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School	:	**Graduate School of Biomedical Engineering**
Thesis Title	:	**Impingement impact assessment in pre-operative and post-operative functional pelvic tilt in standing position**

The ageing population is increasing and consequently the health demands and the chronic diseases such as the arthritis that is affecting over 3.9 million Australians but there are surgical treatments like the hip replacement or also known as total hip arthroplasty that is one of the most successful surgery procedures and can relief pain and restore motion. Even though the procedure is successful, it has a complication rate of 2% to 10% and 17.7% of them due to dislocations and in 90% of the dislocations, the impingement is evident. The impingement after a THA depends of the cup orientation which has a direct relationship to the functional pelvic tilt. And based on a previous study, the measurement of the preoperative pelvic tilt can predict the postoperative pelvic tilt. Consequently, this research aims to predict postoperative bone impingement through an impingement assessment by a 3D simulation of the preoperative models of the pelvic and femora bones of 213 patients.

The simulations are performed by obtaining the 3D bone models from the CT scan images through segmentation and landmarking and measuring the hip centres from the femur models with the Synopsis Simpleware software. Then the resection of the 3D model femoral heads is realised with the use of the Solidworks software and finally a range of motion is simulated with previously obtained models in the ADAMS software.

The results demonstrated that there is no lineal relationship between the functional pelvic tilt and the minimum flexion angles which will not able to predict a postoperative impingement angles, but it did show that there is a difference between male and female flexion angles.

There were many limiting factors regarding the quality of the data such as the medical images and the anatomical features of the patient and additional analyses should be performed to review the process and achieve a more correlative data.

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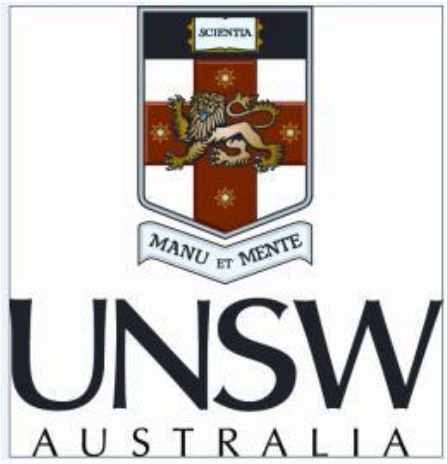
Impingement impact assessment in pre-operative and post-operative functional pelvic tilt in standing position

Jae Hwan Chang

A thesis in fulfilment of the requirements for the degree of

Master in Engineering Science



Graduate School of Biomedical Engineering

Faculty of Engineering

Supervised by Dr Susann Beier

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Table of Contents

Acknowledgements **2**
Abbreviations **3**
List of Figures **4**
List of Tables **5**

Chapter 1. Introduction **6**
1.1 Total Hip Arthroplasty 6
1.2 Hip Dislocation 7
1.3 Hip Impingement 8
1.4 Functional Pelvic Tilt 8
Chapter 2. Methodology **10**
2.1 Segmentation and Landmarking 10
2.2 Resection of the femoral head 13
2.3 Measurement of the femoral hip centre 14
2.4 Range of motion simulation 14
Chapter 3. Data Analysis **16**
3.1 Obtaining the data 16
3.2 Relationship analysis 17
Chapter 4. Conclusion **21**
4.1 Limitations 21
4.2 Future work recommendations 22
References **23**
Appendices **25**
Appendix A: Segmentation and Landmarking images 25
Appendix B: Resection of the femoral head images 31
Appendix C: Measurement of the femoral hip centre images 33
Appendix D: Range of motion simulation images 34

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Lastly, I want to thank GSBME and Corin Group for giving me a great chance to develop this research and allowing me to have this experience between industry and academy.

Abbreviations and Acronyms

THA	Total Hip Arthroplasty
PT	Pelvic Tilt
CT	Computer Tomography
ASIS	Anterior Superior Iliac Spine
PS	Pubic Symphisis
SPA	Sacral Promontory Anterior
SPP	Sacral Promontory Posterior
AC	Acetabular Centre
TF	Top Fossa
NSAIDs	Nonsteroidal anti-inflammatory drugs

List of Figures

Chapter one: Introduction

Fig 1. Hip replacement with implants
Fig 2. X-ray image of hip dislocation
Fig 3. Types of femoroacetabular impingement
Fig 4. Types of pelvic tilt and the relationship to the acetabulum

Chapter two: Methodology

Fig 5. CT scan images of the pelvis and both legs
Fig 6. Synopsis Simpleware Coronal view of CT scan images
Fig 7. Segmentation of pelvis from femur bones in transversal view
Fig 8. Segmented 3D rendered pelvis
Fig 9. Left ASIS landmarking
Fig 10. Solidworks 3D render of the right femur bone
Fig 11. Head resection of the right femoral bone 3D model
Fig 12. Left hip centre measurement
Fig 13. Operative side range of motion simulation (beginning)
Fig 14. Operative side range of motion simulation (during)
Fig 15. Relationship between minimum flexion angles and functional pelvic tilt (Female patients)
Fig 16. Relationship between minimum flexion angles and functional pelvic tilt (Male patients)
Fig 17. Relationship between operative side flexion angles and functional pelvic tilt (Female patients)
Fig 18. Relationship between operative side flexion angles and functional pelvic tilt (Male patients)
Fig 19. Relationship between contralateral side flexion angles and functional pelvic tilt (Female patients)
Fig 20. Relationship between contralateral side flexion angles and functional pelvic tilt (Male patients)
Fig 21. Relationship between minimum flexion angle and age (Female patients)
Fig 22. Relationship between minimum flexion angle and age (Male patients)

List of Tables

Chapter three: Data Analysis

Table 1. Data obtained from the procedures (View of 35 out of 213 patients)

Chapter 1. Introduction

The current health state of the world based in the World Health Organization, demonstrates that the average expectancy of life globally is increasing, just in the range between the years 2000 and 2015, the life expectancy added 5 more years, and this is concerning because of the chronic diseases and the lack of planning that the countries have to meet with the health demands in the ageing population. One common chronic disease is the arthritis which only in Australia, over 3.9 million people is affected by it and more than half of this population are in the working age. There are many treatments such as the use of medications like analgesics, NSAIDs, corticosteroids, etc., going to therapy that can help by improving the mobility and by strengthening muscles or through surgery methods that performs repairing, replacements or fusions on the joints. And between the most common replacement surgeries are the hip replacements [16], [17], [18], [19], [20].

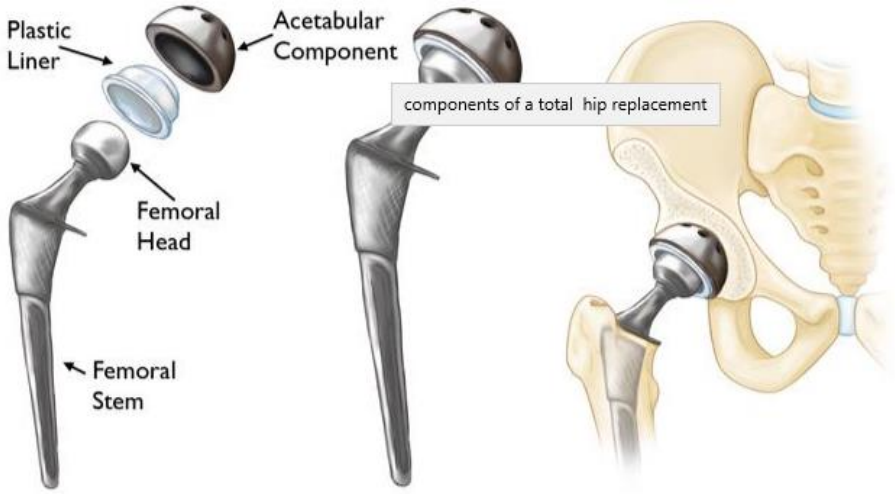

Figure 1: Hip replacement with implants [1]

1.1 Total Hip Arthroplasty

Considered as one of the most successful surgical techniques in medicine, total hip replacement or also commonly known as total hip arthroplasty (THA) has been performed since 1960s and is a procedure that causes pain relief and restoring of motion by removing the affected femoral head and the acetabular surface and replacing with prosthetic implants such as stems, heads, and acetabular cups. This operation is realized to treat hip pains which are caused by common types of arthritis (pain or disease in a human body joint) such as osteoarthritis, traumatic arthritis and rheumatoid arthritis. Even though there

are 300,000 THA procedures in a year, only in the United States and globally is predicted to increase by 170% by 2030, the rate of complications extends from 2% to 10% after a primary hip replacement due to complications such as aseptic conditions loosening (36.5%), other types of infections (15.3%) and dislocations after a THA (17.7%). And annually, 8 % to 12% of the hip surgeries are for revisions and 11% to 24% of the revisions are due to treat dislocations [1], [2], [3].

1.2 Hip Dislocation

A dislocation in the hip is caused during the event of a trauma, when the femoral head has a displacement out of the acetabulum of the pelvic bone by a large quantity of force and depending of the forward or backward direction of displacement, the dislocation can be either posterior or anterior. At the moment of dislocation, the surrounding tissues such as muscles, ligaments and even nerves can be damaged. Based on the Clinical Orthopaedics and Related Research, a mode of failure that is frequent of the THA, are the dislocations in the hip with a rate of 0.5% to 10% following a primary hip replacement and 10% to 25% post-revision surgeries. And according to the Journal of Engineering in Medicine, impingement is evident in 90% of the dislocations [4], [5], [6].

Figure 2: X-ray image of hip dislocation [4]

1.3 Hip impingement

Hip impingement or also called femoroacetabular impingement is the result of extra bone growth either in the head of the femur or in the acetabular surface, which causes damaging contact at the joint causing pain and affecting motion. Depending of the abnormal growths, it results in three types of impingements: pincer (bone growth in the acetabular rim), cam (bone growth in the femoral head), and combined (bone growth both in acetabulum and femur head). But in the other hand, impingement after THA depends on the contact between the prosthetic implants and prosthetic implants with bones, and this is caused due to the type of surgical method and the type of implants used. One of the considerations during surgical methods, is the cup orientation, that can increase or decrease the percentage of dislocation by impingement depending of the anteversion and lateral opening angles [7], [8]. And there is a direct relationship between the cup orientation and the functional pelvic tilt [9].

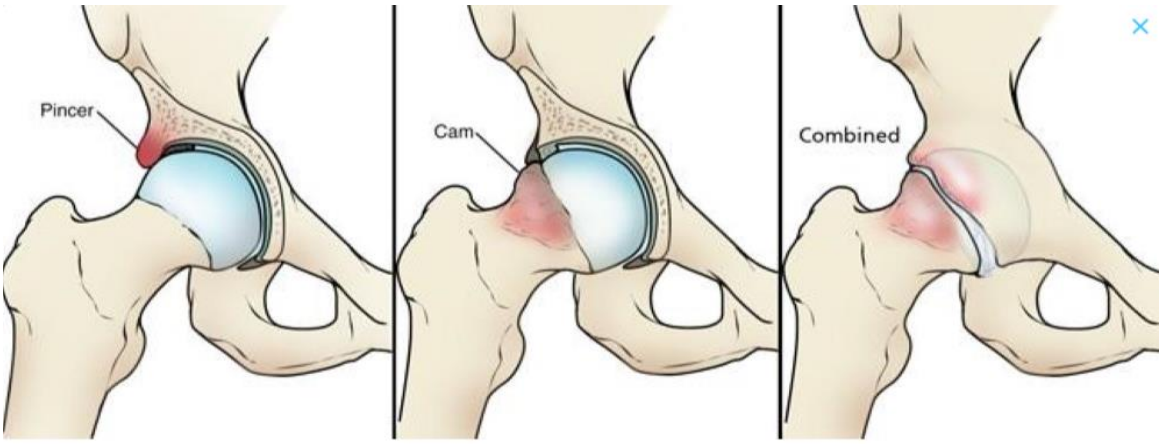

Figure 3: Types of femoroacetabular impingement [7]

1.4 Functional Pelvic Tilt

Functional pelvic tilt (PT) is “the angle between a vertical reference line (the pubic symphysis) and the anterior pelvic plane (a line joining both anterior superior iliac spines)” and in the case of the supine position, the pelvic tilt is “the angle between the horizontal reference line and the anterior pelvic plane”, which are measured from CT images [10]. Due to its anteriorly mentioned relationship to the cup orientation, the changes in pelvic tilt can either increase or decrease hip impingement and consequently result in a dislocation. A study performed by the Japanese Orthopaedic Association showed, “preoperative anterior pelvic tilt represented posterior changes postoperatively and preoperative posterior pelvic tilt didn’t showed significant changes”; another research realized in the Bone & Joint Journal demonstrated that “pelvic tilt sagittal rotations from supine positions,

fail to predict significant clinical changes in the acetabular orientation due to individual pelvic kinematics and an optimal orientation is patient specific and requires a preoperative analysis of the functional pelvic tilt" and relatively an article from Corin Group, presented that the "best way to predict postoperative functional pelvic tilt is by measuring the preoperative pelvic tilt" [11], [12], [9].

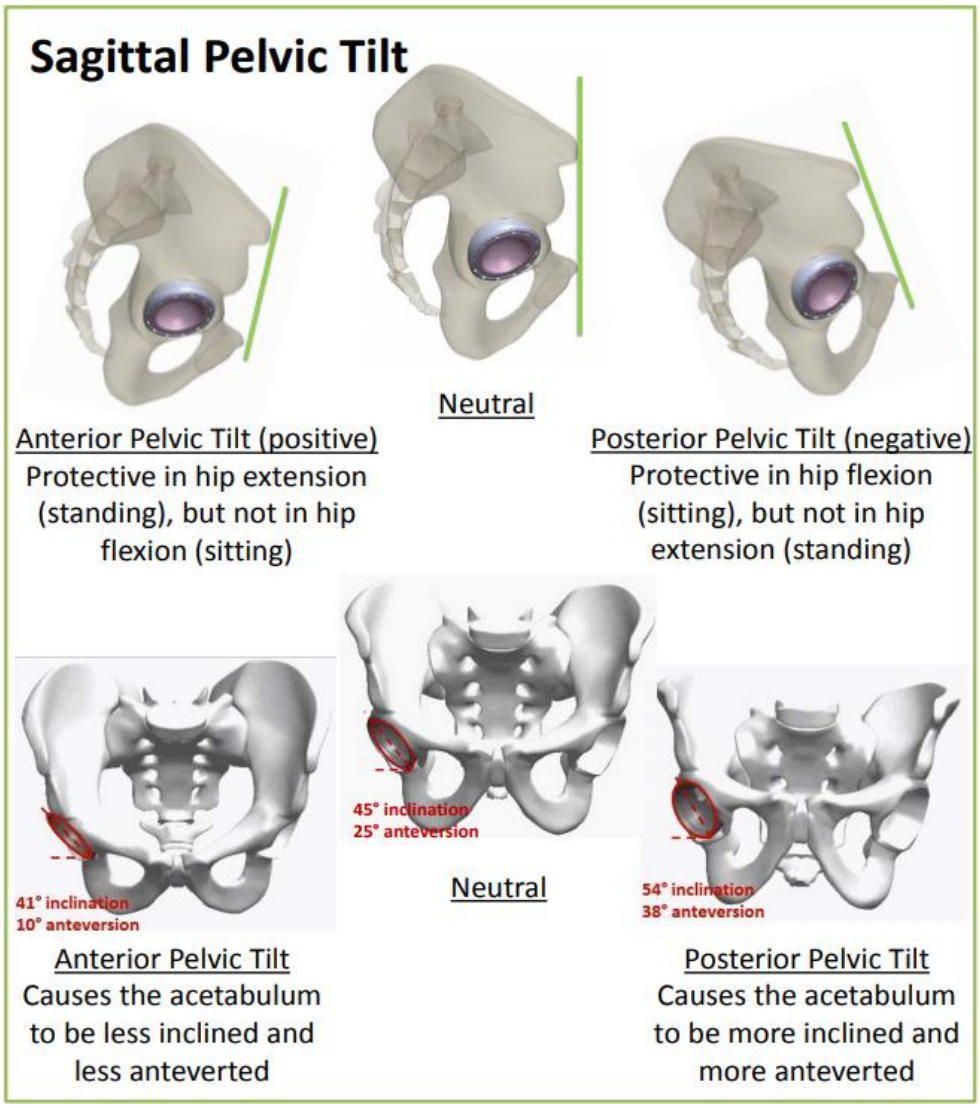

Figure 4: Types of pelvic tilt and the relationship to the acetabulum [10]

In regard to the previously mentioned studies, the aim of this research is to predict post-operative bony impingement due to the preoperative and postoperative pelvic tilt relationship through an impingement assessment performed by a 3D simulation of the preoperative models of the pelvic and the femoral bones of multiple patients that had been performed a THA procedure and analyse the predictive nature of the data and compare with the previous researches [9].

Chapter 2. Methodology

The prediction of postoperative bony impingement is by obtaining preoperative impingement data through 3D simulations of 213 patient cases that had been realized a THA procedure and the simulations are developed by several stages in 3D computerized modelling which are segmentation and landmarking, resection of the femoral heads, measurement of the femoral hip centre and the range of motion simulation.

2.1 Segmentation and Landmarking

The segmentation is performed using CT scan images of the pelvis and the legs of the patients and creating a 3D rendered model of the bone structures by segmenting the bone from the soft tissue such as muscles, ligaments and organs.

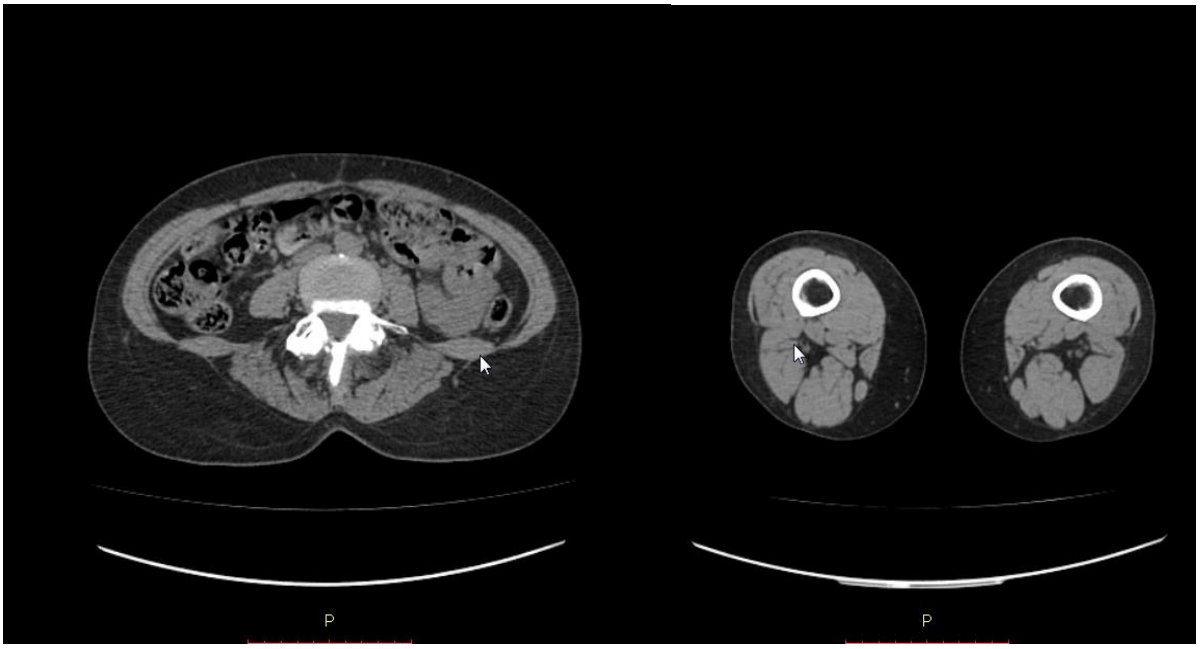

Figure 5: CT scan images of the pelvis and both legs

This is produced by using Synopsis Simpleware software with Corin Group customizations.

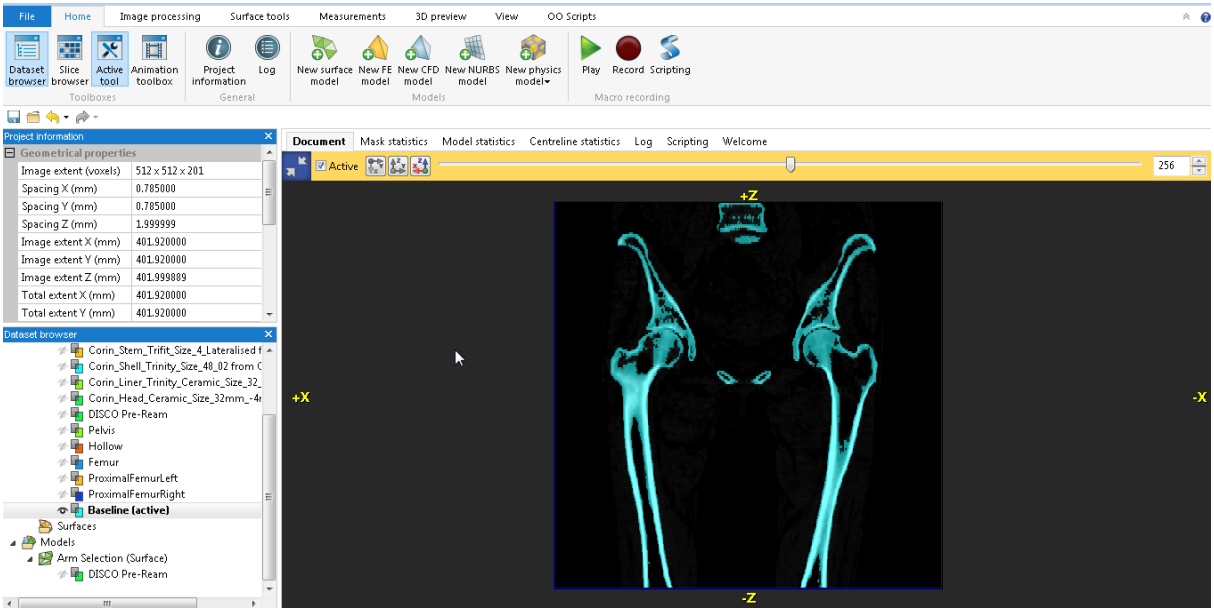

Figure 6: Synopsis Simpleware Coronal view of CT scan images

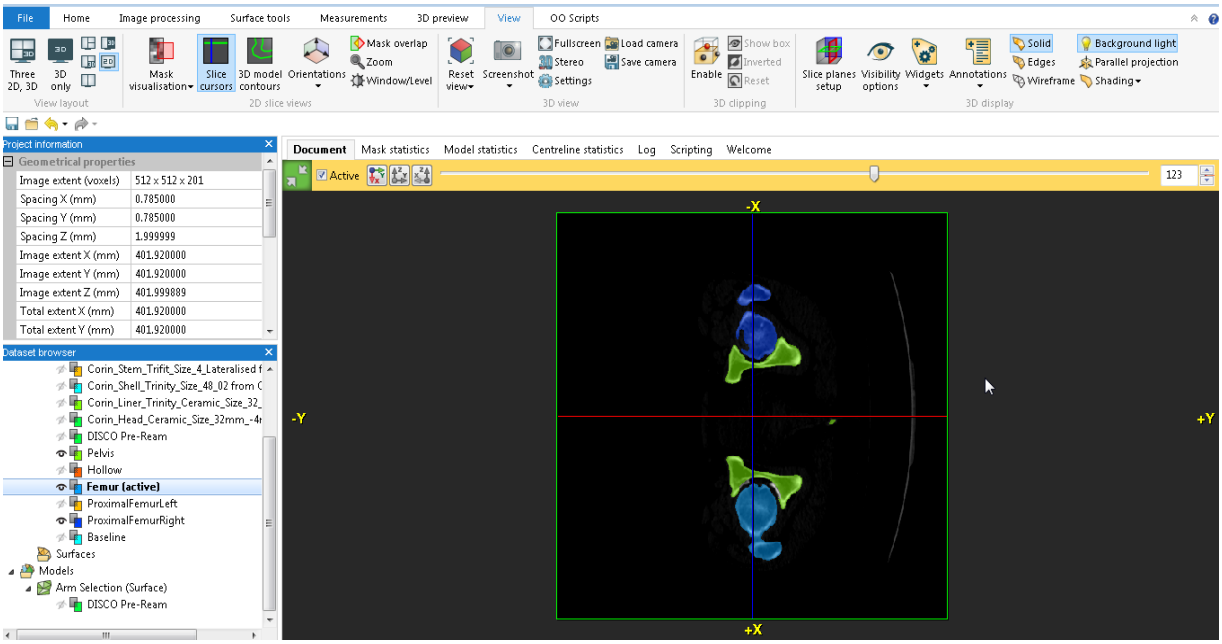

Figure 7: Segmentation of pelvis from femur bones in transversal view

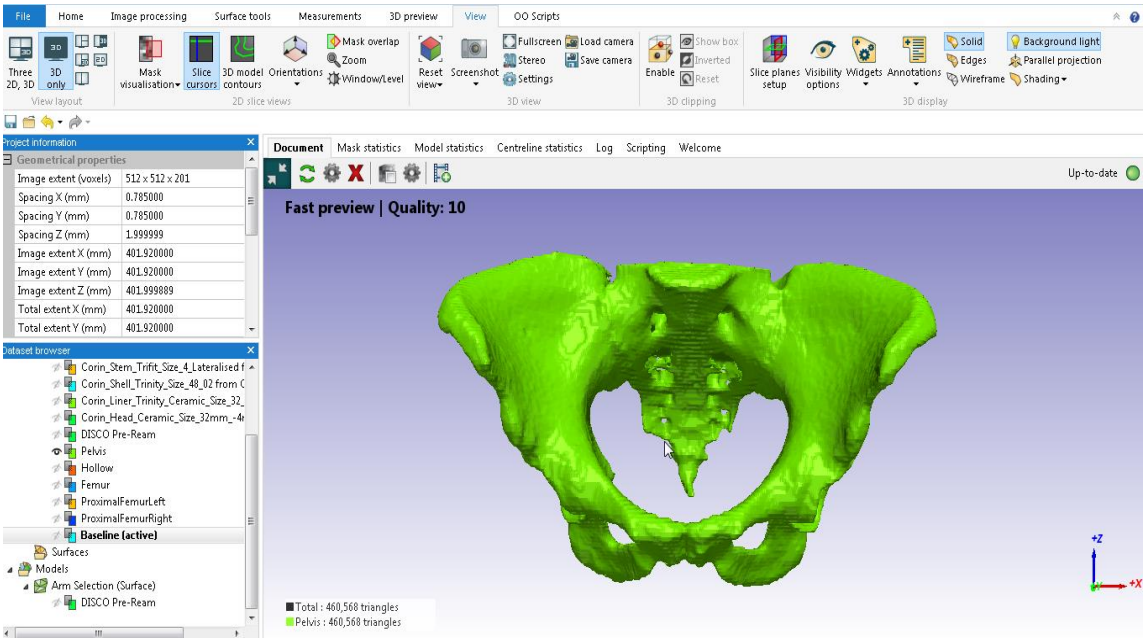

Figure 8: Segmented 3D rendered pelvis

The landmarking uses the same mentioned software and is done after the segmentation by obtaining the coordinates of the established landmarks by Corin Group OPS technology in the pelvic and femoral bones of the recreated model. These landmarks are the points in the ASIS, PS, SPA, SPP, AC and TF, which correlates with each other to determine measurements such as the pelvic tilt [13].

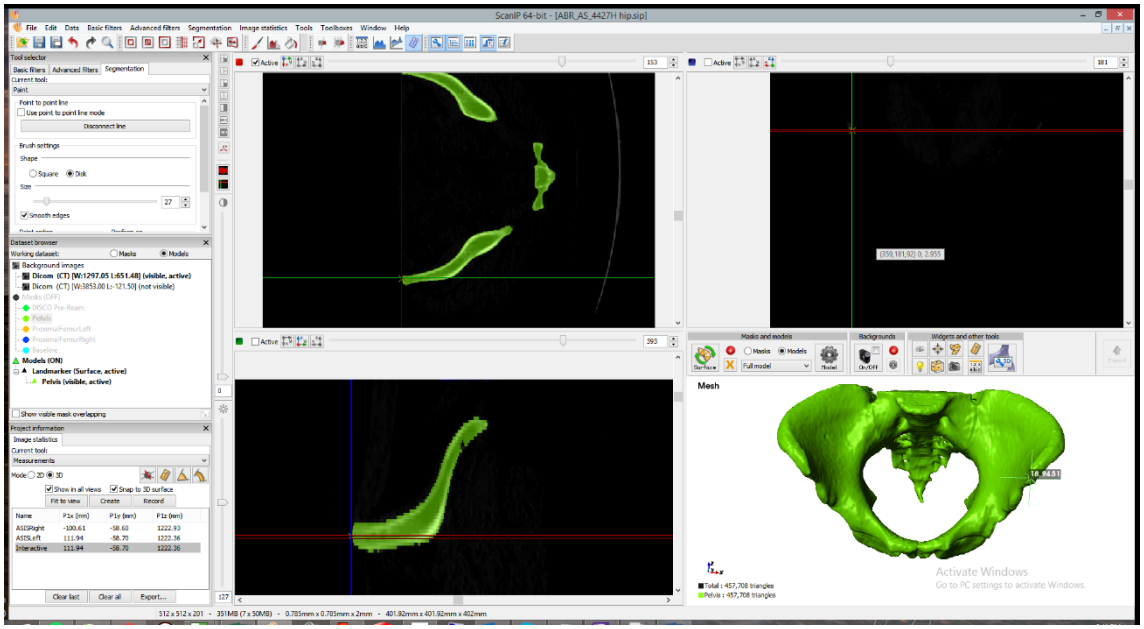

Figure 9: Left ASIS landmarking

2.2 Resection of the femoral head

Once the 3D models of the femoral bones are produced, a resection of the femoral head is needed for the following range of motion analysis. The resection is realized in the Solidworks software by subjectively determining the end part of the head and removing it from the 3D model [14].

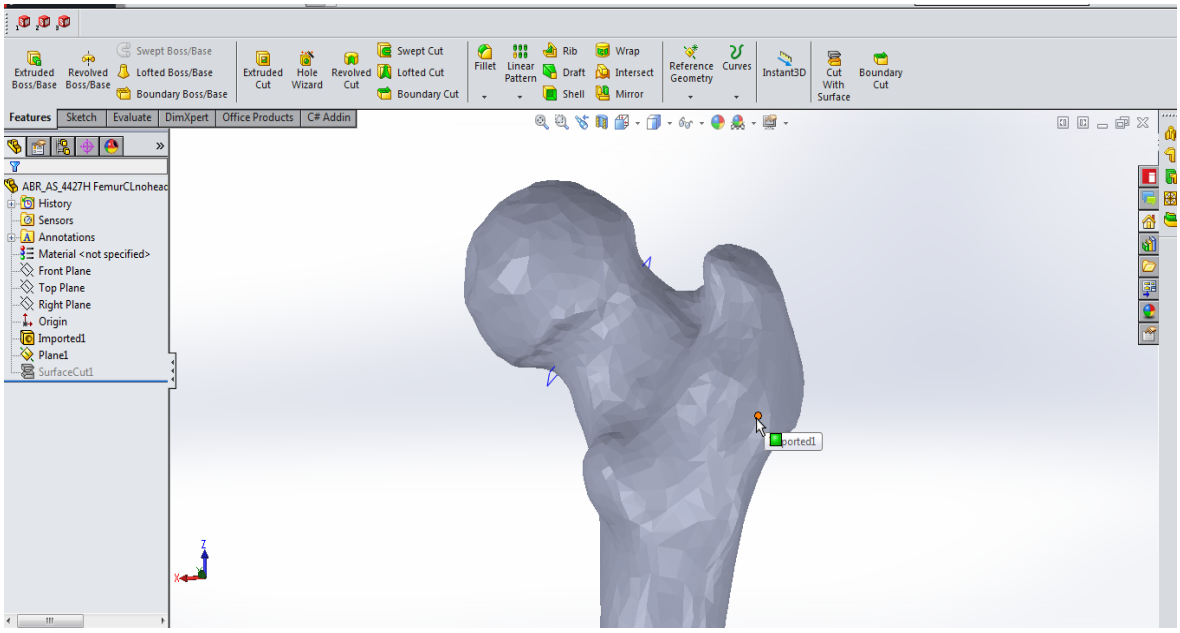

Figure 10: Solidworks 3D render of the right femur bone

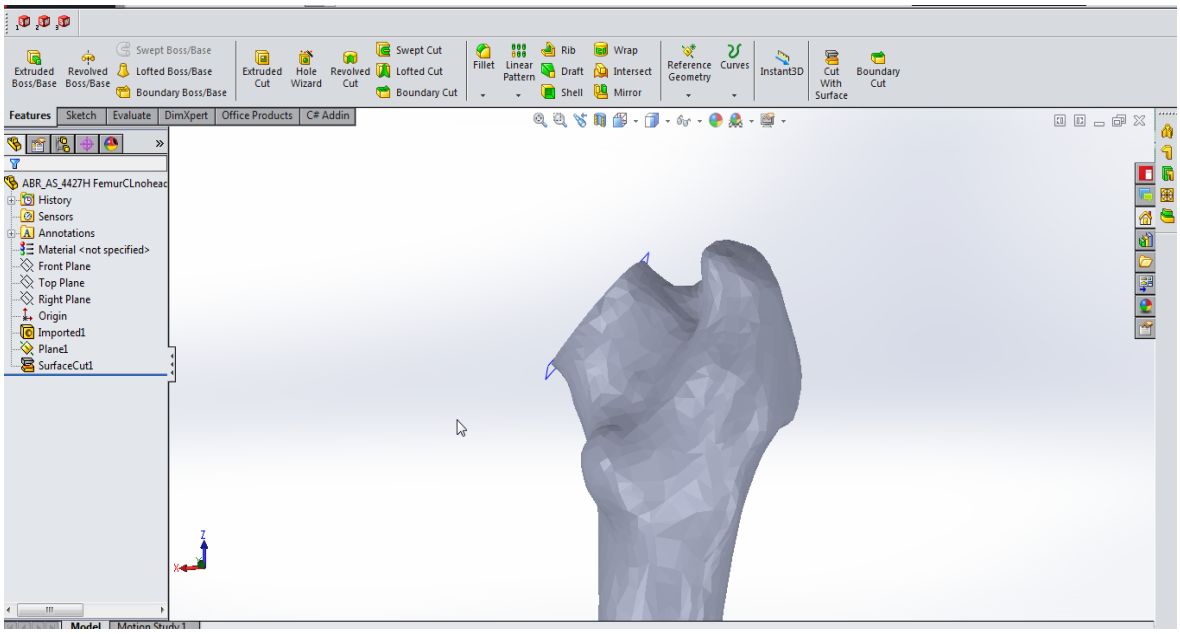

Figure 11: Head resection of the right femoral bone 3D model

2.3 Measurement of the femoral hip centre

The measurement of the hip centre, contrary to the name of the procedure, it is determined from the femoral head by obtaining its 3 dimensional centre, which will define the point of origin for the rotations in the 3D axis and this is performed in the previous Synopsis simpleware software by positioning and assimilating a sphere function to the head of the femur of the already built 3D model. This process differs for the preoperative and the postoperative pelvic tilt measurement because in the postoperative procedure, the hip centres are obtained by considering the operative femur head similar to the contralateral or the healthy femur head, while in the preoperative case, the hip centre must be the original or the damaged head [13].

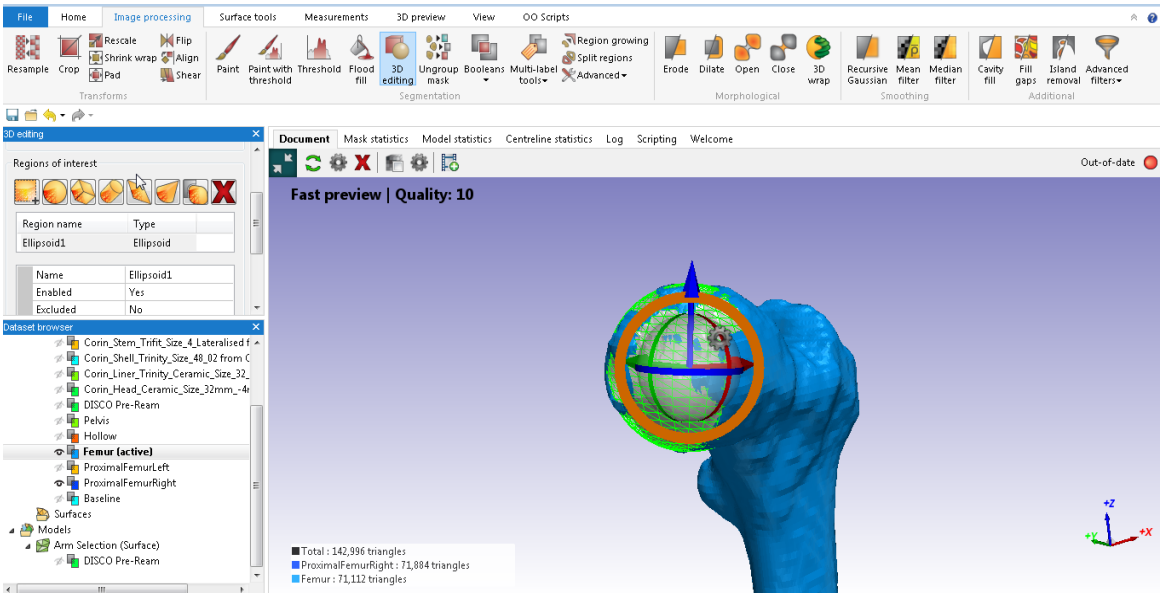

Figure 12: Left hip centre measurement

2.4 Range of motion simulation

The range of motion analysis produces a set of data which includes the flexion angles of each femurs (right and left), which are related to the pelvic tilt and the acetabular orientation and consequently to the impingement at every motion angles. This analysis uses the ADAMS software that simulates a range of rotational motions of the femurs at each corresponding acetabulum and considers the points of contact between the bones or implants during the simulation to produce the data [15]. The previously mentioned stages are necessary because the simulation requires a 3D model with specific coordinates in a 3D space in relation between the bone structures and in the case of the resection, the resected femurs allows to analyse impingement without the limitation of the

femoral head but both non-resected and resected are simulated simultaneously to have a more accurate analysis. The simulations are performed in a standing position of the pelvic bone.

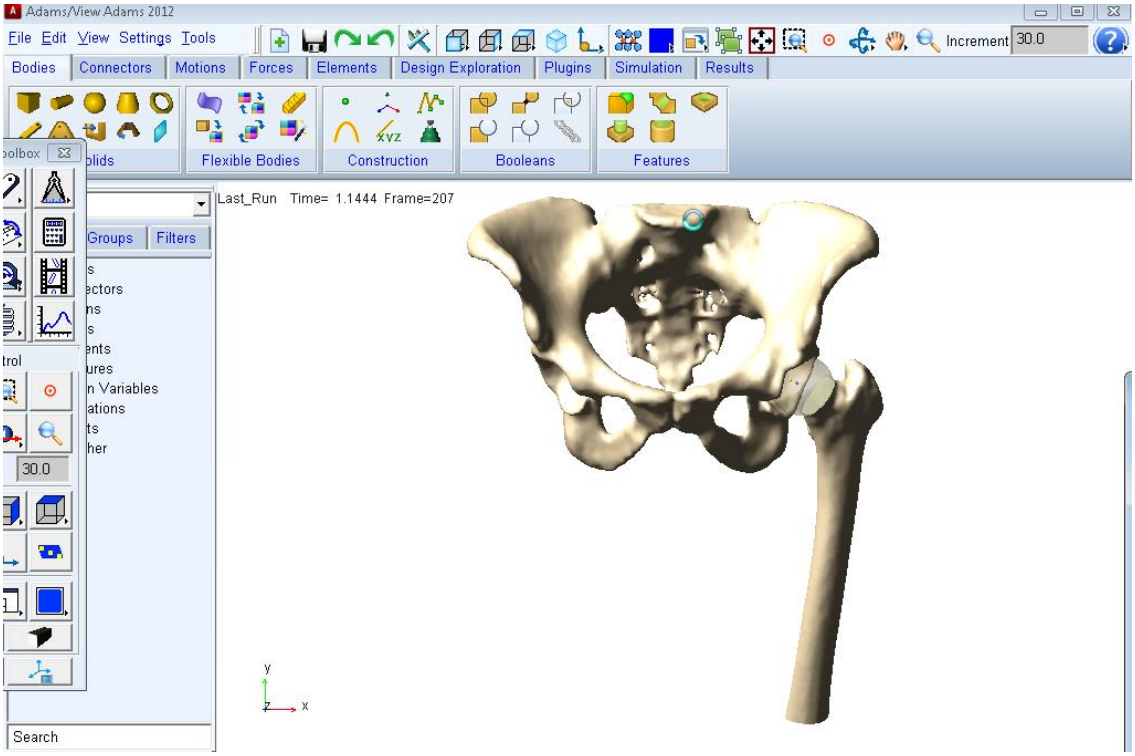

Figure 13: Operative side range of motion simulation (beginning)

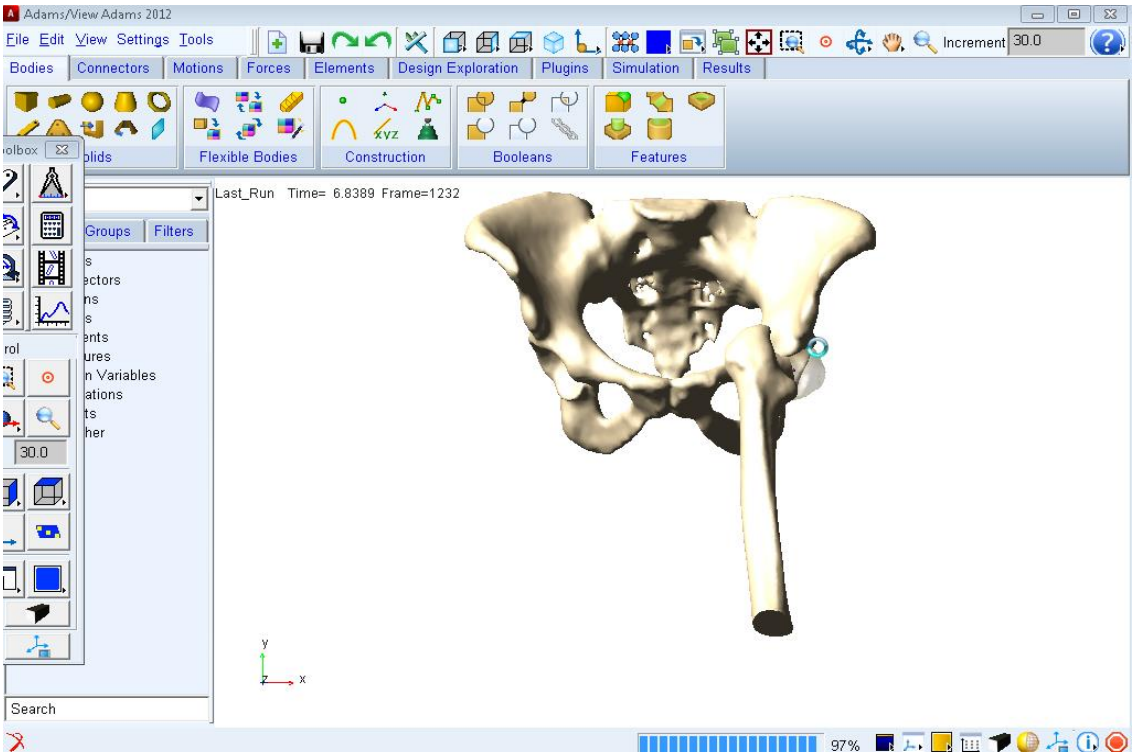

Figure 14: Operative side range of motion simulation (during)

Chapter 3. Data Analysis

3.1 Obtaining the data

Once all the procedures are performed, the following data is acquired: age, functional pelvic tilt, flexion angles in the operative and contralateral side and gender of the patient. The functional pelvic tilt is obtained by using the following equation:

$$Functional\ Pelvic\ Tilt = 90 - Standing\ Pelvic\ Tilt + Seated\ Pelvic\ Tilt$$

The 90 degrees is used as a vertical reference and the standing and seated pelvic tilt are previously obtained through the database of Corin Group Ltd, which are the pelvic tilt angles measured from standing and seated position x-rays of the patients. The flexion angles are given by the ADAMS software simulations.

Table 1: Data obtained from the procedures (View of 35 out of 213 patients)

Patiend ID	Age	Gender	PreOp Stand PT	PreOp Seated PT	90-StandPT+SeatedPT	FLX(OP)	FLX(CL)	FLX(MIN)
Patient 1	62	Female	-1.1	-7.8	83.3	104	112	104
Patient 2	76	Female	5.1	-12.6	72.3	69	112	69
Patient 3	69	Male	-14.1	0.4	104.5	105	111	105
Patient 4	58	Male	4.5	-8.5	77	95	101	95
Patient 5	66	Female	-4.9	-13.3	81.6	80	119	80
Patient 6	74	Male	-3.5	1.8	95.3	117	118	117
Patient 7	84	Female	-6.7	13.9	110.6	121	121	121
Patient 8	66	Male	5.8	5.4	89.6	98	111	98
Patient 9	73	Male	-5.2	19.1	114.3	92	109	92
Patient 10	58	Female	0.4	9	98.6	108	121	108
Patient 11	63	Male	7.6	4.3	86.7	99	128	99
Patient 12	71	Female	-1.7	-10.2	81.5	105	89	89
Patient 13	55	Female	3.7	10.6	96.9	111	126	111
Patient 14	46	Female	-1.9	7.1	99	136	139	136
Patient 15	78	Female	-18.4	-14.5	93.9	155	142	142
Patient 16	71	Male	-17.3	-18.2	89.1	139	97	97
Patient 17	65	Male	-0.9	-8.3	82.6	87	116	87
Patient 18	68	Female	4.5	-3.5	82	93	97	93
Patient 19	71	Male	-11.3	15.8	117.1	109	109	109
Patient 20	62	Female	1.2	-20.4	68.4	63	95	63
Patient 21	71	Female	-2.9	10.9	103.8	100	94	94
Patient 22	66	Male	-5.3	-8.9	86.4	108	88	88
Patient 23	75	Male	-8.5	2.5	101	122	116	116
Patient 24	62	Female	1.9	-12.6	75.5	102	116	102
Patient 25	74	Female	-0.9	1.9	92.8	112	102	102
Patient 26	55	Male	0.3	-3.5	86.2	88	106	88
Patient 27	56	Female	1.9	-4.5	83.6	64	77	64
Patient 28	66	Female	7.2	-6.7	76.1	67	93	67
Patient 29	60	Male	-6.6	12.7	109.3	122	95	95
Patient 30	72	Male	-0.6	-2.2	88.4	79	65	65
Patient 31	63	Male	-4.4	16.5	110.9	136	130	130
Patient 32	71	Male	7.8	7.5	89.7	100	85	85
Patient 33	72	Male	-5.8	-28.7	67.1	118	105	105
Patient 34	72	Male	2.6	5.9	93.3	106	107	106
Patient 35	77	Female	-6.3	15.1	111.4	128	117	117

3.2 Relationship analysis

Based on the previous data a set of graphs are developed to recognize a linearity relationship (due to the predictive relationship between the preoperative and postoperative pelvic tilt) between the functional pelvic tilt and the flexion angles in the operative and contralateral sides of the pelvis and consequently a relationship to the impingement angles [9].

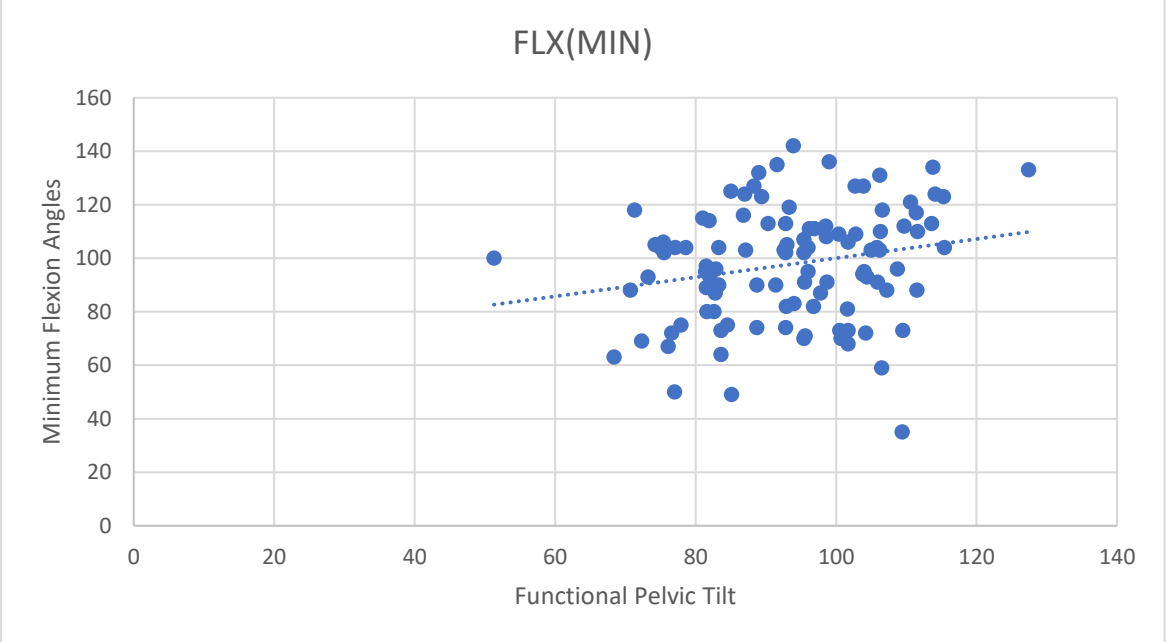

Figure 15: Relationship between minimum flexion angles and functional pelvic tilt (Female patients)

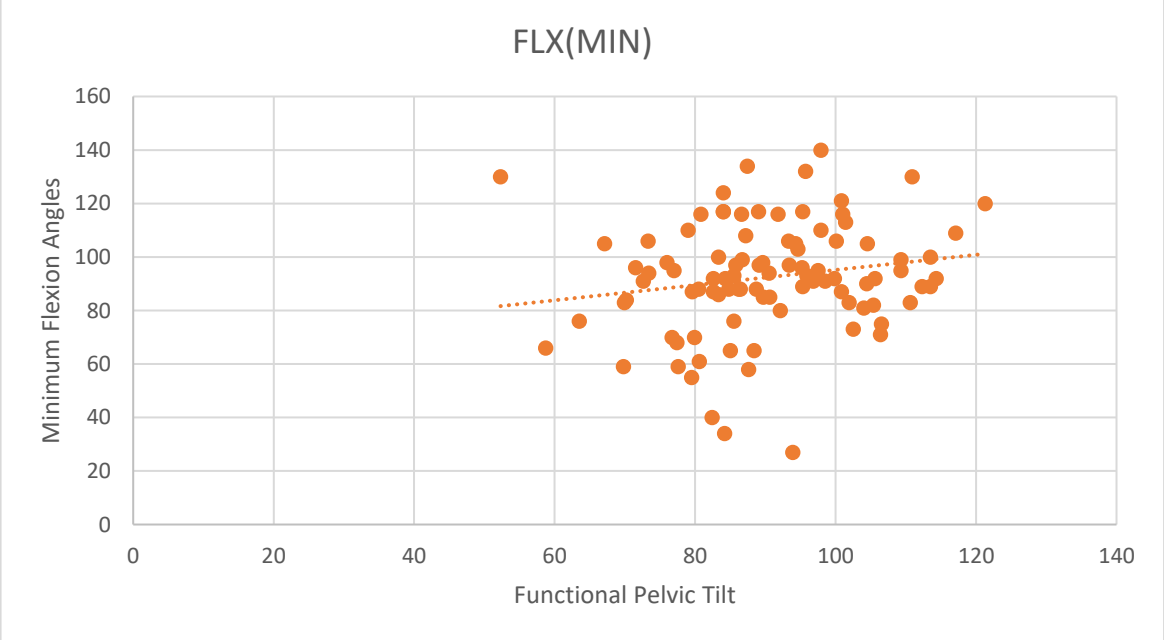

Figure 16: Relationship between minimum flexion angles and functional pelvic tilt (Male patients)

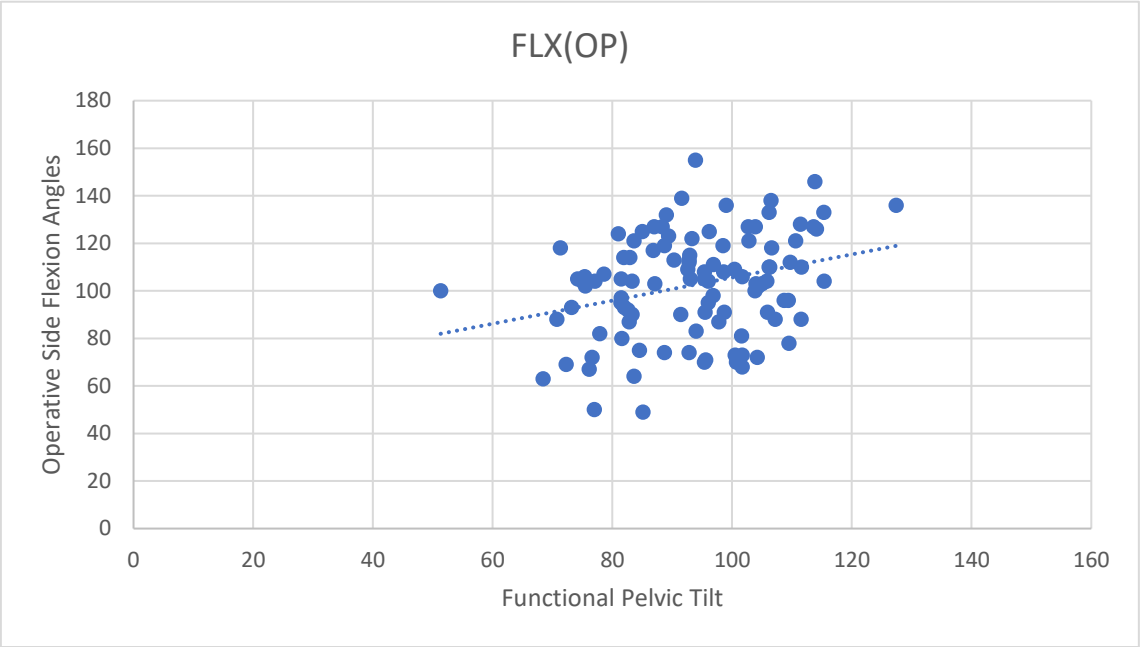

Figure 17: Relationship between operative side flexion angles and functional pelvic tilt (Female patients)

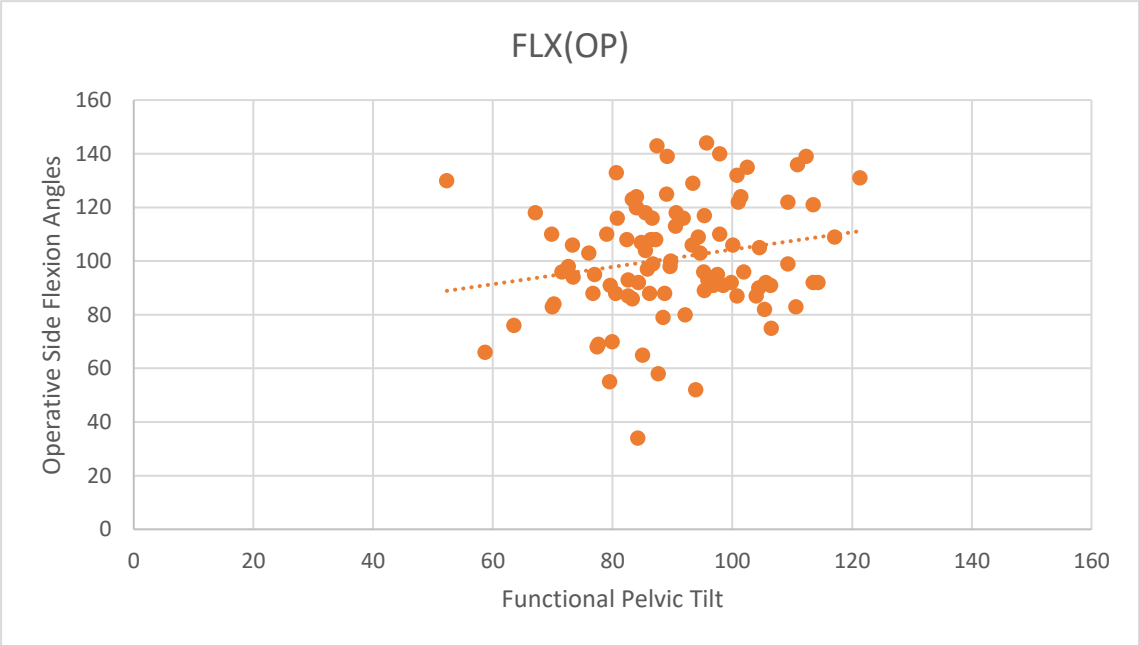

Figure 18: Relationship between operative side flexion angles and functional pelvic tilt (Male patients)

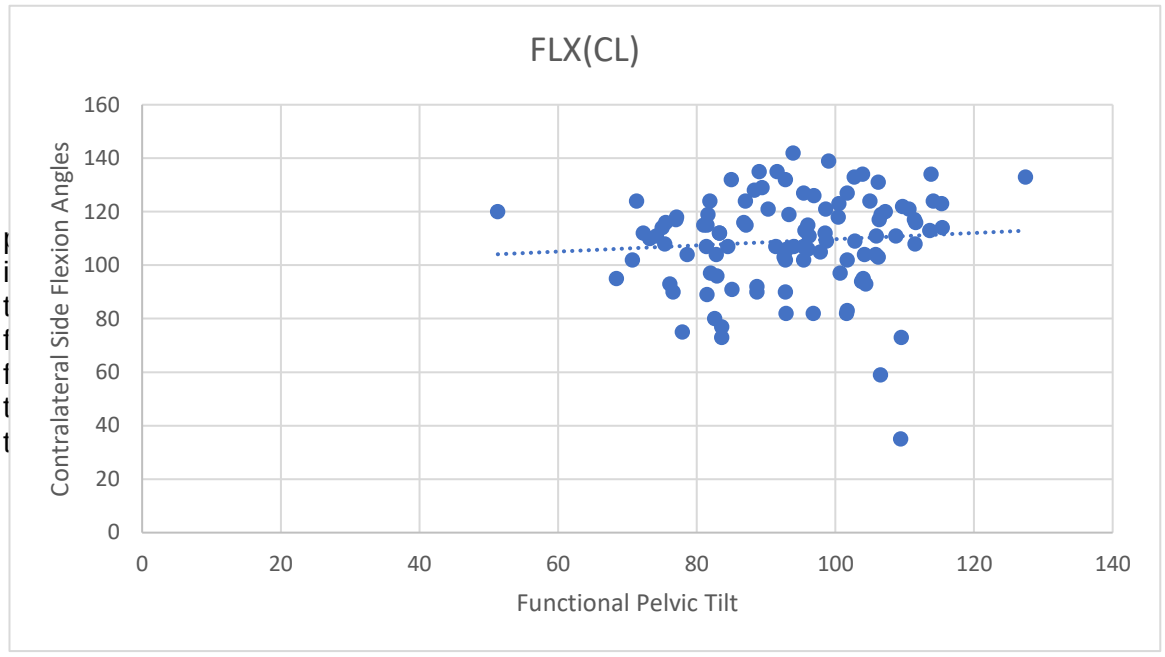

Figure 19: Relationship between contralateral side flexion angles and functional pelvic tilt (Female patients)

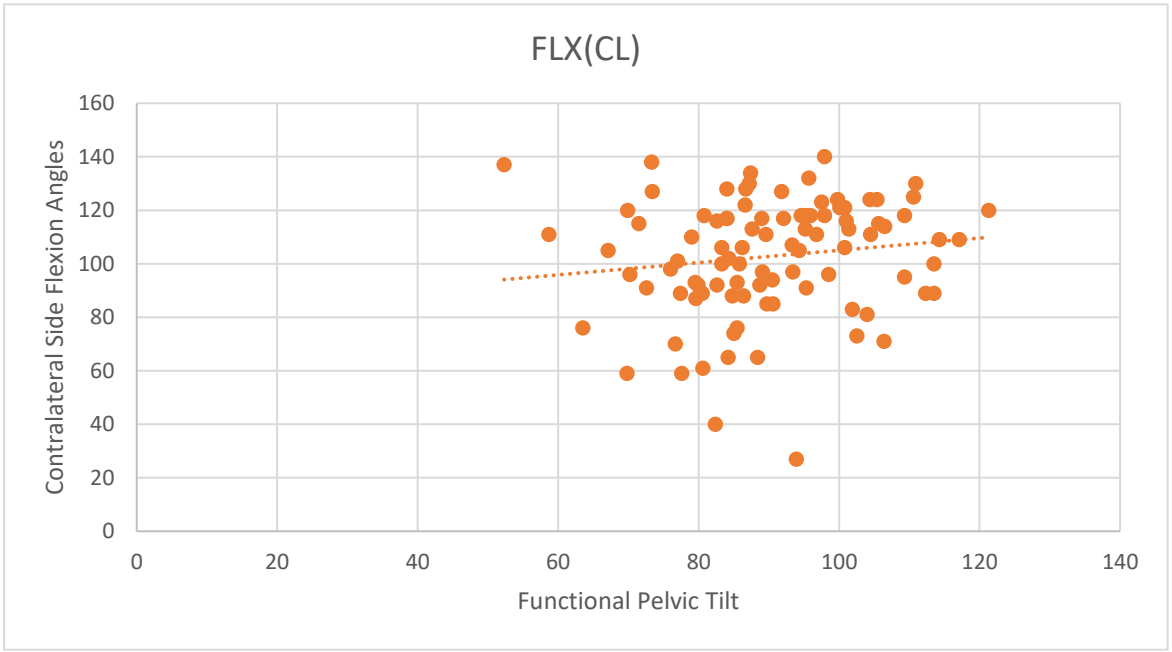

Figure 20: Relationship between contralateral side flexion angles and functional pelvic tilt (Male patients)

According to the graphs, the relationship of the functional pelvic tilt and the flexion angles in both the operative and the contralateral sides does not represent a distinguishable linear relationship because it is very spread in a range of each data set which is unexpected in relation to the previous prediction study in preoperative and postoperative pelvic tilt performed by Corin Group. The data is divided mainly by male and female patients to find out mobility differences between gender but in this case is negligible due to the characteristics of the data.

Regarding the difference between the contralateral and operative sides, the first one presents less flexion angle range in female patients and in male patients the range is very similar. Also, the minimum flexion angles which are the angles before impingement, assimilates to the operative side flexion angles in female patients indicating the reason of its need for surgical procedure but in the case of the male patients, the difference is minimal between the different flexion measurements.

Additional relationship is analysed between age and minimum flexion angles which could be used as a variable to have a better prediction in postoperative minimum flexion angles before impingement, but it also presents a very spread range between the data unable to obtain a relation.

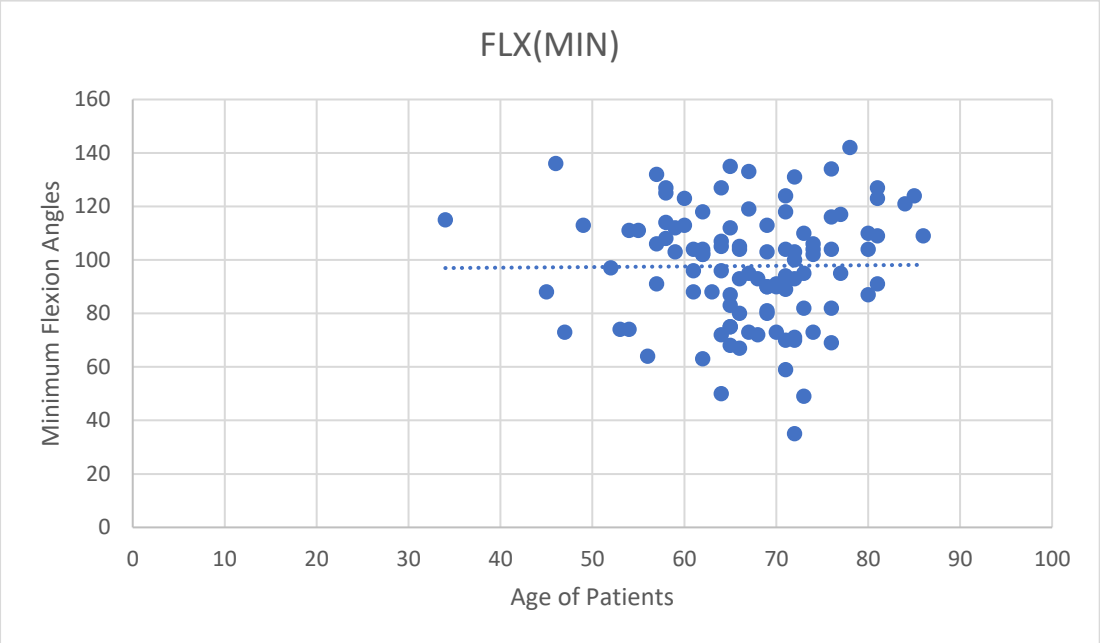

Figure 21: Relationship between minimum flexion angle and age (Female patients)

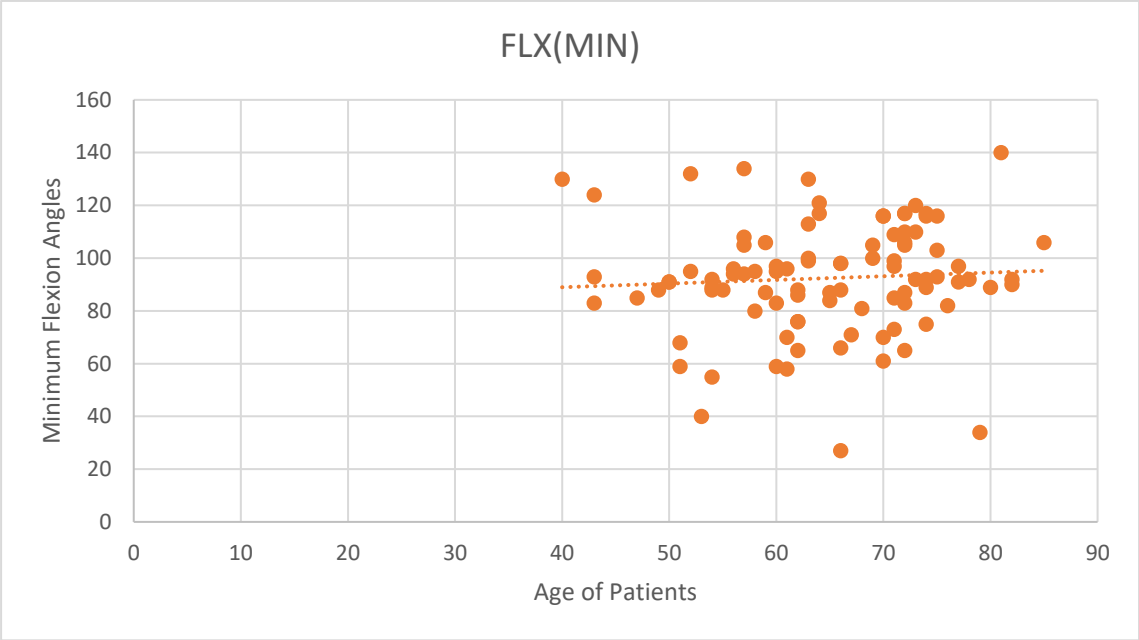

Figure 22: Relationship between minimum flexion angle and age (Male patients)

Chapter 4. Conclusion

Through the use of medical imaging, 3D modelling and simulations, functional pelvic tilt and operative and contralateral flexion angle data is obtained and demonstrates that even though there is a predictive relation between the preoperative and postoperative pelvic tilt based on a previous study, the relationship between the preoperative and postoperative bone impingement is not correlative because the consequent relation between preoperative functional pelvic tilt and the minimum flexion angle does not have a linear similarity.

4,1 Limitations

The previous lack of correlation between the data is possible due to many limiting factors regarding the quality of the data, such factors are: low quality CT scan images that affect the 3D modelling of the pelvic and femur bone, nonconforming positioning of the patient in standing and seated pelvic tilt data from x-ray images, abnormal bone growth structures in the acetabular area which are removed during surgery affecting the resulting

mobility and the subjective resection of the 3D femoral head model that has an impact during the range of motion simulations.

Another clear limitation was the usage of the old patient files with the new updated systems and processes from Corin Group which affected the schedule and timing for each of the various stages involving the development of the research.

4.2 Future work recommendations

Additional analyses are required to check which stage of the process are needed to review and verify each output data and determine an upgrade to produce the linear relationship outcome between the functional pelvic tilt and the flexion angles before impingement which will benefit a patient range of motion after a THA procedure.

Standardization of certain procedures such as the resection of the femur head which could possibly be a separate research regarding the length of the cut and its effect in the flexion angles before impingement. And the measurement of the hip centre according to abnormal femoral heads which were performed subjectively in this research.

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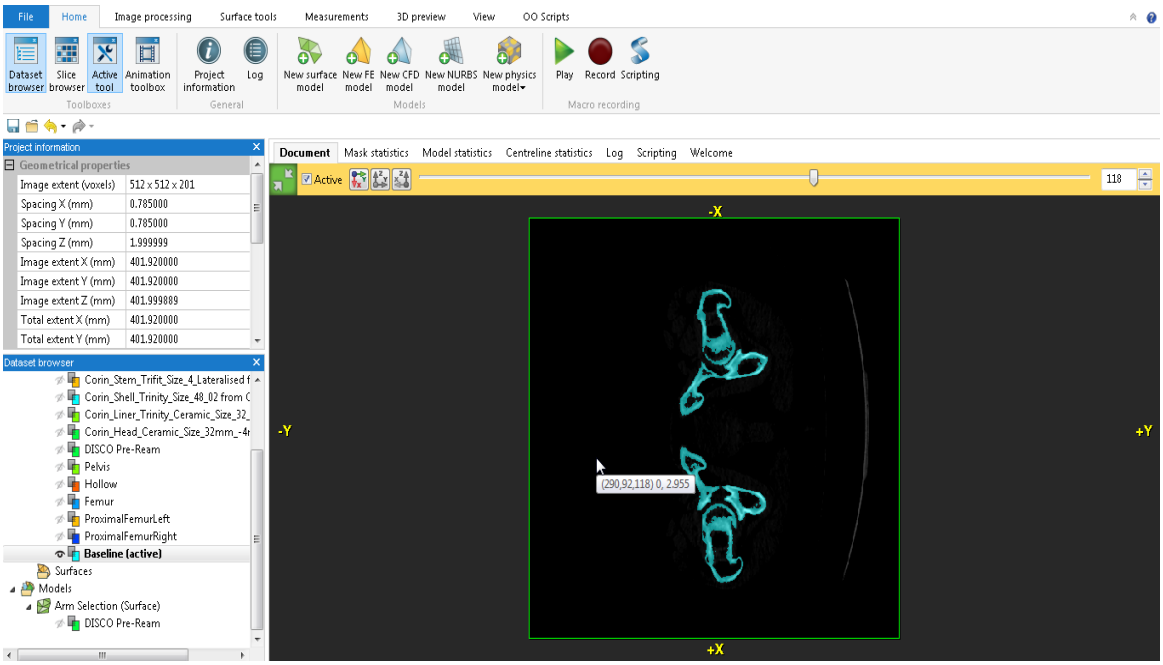
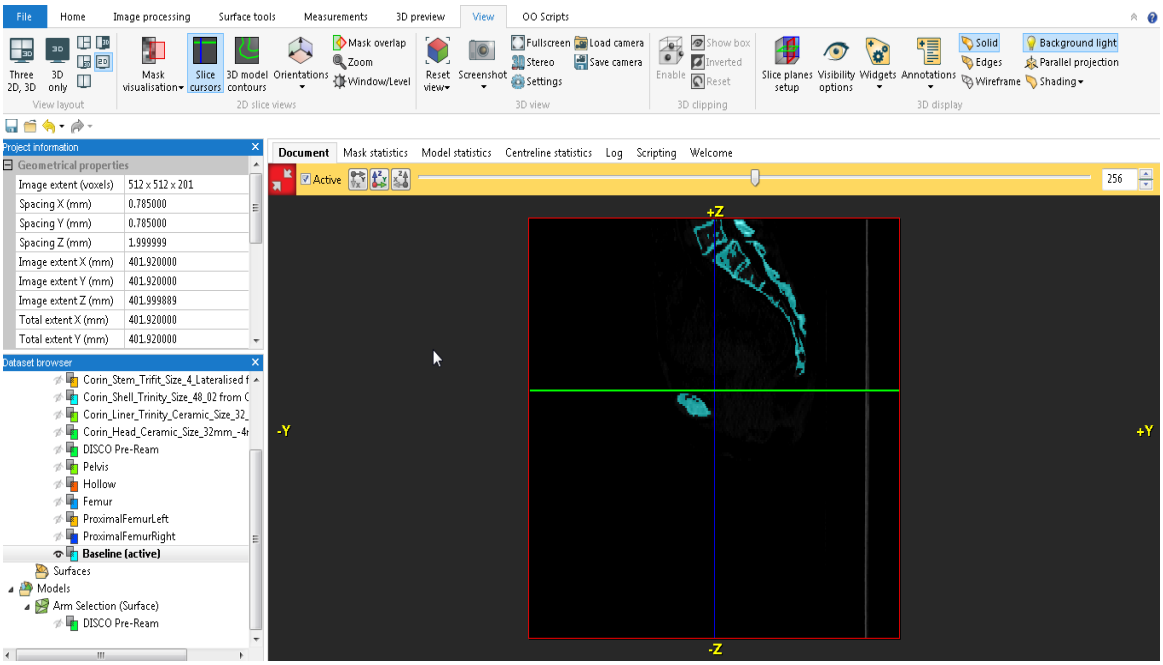
Appendices

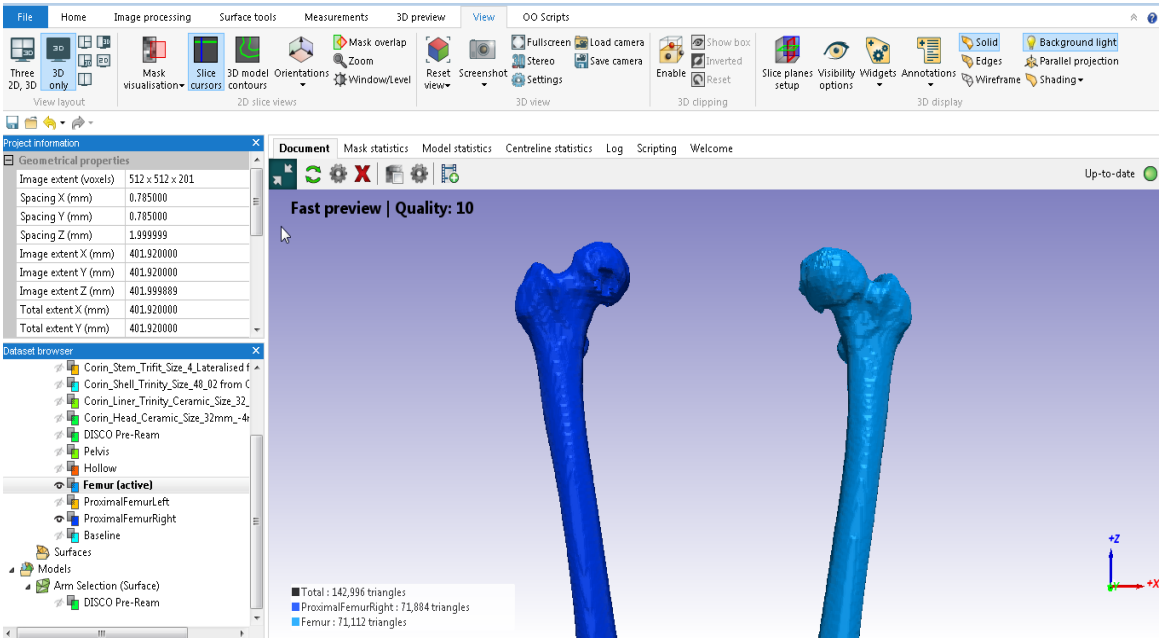
Appendix A: Segmentation and Landmarking images



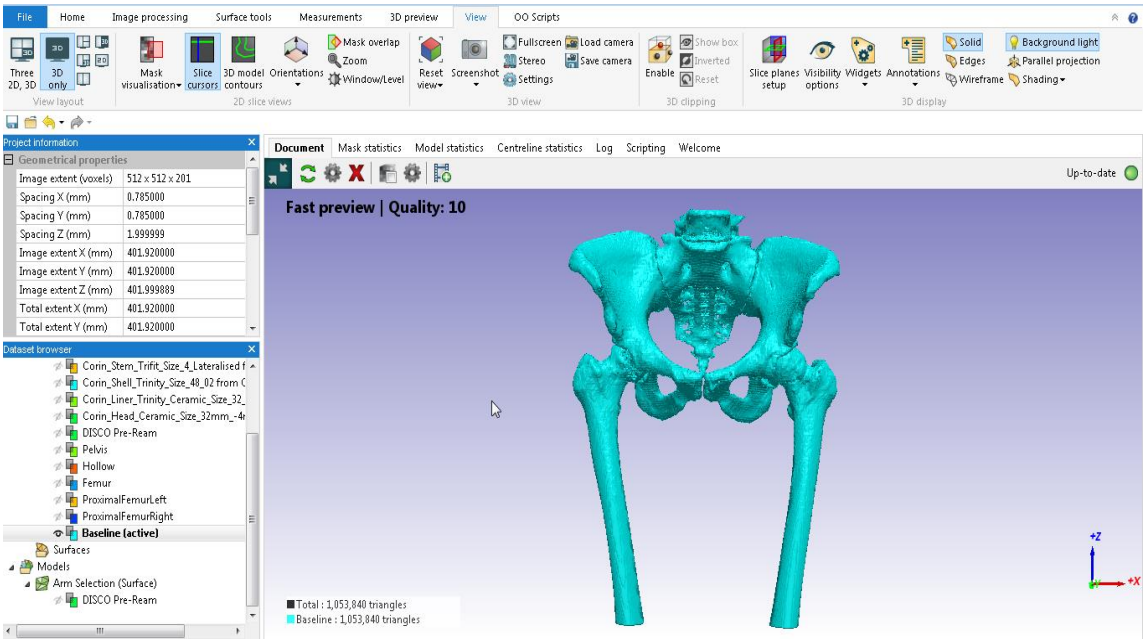
Synopsis Simpleware transversal view of CT scan images



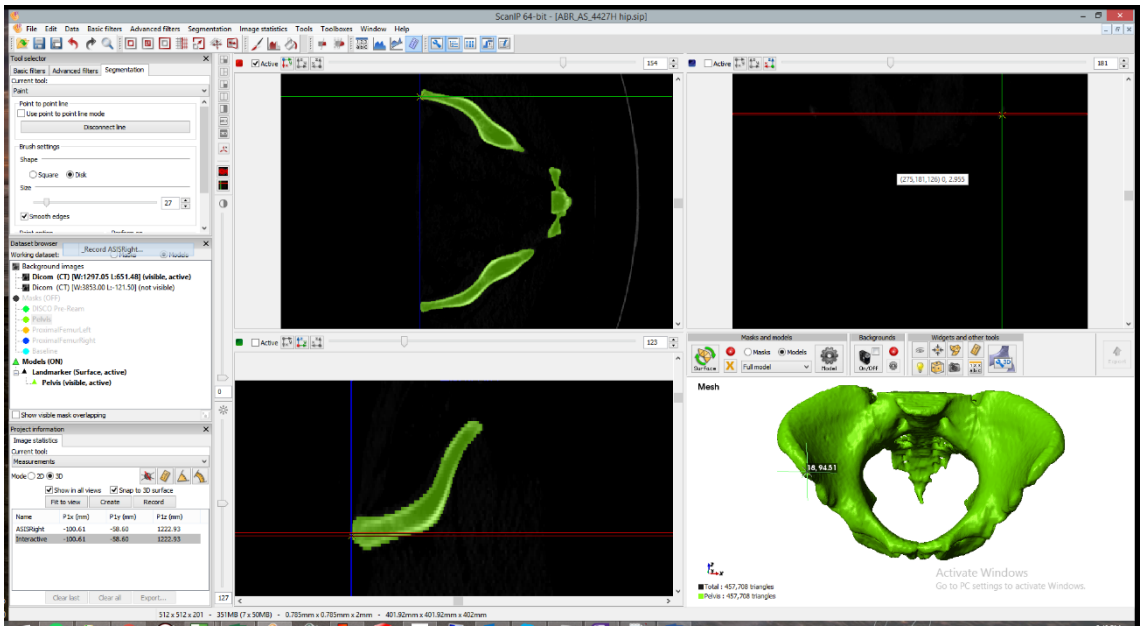
Synopsis Simpleware sagittal view of CT scan images



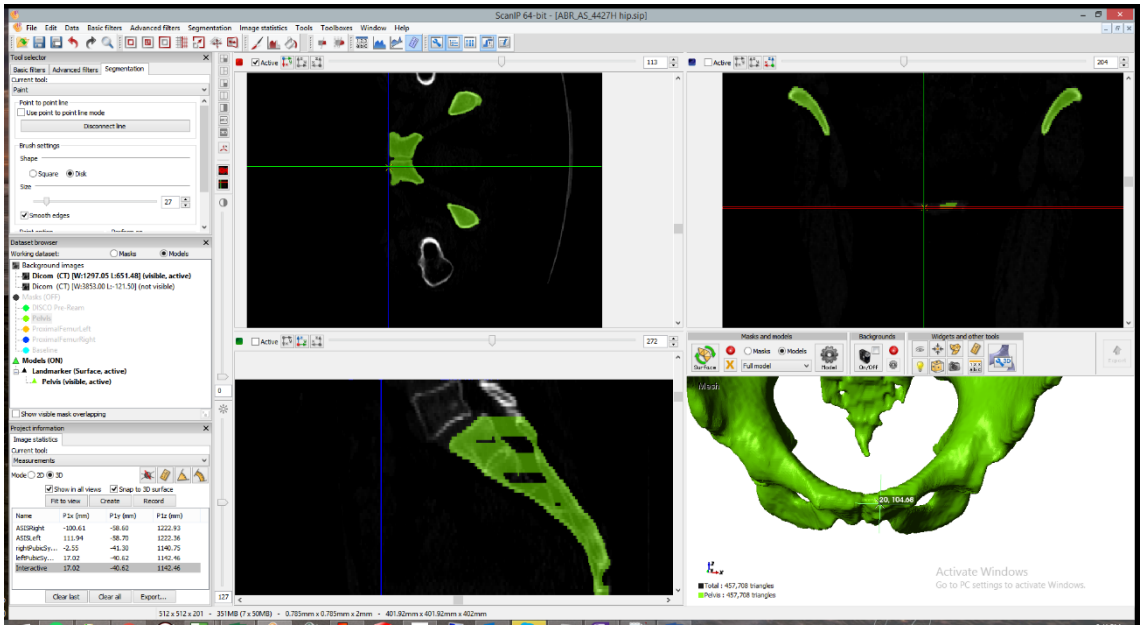
Segmented 3D rendered femur bones



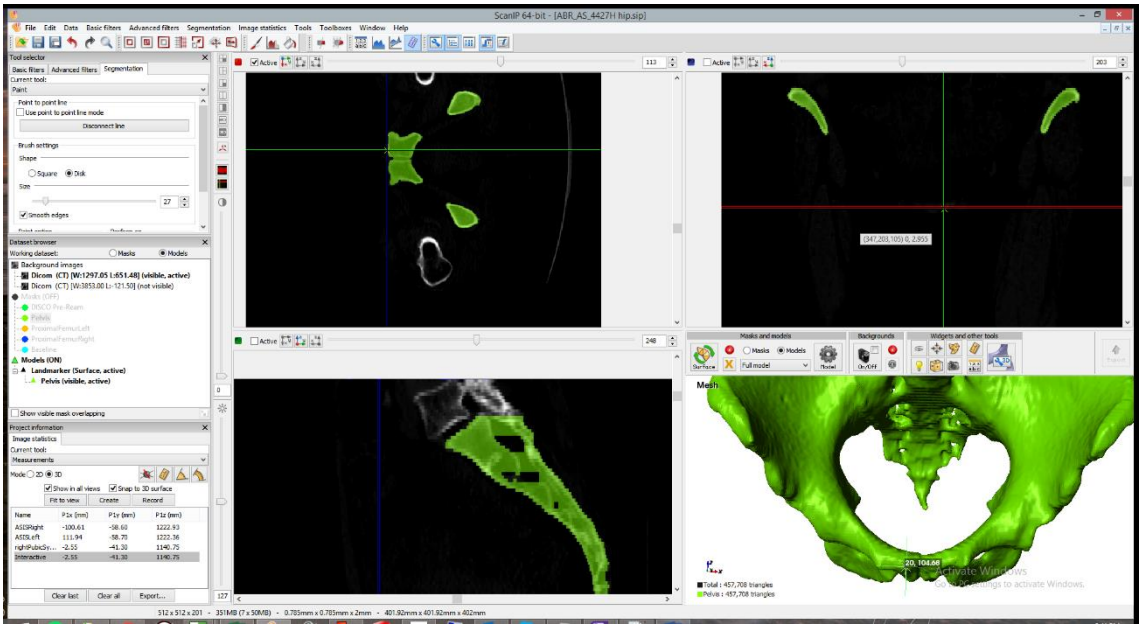
Segmented 3D rendered pelvis and femur bones



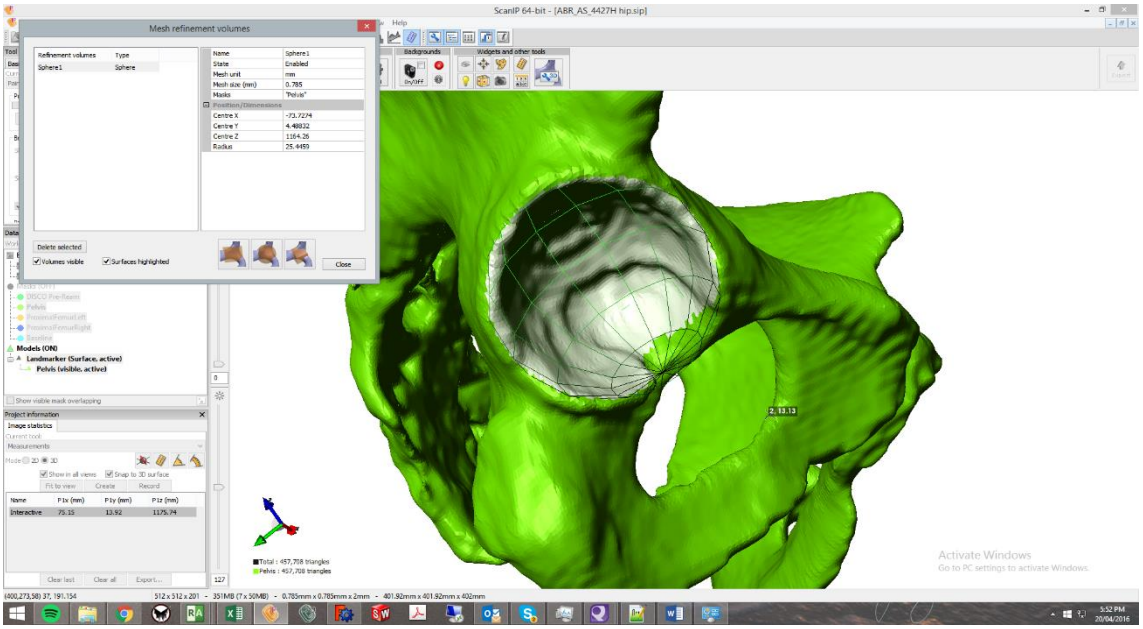
Right ASIS landmarking



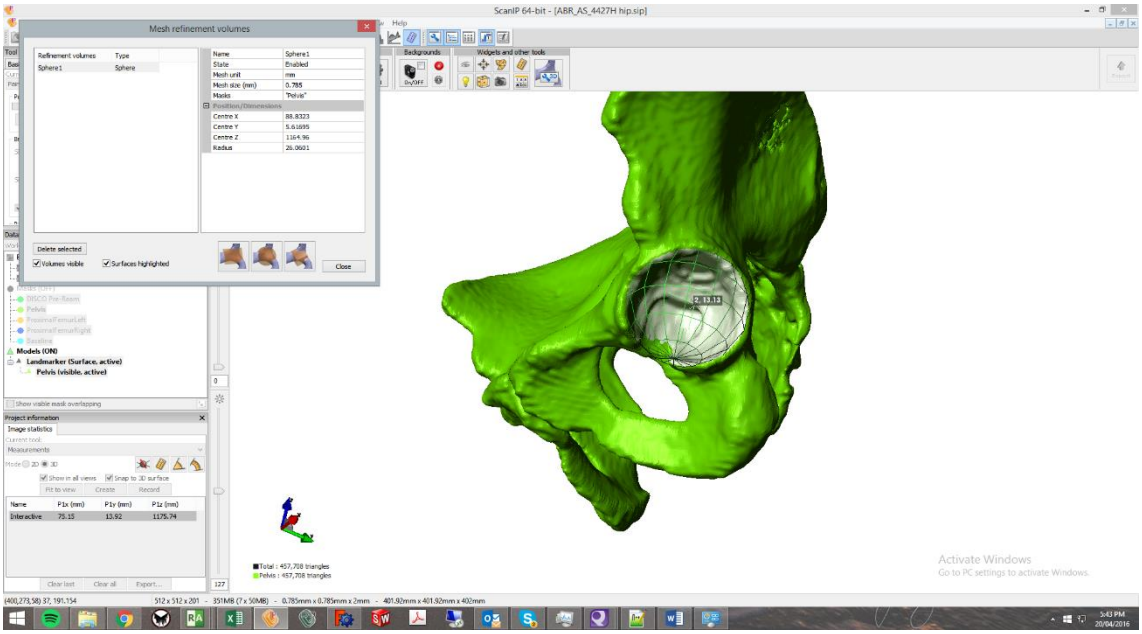
Left PS landmarking



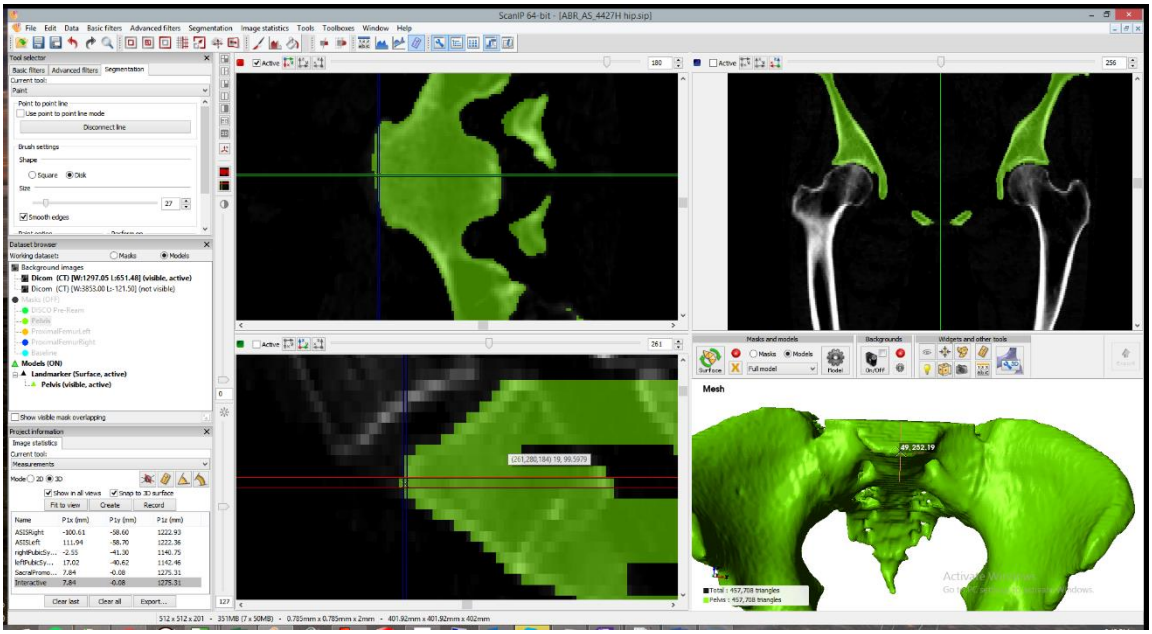
Right PS landmarking



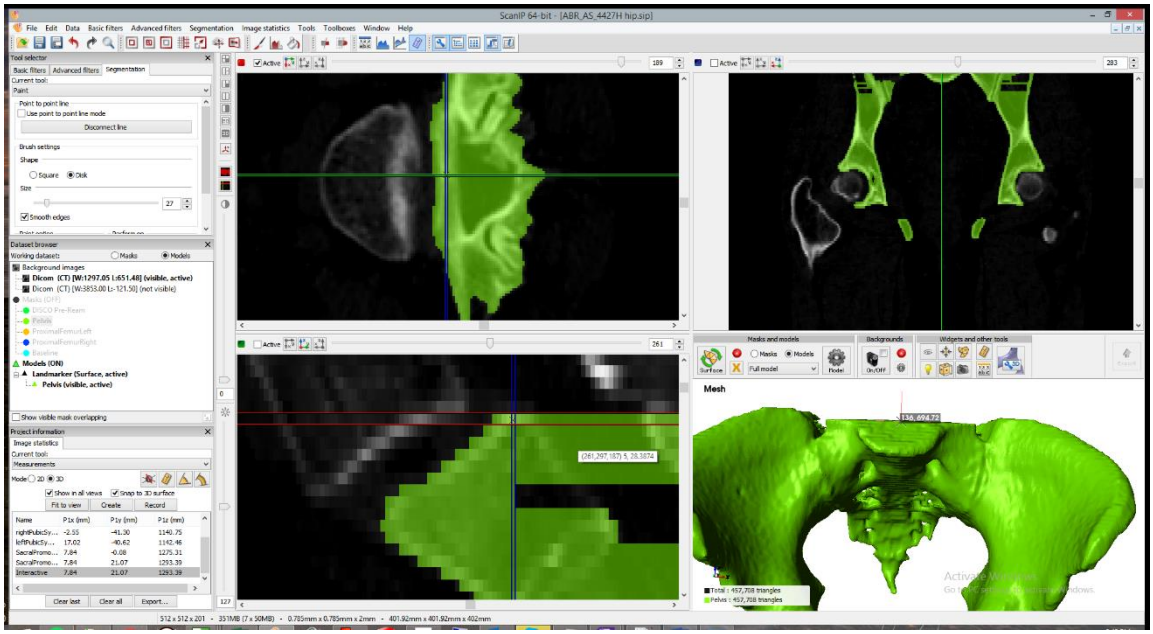
Right pelvis center landmarking



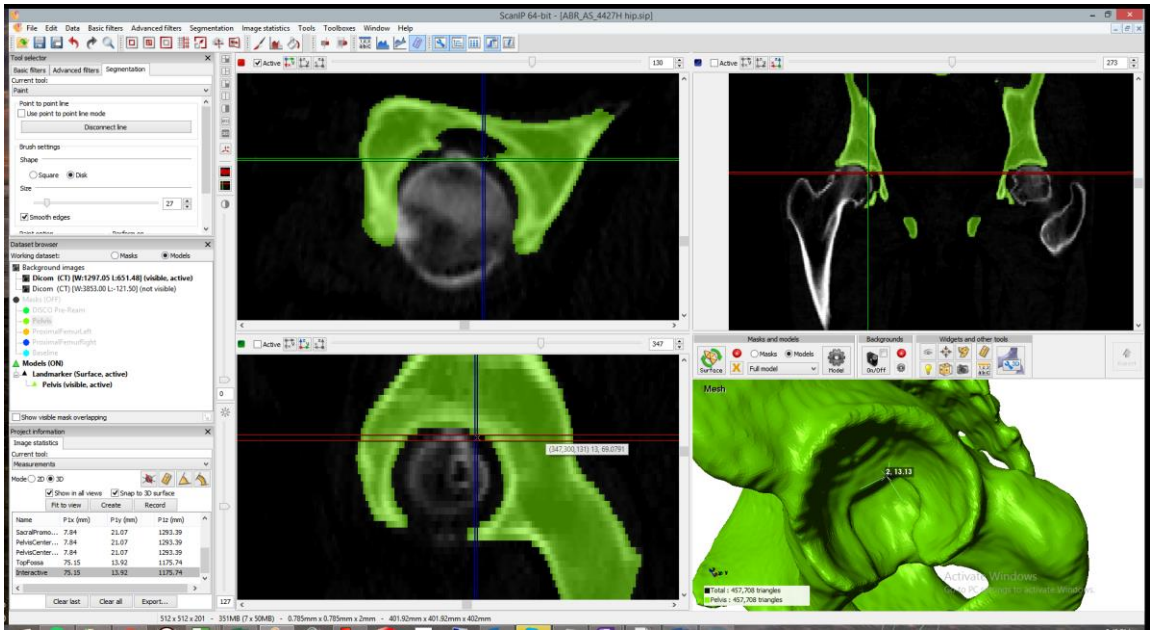
Left pelvis center landmarking



SPA landmarking

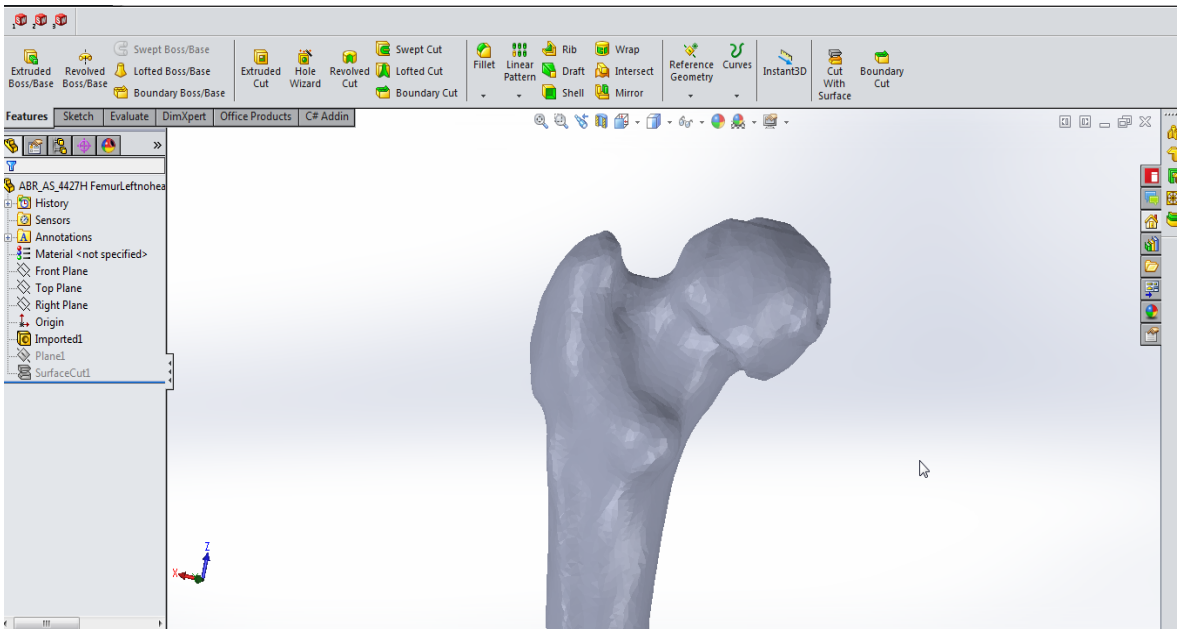


SPP landmarking

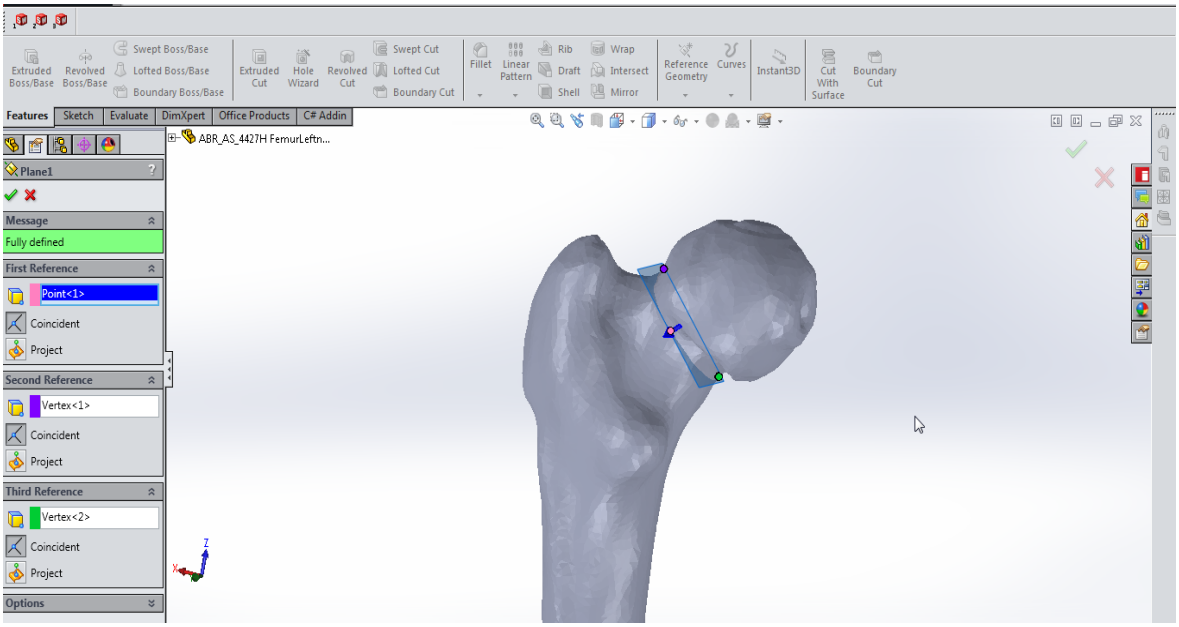


Top Fossa landmarking

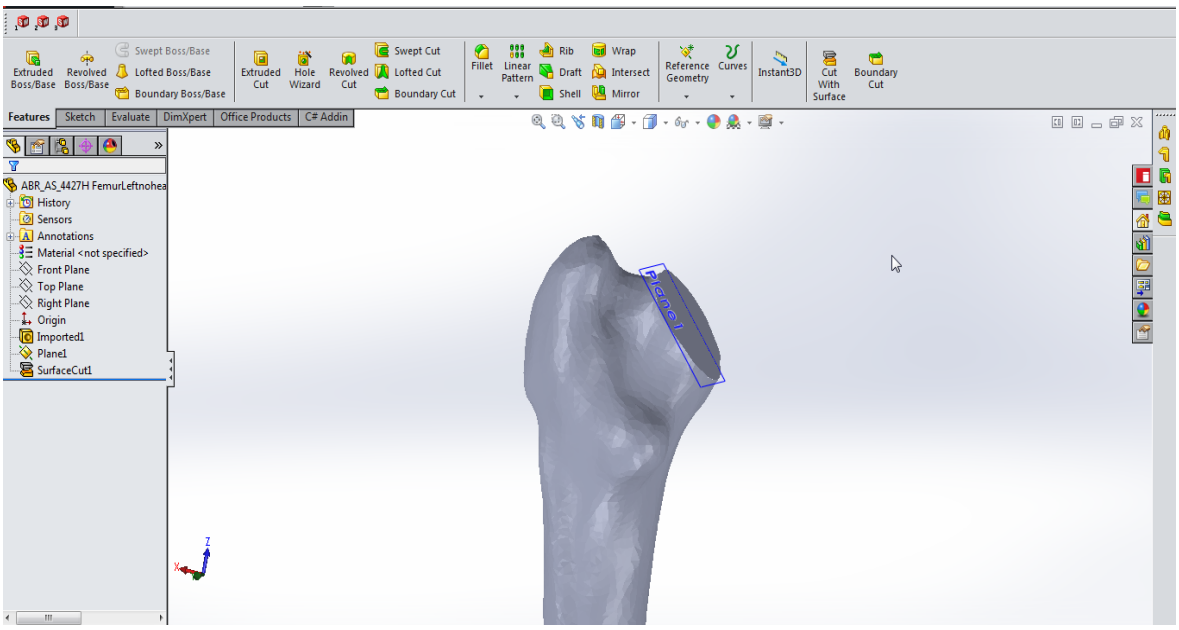
Appendix B: Resection of the femoral head images



Solidworks 3D render of the left femur bone

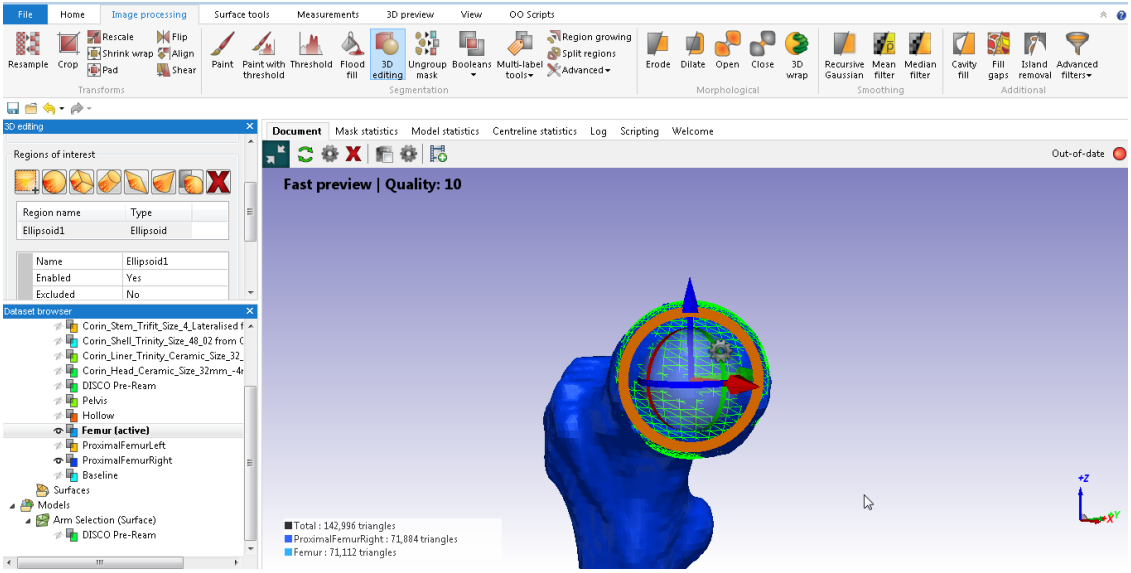


Creation of 3D plane for head resection of the left femur bone



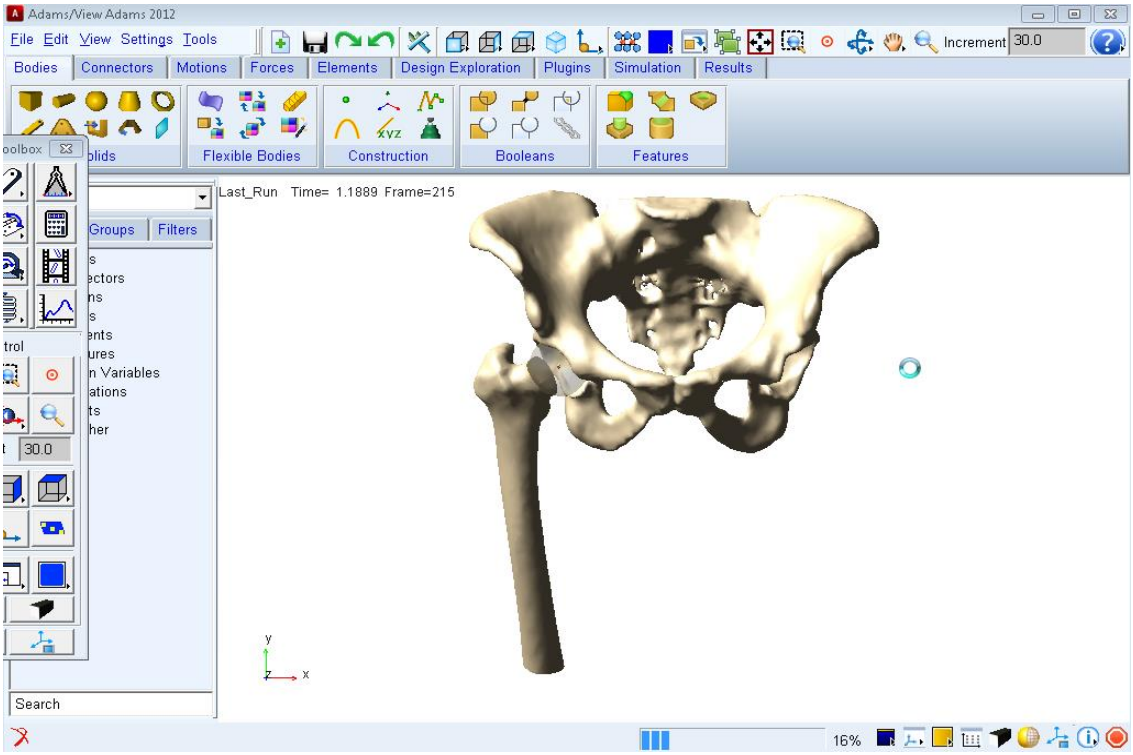
Resected head of the left femur bone

Appendix C: Measurement of the femoral hip centre images

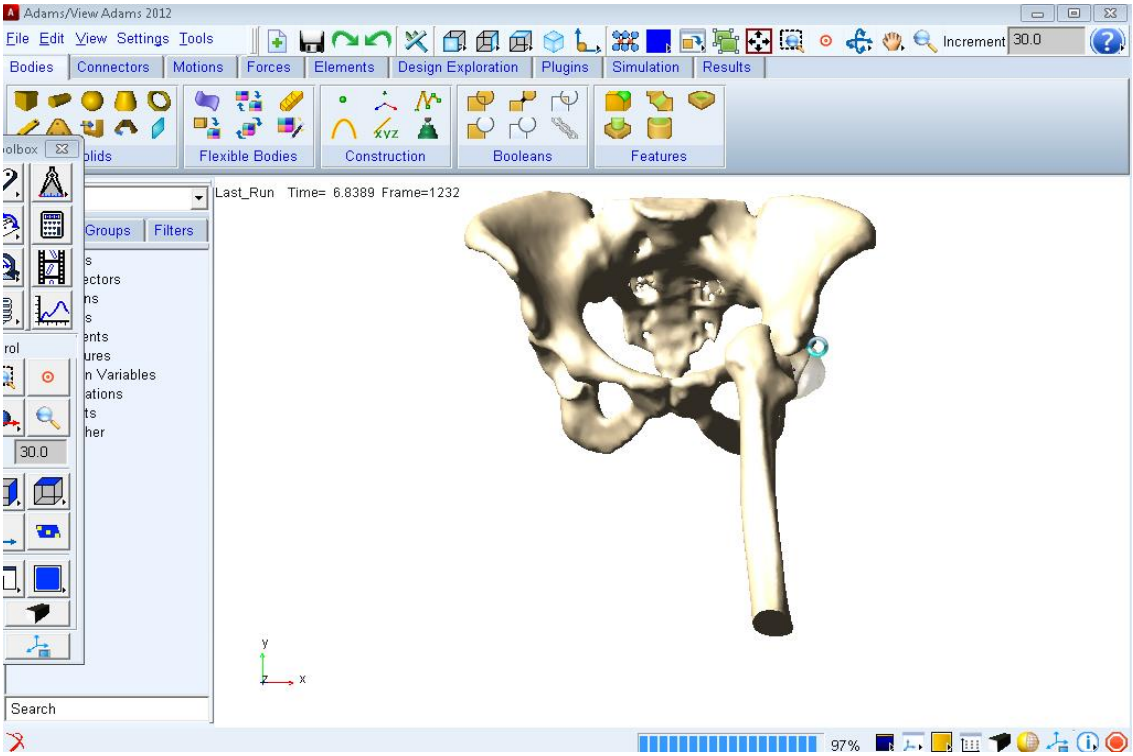


Right hip centre measurement

Appendix D: Range of motion simulation images



Contralateral side range of motion simulation (beginning)



Contralateral side range of motion simulation (during)