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INFLUENCE OF POSITIONING IN SOME 2D/3D ROTATIONAL MEASURES OF THE LOWER LIMBS

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Aos meus amados Pais,

À minha Avó.

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Resumo

Quando comparamos a tecnologia EOS com a tomografia computorizada, apercebemo-nos de que esta última apresenta limitações óbvias: a irradiação, o custo e o facto de que os doentes têm de estar em posição horizontal. É fundamental ter em conta a posição do doente na medição de parâmetros pélvicos e dos membros inferiores, tais como a torção femoral e o ângulo femoral mecanico-anatómico, nas suas posições naturais.

Os métodos avaliados neste trabalho baseiam-se no sistema EOS. Este dispositivo de imagem consiste num braço biplanar que se move verticalmente, e no qual estão montados dois sistemas radiográficos de aquisição. O doente é examinado em posição de carga ou sentado no centro da cabine, permitindo a realização simultânea de duas radiografias de corpo inteiro ou de uma zona anatómica específica.

Este sistema de aquisição tem ainda a vantagem de utilizar uma menor dose de radiação do que os sistemas de radiografia convencionais.

Palavras-chave: EOS, reconstrução 3D, posição de carga, membros inferiores, baixa dose de raios-X

Abstract

When we compare the EOS technology with CT, we realize that the last one has obvious limitations: the irradiation, the cost and the fact that the patients are lying down. It is crucial to take into account the patient's position when measuring parameters of the pelvis and lower limbs, such as femoral torsion and femoral mechanical-anatomical angle, in its natural positions.

The methods evaluated in this paper are based on the EOS system. This imaging device consists of a bi-planar arm that moves vertically, upon which two radiographic acquisition sets are coupled. The patient is scanned in weight-bearing position or seated in the center of the cabin, allowing simultaneous acquisition of two total body scans or one particular anatomic area.

This acquisition system has also the advantage of giving off less radiation than conventional radiographic systems.

Keywords: EOS, 3D reconstruction, weight-bearing position, lower limbs, low dose X-ray

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CHAPTER 1 INTRODUCTION

1.1. Motivation

Nowadays, doctors use imaging methods widely to perform reliable diagnostics. The many methods at their disposal (MRI, radiology, ultrasound, CT) are complementary with each other, since the images they generate do not return the same information.

Historically, one of the first medical imaging techniques is radiography which was largely developed by Wilhelm Roentgen in late 19^{th} century. The other techniques have not been developed until much later in the course of the 20^{th} century. Even if now we can “see” through soft tissue due to radiography, its main use is the observation of the bone structure of a patient to detect fractures and/or diseases/abnormalities of the bone tissue.

Radiology has changed since its beginning and many different techniques have been developed afterwards. In addition to plain radiographs, computed tomography (or CT scan), produces 3D images. All these techniques use ionizing x-rays, making examination of the human body invasive.

The company EOS Imaging focuses on medical imaging through x-ray. In this context, it develops and markets an imaging system called EOS™ and 3D reconstruction software named SterEOS™ for musculoskeletal applications [1]. This methodology has the advantage of using very low doses of irradiation to the human body which is positive in the context where the harmfulness of nuclear imaging techniques raises questions [2].

Indeed, taking x-ray in weight-bearing position provides new information on support structures, mainly of the spine and lower limbs, being the most interesting applications. The joints most commonly studied nowadays are the hip and knee, but in the near future reconstruction will be possible for the entire skeleton and new applications will then see the day [3].

After analyzing some medical needs, bibliographic research and experiments were made in this context, and their results will be described becoming the axis of future research.

1.2. Aims

I have been under the supervision of the clinical studies responsible, as well as of the marketing director. At this department, the goal is to help doctors to submit articles, to publish them and to present them at conferences, in order to promote the company.

I have been in permanent contact with the medical staff at a private clinic and of a public hospital that uses the EOS system. One of my missions was to always ensure the satisfaction of the medical staffs, as well as to find possible “bugs” and technical problems of the system.

In order to achieve these goals, I cooperated with the development team, which helped me with some manipulations of the EOS device and also during the design of the knee’s slice processing software.

Since my application to this training period, I found innovative technologies inside the company, and together we agreed to implement several tasks, including:

- clinical validation of the 3D modeling software SterEOS;
- design of a Matlab prototype to do surgical planning of lower limbs;
- management of the references database.

CHAPTER 2 STATE OF THE ART

2.1. Spinal balance and hip complications

Spinal balance is the manifestation of a postural strategy conditioned by anatomic and functional characteristics, sometimes very different from one person to another. Degeneration of this steady state, often associated with spinal aging, can generate a cascade of functional, neurological, and mechanical events [4]. The role of the pelvic area in spinal balance is evident for surgeons, who consider sacral slope, pelvic incidence and pelvic tilt in their surgery planning and analysis [5, 6].

Human beings are the only vertebrates to maintain an upright, totally vertical, bipedal position under the force of gravity. Unlike other vertebrates, the human spine comprises successive opposing curves which allow the trunk to maintain an erect position. Lumbar lordosis, for example, is found in no other primate species [7].

The erect position is linked with pelvic rotation and enlargement, associated with modifications of the spinal sagittal curvatures and muscle adaptations [8]. Human bipedalism is exclusive, stable and ergonomic. In order to maintain this posture for prolonged periods, the erect position should be economical in terms of energy expenditure. To correctly analyze the erect posture, it is necessary to define spinal and pelvic parameters, and to correlate those parameters with global ones in a weight-bearing position.

Since Hippocrates provided a precise description of the segments and normal curves of the spine over 2000 years ago, clinicians have attempted to understand the mechanics underlying spinal balance [9]. In order to maintain the standing up position, for any individual, there will be an optimal combination of spinal, spino-pelvic and lower limb joint alignments, requiring the least muscle energy expenditure combined with the least discomfort, potentially caused by stretching of ligaments and joints.

The influence of the coxofemoral joint is underestimated and inadequately explained by conventional radiology. These anatomic and functional considerations often remain unfamiliar to hip surgeons, who focus on the bone landmarks of the pelvis for their navigation. The anteroposterior or frontal image of the pelvis is the “gold standard”; a lateral view of the pelvic area is rarely used [10].

The hip joint, instead of only being considered as a joint allowing femoral movement against a fixed pelvis, should be taken as a joint that allows rotation of the pelvis against fixed femurs [11]. Rotation of the hip joint can, therefore, be considered as a fundamental factor that can interfere with the spinal shape through the pelvic anatomy.

2.2. Osteoarthritis of the hip and knee

Osteoarthritis (OA) is the most common rheumatic disease, and it is becoming a major public health problem with the ageing of the population and the growing incidence of obesity in developed countries [12]. Treatment aims both to reduce symptom severity and to prevent or slow down disease progression and loss of activity.

Many therapies have been proposed with different levels of evidence; however, there is still no treatment with proven efficacy in preventing, stopping, or retarding the disease process.

The structural process in OA affects cartilage, which is decreased in quality and thickness. Other structures may be involved in the damage observed in OA, including subchondral bone, articular capsule, synovia, meniscus and soft periarticular tissues.

Hip OA is very common. The prevalence of symptomatic hip OA increases dramatically with age.

Recently published recommendations advocate the use of manual or digitalized measurement of joint space at the narrowest point on plain radiographic views of the pelvis [13]. However, there remains uncertainty concerning the optimal view in order to perform the correct measurement.

Knee osteoarthritis is the most common joint disorder, being characterized by abnormal articular cartilage and subchondral bone of the tibiofemoral joint [14]. There is growing evidence that several biomechanical factors contribute to the development of knee osteoarthritis [15].

There are several studies pointing out the relationship between the lower limb torsion, axial plane coverage of the hip and osteoarthritis of the hip [16, 17], as well as a study reporting the relationship between femoral torsion and knee osteoarthritis [18]. In addition, there is a high probability of coincidental diagnosis of primary osteoarthritis of the hip and knee of the same limb, both at clinical and/or radiographic evaluations.

Knee OA also substantially increases the risk of disability due to other medical conditions [19]. Due to the aging of the population, the prevalence of OA is expected to increase substantially in the upcoming decades.

Malalignment (valgus or varus) of the knee is assumed to correlate with unicompartmental OA of the knee. However, it is still unknown whether it precedes the development of radiographic OA, whether it is a result of OA, or (even more likely) whether the relationship between malalignment and OA is bidirectional. A reason for the relatively small number of epidemiologic studies dealing with malalignment might be that it is mainly measured by means of the hip-knee-ankle (HKA) angle on full-limb radiographs, assessing the mechanical axis in the knee.

Full-limb radiographs are used specifically to determine the HKA angle and, in most cases, to surgically adjust this angle. However, this method is heavy, requires specialized equipment and expertise, and it is expensive (particularly for large epidemiologic studies).

In clinical practice, obtaining anteroposterior (AP) knee radiographs is the most common way to evaluate knee OA radiographically. These radiographs are also used in most large epidemiologic studies. On AP radiographs, the femorotibial (FT) angle can be measured, defining the anatomic axis in the knee. It was recently shown that this method correlates moderately with measurement of the HKA angle on full-limb radiographs [20]. Even more recently, *Hinman et al.* [21] confirmed, in another study, that the anatomic axis is a valid alternative to the HKA angle for determining frontal plane knee alignment. This method, however, has not been used to determine the influence of alignment on the development of knee OA.

2.3. Femoral torsion

It has been shown that abnormal anteversion of the femoral neck correlates with several disease processes. Osteoarthritis of the hip and knee, slipped capital femoral epiphysis, knee and patella instability, and in or out-toeing gait patterns have all been shown to correlate with abnormal femoral neck version [22, 23]. Accurate assessment of femoral neck version may be important for guiding diagnosis as well as treatment [24].

Although computed tomography (CT) has been regarded by some researchers as the gold standard, no study has proven that CT measurement of anteversion is correlated with any other relevant variable. Furthermore, although multiple techniques for measurement of version have been described [25, 26], there still remains no consensus on the imaging modality to choose.

In clinical practice, the physical examination findings and injury patterns of patients with hip pathology have been inconsistent with the CT and magnetic resonance imaging (MRI) assessment of femoral neck version. These observations have led to the suspicion that these particular imaging modalities may provide an inaccurate description of true femoral rotational anatomy.

The idea that CT and MRI are not adequate modalities has also been suggested in many other studies, flaws of these techniques contributing to the controversy. The challenge of accurately summarizing the three-dimensional rotational anatomy of the femur using a single number is reflected in the multiple existing methods used to measure anteversion on CT or MRI [27].

2.4. Total knee arthroplasty

In total knee arthroplasty (TKA), the aim is to restore the mechanical axis with a joint space parallel to the ground. Perpendicular resection of the distal femur relative to the mechanical axis of the femur (FMA) is necessary. When using an intramedullary guiding system, the surgeon needs to know the angle between the anatomical axis of the femur (given by intramedullary axis) and the FMA. For this purpose, taking radiographies of the hip and lower extremities while the patient is standing is recommended in the pre-operative period [28].

Surgeons tend to regard this procedure as heavy and perform instead the distal femoral resection as a routine.

Recently, measurement of femoral axis through radiographies and CT scout films in knee replacement was reported as a reliable method [29]. However the clinical validity of this technique is yet unclear.

Many variables, including the surgeon's skill, can impact upon prosthetic longevity and patient outcome [30]. Nevertheless, the factor of greatest importance during total knee arthroplasty remains the prosthetic alignment, and in particular, femoral component alignment is crucial to function and long-term survival [31].

Total knee arthroplasty (TKA) is a very successful procedure and implant survival now approaches 95% at 15 years (Figure 1) [32]. The success of this procedure involves pain relief, improved function and implant longevity, and is correlated with prosthetic, patient and surgical factors.

The relationship between implant malalignment and longevity has been previously described. For example, deviations of coronal alignment greater than 3° of varus have been correlated with poorer implant survival [33].

Deviations of mechanical axis from the neutral position are associated with patterns of femorotibial tracking, which is associated with abnormal stresses at the bearing surface that can lead to faster wear [34]. A number of studies have reported that even in major arthroplasty centers the incidence of unacceptable implant alignment may exceed 25%, thus potentially exposing a large number of patients to reduced implant longevity [35].

Achieving a near neutral mechanical axis is the aim. However, this has not been the subject of much investigation and what has been reported to date remains inconclusive.

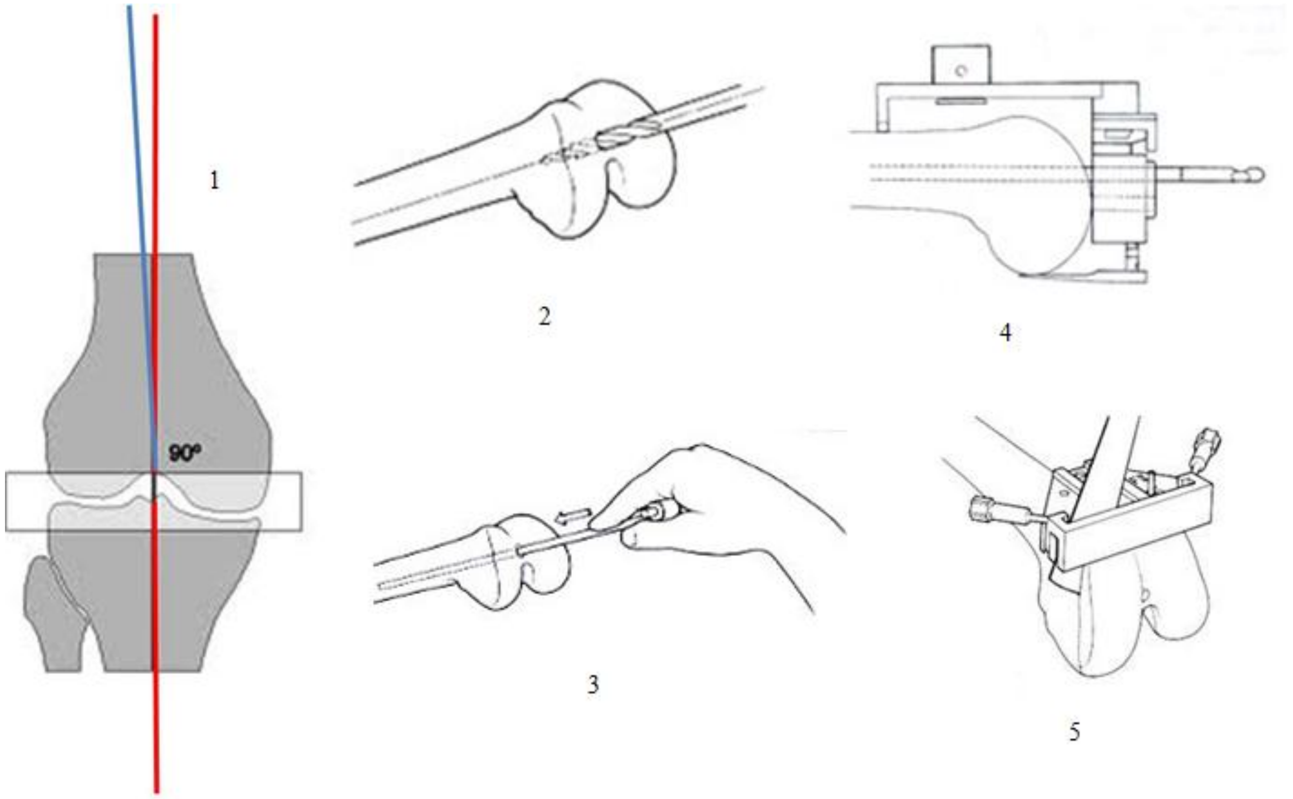


Figure 1: Total knee arthroplasty procedure.

CHAPTER 3 TECHNOLOGY AND CLINICAL CONTEXT

3.1. EOS Imaging

Since 1959, Georges Charpak, physicist, is involved in CERN, Conseil Européen pour la Recherche Nucléaire. He worked over thirty years on the detection of particles and has numerous patents on different devices, including the proportional multiwire chamber, who afterwards allow him to receive the Nobel Prize in 1992. He found the company Biospace in 1989, which was renamed recently EOS Imaging.

EOS Imaging is a medical imaging company whose ambition is to be a leading global player in the musculoskeletal segment. To achieve this purpose, two types of medical devices referred as EOS and SterEOS have been developed in partnership with two academic laboratories, ENSAM (École Nationale Supérieure des Arts et Métiers) in Paris and ETS (École des Technologies Supérieures) in Montréal.

EOS is a revolutionary system of low dose imaging that combines the use of the particles' detector by Georges Charpak to an acquisition technique by linear sweep. With these two innovations, EOS allows simultaneous acquisition of two images, frontal and lateral, of the full body, with up to 10 times less dose than a radiographic film, without compromise of image quality (Figure 2).

SterEOS is a single workstation which allows to reconstruct the 3D model of the patient's skeleton in the anatomical position, from two images acquired with low-dose EOS. Over 100 clinical measures of angles and lengths are automatically calculated from the 3D reconstruction.

Both medical devices designed by EOS Imaging allow a range of medical specialties including orthopedics to access new functional information unavailable with existing modalities. EOS and SterEOS thus offer new perspectives both for the diagnosis, treatment planning and monitoring procedure.

With radiation doses from 100 to 1000 times lower than conventional scanners, EOS produces digital whole body radiographs and restores from two plane views the three-dimensional structure of the skeleton in its natural position. After a prototyping phase and clinical essays, the company engages in the industrial and commercial development of EOS, which intends to become within 5 years the reference for the examination of the musculoskeletal system.

Figure 2: EOS cabin.

The device multiple applications, both in physiology, bone and joint pathologies, bring a new field of investigation. The major advantage of the system is the considerable decrease in x-ray doses, with known risks, ranging from a reduction factor of 10 for 2D conventional radiographies to a factor of 800 to 1000 for 3D reconstructions obtained subsequently (CT). These reconstructions also have the disadvantage of being used only in the supine position.

3.2. EOS System: a musculoskeletal imaging device

Operating characteristics

The x-ray machine EOS has three characteristics that are unique and that make it a particularly innovative device: the possibility of obtaining radiographs using a lower dose of radiation, the simultaneous acquisition of two x-ray head to feet, and finally, the reconstruction using its dedicated software, SterEOS, which allows obtaining a 3D image of the bone structures.

A low dose x-ray machine

The first innovation introduced by the EOS radiographic system is the considerable reduction of x-ray dose received by the patient: 8 to 10 times less than for conventional radiography.

This was made possible by the gas detectors (Figure 3) invented by Georges Charpak. These sensors allow the conversion, in a pressurized gas such as xenon, of x-photons into electrons. These electrons are amplified by the avalanche effect, which means they are multiplied in the electric field and detected by an adapted electronic circuit. These detectors are, therefore, sensitive to a single x-photon and allow to obtain an image using a very low patient irradiation. They are more directional and are thus insensitive to scattered radiation, which allows the acquisition of high-quality images.

Finally, thanks to the strong sensitivity of the detectors, the resulting images have a very important number of discernable gray levels: 30 to 50 000, against the order of one hundred levels for a traditional radiological film. The display on a digital screen allows selecting the range of gray levels that are needed for analysis and thus varying the contrast of the image. The low dose is a major asset to the field of pediatric radiology in terms of patient irradiation.

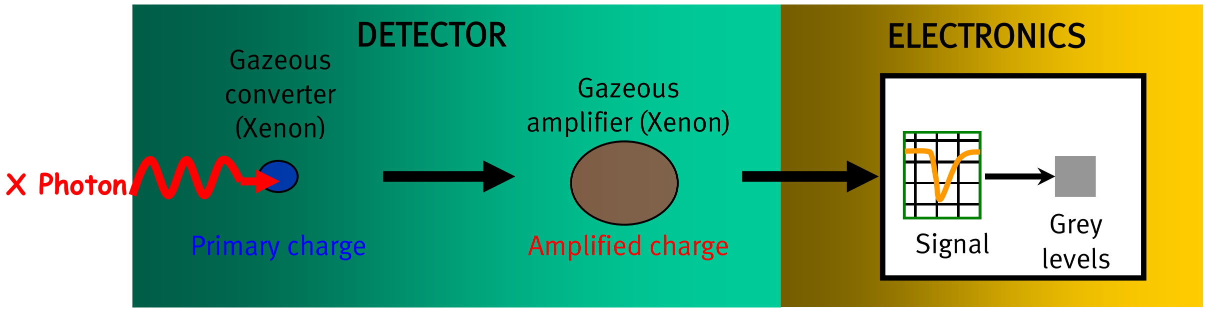


Figure 3 : Principle of the Charpak's particle detector.

Simultaneous images of frontal and lateral views in standing position

The device is a cabin containing two orthogonal sets, each one composed of an x-ray source and detector, physically attached for shooting at the same time frontal and lateral images (Figure 4). The patient is placed inside the cabin while the two images are taken simultaneously and thus there is no need to change his position.

The x-ray source emits a vertically collimated beam of photons in the form of a very fine trapeze, horizontally extended. Each set source/detector performs a vertical scan of about 10 cm/sec, which gives a fast image of the patient from head to feet.

The direction of the emitted beam has two major advantages. First, it contributes to the reduction of x-ray dose, since each emitted photon is captured by the detector with a significant decrease of the scattered radiation. Second, the vertical scanning beam eliminates the distortion inherent to the projection of an object in a plane by a divergent beam. This divergence is still present horizontally, but a software has been set up to resize the image and to correct the magnification in the horizontal direction, this in a reference plane chosen by the user.

This leads to two simultaneous images of the patient standing or sitting and without magnification.

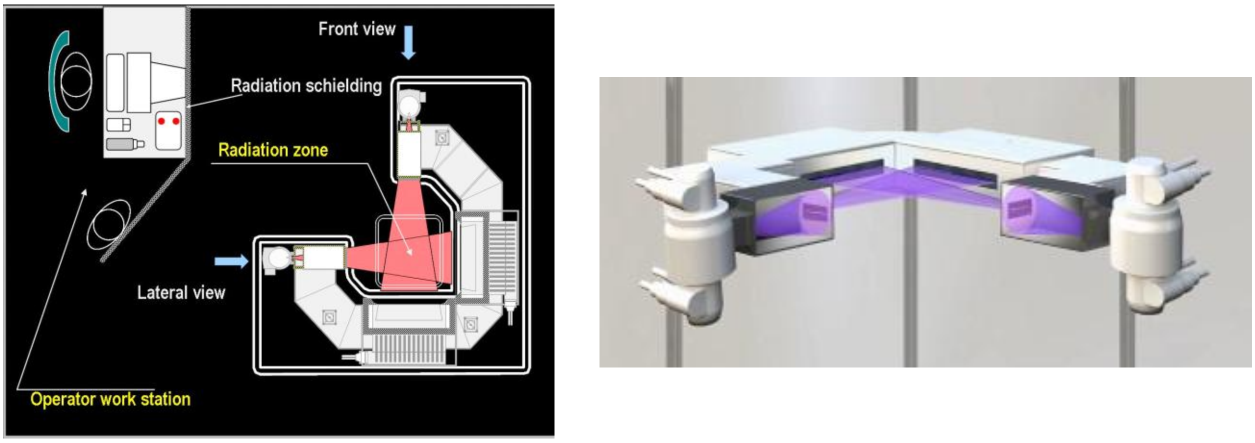


Figure 4 : Vertical linear scanning sources/detectors.

3D reconstruction with the software SterEOS

Dimensional reconstruction is obtained from face/lateral calibrated radiographic images given by the EOS (Figure 5). Since the physical link between the source-detector, the spatial position of sensors and x-ray sources are well known, the radiographic settings are pre-calibrated.

The reconstruction begins with the identification over the radiographic images of reference points and specific anatomical contours. Some reference points are identifiable simultaneously on the two radiographic images (stereo-corresponding points) and are associated with a specific anatomical point; others can only be associated with a region.

The projection of the x-rayed bone, identified reference points and outlines on it are compared with those of a virtual object, called *generic object*, which has an approximate shape. This object will be distorted, first by a succession of translations, rotations, dilations, and then by a nonlinear deformation until a superposition of real and virtual boundaries is achieved.

This *generic object* could be obtained from a 3D CT reconstruction of an anatomic specimen or from a statistical model. It is defined by the coordinates of a cloud of points distributed on its surface (400 to 9000 points, depending on the complexity of the object). Solving this problem requires complex algorithms and a deep understanding of bone structures.

3D reconstruction can be achieved within an acceptable 15 to 30 minutes for a complete spine, for example, and provides a 3D virtual object whose surface areas are associated with known anatomical areas. This allows then, using appropriate software, to perform measurements on the object in three dimensions (measurements of lengths or angles between the mechanical axes of certain bones). This new information will surely bring orthopedists to change their treatment practices.

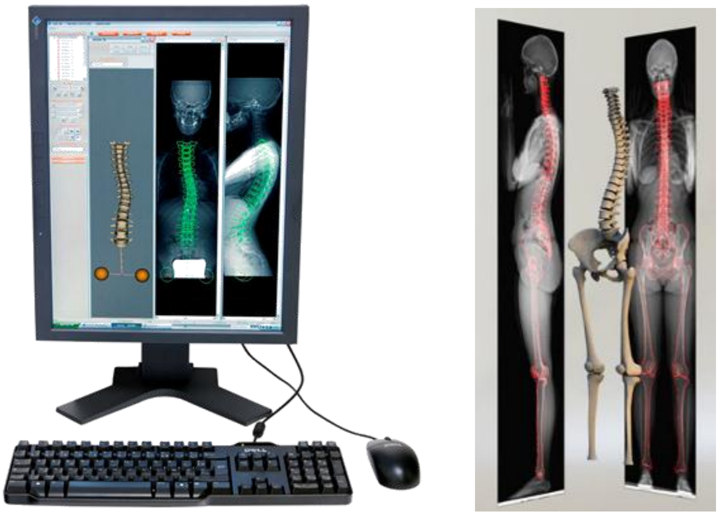


Figure 5 : SterEOS workstation (left) and a full body 3D reconstruction (right).

Clinical Applications

The main applications of the imaging system EOS are associated with bone and joint structures of the trunk and lower limbs. Indeed, taking radiographs in the standing position provides new information, mainly for the structures of the spine and legs.

The joints most commonly studied today are hip and knee, but in the near future the reconstruction will be possible for the entire skeleton and new applications will then see the day. For now, the major advances over conventional radiography were the reduction of radiation dose, which is of interest in pediatric orthopedics, the possibility of obtaining images of bone structures in 3D and the possibility of obtain an overall analysis of patient position and relationship between the joints.

The pediatric orthopedics

Reducing the radiation dose is particularly useful for young patients who are more sensitive and affected by repeated irradiation. Indeed, certain organs, such as the genitals, are very sensitive and the risk of infertility exists. In addition, these patients are object of regular monitoring through their growth to control the disease progression, and this often requires repeated imaging tests. This is particularly true for scoliotic patients whose spinal deformity worsens throughout growth and more strongly in puberty. Therapeutic monitoring during this period is on average every six months and may become trimestral if the pathology changes quickly.

Three-dimensional vision

Three-dimensional reconstruction provides a new perspective on the treatment of diseases because it provides new and measurable information.

With conventional radiography, the clinician has, in the best scenario, two radiographs (anteroposterior and lateral) to make a diagnosis and choose the appropriate therapeutic treatment. For some anatomical regions, the lateral view is not functional, as in the case where the pelvis bone contours overlay makes difficult the readability and interpretation of such radiographs. But even two radiographs in two different projections do not allow a complete and accurate vision of deformations; to understand an entire three-dimensional problem, at least three views are necessary.

The contribution of 3D vision of the skeleton is particularly relevant in orthopedics for each one of the anatomical areas studied: the spine, pelvis and lower limbs.

In the case of the spine, the interest of EOS for the treatment of idiopathic scoliosis (with no clear causal agent) by reducing the radiation dose was mentioned earlier, but the reconstruction is also a substantial improvement. Indeed, in the case of scoliotic patients, the spinal deformity is not two-dimensional, as is has often been considered, but three-dimensional, and associates the rotation of vertebrae from each other in all three spatial directions.

In figurative ways, a scoliotic spine can be represented as a non-stretched twisted rope. The 3D image of the spine allows to know the plan of the space in which the deformation is most important, to quantify this deformation and to know the axial rotation of vertebrae involved.

Hip diseases are diverse but we can distinguish two particularly relevant: in children, congenital malformation of the bones that generally require heavy correction operations such as osteotomies (the bone is cut, reshaped or partially removed to realign the load-bearing surfaces of the joint) of the pelvis or proximal femur; in adults, it is usually osteoarthritis that would dominate and lead to total hip arthroplasty (replacing the entire hip joint with an artificial hip).

In each case, the imaging requested examination is generally limited to a frontal radiograph of the pelvis, where the key element is to assess the coverage of the femoral head by the acetabulum. This poses several problems: first, a single view leaves many uncertainties to the interpretation of radiography, and secondly the image obtained is highly dependent on patient position, as in the case where the pelvis is not parallel to the radiography’s plane.

The geometry of lower limbs also involves three-dimensional phenomena, which are generally distortions or imbalances leading to premature wear of the knee joint. Knowledge of bone deformities angles or angles between the femur and tibia is essential to assess the correct angle to be provided on pre-operative planning, in order to restore the mechanical equilibrium of the leg during a femoral or tibial osteotomy or during a total knee arthroplasty.

The overall assessment of the patient's condition

The third innovation introduced by EOS in diagnosis is the possibility of obtaining an overall assessment of the patient, which means to understand, just in two radiographs, the patient's balance and relationship between joints. Indeed, the overall scanning becomes particularly useful because it is performed in standing position, in contrast to the scanner that is done in supine position (and remember that it requires about 1000 times more radiation) (Figure 6). In effect, the key is to observe the patient in weight-bearing position and the changes that may occur in joints' relationship, in order to compensate any pain or stiffness. An abnormality of a joint will affect the nearest joints.

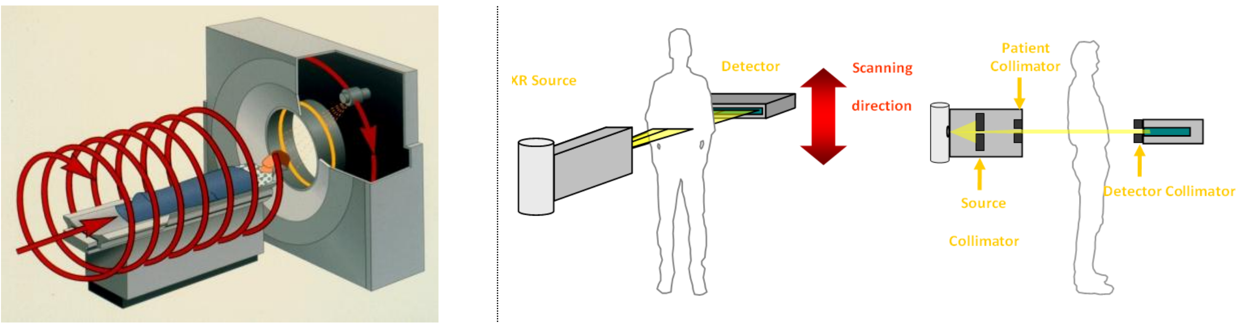


Figure 6 : CT scan (patient in supine position) / EOS scan (patient in standing position).

In the case of the spine, the study in weight-bearing position allows to evaluate the severity of a vertebral collapse that is therefore intensified in standing position.

Spinal deformities have important consequences on the hip because a change on spinal curvature results in a change of pelvis position (which is welded to the last lumbar vertebra). This has consequences on the orientation of the acetabulum, and thus on the orientation of the femoral neck when standing.

Hip pathologies may be a consequence of spinal deformities but also the cause of knee pathologies that will be neglected if the performed radiograph focuses on the hip, as it is usually the case. The origin of the pathologies is rarely unique and joints are often closely related. Thus, the patient adapts to a position of minimum effort and pain, and the mechanic balance of the skeleton and joints adapts itself to allow the patient to preserve maximum mobility.

3.3. SterEOS: 3D reconstruction software

SterEOS is a workstation of medical diagnosis created for analysis, manipulation, communication and storage of images acquired with different imaging devices (except for mammography), such as computed radiography (CR), computed tomography (CT), direct radiography (DR) and magnetic resonance imaging (MRI).

SterEOS comes with a software that supports the evaluation of skeletal morphology for creating 3D images from two planar radiographic images obtained with the EOS system. The software allows the calculation of several clinical parameters of the spine, pelvis and lower limb from the reconstructed 3D image. This software is intended to perform an analysis after the acquisition. It is designed to be used by clinicians, technicians and research staff.

The purpose of EOS 3D reconstruction was described above. It allows a semi-automatic reconstruction of the structures (spine, pelvis and lower limbs), with a comprehensive and specific 3D model of each structure. This semi-automation is based on an initial solution that the operator must manually edit to get an accurate reconstruction in association with 2D radiographs. However, to obtain a precise diagnosis, the 3D models delivered by the software SterEOS should always be used in combination with the corresponding 2D images.

In conclusion, the radiography device EOS, combined with 3D reconstruction software SterEOS, ensures several technological innovations and offers many opportunities in terms of treatment of orthopedic problems by providing new, reliable and accurate information.

CHAPTER 4 CLINICAL STUDIES

4.1. Pelvic parameters

Pelvic parameters are often associated with alignment problems of the spine and complications at the hip [36]. That is why the correct measurement of parameters such as the sacral slope, pelvic tilt and pelvic incidence, becomes increasingly important.

When looking at some images obtained by conventional radiography, doctors found that pelvic parameters are overestimated or underestimated by a wrong positioning of the patients. According to the literature [37], those must be obtained when the patient is viewed by side. More precisely, the acetabulae must appear overlapped in the lateral view radiography, which is not always the case.

The sacral slope can be defined as the angle between the sacral plate (S1) and a horizontal line (Figure 7).

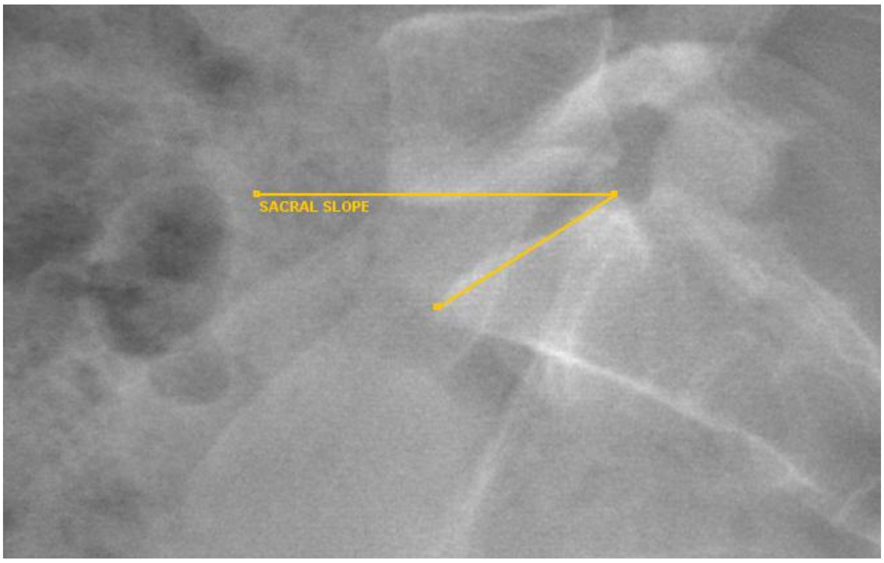


Figure 7 : 2D representation of sacral slope.

Pelvic tilt is the angle that the line joining the midpoint of the sacral plate and the middle axis of the acetabulae makes with a vertical line. To measure it, we start by drawing a line across the sacral plate. Then, the middle axis of the acetabulae is noted (2) and another line connects it to midpoint of sacral plate (3). Finally, the angle between (3) and a vertical line (4) gives us the value of pelvic tilt (Figure 8).

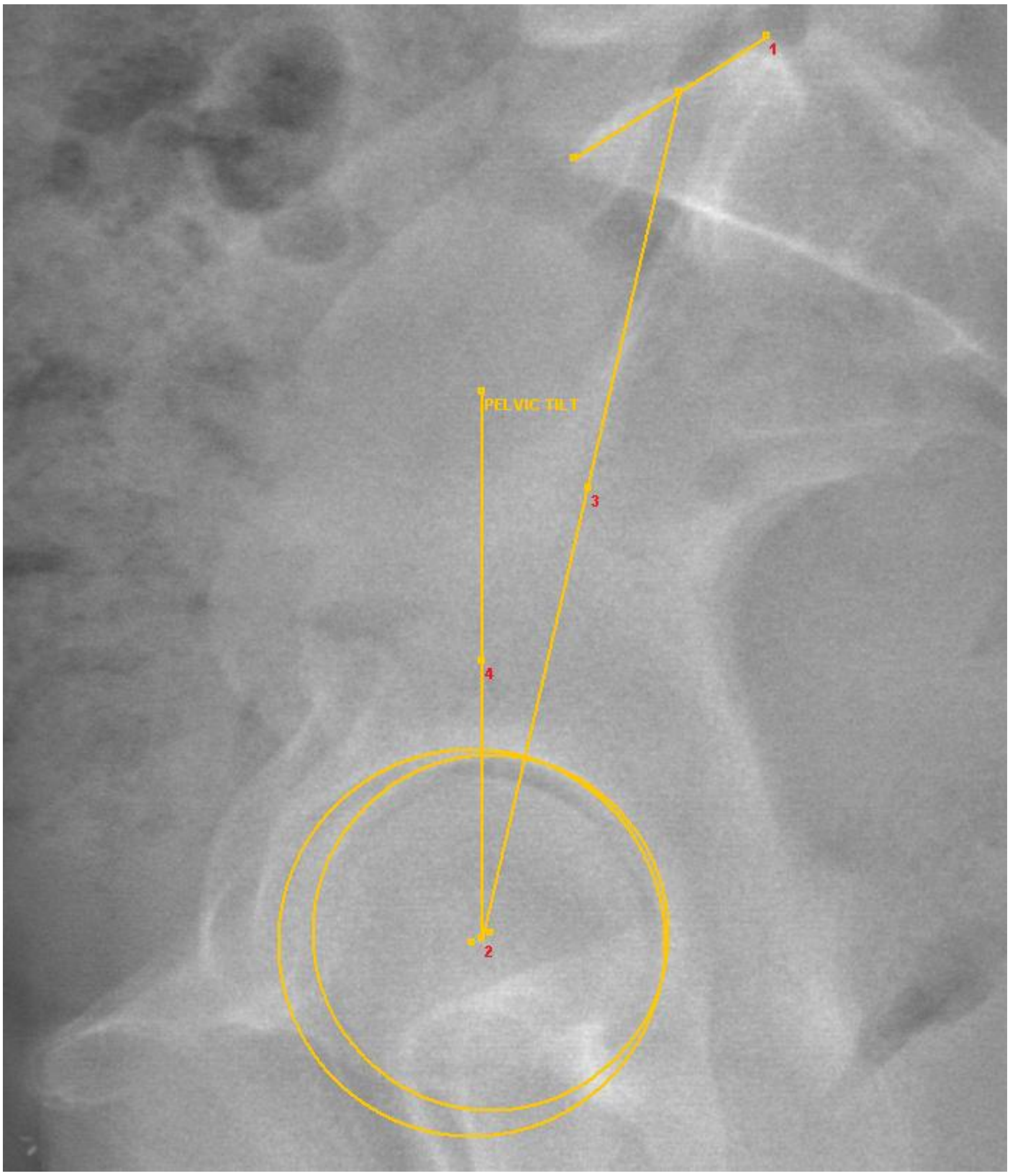


Figure 8 : 2D representation of pelvic tilt.

Pelvic incidence is defined as the angle between the perpendicular line to the midpoint of the sacral plate and the line joining the middle axis of the acetabulae. Then, the pelvic incidence is the sum of sacral slope and pelvic tilt. To measure it, we start by drawing a line across the sacral plate (1) and a second line is drawn perpendicular to this one at its midpoint (2). Afterwards, the middle axis of the acetabulae is noted (3) and another line connects it to midpoint of sacral plate (4). Finally, the angle between (2) and (4) gives the value of pelvic incidence (Figure 9).

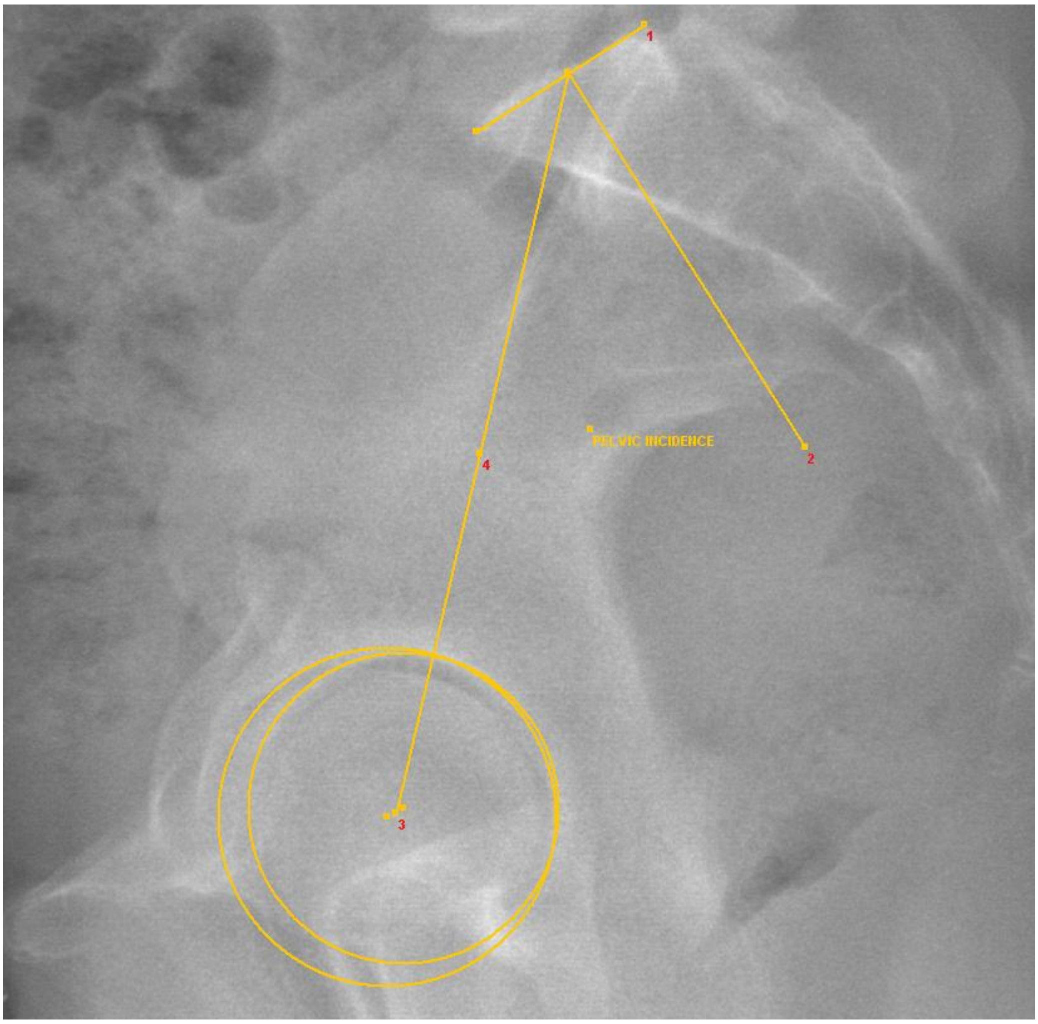


Figure 9 : 2D representation of pelvic incidence.

The goal of the study was to evaluate the interest of making three-dimensional measurements of pelvic parameters using EOS acquisition system. In this context, the following questions have emerged: are 3D measurements of pelvic parameters similar to those obtained in 2D? Is conventional radiography accurate to measure pelvic parameters? Is there a relationship between the measure of these parameters and pelvis rotation?

2D vs. 3D measures

For the first part of this work, 80 patients were randomly selected from the radiographic database of a public hospital (retrospective study), among patients with an EOS acquisition of the full spine.

The pelvic parameters (pelvic incidence, sacral slope and pelvic tilt) were measured by two observers as follows: 2D measure on the side view radiography (manual measurement) and then, after 3D reconstruction with SterEOS, on patient's plane projection (semi-automated measurement).

The intraclass correlation coefficient (ICC) was calculated to evaluate the inter-observer reproducibility. Later, 2D and 3D measures were compared using the t-student test for paired samples.

Pelvis rotation of each patient was also measured using 3D software (Figure 10).

Figure 10 : Overview of parameters on an image of a patient.

Influence of rotation on the phantom

The second part of the study was lead on a synthetic radiopaque pelvis (Creaplast, Verton, France). This one was imaged with the biplane EOS system in different axial rotation positions, ranging from 30° of right rotation to 30°of left rotation, at each 3°, relative to the ideal position (orthogonal to the beams) (Figure 11).

For each of 21 acquisitions, the pelvic parameters were measured on one hand by 2D conventional method on the lateral view, and also in 3D using the dedicated software. 2D and 3D measurements were compared.

We wanted to analyze the influence of the rotation applied to the phantom on its pelvic parameters in 2D and 3D (Spearman's rank correlation coefficient was calculated).

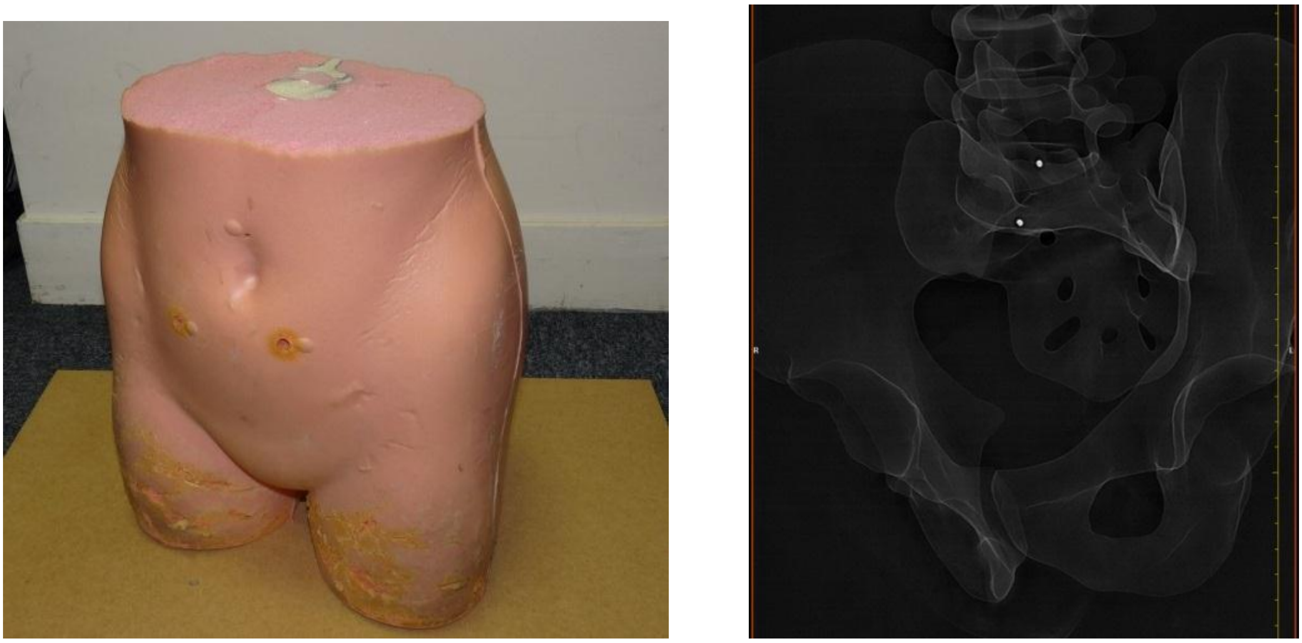


Figure 11 : Pelvic phantom (left) and its radiography obtained by EOS (right).

4.2. Femoral mechanical-anatomical angle

The standard way to evaluate lower limb alignment is to obtain a full length anteroposterior (AP) radiography of the lower limbs. This method is often used in the planning of correction osteotomy or knee arthroplasty. The degree of operative correction is based on the angles measured on the radiography, and this is probably the most critical and difficult part of a correction.

Previous biomechanical and clinical studies have demonstrated that optimal operative correction is essential for clinical success of distal femur osteotomy, and mechanical loosening of knee arthroplasty is related to postoperative alignment [38].

However, limb rotation during the radiographic acquisition will affect the apparent alignment that is seen [39, 40]. It is unknown how large the effect of rotation and flexion is on alignment of the leg. In this study, we suspected the role of the sagittal bowing of the femur on provoking this measurement error.

When a patient is diagnosed with an advanced degree of arthritis in the knee, a total knee arthroplasty is often required to restore the natural alignment of lower limb.

In the case of the femur, surgeons use a rod that they introduce at the trochlea and move through up the femur diaphysis. This rod will serve as a reference to the anatomical axis. After that, a section cut at the distal femur is made [41]

The femoral mechanical-anatomical (FMA) angle, also known as hip-knee-shaft (HKS) angle, is defined as the angle between the anatomical and mechanical axis of the femur (Figure 12). Surgeons adopt by default a cut angle from 5º to 6º, without measuring it or, when they do it, they use a frontal radiography [42]. However, some authors affirm that this procedure is not accurate; the angle must then be measured in 3D [43].

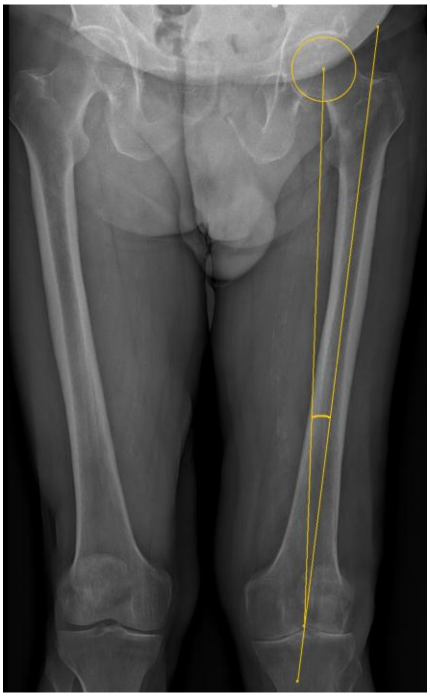


Figure 12 : Femoral mechanical-anatomical angle.

The purpose of this study was to measure the angle between the mechanical and anatomical axes of the femur. Then, it should be possible to verify whether there is such dependence between the measurement of the FMA angle and rotation applied to the femurs.

Osteoarthritic patients

In the first part, 127 lower limbs of 103 osteoarthritic knees from patients, who had undergone a frontal/lateral EOS examination for occasion of a preoperative evaluation of total knee arthroplasty, were retrospectively included in the study. For patients fitted with a hip or knee implant at the time of examination, only the contralateral non-implanted side was used.

FMA angles of each patient were measured in 2D and 3D as follows: 2D measure on frontal view radiography (manual measurement) and then, after 3D reconstruction of the femur, on its 3D projection (semi-automated measurement).

2D measurement was made between the femoral mechanical axis (joining the center of the femoral head to the center of the femoral notch) and the femoral anatomical axis (joining the center of the femoral notch to the center of the diaphysis at his distal third) (Figure 12).

3D measurement was made using dedicated software to perform a "fast 3D reconstruction" of the femur as described by *Chaibi et al.* [44]. This consisted in identifying on both radiographies some anatomical landmarks: the femoral head, the center of the femoral notch, the center of the diaphysis at his distal third, medial and lateral condyles.

2D and 3D measurements were compared and the existence of a bias between 2D and 3D FMA was checked with the t-student test for paired samples, as well as with the Fisher's exact test for paired samples (in order to compare variances).

Physical models

Subsequently, the left femurs of 2 patients, who undergone a biplane EOS examination and 3D reconstruction, have been rebuilt in form of a physical model by stereolithography (Creaplast, Verton, France) (Figure 13).

These femurs were distinguished mainly by their bowing in the sagittal plane. The flat femur had a low curvature (radius of curvature of about 158 cm) while the bowed femur presented a significant curvature (radius of curvature of about 72 cm). The sagittal bowing was measured on the lateral radiographies following the method described by *Harma et al.*[45].

Figure 13 : A – biplane acquisition, virtual 3D model and physical model of flat femur; B - acquisition, virtual 3D model and physical model of bowed femur.

Each physical femur model was then imaged in the EOS system in different positions of axial ranging from 20° of external rotation to 20° of internal rotation, with increments of 5º. Thus, 9 biplane acquisitions of the flat femur and 9 biplane acquisitions of the bowed femur were obtained.

On each acquisition, FMA angle was measured between the femoral mechanical axis and femoral anatomical axis, first in 2D on the anteroposterior view, and also in 3D using dedicated software.

2D and 3D measurements were compared, including checking whether there was an influence of the FMA angle on rotation applied to femurs, using the Spearman's rank correlation coefficient. SPSS 15.0 (SPSS, Chicago, IL) software package was used to perform the statistical analysis.

4.3. Femoral torsion

Often idiopathic disorders associated with femoral torsion may be post-traumatic or due to certain pathological conditions, such as cerebral palsy. Whatever their cause, many studies have shown that deformations in the axial plane may have an influence on the development of various knee pathologies, such as femoro-patellar instability, gonarthrosis, or even coxarthrosis. To deal with these rotational disorders of the lower limb, an accurate and reproducible way of measuring femoral torsion is essential.

Femoral torsion measurement is subject to greater debate. The main difficulty with this measurement lies in determining the axis of the femoral neck. Several described methods rely on axial slices in order to determine the orientation of the femoral neck. However, the choice of slices strongly influences the value being measured.

The femoral torsion, also known as femoral anteversion, is described in the literature as the angle defined by the plane tangent to the posterior condyles and the axis that passes through the centers of the femoral head and femoral neck (Figure 14) [46].

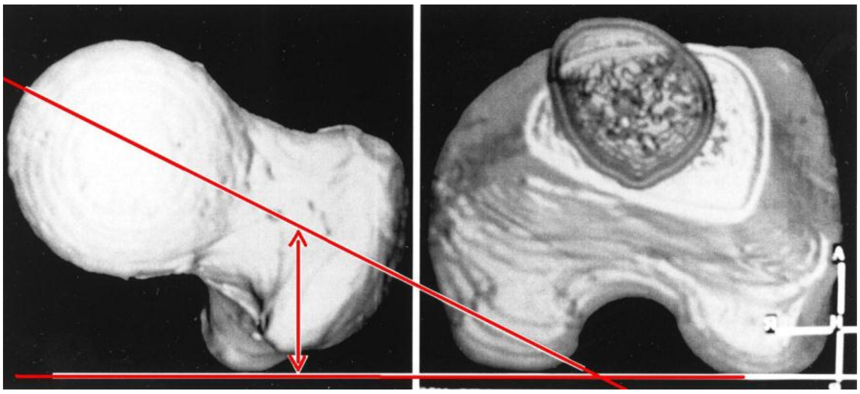


Figure 14: Femoral torsion (double-headed arrow) in a 3D proximal and distal femur.

Although various techniques such as ultrasound, fluoroscopy and MRI have been described, computed tomography (CT) remains the "gold standard" for measuring femoral torsion [47]. However, this method has been questioned in several articles, since the measurement is distorted by femur positioning [48, 49].

The purpose of this study was to evaluate the correlation between CT and EOS measurements of femoral torsion. We hypothesized that CT measurements of torsion would be related to rotational range of motion. In this context, some questions have arisen: is the CT measure of femoral torsion reliable? Does position of the femur have an influence on the measure of its torsion?

For this work, 20 femurs of dry cadaver specimens were selected and imaged both with a private clinic's scanner and with EOS. Each femur was imaged in the 6 following positions: neutral (by aligning the mechanical axis of the femur with the axis of movement of x-ray source), 10° of abduction, 10° of adduction, 5° of flexion, 10° of flexion and 5º of extension.

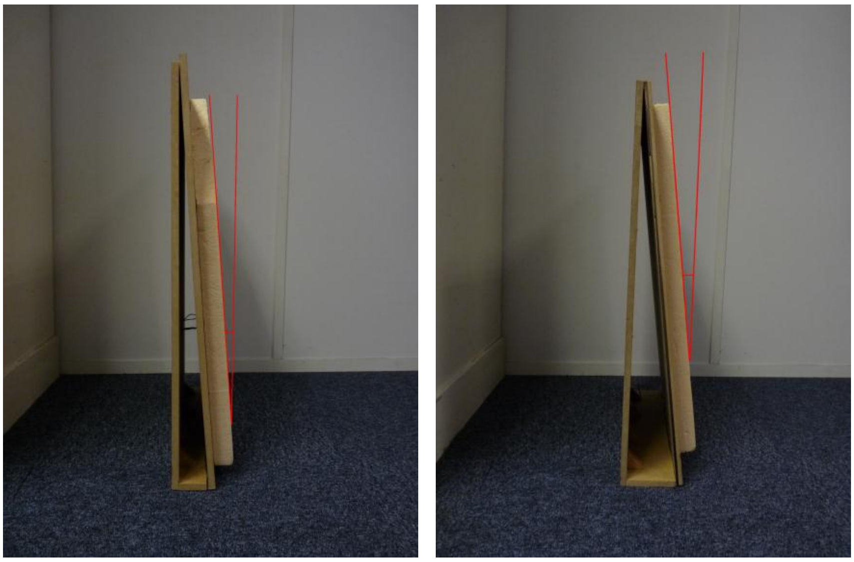


Figure 15 : Wooden wedges and their inclination to produce 5º of flexion (left) and 10º of flexion (right).

These positions have been suggested by a clinician, who supervised me in this study, as they truthfully represent the positioning of patients upon scanner examinations. In order to produce these different inclinations, three wooden wedges were built (Figure 15), with a radiolucent foam between the femurs and the wooden wedges (Figure 16).

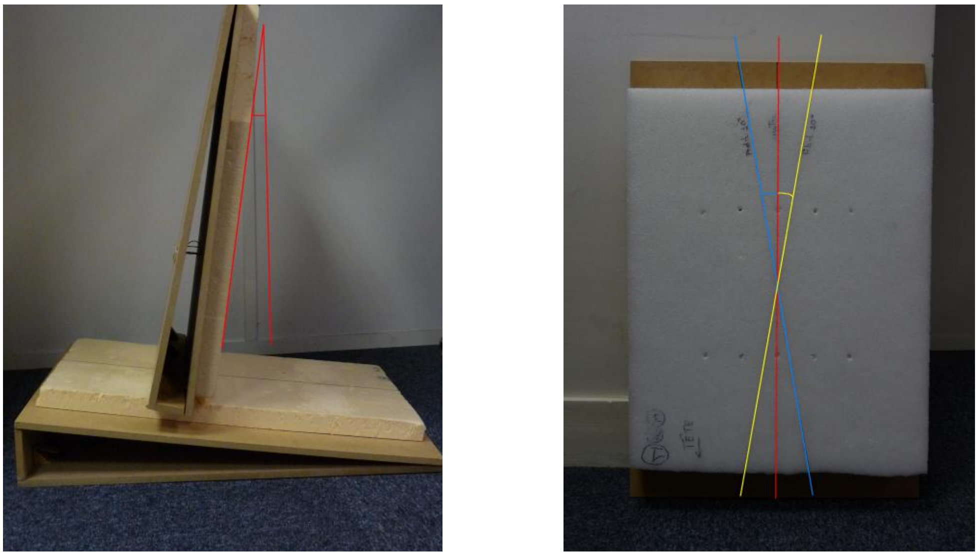


Figure 16 : Wooden wedges and their inclination to produce 5º of extension (left), neutral position (right – red line), 10º of abduction and 10º of adduction.

CT measurement

Femoral torsion was measured using a CT scanner (Somaton, Siemens, AS 40 slice definition, Erlangen, Germany). Working from a frontal topogram, two acquisition zones (hip and knee) were defined. For each zone, 1.25 mm thick slices were acquired in compliance with the manufacturer's protocol. The femurs were fixed in the several positions, attached to the wedges in order to avoid any mobilization during image acquisition.

The femoral torsion measurement was carried out in accordance with the method described by *Reikeras et al.* [46] (Figure 17). Two slices were first superimposed in order to determine the femoral neck axis: one in the center of the femoral head and another going through the middle part of the femoral neck (where anterior and posterior cortices are parallel). The neck axis was defined on the superimposition of both slices as the line passing through the center of the femoral head and the midpoint of the diameter of the neck. The femoral bicondylar axis was determined as the dorsal line tangent to the femoral condyles, on a slice acquired at the most convex point of the femoral condyles, often marked by the fabella when it is present or by the "roman arch" shape of the notch. The angle of femoral torsion was measured between the neck axis and the bicondylar axis. It was considered positive for anteversion and negative for retroversion.

The measurements were made using ORS Visual (Object Research Systems, Montreal, Canada) (Figure 19).

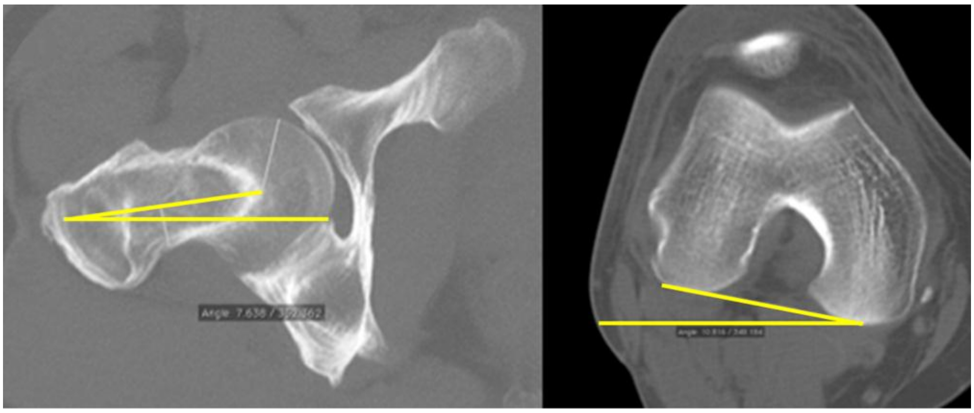


Figure 17 : Method described by *Reikeras et al*. to determine femoral torsion.

EOS measurement

On the basis of a biplanar acquisition, an operator can visualize the femur's bony envelope in 3D using specially-designed software (SterEOS, EOS imaging, Paris, France). Working from 3D models, the software automatically calculates a set of clinical parameters for the lower limb, including femoral torsion [50]. On the femur model, the axis of the femoral neck (joining the center of the femoral head to the base of the femoral neck) and the dorsal tangent line to the femoral condyles are semi-automatically determined. The femoral torsion is calculated between the projections of these two lines on the transversal plane of the femur (defined as orthogonal to the femoral mechanical axis) (Figure18).

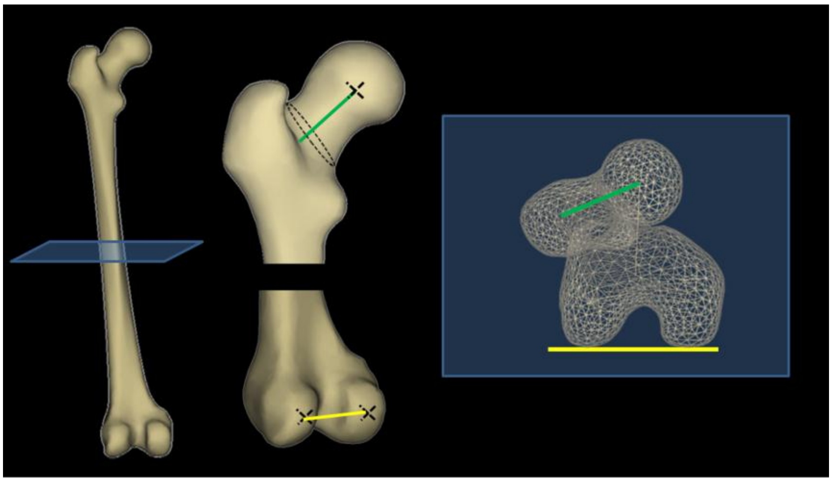


Figure 18 : Femoral torsion calculated in SterEOS.

CT and EOS are thus superimposable in terms of anatomical landmarks used for the measurements (femoral neck axis and dorsal lines tangent to the femoral condyles).

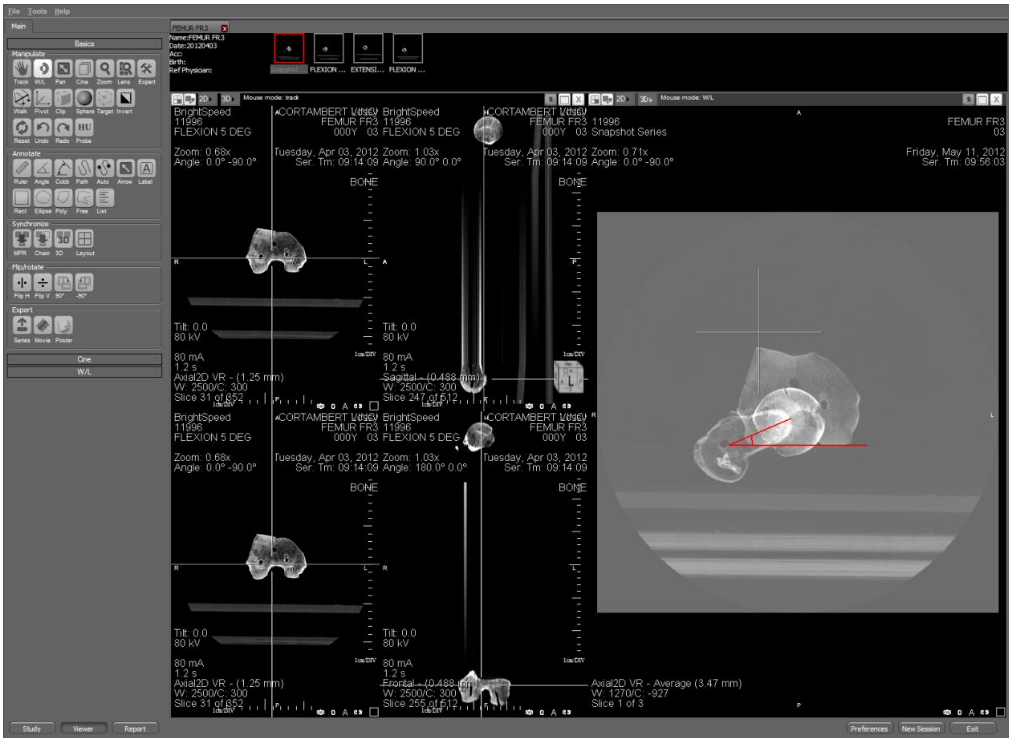


Figure 19 : ORS software and femoral torsion.

CHAPTER 5 RESULTS

4.1. Pelvic parameters

2D vs 3D measures

The average age of patients was 46 ± 22 years. The inter-observer reproducibility was excellent and equivalent to the three parameters in both 2D and 3D, with all coefficients between 0.95 and 0.99 (Table 1).

Table 1 : Intraclass correlation coefficient (ICC) of 2D and 3D measurements.

Parameters	2D	3D
Pelvic incidence	0,97	0,97
Sacral slope	0,96	0,95
Pelvic tilt	0,99	0,99

Table 2 : 2D and 3D measurements of pelvic parameters made in the radiographies of patients.

Parameters	2D	3D	P (t-test)
Pelvic incidence (°)	52,9 (±15,4)	52,1 (±15,5)	p ≤ 0,01
Sacral slope (°)	38,0 (±12,0)	37,2 (±11,9)	p ≤ 0,01
Pelvic tilt (°)	14,9 (±10,6)	14,8 (±10,6)	0,5

All patients had a pelvic rotation below 10° and 78% had pelvic rotation less than 5°.

Influence of rotation on the phantom

By default, when the pelvis rotates towards the right side, the rotation becomes negative; when pelvis is rotated towards the left side, the rotation is positive (Figures 20, 21, 22).

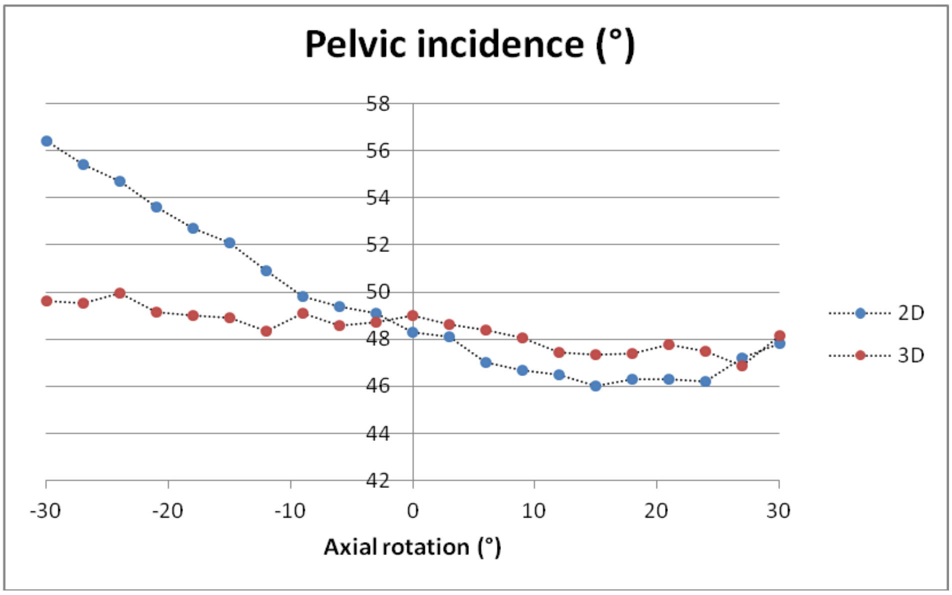


Figure 20 : 2D and 3D measures of phantom's pelvic incidence according to the rotation applied.

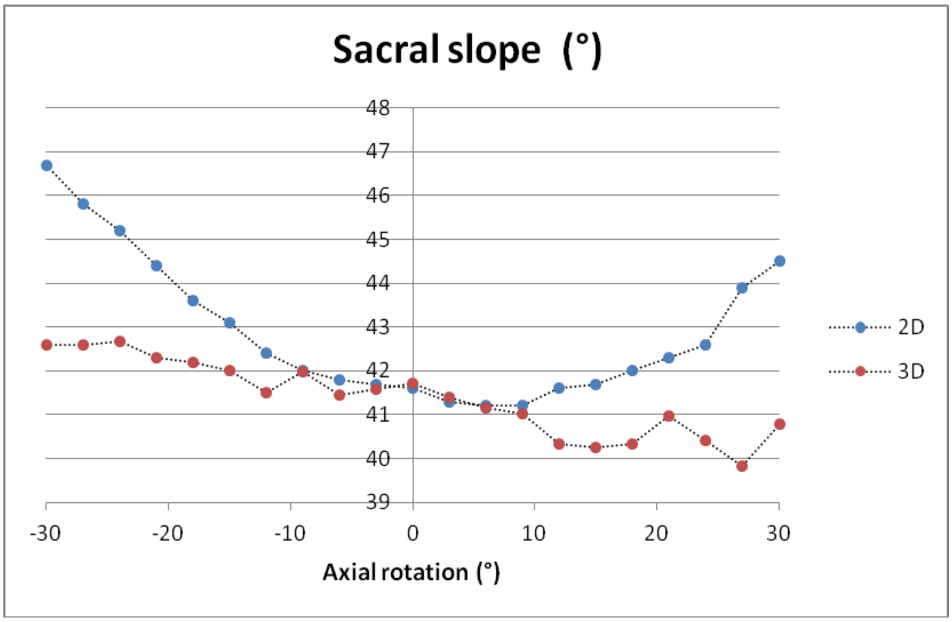


Figure 21 : 2D and 3D measures of phantom's sacral slope according to the rotation applied.

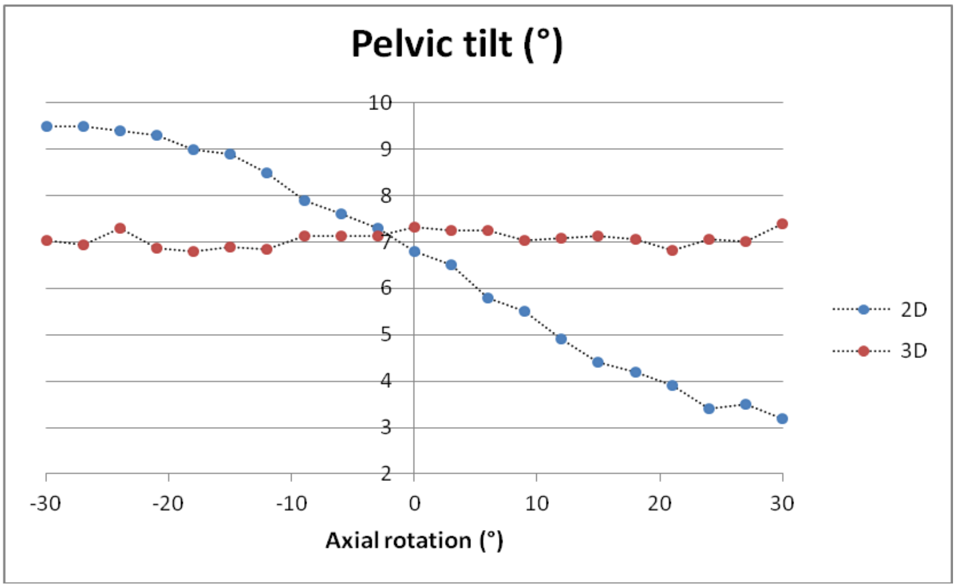


Figure 22: 2D and 3D measures of phantom's pelvic tilt according to the rotation applied.

There was a correlation between 2D measures and rotation applied to the phantom (ρ = 0.63 for the pelvic incidence, ρ = 0.77 for the sacral slope, ρ = 0.63 for pelvic tilt). In 3D measures, only the pelvic tilt showed a dependence towards the rotation applied (ρ = 0.08 for the pelvic incidence, ρ = -0.21 for the sacral slope, ρ = 0.72 for the pelvic tilt) (Figure 23).

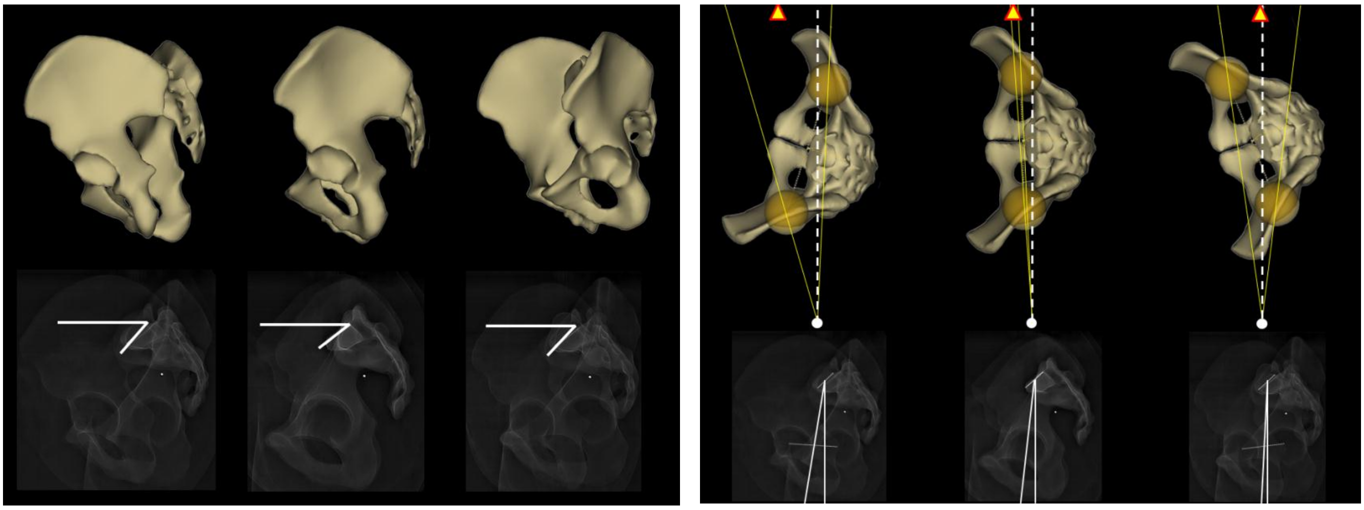


Figure 23: Influence of rotation on 2D measurement of the sacral slope (left) and pelvic tilt (right).

Conclusions

In a cohort of 80 EOS acquisitions, measuring pelvic parameters in 2D and 3D had an excellent inter-observer reproducibility.

2D measures of pelvic incidence and sacral slope were significantly different from those obtained in 3D (Tab. 2). 22% of patients have the pelvis radiographed of more than 5° with respect to the ideal position.

Moreover, the pelvic rotation significantly influences the measures of pelvic parameters in 2D. 3D measurement of pelvic incidence and sacral slope is not affected by the rotation of the pelvis. Only the pelvic tilt does not vary significantly between 2D and 3D as it is influenced by the rotation in both 2D and 3D.

4.2. Femoral mechanical-anatomical angle

In this study, 2D and 3D measurement of FMA on an osteoarthritic population were compared, in order to evaluate the interest of this new 3D method in clinical routine. Then, it was aim to confirm that 3D FMA measurement is not affected by a potential limb rotation during acquisitions (Figure 4). This was done using 2 physical models of femurs of 2 patients obtained with a 3D printer.

Osteoarthritic patients

The average age of patients was 69 ± 12 years.

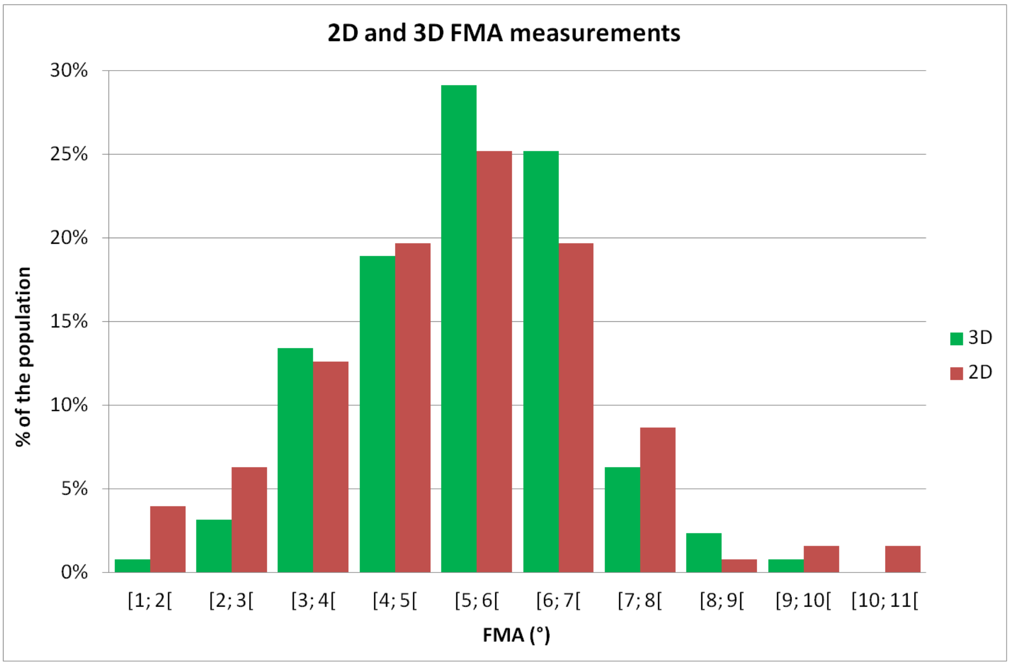


Figure 24 : Distribution of the FMA angle in the studied sample.

The absolute difference between 2D and 3D measurements was 0.6° ± 0.5° ($\rho = 0.07$) with a maximum difference observed at 2.8°. In 5.7% of cases, the difference between FMA 2D and FMA 3D exceed 1.5° (Table 3).

Table 3 : Repartition of the differences between 2D and 3D measurements.

Difference between 2D FMA and 3D FMA	Occurrence frequency in the population
[0° ; 0,5°]	48,6 %
[0,5° ; 1°]	34,3 %
[1° ; 1,5°]	11,4 %
› 1,5°	5,7 %

Table 4 : 2D and 3D measurements of FMA angle obtained by EOS compared with similar studies.

FMA (°)	Studies					
	EOS 2D	EOS 3D	a)	b)		c)
Mean	5,2 ± 1,7	5,4 ± 1,3	5,7 ± 1,2	6,3 (varus)	4,7 (valgus)	5,4 ± 0,9
Min	1,7	2,4	2			3,3
Max	10	8,9	9			7,6

Table 5 : Published data of similar studies.

a) *Deakin; Knee. 2012 Mar; vol. 19(2) pp. 120-3*

174 radiographies arthritic knees (157 patients, 87 women and 70 men, mean IMC of 31.8)

b) *Desmé; Rev Chir Orthop Reparatrice Appar Mot. 2006 Nov; vol. 92(7) pp. 673-9*

136 *genu varum* and 28 *genu valgum* among candidates for total knee arthroplasty, by using digital radiographies

c) *Kharwadkar; Knee. 2006 Jan; vol. 13(1) pp. 57-60*

CT films of 83 patients with arthritic knees (44 men and 39 women), among candidates for total knee arthroplasty

Physical models

By default, external rotation becomes positive while internal rotation is negative (Figures 25, 26).

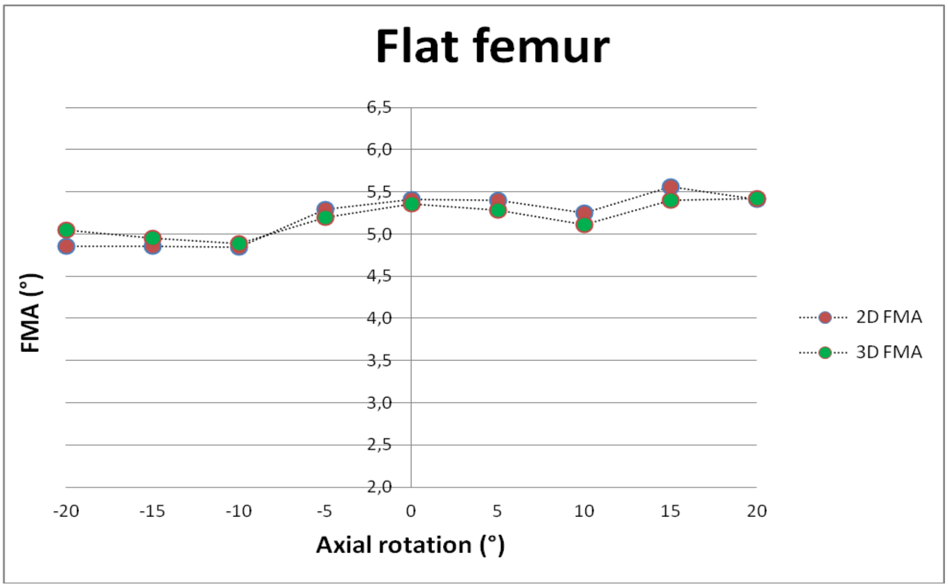


Figure 25 : 2D and 3D measurements of the FMA angle in flat femur varying the rotation.

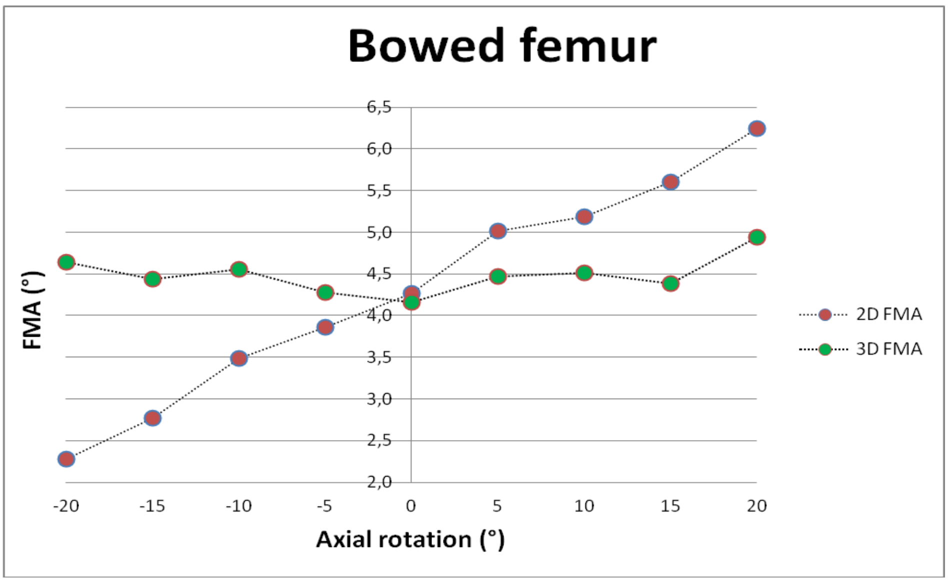


Figure 26: 2D and 3D measurements of the FMA angle in bowed femur varying the rotation.

The 2D measure was strongly correlated with rotation ($\rho = 0.66$ for the flat femur and $\rho = 1$ for the bowed femur), unlike 3D measurement ($\rho = 0.55$ for the flat femur and $\rho = 0, 02$ for the bowed femur).

Conclusions

We found in our population of arthritic knees a mean 3D FMA of 5.4, in accordance with other published data (Table 5).

There was no statistically significant difference between the mean of 2D measurement and the mean of 3D measurements. However, the variance of 2D measurements was higher than the variance of 3D measurements ($p < 0.01$).

2D measurement found 17 lower limbs outside the [3º - 9º] range of FMA. According to the 3D measurement, only 6 were outside this range.

We conclude that axial rotation has an impact in the measurement of FMA 2D, particularly if the sagittal bowing of the femur is important (Figure 26).

4.3. Femoral torsion

SPSS 15.0 software package was used for the statistical analysis. A descriptive statistical analysis was first carried out for the complete set of data. The t-student test for paired samples was used to determine whether there was a significant bias between the two methods.

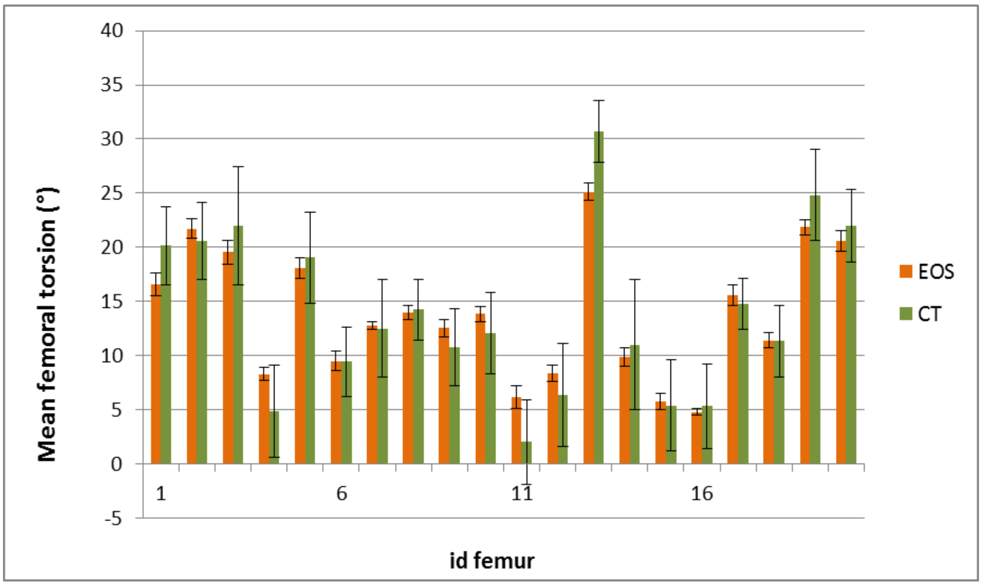


Figure 27 : Mean and error bars of femoral torsion from each imaged femur.

The t-student test found some significant differences between the two measuring techniques, particularly in flexion, extension and adduction positions (Table 6).

Table 6 : Mean EOS and CT measurements of femoral torsion for each position.

Position	*neutral*	*flexion*		*extension*	*abduction*	*adduction*
	0°	5°	10°	5°	10°	10°
EOS	13,8°	13,8°	13,7°	13,7°	13,9°	14,0°
CT	14,9°	11,2°	8,4°	18,7°	14,0°	16,6°
P (t-test)	0,1	p ≤ 0,01	p ≤ 0,01	p ≤ 0,01	0,9	p ≤ 0,01

Conclusions

CT is considered the method of choice to determine torsion or rotational malalignment of the femur. Although some authors have questioned it, in the literature and daily practice CT measurements are always considered highly accurate. This high accuracy of measurements is necessary in order to perform treatments such as osteotomies to correct post-traumatic rotational deformities.

This study revealed that the accuracy of CT-determined femoral torsion is questionable. Between two measurements in different positions there was a mean difference of 10.3°. The inaccuracy in measuring the CT image is due mainly to the inaccuracy in drawing the line through the femoral neck. In my opinion, CT slices not imaging the femoral head, femoral neck, and greater trochanter in one image caused the problem. Since the regular CT slices are perpendicular to the femoral shaft, there was often not one particular slice exactly crossing all three anatomical structures; this occurs only in the abduction. It then proves to be difficult to define a line representing the femoral neck axis.

CT accuracy is not improved by taking the average of more measurements and a more accurate measuring method like EOS is warranted to accurately assess femoral torsion in patients.

CHAPTER 6 ARTHROPLASTY'S SOFTWARE PLANNING

This work arises mainly due to a surgical need. During a total knee arthoplasty (TKA), some surgeons reveal the will of having an additional support, beyond the simple use of the rods. Moreover, the use of rods should be avoided because it may represent a source of error [51, 52].

Clinical aspects

The challenge was to develop a prototype software of knee's slicing that allows to know the distance of the cutting plane to both condyles, as well as to do a pre-operative simulation.

This prototype has the distinction of always doing the "cut" orthogonal to the femur and tibia mechanical axes. In the case of the femur, this may be an advantage because there is no need to measure the FMA angle prior to surgery. Thus, the use of rods can be avoided.

Technical aspects

In this work, Matlab 7.5 was used as the main tool (Figure 29). A menu was built with the graphical interface and some functions were automatically generated. As input data, 3D reconstruction of the lower limbs and anatomical landmarks obtained by SterEOS were used (Figure 28).

Per patient:

- 4 *DICOM* files and subsequent *.wrl* files containing bone models,
- 1 text file containing the coordinates of points on which the calculation is based, including:
    - mechanical axis
    - center of the femoral head
    - center of the trochlea
    - posterior medial/lateral condyles
    - tangential axis of the distal condyles
    - axis connecting the centers of the tibial plateau
    - tangential axis of the tibial plateau
    - bimalleolar axis.

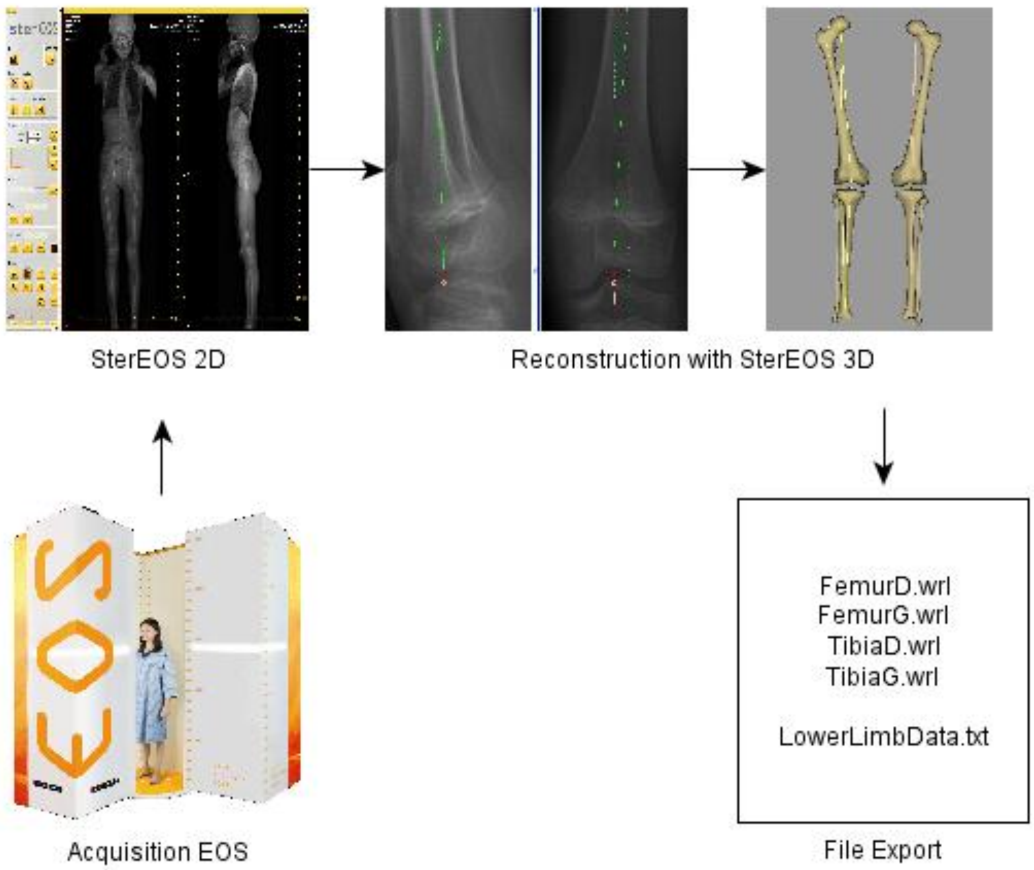
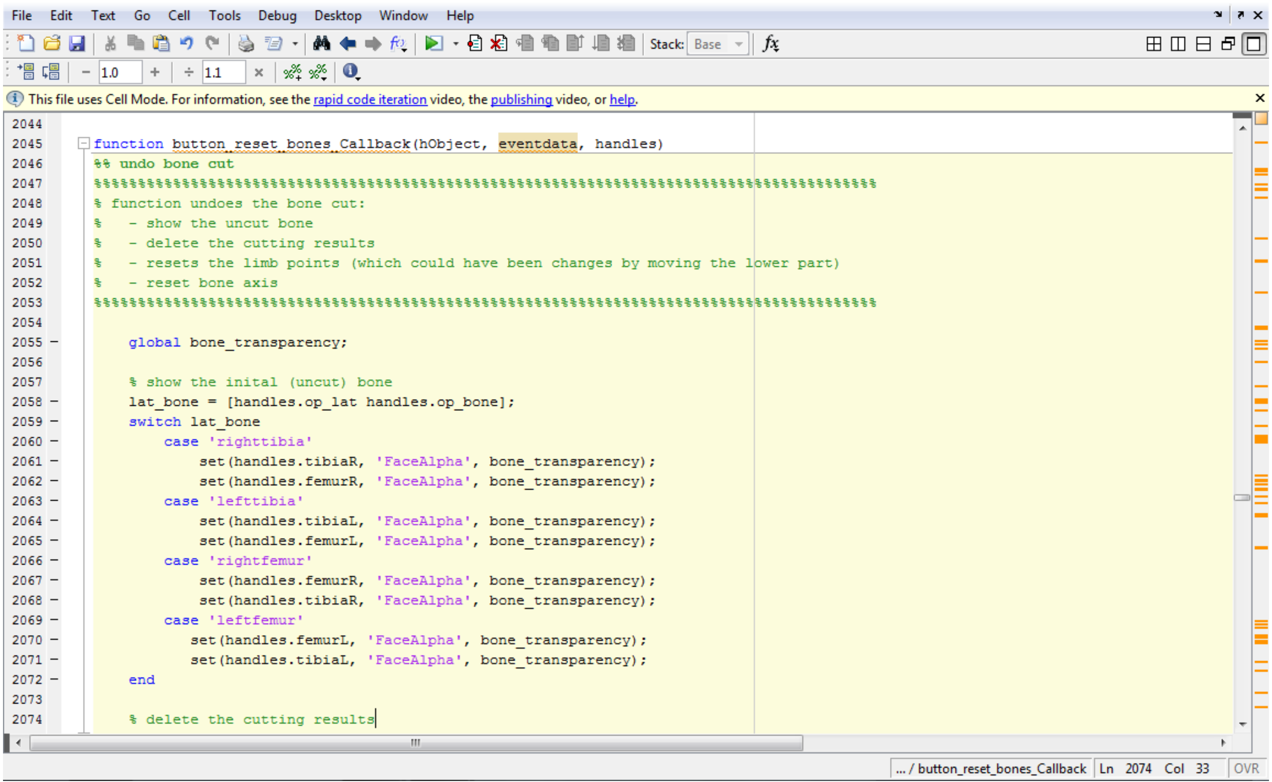


Figure 28 : Followed workflow to obtain input data.

Programming stages

1. Read of DICOM files, femur coordinates and display of wrl files.
2. Change of reference using a transfer matrix:
   - EOS reference ⟶ local reference of the bone
   - Local reference of the bone (origin = center of the trochlea)
     - Z-axis through the center of the femoral head and the origin
     - X-axis through the origin and orthogonal to the Z-axis (anteroposterior)
     - Y-axis through the origin and orthogonal to the X and Z-axis (right to left)
3. Positioning and movement of cutting plan in 3D space (initial cutting plan in frontal view).
4. Calculation of distance to both condyles.


```
function button_reset_bones_Callback(hObject, eventdata, handles)
%% undo bone cut
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% function undoes the bone cut:
%   - show the uncut bone
%   - delete the cutting results
%   - resets the limb points (which could have been changes by moving the lower part)
%   - reset bone axis
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

    global bone_transparency;

    % show the inital (uncut) bone
    lat_bone = [handles.op_lat handles.op_bone];
    switch lat_bone
        case 'righttibia'
            set(handles.tibiaR, 'FaceAlpha', bone_transparency);
            set(handles.femurR, 'FaceAlpha', bone_transparency);
        case 'lefttibia'
            set(handles.tibiaL, 'FaceAlpha', bone_transparency);
            set(handles.femurL, 'FaceAlpha', bone_transparency);
        case 'rightfemur'
            set(handles.femurR, 'FaceAlpha', bone_transparency);
            set(handles.tibiaR, 'FaceAlpha', bone_transparency);
        case 'leftfemur'
           set(handles.femurL, 'FaceAlpha', bone_transparency);
           set(handles.tibiaL, 'FaceAlpha', bone_transparency);
    end

    % delete the cutting results
```

Figure 29 : Fragment of the algorithm (function that undoes the bone cut).

Sequence of use

When launching the software, it will display the lower limbs set. Then, the laterality and first bone to “cut” should be chosen. After choosing the condyle reference, the cutting plane is displayed and the distance to each condyle is calculated (Figure 30). The cutting plane can be moved vertically and, each time it is done, the distances to the condyles are recalculated. Finally, the cutting plane is adapted to fit with bone surface and cut is made, making the cut fragment invisible.

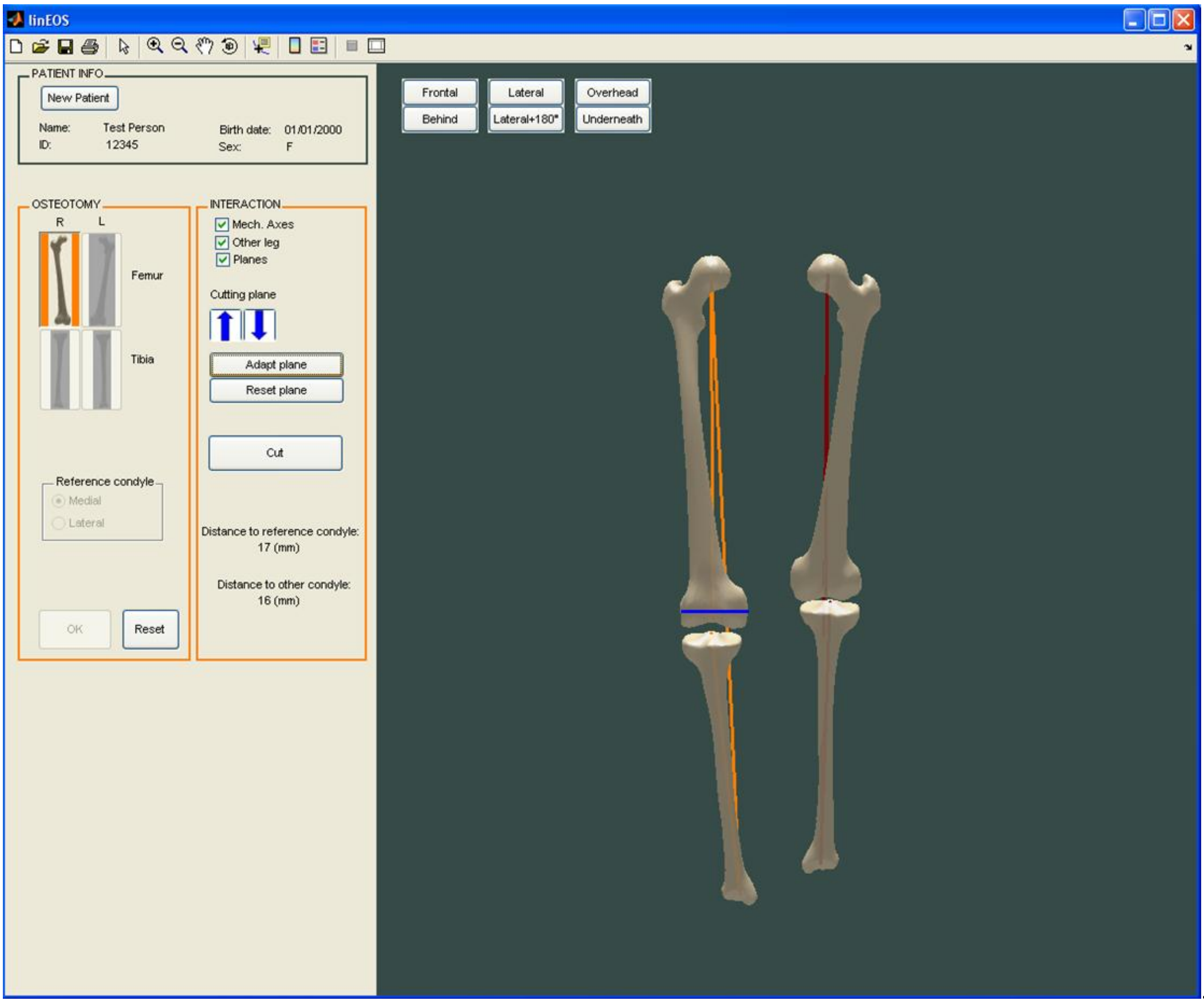


Figure 30: Overview of the software.

Future work

- automatically fit of the cutting plane to bone surfaces,
- to develop "cuts" in different inclinations from the orthogonal to the mechanical axis,
- display pre- and postoperative parameters,
- visual correction of mechanical axis, including the HKA (Hip-Knee-Ankle) for a proper alignment of the entire lower limb (it can be achieved by translation of bones along X and Y directions).

CHAPTER 7 CONCLUSIONS

This paper traces the path of my six months internship within the medical imaging company EOS Imaging. The purpose of my internship was to participate in some clinical studies in order to assess preoperatively, positioning of the pelvis and lower limbs from frontal/lateral EOS acquisitions.

Clinical studies were lead on three main issues: the measure of pelvic parameters, femoral mechanical-anatomical angle and femoral torsion. The order of the tasks that was followed was chosen according to availability and study partners.

The interest of the EOS imaging system is, in addition of using a low radiation dose, that it allows to take radiographs of patients in a standing (weight-bearing), sitting or squatting position. Thus, the lower limb joints can be analyzed in a functional position.

Following the study of pelvic parameters, it was decided to submit it to SOFCOT (Société Française de Chirurgie Orthopédique et Traumatologique) and it was also presented in SFCR Congress (Société Française de Chirurgie Rachidienne) from 7 to 9 June 2012, in Strasbourg.

The study of the femoral mechanical-anatomical angle was also submitted and will be presented at SOFCOT.

Currently, my work with the arthoplasty software is being integrated into the software marketed by EOS Imaging, which will later develop other slicing in different inclinations from that orthogonal to the mechanical axis, as well as to display the pre-and postoperative parameters, including the HKA (Hip-Knee-Ankle) angle for visual correction.

The internship was a very rewarding experience, both on a professional and personal point of view. I had the chance to discover the world of an innovative company in the medical imaging market. Their products, the EOS 2D/3D imaging system associated with the 3D reconstruction workstation SterEOS, suggest some promising prospects.

From the beginning I had to familiarize myself in one hand, with anatomy (bones and joints) of the pelvis and lower limbs, which allowed me to acquire basic knowledge in orthopedics and radiology, and on the other hand, with Matlab, which is a programming tool almost essential in this area. I also had the opportunity to manipulate the EOS equipment, making acquisitions on the pelvic phantom for the study of pelvic parameters, and in femurs for the study of torsion.

This internship also allowed me to learn the standards of statistics used to evaluate the correlation between measures and reproducibility between operators. I saw the difficulty in comparing measures obtained in the literature, as the employed statistical methods are rarely explicit. I also had the opportunity to gather feedback from medical staff. I was able to contribute to the updating of the literature database, using the EndNote software. Thus, I was able to interact with the marketing and development teams of EOS Imaging, clinicians, surgeons and technicians.

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