Osteochondroplasty of the Femoral Head-Neck Junction in Cam-type Impingement Using a Navigated Milling Device – An Accuracy Study

1,2 Puls, M; 1,2 Eckert, TM; 1 Steppeacher, SD; 1,2 Siebenrock, KA; 1 Kowal, JH; 1 Tannast, M
1,2 Department of Orthopaedic Surgery, University of Berne, Switzerland, 1 ISTB, University of Berne, Switzerland

Moritz.Tannast@insel.ch

Introduction:
Osteochondroplasty of the femoral head neck junction in patients with cam type impingement is a frequently performed joint preserving surgery. One surgical option is the resection of the osseous incongruities by using round burrs or similar reaming devices. Several attempts to navigate instruments for this purpose intraoperatively have been introduced. However, none of these attempts contained a planning module and a subsequent navigation application that was able to visualize the progress of the actual osteochondroplasty in real time on a 3D model. We developed a planning and navigation application for impingement relief, using surgical reaming devices. Despite knowing that factors such as tool bending, vibrations during reaming process and difficulties in reshaping complex geometrical constructs might have a negative impact on navigation accuracy, we hypothesized that our application will enable the surgeon to accurately perform an osteochondroplasty with a navigated reaming device according to a distinct preoperative plan.

Methods:
An experimental, in-vitro accuracy study was performed, evaluating the ability to navigate reaming devices for osteochondroplasty of the hip joint. Prior to this, a FAIPlanning application had been implemented utilizing the MARVIN development framework for medical applications. This application provides the possibility to virtually remodel the femoral head-neck junction based on a simple and easy-to-use interface. For evaluation, eighteen identical plastic bones (Synthes AG, Oberdorf, Switzerland) with a distinct cam impingement were scanned with a tracked hand-held laser scanner (Steinbichler Optotechnik GmbH, Traunstein, Germany) and subsequently 3D computer models were generated. These were transferred to our FAIPlanning application. Two orthopaedic surgeons performed a virtual osteochondroplasty for cam impingement with creation of a sufficient femoral head-neck junction. The planned 3D model was then transferred to our developed FAINavigation software, which was also implemented using the MARVIN development framework. The tool of choice was an Electric Pen (Synthes AG, Oberdorf, Switzerland), which was equipped with a dynamic reference base (DRB), in order to be tracked by a Polaris camera system (Northern Digital, Inc., Ontario, Canada). A second DRB was attached to the proximal femur, which was subsequently registered against the 3D model, using a restricted surface matching. Employing a customized calibration device (ARTORG Research Center, Bern, Switzerland), the high-speed burr was then calibrated. Afterwards, the orthopaedic surgeons performed a navigated osteochondroplasty guided by the on-screen information of the FAINavigation software according to the previous plan. The instrument tip of the round burr and the associated reaming process after contact with the bone is calculated and visualized in real time by using a computed binary space partitioning tree. Moreover, the remaining reaming distance according to the planned resection depth is shown by a color-coded surface.

Three different virtual osteochondroplasties for relief of cam impingement were planned with the FAIPlanning software. Then, the two surgeons navigated each plan three times using the identically shaped bones. After the procedure, the reshaped plastic bones were scanned with the 3D handheld laser scanner again. By using the Amira Visualization Software (Mercury Computer Systems Inc., Chelmsford, MA, USA), the scanned models could be registered and compared as a gold standard to the planned, as well as the virtually reamed models. Statistical analysis was performed. For test-retest reliability regarding mean distance error between the actual reamed models and the planned models we calculated an intraclass correlation coefficient (ICC) for each of the three preoperative plans for each examiner. In addition an ICC for interobserver correlation between both examiners was calculated. In order to assess the application’s capability of accurately visualizing the reaming process, an intra- and interobserver ICC was computed for the mean distance error between the reamed and visualized models. The following convention was used to aid interpretation of the coefficient: ICC <0.2 ‘slight agreement’; 0.2 ≤ ICC <0.4 ‘fair agreement’; 0.4 ≤ ICC <0.6 ‘moderate agreement’; 0.61 ≤ ICC <0.8 ‘substantial agreement and ICC ≥0.8 ‘almost perfect’.

Results:
The mean distance error between the actual reamed models compared to the planned preoperative models was less than 1mm with a standard deviation of also less then 1mm and a maximum error of less than 2mm. The mean distance error between the actual reamed models and the visualized models was also constantly less than 1mm with a standard deviation of less than 1mm, however, there was one outlier with a mean difference of 1.22 mm The maximum error was less than 2.2mm. The intraclass correlation coefficients for intra- and inter observer test-retest reliability for comparison of the actual reamed models to the planned models proved to show moderate to substantial agreement for both observers. The interobserver correlation showed substantial agreement in two plans and moderate agreement for the third plan. Measuring the ICC for intraobserver test-retest reliability for comparison of the actual reamed models to the visualized models, we found moderate to substantial agreement for both observers. The overall interobserver ICC showed substantial agreement among observers.

Discussion:
Our study revealed that navigating a reaming device for osteochondroplasty of the proximal femur according to a preoperative plan, can be achieved with good accuracy and good reliability and reproducibility. Moreover, it shows that influence factors such as tool bending, vibrational disturbances and three-dimensional geometrical issues do not necessarily distort navigation results. Furthermore, we have shown that it is possible to virtually simulate and visualize the actual reaming process in real time on a 3D model and thus guide the surgeon regarding the remaining amount of bone to resect.

Possible sources of errors might derive from the typical navigation-related problems. These include registration errors, errors during model generation and scanning artifacts. Furthermore, additional research including higher numbers of plastic bones reamed by several observers and analogous cadaver- and in-vivo studies need to be conducted. Nonetheless the obtained results are promising. Especially in the light of the current trend towards less invasive impingement surgery, our application bears a great potential as a basis for navigated arthroscopic approaches to FAI. However, further investigation, especially regarding the applied registration of the 3D model to the patients’ anatomy will have to be performed. Techniques of choice might be 2D-3D or 3D-3D registration algorithms employing fluoroscopy or ISO-C 3D scans.