 0.037 mm. A representative cam lesion with geometry based on clinical data was then cast onto the surface of the femur in the anatomically relevant anterosuperior region [4] of the femoral neck using black casting resin (Alumilite Regular, Alumilite Corporation, Kalamazoo MI), creating a clear visual resection boundary to guide the mock surgical procedure.

Two binary factors were tested, resulting in four test conditions: (1) Braced vs. Unbraced – in the unbraced case, the tool was held using a grip approximating that used in current surgeries; in the braced case, the tool was supported using a spherical bearing mounted in the approximate anterolateral arthroscopic portal position, as illustrated in Figure 1A. (2) Speed vs. Accuracy – the subject was instructed either to perform the resection as quickly as possible with moderate regard for accuracy or as accurately as possible with moderate regard for time. Pilot test subjects were 4 adult males (25 +/- 3 years) with no surgical experience; each performed one resection under each test condition, for a total of 16 samples, using a Dyonics shaver handpiece and 5.5mm Acromioblaster burr (Smith & Nephew Advanced Surgical Devices, Memphis TN). Following the removal of the lesion, femurs were laser scanned as described previously to acquire the post-resection surface geometry.

Pre- and post-resection laser scans were transformed into 3D models using Rapidform XOR2 (3D Systems Corporation, Rock Hill SC), with the pre-resection model acting as the control for mesh comparisons. The 3D models were registered to one another and then trimmed to the anterior side of the femoral head-neck region where the lesion was located to eliminate extraneous information. The trimmed models were then loaded into Rapidform XOV2 (3D Systems Corporation, Rock Hill SC) to inspect the meshes, and a whole-mesh deviation analysis was performed by comparing the pre- and post-resection models to one another. The deviation was calculated by projecting the scanned points (post-resection) onto the nominal (pre-resection) data and determining the gap between the two; the results are reported as RMS deviations over the trimmed surface.

**Results:** The effects of bracing on time and accuracy of femoral head-neck osteochondroplasty are shown in Fig 1B with data presented as the mean and standard deviation of the 4 subjects. As expected, when asked to emphasize accuracy over speed, accuracy improved and time increased under both bracing conditions. In both accuracy and speed cases, bracing tended to reduce errors (on the order of 7-12%) and task duration (on the order of 24-34%), although given the small number of subjects in this pilot study, these differences were not statistically significant.

**Discussion:** In this pilot study, the results provide some encouragement that our hypothesis that bracing can improve both speed and accuracy of cam lesion resection by untrained subjects may be true. The standard deviations between subjects are high and are likely due to both the difficulty of the task and differences in experience using handheld power tools, so additional subjects would be needed to verify the trends identified here.

The simple brace used in this study would not be directly suitable for use in live surgical procedures as it greatly reduced the workspace of the arthroscopy shaver and thereby, in combination with the shape of the greater trochanter, prevented full resection of the lesion; this workspace limitation potentially led to an underestimate of the value of bracing in this study. In addition, other studies have shown that reversed motions due to operating across a fulcrum point, as was done here, can impair performance in laparoscopic tasks [5], and we hypothesize that performance in a braced configuration could be further improved by altering the brace design to prevent motion reversal.

In future work, we intend to focus on designing and fabricating a more effective brace for the targeted surgical task that will provide a more acceptable workspace and will have the potential to be translated to the operating environment. We also intend to test subsequent designs with a larger pool of subjects,
particularly those with surgical experience, in order to test whether the performance improvements observed here can be achieved in live surgeries.

References