Introduction

This study is about the human pelvis which is the set of bones of the waist located between the spine and the lower limbs, in order to obtain a better understanding of its mechanisms and thus be able to prevent or cure dysfunctions that touch this part.

In some cases, the pelvis can be subjected to dysfunctions such as the sacroiliac joint disease which is an abnormal motion (too big or too small) of the sacroiliac joint. This disease can lead to heavy consequences, from pain to complete immobility of certain part of the body.

To reduce the pain created by this dysfunction, several conservative or non-conservative medical methods can be used. This research focuses on the fusion surgery which consists in inserting fixations within the pelvis to fix the joint, minimize the motion between the different bones and stimulate the ossification of the joint.

Two kinds of fusion surgery are possible:

- Anterior fusion surgery, the fixations are placed from the front side of the body. It is a strong fixation with good results and significantly reduced pain. It is however very intrusive due to the presence of many organs, and it is especially difficult to perform for people with obesity.

- Posterior fusion surgery, the fixations are placed from the back side of the body. There are few organs present, with only a few tissues to care about such as nerves so it is much easier to perform. However, clinical results from patients show that remaining pain is recurrent, and the fixation is considered weaker than the front side.

In this study, finite element models of the pelvis with sacroiliac joint fixations were developed in order to compare different configurations of fixations and improve posterior fixations so that results can come closer to anterior fixations. Stress distribution of the pelvic bones and sacroiliac joint’s cartilage, as well as ligaments’ loads and hip bone’s displacement were evaluated and compared with a previous study [1].

Methods

A finite element model was obtained from Prof. Hammer (University of Otago, NZ) to perform a finite element analysis [2]. It comprises the sacrum, the left and right hip bones, the pubic symphysis, the different surrounding ligaments (Springs) as well as the left and right sides’ sacroiliac joint’s cartilage and ligament (Fig. 1).

Figure 1. Geometry in the pelvic model. (a) Anterior view. (b) Posterior view. (c) Lateral view. (d) Left sacroiliac joint.

Models

All fixations are placed on the left side of the pelvis. Four models were considered from a previous study:

- Model without any fixation (N) used as a referential model. Obtained from Prof. Hammer.
- Model with posterior fixations, 1 rod and 3 screws (P1) easily done in surgery.
- Model with posterior fixations, 1 rod and 3 screws (P2), difficult to perform in surgery. This model was considered improved in the previous study due to better results. Its difficulty to realize however represents a strong barrier in surgery.
- Model with anterior fixations (A), 1 plate and 5 screws, known as the best kind of fixation until now in terms of results.

Six new models were added, by inserting a cage (Small cylindrical implant which can be placed between screws) with different directions in the previous models. In configuration 1 (C1), the cage is placed along the joint, its longitudinal axis is close to the perpendicular of the normal axis of the joint’s cartilage. In configuration 2 (C2), the cage goes through the joint, its longitudinal axis is close to the normal axis of the joint’s cartilage. Those two configurations are placed in models N, P1 and P2, thus creating [N+C1 and N+C2], [P1+C1 and P1+C2] and [P2+C1 and P2+C2].

The desired result of the cage is to obtain as good results as P2 alone (considered as the best posterior fixation but difficult to perform in surgery) by adding the cage to P1 (easy to perform), in other words having similar results to P2 with P1+C1 or P1+C2.

Loadings

The different loadings correspond to different human postures. The Sacral Slope (SS), angle between the horizontal and the tangent to the surface of the first vertebrae of the sacrum in
the pelvis, permits to differentiate the different postures [3]. Four postures are from a previous study:

- Standing on two legs SS 35
- Sitting SS 35 considered a good sitting posture
- Sitting SS 20
- Sitting SS 05 considered a bad sitting posture

Four postures are added:

- Standing on left leg SS 35
- Spreading legs, left leg at the front SS 35 (LF)
- Spreading legs, right leg at the front SS 35 (RF)
- Extreme loading (or “jumping”) SS 35

Results

Results are mainly observed for the left side of the pelvis. They indicate (not shown here) that placing the cage C1 permits to obtain better results than C2 for any studied parameter.

Stress distribution

As for stress distribution within the left side’s sacroiliac joint’s cartilage, anterior fixation (A) is better than posterior ones P1 and P2, with P2 being slightly better than P1 (Fig. 2). Furthermore, P1+C1 and P2+C1 are equivalent, and can even be better than (A), albeit with a distribution of stress being less homogeneous, which could be a cause of pain. Spreading legs LF has almost no stress, while spreading legs RF has high stress close to jumping. Finally, the higher the loading (jumping, spreading legs RF), the more efficient are the fixations, and the bigger is the gap between fixations.

A study of the right side’s sacroiliac joint’s cartilage also reveals that only the anterior fixation (A) has an influence on the other side of the pelvis, and this influence is bigger for higher loads.

Loads in surrounding ligaments

As for the loads generated in the left sacroiliac joint ligaments surrounding the left sacroiliac joint, the loads decrease for previous loadings (not shown here) in the order N, P1, P2 and A. Moreover, P1+C1 obtain similar or better results than P2, so the initial goal is achieved. The same results can be observed for new models Standing on left leg and “jumping” (Fig. 3).

However, irregularities can be seen for spreading legs loadings. Inserting fixations in spreading legs LF (P1 and P2) actually increases loads on ligaments, and adding the cage permits to come back to standard loads on ligaments in model N. As for spreading legs RF, anterior fixation A is for the first time not the best kind of fixation, with P2, P1+C1 and P2+C1 being much better than A. This discovery implies that it is very difficult, or maybe impossible to find one kind of fixation that is the best for every posture of the human body, which is a real problem for surgery.

Maximum displacement of the hip bone

As for maximum displacements of the left hip bone, considering the same nodes (selected in model N) for Standing and “Jumping” loadings, the maximum displacement decreases with the following fixations N, P1, P1+C1 and A (Fig. 4). Only those fixations were considered, as they are the most likely to be performed in real surgery. The anterior fixation A remains the best as it decreases the displacement of the hip bone compared to the central bone (sacrum) the most. However, adding C1 to P1 (P1+C1) permits to obtain good results that brings the maximum displacement closer to A.
Discussions

The previous study concluded that P2 is the best kind of posterior fixation in terms of stress distribution and ligaments' load. However, the surgery is hardly realizable, and surgeons would favor P1 that can more easily be performed. In fact, for the P2 configuration, one of the screws is going through the top of the hip bone which is curvy and thin, and it is thus impossible to insert a screw within it without going out of the bone and creating fracture and damage. That is why it is necessary to perform P1 in surgery, where the screws go in the lower thick part of the hip bone.

To use the P1 fixation and improve its efficiency, a cage can be inserted. The closer its longitudinal axis is to the perpendicular of the normal of the joint's cartilage (C1), the more difficult it is to perform but the better are the results. The surgeon thus must choose depending on the individual's pelvis' configuration and his skills. Adding the cage to P1 (P1+C1) thus permits to obtain similar or even better results than P2, which was one of the goals of this research. P1+C1 is the best choice in terms of posterior fixations, for the fixations considered in this research. However, it is still not possible to make it better than the anterior fixation A which is overall the best choice if we don’t consider the difficulty of such a surgery.

Finally, there is a real behavioral complexity depending on the kind of fixation and the loadings. As for the spreading legs cases, a fixation’s efficiency can be lower than expected in some specific postures. This phenomenon represents a real issue for curing the sacroiliac joint dysfunction because it means that it is impossible to have a fixation that can be judged the best for every kind of posture, or at least that it would be a real challenge to find one.

Conclusions

As the outcome of this research, several conclusions can be done about the different kinds of fixations. Firstly, a fixation’s efficiency is not always the same and is dependent on the type of loading that is applied to the pelvis. When spreading legs, a posterior fixation can become more useful than an anterior fixation, or in reverse become worse than no fixation at all, which is contradictory with the previous study that considered only standing and sitting postures. Secondly, adding a cage to a fixation permits to reduce further the strain on ligaments the stress on sacroiliac joint’s cartilage and the overall motion of the hip bone. Moreover, the closer the longitudinal axis of the cage is from the perpendicular of the cartilage surface’s normal (C1), the better the fixation becomes but the harder it is to perform the surgery. Thirdly, using a fixation as model P2 can’t be easily performed in reality, and adding a cage to P1 (P1+C1) allows to obtain similar results to P2. Finally, as of now, P1+C1’s type of fixation is the best choice to do when performing a posterior surgery. However, it is still not as efficient in terms of stabilization of the pelvis as the anterior fixation (A), which is also able to slightly improve the stability of the other side of the pelvis.

Other methods could be interesting to investigate following this study. For example, adding a second cage above the first one or finding a new configuration of screws for posterior fixations that could be done in surgery. Moreover, having access to a more precise model with more elements such as femurs under the pelvis could also permit to further understand the real behavior of the pelvis under loadings.

References


Acknowledgements

I would like to express my great appreciation to Doctor Daisuke Kurosawa (JCHO Sendai Hospital) for his cooperation in this research. He patiently imparted me his medical knowledge about sacroiliac joints and surgery. His useful participation in this project has allowed me to join at the same time real surgery related data used nowadays with research. Doctor Niels Hammer (University of Otago, New Zealand) provided me with a pelvic model as the foundation of this research. His advanced and detailed model allowed this research to obtain bountiful results and I wish to express him my sincere thankfulness.