Morphometric Study of the Human Clavicle for the Development of an Anatomical Plate
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Introduction: Recent studies have shown the efficacy of open reduction and internal plate fixation with high union rate and low complication rate [1-2].
Several complications like lack of fixations, breaking or loosening of the plate happen [3] and are partially due to bending of a straight plate.
We believe that a set of osteosynthesis plates that is adapted to the shape variation of the human clavicles will not only reduce these complications but will also minimize the amount of bending required to adapt a plate to a specific clavicle during surgery.
In this study, a morphometric study of the variation was performed to predict whether or not an anatomically correct plate would be feasible to cover a broad population of patients.

Materials and Methods: In this study, 38 pairs and 14 individual clavicles from human cadavers were dissected and investigated. This set of clavicles represented 32 male and 20 female specimens with a mean age of 71 years (range: 25 to 99).
All clavicles were scanned with a GE Lightspeed VCT with a spatial resolution of 500x500x600 μm3.
Next, the CT reconstructions were automatically segmented by morphological image processing operations. Due to the usage of a zinc chloride solution in the embalming procedure, the contrast of bone and soft tissue was low. Therefore, manual correction with “AMIRA” software was performed to correct the affected segmentations.
After having generated a surface based correspondence with a cylindrical parameterization technique, each clavicle was represented by a point in a multidimensional shape space [4]. By clustering these points, the clavicles having similar shape were grouped.

To evaluate if the number of clavicles used was representative for the population, a sample size variability curve was calculated. To this end, K clavicles (K=2,…,N) were randomly selected from the set of N clavicles and the variation between the K clavicles was calculated; this was repeated 100 times.

To get a clinical idea about the anatomical plate, a desirable region of contact between clavicle and plate was defined on the mean shape and mapped to each clavicle by the correspondence. This region of interest was placed on the superior surface and covers the two curvatures of the clavicle as shown in figure 2. From this region of interest a number of virtual plates was determined by a k-means clustering algorithm.

Results: For the first tests we used a sample size of N=78 clavicles. Figure 1 shows the sample size variability. A leveling of the curve can be observed at about the 40th clavicle and a clear flat curve is visible at the last clavicles.
The average error of the templates is presented in Figure 3. The average error for 2 templates is 2.5 mm and decreases to 1.33 mm with 20 templates. The maximal error at 20 template is 6 mm.

Discussion: From the sample size variability study, it can be concluded that a sample size of 78 clavicles is representative for the population of clavicles.
The region of interest, as depicted in figure 2, that we choose represents a broad idea for the development of an anatomical plate. The average error at 10 to 20 templates is less than 2 mm. To our view, this is acceptable and we believe that this accuracy would be sufficient for the developing of a set of plates. On the other hand, the maximal error is still high, caused by a small number of clavicles with extreme shapes. We believe that a smaller region of interest, in other words smaller plates at different locations on the clavicle would lower the error even more and could lead to a clear set of plates that can be applied to fractures of the midclavicular type. Furthermore, we want to apply a similar virtual plate on the anterior side of the clavicle as it is also used to treat these fractures [2].

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Figure 1: sample size variability curve
Figure 2: A ROI delineated on the mean clavicle (red)
Figure 3: Mean and maximum approximation error of the virtual plates to clavicle ROIs