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Towards a Y-shaped pelvic osteotomy to address loss of lumbar lordosis

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Abstract

Introduction In severe cases with lumbar lordosis loss > 25°, pedicle subtraction osteotomy is performed surgically to restore the sagittal malalignment. But it has severe limitations. So, we are developing a new Y-shaped pelvic osteotomy that targets the pelvis rather than the spine. This work presents a fixation system tailored to the Y-shaped pelvic osteotomy.

Methodology Criteria for the fixation system were set: Offer compressed fixation on the posterior side (closed wedge), maintain a 15° wedge opening on the anterior side and use conventional fixation components. This resulted in combining a lag-screw posteriorly and a patient-specific osteosynthesis plate anteriorly. To assess feasibility, a basic finite element analysis (FEA) was performed using loads derived from a static free body analysis, and a preliminary test was performed on a Sawbones model to assess surgical usability and osteotomy accuracy.

Results The load input to the FEA was determined to be 397 N in x-direction, 832 N in z-direction, and 18 Nm moment. The FEA showed that the width of the T-shape of the plate crossing the osteotomy should be at least 15 mm to remain below allowable material stress level.

The usability gave a score of 3.9 out of 7 for the fixation system. The Sawbone test showed obtained osteotomy angles of 16.6° and 19.5°, respectively compared to the set 15°. The bone contact area was 62% compared to the planned 61%.

Conclusion The preliminary results indicate the feasibility of the Y-shaped pelvic osteotomy executed bilaterally in combination with the new fixation system.

1 Introduction

The spine plays an essential role in human biomechanics. Severe flattening of the lumbar lordosis (L1-L5) caused by disk degeneration, trauma or adult acquired spinal deformity causes chronic back pain, forward-leaning posture, severe sagittal malalignment, and imbalanced compensatory mechanisms [1-3]. In cases of lumbar lordosis loss > 25°, pedicle subtraction osteotomy is performed surgically to restore the sagittal malalignment. However, this technique shows high complication rates including significant blood loss, deep wound infections, and neurological deficits [4].

To address these complications, inspired by dysplasia correction osteotomies [5], the University Medical Centre Utrecht is developing a new Y-shaped pelvic osteotomy that targets the pelvis (bilaterally) rather than the spine [6], which is created by first making a bilateral cut through the ilia followed by a second cut from the posterior side towards the midpoint of the ilia to remove a wedge at an angle of 15° (Figure 1). This allows rotation of the cranial and caudal ilia bone segments to straighten the spine (Figure 1). The removed wedge is re-inserted in the anterior gap. This work presents the development of a fixation system tailored to the Y-shaped pelvic osteotomy.

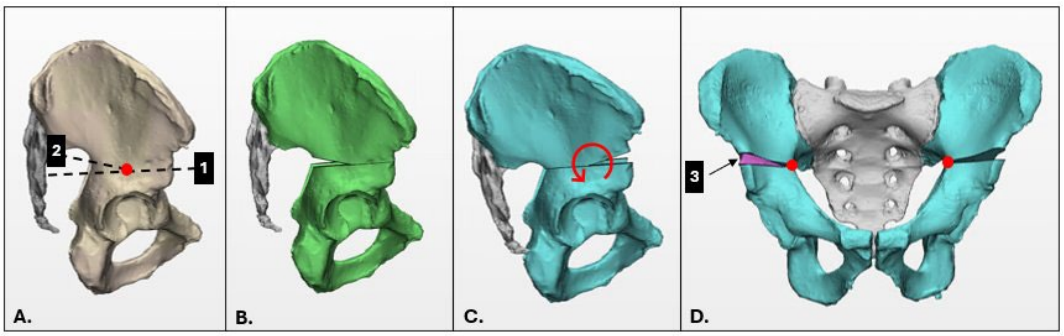

Figure 1: A. Single ilium showing both Cutline 1 and 2. B. and C. show the resulting corrective rotation of the cranial and caudal bone segments making a closed wedge posteriorly and an open wedge anteriorly. D. Entire pelvic area in frontal view, showing the envisioned Y-shaped pelvic osteotomy of 15° as indicated at 3.

2 Methodology

For the Y-shaped pelvic osteotomy to become successful; first, the optimal level and inclination of the osteotomy in the ilia was determined. The entry point was set between the superior iliac spine and the acetabulum just above the rectus femoris insertion along the lateral-anterior ilium. The endpoint was placed just below the sciatic notch on a flat area. This cutline gave maximal bone contact area, and minimal malalignment.

Second, proper fixation strategy until bone healing is achieved should be offered using as much as possible proven components (screws, osteosynthesis plates). To this end, 5 primary criteria were determined:

- Fixate anterior and posterior sides of both ilia and withstand loads in static standing position
- Offer compressed fixation on the posterior side (closed wedge) and maintain a 15° wedge opening on the anterior side (Figure 1)
- Fixation components must not interfere with sacroiliac joint, acetabulum and sciatic nerve
- Fixation components must be inserted via available surgical access incisions
- Osteosynthesis plates must be either preformed to match the individual patient's anatomy or custom-made

Because of these strict criteria, not many options remained, resulting in a fixation system combining a lag-screw (Ø 6.5mm) posteriorly and a patient-specific titanium osteosynthesis plate (thickness 3-3.5 mm) anteriorly fixated by bi-cortical screws (Ø 5mm) (Figure 2).

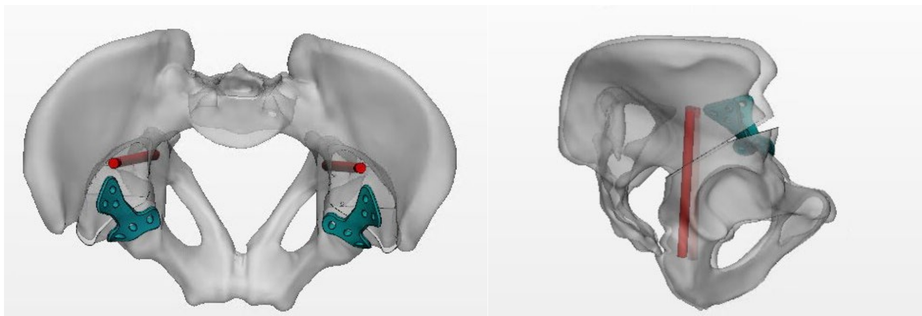

Figure 2: Left. Top view of the pelvis with the fixation system consisting of a lag screw and patient-specific t-shaped osteosynthesis plate presented in both ilia. Right: Side view of the fixation system.

To verify that the fixation system is able to withstand the loads, a free body diagram (FBD) was generated to derive realistic loads, which served as input to Finite Element Analysis (FEA) of the osteosynthesis plate design. Assumptions set for the FBD were:

- Weight of upper body acts through the center of the pelvis in a two-legged stance with equal loading between the legs (meaning left-right loading is equal)
- Loading of the plate can be determined by considering the static equilibrium of the osteotomized caudal section of one ilium
- The only forces acting on the osteotomized section are forces/moments in the osteotomy, forces exerted by the femoral head, and compressive forces in the pubic symphysis
- Two extreme cases are 1) that the contact forces in the pubic symphysis are zero and 2) that only forces but no moment are transferred by the plate. Since case 1 leads to the higher stresses, we only consider this one.
- Joint reaction forces are centered in the acetabulum at 13°angle, and act on the ilia with 397N in medial-lateral direction (x-axis), with 50N in anterior posterior direction (negative y-axis) and with 832 N in cranial direction (z-axis) [7]
- Dimensions of frontal plane are based on [8] and sagittal plane on [9]

The FBD gave the resulting loads acting in the osteotomy plane when the fixation system bears the full moment; and were used to perform a preliminary FEA evaluation of the loads on the patient-specific osteosynthesis plate. To this end, the resulting loads were equally distributed over the 6 fixation screws, the plate was assigned material properties of Ti6A14V, and a tetrahedral mesh was generated with edge length of 2 mm.

To verify the clinical feasibility, the entire procedure was executed by a single expert orthopedic surgeon on a Sawbone model. To this end, sawing guides and the patient-specific osteosynthesis plate were designed using a CT-scan of the Sawbone model and subsequently 3D printed. Surgeons feedback was gathered via direct observation, the USE questionnaire [10], and semi-structured interview. The accuracy of the achieved correction angle and bone contact was assessed by a 3D scan.

3 Results

The results of the FBD gave 397 N in x-direction, and 832 N in z-direction, and 18 Nm moment for the extreme case. The FEA showed that the width of the T-shape of the plate crossing the osteotomy (Figure 2) should be 15 mm to prevent Von Mises stress exceeding the allowable material stress level.

The USE questionnaire gave a score of 3.9 out of 7 for the fixation system. The surgeon liked the ease and precise control pf the fixation. The results of the Sawbone test showed that the achieved osteotomy angles were 16.6° (right) and 19.5° (left), respectively compared to the set 15° (Figure 1). The bone contact area was 62% compared to the planned 61%.

4 Discussion

The Y-shaped pelvic osteotomy was further detailed and elaborated with a fixation system. Preliminary simulations and Sawbone test results indicate its feasibility. However, this study has limitations. First, the FEA was executed in a basic manner merely indicating feasibility. A more detailed FEA with advanced modelling is required. Similarly, more in depth testing is required preferably on cadavers with actual titanium and stainless-steel fixation components should provide true proof of concept, especially regarding the clinical feasibility and avoidance of damaging nerves and other delicate structures. Furthermore, the sawing guides need to be optimized for efficient and ease of use. Concluding, the Y-shaped pelvic osteotomy could overcome the issues with the bilateral extended pelvis osteotomy [6], as an alternative for patients where lumbar PSO is not an option.

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