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USE OF ROBOTIC TECHNOLOGY IN CAM FEMOROACETABULAR IMPINGEMENT CORRECTIVE SURGERY

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SUMMARY

Cam type femoroacetabular impingement is a hip disorder, characterized by loss of the concavity of the femoral head/neck junction that may lead to osteoarthritis. Over/under correction of bony cam impingement lesions may lead to unfavorable outcomes in hip surgery. In this study, use of robotic technology was assessed as it can potentially improve the accuracy of this delicate procedure. CT scans of three patients' hips with severe cam deformities were obtained and used to manufacture 3D dry bone models. These scans were then segmented to create 3D surface models. Surgical plans were made using custom written software and imported into a surgical robot. Forty-two femoral models were sculpted (14 femurs in each subset). Post surgery models were then CT scanned to assess the accuracy and consistency of resection by calculating 3-D α angles around the entire neck and head neck ratios (HNRs) at distances r/4, r/2, 3r/4 and r from the head centre, where r is the radius of femoral head. Mann-Whitney U tests were used to compare differences in α angles pre and post-resection. The maximum α angle in the original three models were 91°, 91° and 87°. These were significantly reduced postoperatively 48°±3°, 53°±5°, 47°±2° $p<0.001$. The HNRs for the original models prior to surgery were 3.2, 3.4 and 3.1. Postoperatively HNR were reduced to 3.0 ± 0.1, 3.1 ± 0.1 and 3.1 ± 0.0 respectively. This study suggests that robotic technology may be used in cam surgery to prevent over/under correction associated failures.

INTRODUCTION

Cam type femoroacetabular impingement (FAI) is an anatomical hip disorder, characterized by loss of the normal concavity of the femoral head neck junction that may lead to developing of osteoarthritis (OA) [3]. Failure to completely address the bony impingement lesions during surgery has been the most common reason for unsuccessful hip arthroscopy and subsequent revision surgery [7]. α angle measurement (defined as the angle formed between the neck axis and a line drawn to the point where the bone first exceeds the radius of the femoral head) is an objective calculation of the prominence of the anterior femoral head-neck. In 2D studies, an α angle greater than 55^{o} was considered abnormal however limitations of 2D α angle measurement have led to the development of 3D methods [4, 6].

Robotic technology has facilitated more accurate surgery in comparison to the conventional means. The Acrobot Sculptor (Stanmore, UK) has previously been used for uni-condylar knee replacement [1]. Excessive resection is prevented by the robot's "active constraint" technology which defines regions within which cutting is permitted, but the surgeon is prevented from cutting outside of these regions [2]. In this study we aim to assess the potential application of robotic technology in dealing with this technically challenging procedure of cam sculpting surgery by assessing pre and post operative 3-dimensional α angles and head neck ratios [4, 6].

METHODS

CT scans of three patients' hips with severe cam deformity (here referred to as A, B and C models) were obtained and used to construct 3D dry bone models (Figure 1). The scans were segmented to create 3D surface models for each of these bones. A 3D surgical plan was then made using custom written software. The femoral head centre, radius and neck axis were measured for each model. Each 3D plan was imported into the Acrobot Sculptor robot. The robot was calibrated and the plastic model was registered to the imported surface model data. Bone resection was carried out while the operator received a real-time visual feedback from an on screen display using a hyperboloidal constraint [5]. In total, 42 femoral models were sculpted (14 femurs in each subset), thirty of which were performed by a single operator and the remaining 12 femurs were resected by two other operators. CT of the pre- and post resected specimens was segmented and a 3D model was created to assess the accuracy and consistency of resection. 3-Matic (Materialise®, Belgium) software was used to obtain the asphericity contour 360° round the entire neck and Matlab (Mathworks®, USA) measure the pre- and post- resection α angles based on original neck axis and femoral head radius. The frame of reference was defined so that looking along the neck axis where 0° is the most superior point, and 90° is anterior. The 3D Summation of head neck ratio (HNRs) was also calculated at four points along the neck (at distances r/4,r/2/3r/4 and r from the head centre, where r is the radius of femoral head) prior to and post resection [6]. Mann-Whitney U test was used to compare differences in α angles pre and post- resection. Coefficient of variation (CV) was used to determine the degree of variation between the mean

and maximum observed α angles for inter- and intra-observer repeatability

RESULTS AND DISCUSSION

The maximal α angle in cam A, B and C (91°, 91° and 87°) is shown in Figure 1. There was significant reduction $p<0.001$ (48°±3°, 53°±5°, 47°±2° respectively) in maximum α angles post-operatively within all three models when compared to original model (Figure 1). The HNRs for cam A, B and C prior to surgery were found to be 3.2, 3.4 and 3.1 respectively that were reduced to a mean of 3.0 ± 0.1 , 3.1 ± 0.1 and 3.1 ± 0.0, following resection surgery. The results of the intra and inter-observer repeatability study found good reproducibility (CV<10%) of the maximum and mean α angles between the 12 resected femurs.

In this study we evaluated the use of a robotic system to perform cam correction surgery by evaluating the 3D morphology of head/neck prior to and post surgery. With existing surgical options there is a potential for under or over-resection of the cam lesion, which runs the risk of the need for further surgery or rarely neck fracture and dislocation. Based on the calculated α angles and HNRs we have shown that we can successfully perform the surgery in-vitro by avoiding under and over resection respectively.

CONCLUSIONS

A more accurate bony resection performed here may minimize the complications due to over and under resection and hence will decrease the burden on the health service.

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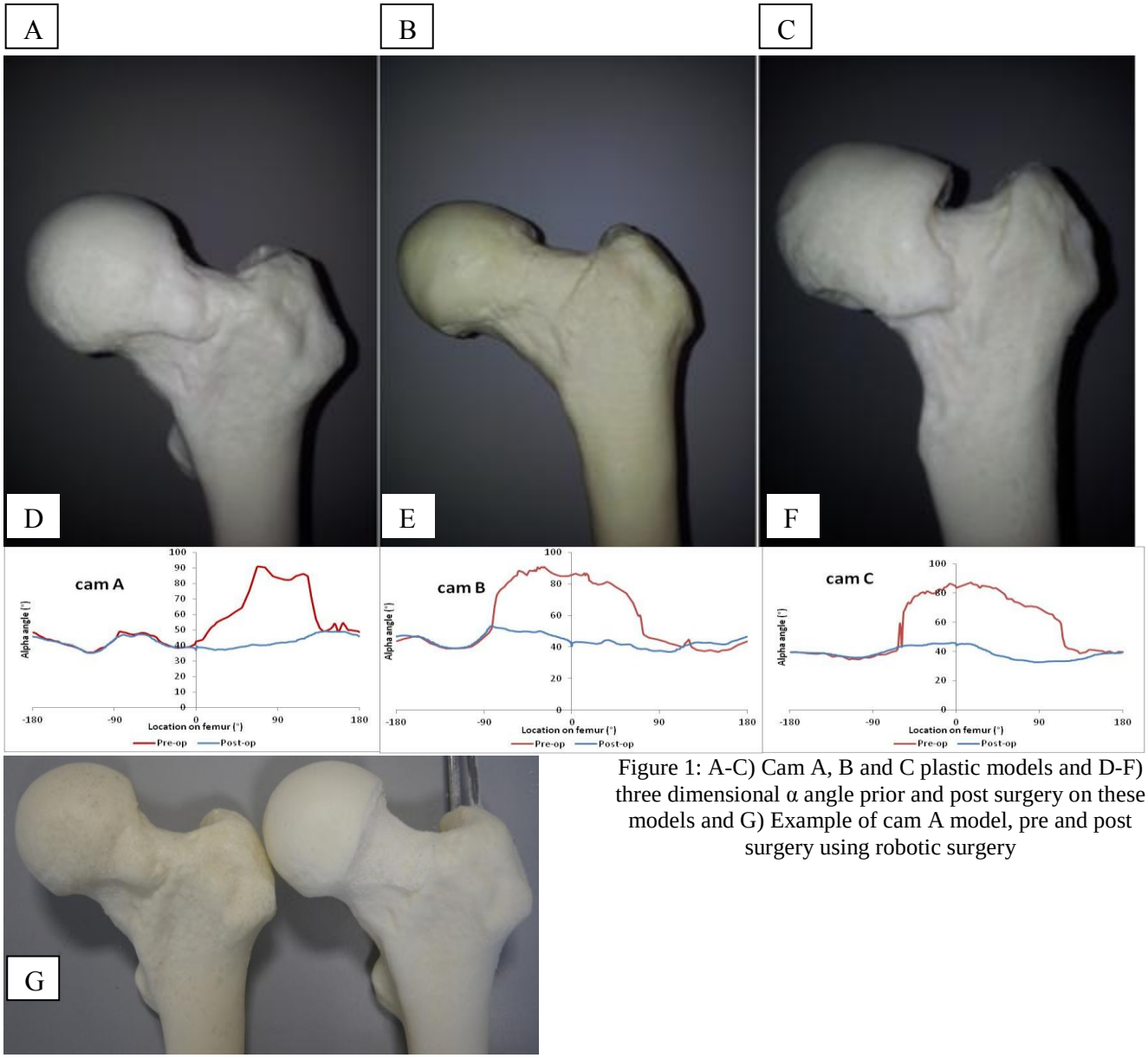

Figure 1: A-C) Cam A, B and C plastic models and D-F) three dimensional α angle prior and post surgery on these models and G) Example of cam A model, pre and post surgery using robotic surgery