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Semi-Automatic Generation of Preoperative Surgical Plans for Complex Femoral Deformity Correction

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Abstract

Complex bone deformation of the femur can occur in bone disease. This can cause significant functional impairment and is often an indication for surgery. Current technology enables preoperative planning and execution of these complex multi-planar osteotomies with high accuracy. A novel solution is presented that generates preoperative plans using Blender. The model automatically optimizes femoral shaft shape within the boundaries of clinical constraints. 20 cases of femoral deformity were processed by the model retrospectively. Eighteen of twenty preoperative plans were accepted by two independent clinical experts. This shows the ability of the model to generate preoperative plans of sufficient clinical quality. Four random cases were compared to manual preoperative planning. These showed comparable results. The collum anteversion angle was normalized in four cases in the automatic group and only in one for the manual group. The manual planning process was slower in every case, ranging from 31% to 575% slower. The proposed method, allows fast interactive surgical planning within a constraint based design and is a promising aide for complex femoral correction planning.

1 Introduction

Diseases of bone can result in significant complex femoral deformation. Examples of causes are fibrous dysplasia, rickets and osteogenesis imperfecta [9, 8, 3]. Deformation often occurs due to bending over a larger zone, in contrast to to post-traumatic deformity that mainly involves a single localization. It can limit range of motion or create biomechanical imbalances. Correctional osteotomy is often advised in case of functional impairment. As these surgeries often require multiplanar corrections these are highly demanding.

Pre-operative planning and surgical guide use can significantly improved surgical workflow and result in significantly shorter surgery time and decreased bloodloss [5].

The design of a preoperative plan is however often difficult and time-consuming [6]. The goal of this study is to develop an automated system for femoral deformity correction.

2 Method

An in-silico study was performed at the Leiden University Medical Center (LUMC). Patients with femoral deformity with a CT scan were included, post-traumatic origo was excluded. The

algorithm is focused on achieving improved clinical parameters. These are the collum anteversion angle (CAA), femoral neck shaft angle (FNSA), articulo-trochanteric distance (offset, ATD) and femoral bone length as well as reconstructing the shape of a non-pathological bone, Figure 1.
Preoperative plans generated are scored by 2 independent experts and objectively validated based on morphometric characteristics and planning time.

2.1 Model architecture

The femoral shape has to quantified and combined with anatomical constraints in a global cost function. The femoral shape error is defined as the dissimilarity of the femoral centreline after osteotomy and the centreline of a given intramedullary nail. The postoperative configuration is compared to a nail, as these are designed to resemble normal shaft anatomy. The dissimilarity of the shapes is calculated by multiplying the mean shortest distance and the Hausdorff distance. The cost function is minimized using a genetic algorithm. A multi-objective optimization approach aims to find a good approximation of the Pareto-front, spanned by the shaft shape and the agreement to morphomentric characteristics. This optimization is performed using the SMS-EMOA algorithm from the PyMOO Python module [2].

2.2 Model validation

Two independent clinicians experts are involved in an interactive user test, after which they are asked to fill in a survey.
In a second test the preoperative plans generated by a technician, are presented to the same reviewers and scored with a grade ranging from 1 to 5. Preoperative plans scoring a 3 or lower are revisited and scored anew until all preoperative plans score a 4 or higher.
In a third test preoperative plans are generated for 4 randomly chosen deformed bones from the database, both manually and automatically. Preoperative plans are compared on time and morphometric characteristics.

3 Results

14 patients were included, 20 femora in toto. 13 patients had polyostotic fibrous dysplasia, 1 a deformity secondary to hypophosphatasia. 4 femora had a shepherds crook deformity, 2 femora had bowing without a clear centre of rotation of angulation.

3.1 User test

The mean score of the examiners was 3.8 or higher. Both clinicians strongly agreed with the statement: "The tool enables the creation of a preoperative plan with minimal technical expertise".

3.2 Subjective plan assessment

In first proposal, eight out of twenty preoperative plans were accepted. In the second, 9 more (16/20). For the third 2 more for a total of 18/20 accepted. One was deemed not a surgical indication, one was rejected due to a very oblique osteotomy.

3.3 Manual vs Automatic

Analysis is stated in Figure 2. The designer of preoperative plan 1 and 3 took 357% times longer to complete its plans. The designer of plan 2 and 4 took 57% more time.

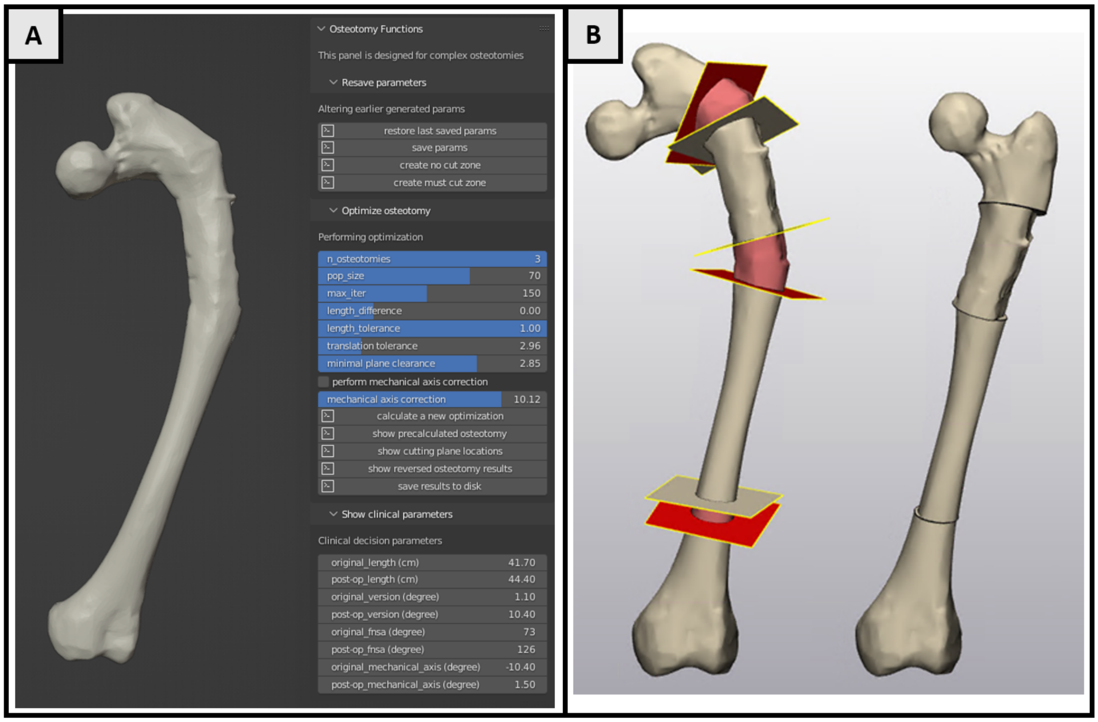

Figure 1: Image of the interface of the tool. The second panel shows a 3d view of an automatically planned correction.

	Automatic/ Manual	Planning Time [mm:ss]	FNSA [deg]	CAA [deg]	ATD [mm]	Femoral Length [mm]	Mean Wedge Height [mm]
Case 1	Automatic	08:09	125	12.1	1.8	338	4.9
	Manual	55:00	114	18.6	-3.7	336	3.1
	Difference	46:51	11	6.5	5.5	2	1.8
Case 2	Automatic	08:08	121	8.6	13.5	390	5.1
	Manual	15:00	111	0.6	7.8	379	11.0
	Difference	06:52	10	8.0	5.7	11	5.9
Case 3	Automatic	18:07	145	13.0	24.5	393	20.1
	Manual	65:00	133	5.9	16.1	396	11.3
	Difference	46:53	12	7.1	9.4	3	8.8
Case 4	Automatic	09:09	133	13.2	25.7	457	6.3
	Manual	12:00	125	8.9	19.9	448	8.8
	Difference	02:51	8	4.3	5.8	9	2.5
Mean	Automatic	10:53 (08:08-18:07)	131 (121-145)	11.7 (8.6-13.2)	16.4 (1.8-25.7)	395 (338-457)	9.1 (4.9-20.1)
	Manual	36:45 (12:00-65:00)	121 (111-133)	8.5 (0.6-18.6)	10 (-3.7-19.9)	390 (336-448)	8.6 (3.1-11.3)
	Difference	25:52 (2:51-46:53)	10 (8-12)	6.5 (4.3-8.0)	6.4 (5.5-8.4)	6 (2-11)	4.8 (1.8-8.8)

Figure 2: This table lists the time needed to produce the preoperative plans and summarizes the morphometric characteristics.

The FNSA and ATD are consistently larger in the automatic post-operative anatomy in comparison with the manual post-operative anatomy. The mean difference in anteversion angle is 6.5 degrees. In the automatic optimization all CAAs are within the range of the anatomical normal. In the manual group only in a single case the CAA was within normal anatomical range.

4 Discussion

The planning and surgery of multiplanar corrections of femoral bone deformity are highly complex. This study shows that the proposed algorithm can achieve semi-automatic preoperative planning for a range of femoral deformities, including shepherds crook deformity and femoral bowing. It can also optimize morphometric characteristic correlated to patient function. Interactive shape optimization bounded by clinical constraints, is a powerful method to semi-automatically generate preoperative plans.

Very limited research on the automatic osteotomy planning has been performed. Two papers describing single and double osteotomy were released by the Helmholtz-Institute for Biomedical Engineering [7, 1]. The planning tool differs strongly from the one proposed in this study. The optimization of the osteotomy planes in their proposed model is based on normalizing four deformity parameters, disregarding the femoral shape.

Carrillo et al. created a software for automated preoperative planning of forearm osteotomies [4]. The antebrachii model optimizes the postoperative situation and calculates the osteotomy needed to achieve that result. The femur model from this study optimizes the osteotomy planes and the postoperative result is calculated from those planes. This method of finding the postoperative situation first is a feasible method for single osteotomies, but becomes increasingly challenging for multiple osteotomies.

5 Conclusion

In this study a novel method for semi-automatic preoperative planning optimization is presented. The optimization is driven by minimizing the dissimilarity of the postoperative femoral shape and a given target shape, within the bounds of clinical constraints.

Eighteen of twenty cases were accepted in a maximum of three iterations. From this, it can be concluded that the model can generate preoperative plans of sufficient quality that are tailored to the wishes of the clinical expert.

The model enables a user with minimal clinical expertise to create feasible preoperative plans. For all cases less time was needed.

In summary, the automatic planning tool is a promising aide to both technicians and clinicians for fast preoperative planning within the boundaries of anatomical normal ranges.

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