PREVALENCE AND PATTERNS OF SACRAL DYSMORPHISM AMONGPATIENTS PRESENTING TO KENYATTA NATIONAL HOSPITAL: IMPLICATIONS ON SACRAL ILIAC SCREW INSERTION

By

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Declaration

I hereby declare that this dissertation is my original work and has not been presented as a dissertation at any other university.

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Dedication

I dedicate this study to my family and my loving husband; they have made the long hours spent on this project much more bearable.

I pray that this study may be useful to the Kenyan community of orthopaedic surgeons and the world at large.

Acknowledgment

This project would not have been possible without the guidance and support of my mentors Dr.Gakuya and Dr. Sitati. I am grateful for the proof reading and encouragement from Dr. Mordicai Atinga and Dr. Lutomyia. Words cannot express my gratitude for the many hours Dr. Amunga spent to provide radiology advice and training required for the data collection.

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List of Abbreviations

AP	Antero - posterior
CHS	College of Health Sciences
CSV	comma-separated values
CT	computerized tomography
DEFF	design effect
GE	General Electric
KEPH	Kenya Essential Package for Health
KNH	Kenyatta National Hospital
KNH-UoN ERC	Kenyatta National Hospital-University of Nairobi Ethics and Research Committee
L5	fifth lumbar vertebrae
mm	millimeter
MMed	Master of Medicine
MPR	multi planar reconstruction
S1	first sacral vertebrae
S2	second sacral vertebrae
S3	third sacral vertebrae
S4	fourth sacral vertebrae
S5	fifth sacral vertebrae
UoN	University of Nairobi

Abstract

Study background

Use of percutaneous sacral iliac screws is the current gold standard for the fixation of posterior pelvic ring injuries, unfortunately in up to 15 percent of cases screw misplacement occur leading to neurovascular complications. This is directly correlated with the orientation and size of safe corridors of fixation in dysmorphic sacra. This study was conceived as a result of the challenges that orthopedic surgeons face when fixing posterior pelvic wall disruptions via percutaneous sacral iliac screws. The study aimed to raise the index of suspicion for sacral dysmorphism and to enhance the level of pre-operative preparedness for the orthopaedic surgeon when placing percutaneous sacral iliac screws.

Broad objective: To evaluate qualitative and quantitative characteristics of sacral dysmorphism as well as the prevalence of sacral dysmorphism in Kenya.

Study design and site: This was a cross-sectional study carried out at the Radiology Department, Kenyatta National Hospital.

Participants and Methods: It involved radiographic evaluation of 303 stored abdominal pelvic computerized tomography (CT) scans of persons aged 18-70 years for the study period March 2020to March 2021. The evaluation was carried out on CT scans that met the inclusion and exclusion criterion. The data collected included qualitative features of sacral dysmorphism found on reviewed images as well as objective measurements of sacral dysmorphism. These objective measurements included sacral dysmorphism score, and safe zone cross-sectional area. Lastly data on acetabular version angles was collected to evaluate for any correlation with sacral dysmorphism.

Data Management and Analysis: Data was collected using Kobo Collect®; this is a mobile application on Android® phones. The dataset underwent univariate analysis using Stata 14 ® to determine proportions, tables, charts and graphs .A regression analysis was conducted to establish any correlation between acetabular version and sacral dysmorphism.

Results:

The most prevalent feature of sacral dysmorphism was lack of recession of the S1 segment at 82% followed by presence of unfused sacral segment at 77%. The

remaining features of sacral dysmorphism were distributed in only one third of the population There was no significant gender difference noted (p=0.078).

A sacral dysmorphism score of more than 70% was found to be in 63% of the population. The average cross-sectional area of the S1 segment was found to be 370mm^2 for females and 417mm^2 for males. An average acetabular angle of 14 degrees. Gender variation was noted in males presenting with a higher sacral dysmorphism score.

Conclusion,

Further studies are needed to further describe sacral dysmorphism in the African pelvis. Our study has pointed to multiple areas in which further research can be done.

1.0 CHAPTER 1: INTRODUCTION

Percutaneous sacral iliac screws are the current gold standard for fixation of posterior pelvic ring disruptions(1). These screws provide both stability and haemorrhage control. They have been referred to as resuscitation or anti shock screws since they have been associated with quick and effective haemorrhage control in cases of posterior pelvic ring disruption(2)(3)(4).The posterior pelvis and sacrum are cornerstone elements in providing structural support to the entire pelvis(5). Anteriorly, the pubic ligaments provide only 15 percent of the total stability. Posterior pelvic ring disruptions have been linked with significant morbidity which includes chronic pain, sexual dysfunction, bladder and bowel dysfunction and low rates of return to work(5).There are certain fracture patterns such as those that have sacral iliac widening and sciatic notch fractures have been shown to predict major haemorrhage(6).It has been found that 80 percent of the haemorrhage originates from the presacral venous plexus or from the fracture ends(7). Given the above reasons, posterior pelvic injuries should be fixed rather than managed conservatively.

Traditionally, posterior pelvic ring disruptions were fixed with open reduction internal fixation techniques. However, these procedures are fraught with complications such as bleeding, soft tissue injury, heterotopic ossification, and increased length of stay in the hospitals(8). Open procedures are often associated with prolonged operation time due to the above-mentioned challenges.

Percutaneous techniques are increasingly being used and have been found to offer more stable fixations thus allowing faster mobilization postoperatively(9). Another advantage is that these techniques do not decompress the pelvic hematoma, and therefore have reduced blood loss thus allowing for early total care(10)(11). In a study by Elzohairy & Salama in 2017 percutaneous SI screws were associated with a blood loss of about 150cc compared to 500cc in open techniques and subsequent transfusion of two pints of blood compared to only one pint when percutaneous techniques are used(12). This is also attributed to lack of pelvic haematoma decompression in the percutaneous techniques(11).

It is a useful technique where there is traumatized skin and open procedures risk wound breakdown and infections (13).These screws have been found to be biomechanically superior to other techniques such as plates and screws, pedicle screw-rod fixators and transiliac internal fixators(14). In experienced hands, these screws can be placed relatively quickly, therefore limiting the second hit phenomenon and post-operative pain.

Percutaneous sacral iliac fixation is however technically demanding, the main complication being screw misplacement resulting in iatrogenic neurovascular injury (15). The technique is heavily dependent on a *"normal sacral"* anatomy. The term

"dysmorphic or dysplastic" sacra refers to abnormal variations in the upper sacral segments (S1 and S2) that may create a narrow or more angulated intraosseous corridor that would limit the safe passage of percutaneous sacral iliac screws(16).
Sacral dysmorphism refers to a set of features first described by Routt et al in 1996 on review of plain pelvic radiographs(17) These features include:- lack of sacral fusion, irregular sacral foramina, lack of colinearity of the iliac crest, presence of mammillary bodies, acute alar slopes and presence of a tongue in groove phenomenon. Research has been ongoing in this area to evaluate the prevalence of sacral dysmorphism as well as more objective ways of diagnosing sacral dysmorphism. The prevalence of sacral dysmorphism has been found to be high ranging from 40-70 percent in varied populations(18)(19)(16). These studies have mostly been done in European and Asian populations; none has been done in the African set up.

Sacral dysmorphism has an impact on safe placement of sacral iliac screws (20). The risk of screw malposition has been found to be increased in sacral dysmorphism(21). Misplacement of sacral screws is a common challenge which occurs in about 10 – 15 percent of the time(20). The risk factors for screw misplacement are mainly sacral dysmorphism and malreduction of the fracture.

Given the increasing prevalence of pelvic trauma and need for early fixation with the *"resuscitation screw"* it is of great importance for the surgeon to be conversant with identification of sacral dysmorphism to make relevant pre-operative plans.
Knowledge of sacral dysmorphism and its prevalence in our set up is of paramount importance. It is crucial to establish objective techniques for identifying dysmorphic features and predicting the likelihood of safe sacral iliac screw placement. Given the challenges in the use of image intensifier, additional methods to quantify sacral dysmorphism would help the surgeon reduce operation time as they will be more prepared for the expected challenge in dysmorphic sacra.
There is a significant knowledge gap globally on sacral dysmorphism and very few studies have been done in this area. Consequently, the validity and reliability of various qualitative and quantitative techniques of diagnosing sacral dysmorphism is in question. This study endeavors to increase current knowledge on the prevalence as well as the qualitative and quantitative features that may be used in the diagnosis of sacral dysmorphism.

1.1 Statement of Research Problem

Pelvic fractures still present a significant challenge in management today. This is due to the high rates of morbidity and mortality associated with pelvic trauma. With increasing industrialization, high energy trauma is one of the leading causes of pelvic injuries in the young(22). Due to the increasing age of the population we are also seeing an increasing trend in fragility pelvic fractures in the elderly(23). Posterior pelvic disruptions form about 40 percent of all pelvic injuries and are high risk injuries(15). Stabilization of these injuries with percutaneous sacral iliac screws is the current gold standard(1). This procedure is technically demanding as it requires in depth knowledge of the normal sacral anatomy. Studies have found that in dysmorphic pelvis then the rate of screw malposition as well as neurovascular injury increases(20). Being able to identify the "dysmorphic sacrum" is paramount to a successful procedure. Of note is that the prevalence of dysmorphic pelvis has been found to be quite high in certain populations(19). The prevalence remains unknown in Africa. This study aims to find the prevalence of sacral dysmorphism in a prospective trauma population in Kenya as well as describe the qualitative and quantitative features of the dysmorphic pelvis in the Kenyan population.

1.2 Study Objectives

1.2.1 Broad Objectives

The aim of this study was to evaluate prevalence as well as the qualitative and quantitative characteristics of sacral dysmorphism in a prospective trauma population in Kenya.

1.2.2 Specific Objectives

i. To determine the prevalence of sacral dysmorphism.
ii. To determine the qualitative characteristics of sacral dysmorphism.
iii. To determine the quantitative characteristics of sacral dysmorphism
iv. To determine correlation between sacral dysmorphism score and acetabular version.

1.3 Study Justification

This study was proposed due to the lifesaving nature of percutaneous sacral iliac screw fixation in patients with posterior pelvic disruption. The placement of these screws is often challenging to the orthopaedic surgeon usually due to the aberrant anatomy of the upper sacrum. Sacral dysmorphism has been found to have a high prevalence in other parts of the world; research in the African set up is nonexistent. This study therefore formed a good background for surgeons in Africa and aimed to improve their level of pre-operative preparedness.

1.3.1 Impact of sacral dysmorphism on sacral iliac screw fixation

Percutaneous sacral iliac fixation is the current gold standard for fixation of posterior pelvic disruption(24). This procedure is heavily reliant on a normal anatomy of the sacrum. Misplacement of sacral screws is a common complication which occurs in about 10 – 15 percent of the cases (20). The risk factors for screw misplacement include sacral dysmorphism and malreduction of the fracture.

A recent systematic review done on sacroiliac fixation and their complications showed that risk of malposition significantly increased in dysmorphic sacra (21). A dysmorphic sacrum has a sacral vestibule that is 36 percent smaller than the normal(25).The effects of dysmorphism could only be mitigated by raised index of suspicion for sacral dysmorphism and knowledge of alternative techniques as well as use of intraoperative navigation such as fluoroscopy or computer assisted surgery.

1.3.2 Importance of percutaneous sacral iliac fixation

Conservative treatment of posterior pelvic disruption has been associated with numerous long-term complications these include chronic lumbago, anisomelia, neurological deficits, bone nonunion and gait anomalies(26). Hence prompt definitive care is advocated for. Patients may also suffer effects of prolonged immobilization such as deep venous thrombosis, pulmonary embolism , pneumonia which is worse in the elderly population(26).

The sacrum serves a pivotal role in the axial skeleton; it transmits weight through the sacral iliac joint; hence reconstruction of the spino-pelvic junction is pivotal in ensuring early mobilization and better nursing care especially in polytrauma patients(27). It has been found that better functional recovery and return to work are associated with better reduction(28). Even in cases with purely ligamentous injury satisfactory radiological and clinical outcomes have been achieved with fixation of the sacral iliac joint(29).

New technologies to provide stabilization of pelvic ring fractures in the acute scenario have been useful. These include pneumatic antishock devices for hemorrhage control as well as external fixators and pelvic clamps. However, they do not provide maximum stability for the posterior pelvis. This is best achieved through percutaneous sacral iliac screw fixation and it has been appropriately referred to as the resuscitation screw(2). Once learned and taking into consideration the issues of sacral dysmorphism this is a safe and reproducible technique(27).

1.5Conceptual Framework

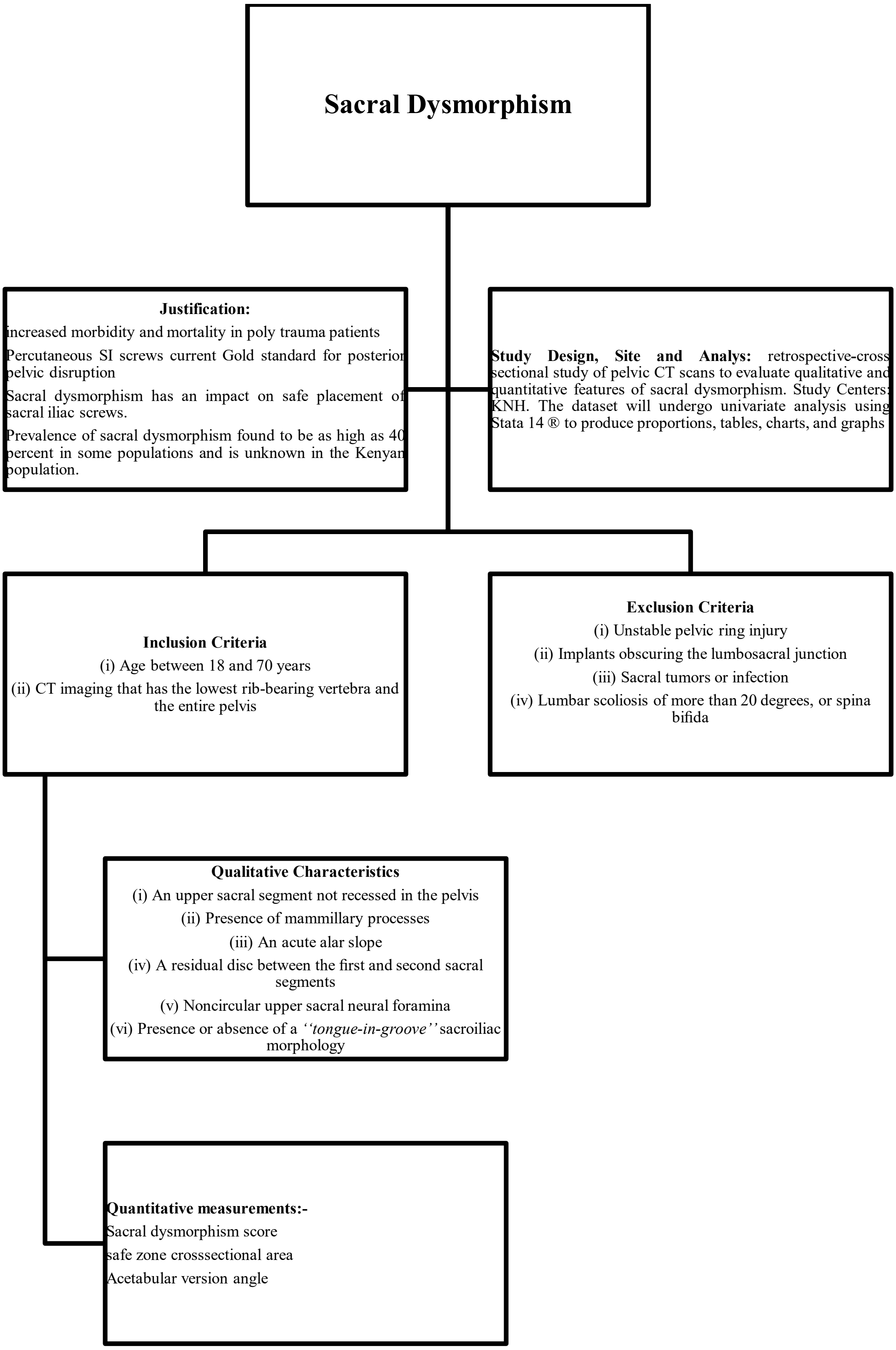

Figure 1: Conceptual Framework

2.0 CHAPTER 2: LITERATURE REVIEW

2.1 Embryology of the Sacrum

The development of the sacrum begins in the third week of intrauterine life and lasts until the third decade of life(30). This happens through four stages: -mesenchymal, chondrification, primary ossification and secondary ossification.

2.1.1 Mesenchymal Stage

The notochord process forms between days 17-19. The notochord has an important role in maintaining the structural integrity of the embryo by providing the spinal axis and stimulating the surrounding tissues. The overlying ectoderm forms the neuroectoderm which gives rise to the neural plate that subsequently forms the neural tube and later the brain and spinal cord. The notochord persists to form the nucleus pulposus. Once the notochord forms the mesoderm lateral to it forms the paraxial mesoderm which at the end of the 5th gestational week forms (42-44) somites. The somites develop around the notochord in a cranial caudal direction forming sclerotomes where two adjacent sclerotomes fuse to form a vertebral body in a process defined as “segmentation”(31). The sacral and coccygeal somites are usually the last to appear at about day 31 of intrauterine life(32).Each somite has three parts:- sclerotome, myotome and dermatome. The sclerotome forms the future vertebrae and intervertebral discs; myotome forms future muscles, and the dermatome the connective tissue underlying the epidermis.

2.1.2 Chondrification Stage

This begins in the 5th week of gestation and forms a cartilaginous framework for the vertebral column.

2.1.3 Ossification of the Sacrum

Endochondral ossification begins in three main centers: - neural, coastal, and central. The costal ossification centers form part of the lateral mass that later develops into the sacral ala. Discs separate the vertebrae in childhood with the lower segments S3-S4and S4-S5fusing in adolescence and the upper segments by the 3rd decade of life(30).

2.2 Definition of Sacral Dysmorphism

2.2.1 Qualitative Description

There is a scarcity of literature on sacral dysmorphism(33). Sacral dysmorphism also known as *"dysplastic sacrum"* was first described as morphological variations found in the upper sacral segment (S1). This term was first employed by Routt et al in 1996using pelvic radiographs(17). The qualitative description includes presence of any of the following morphological features:-mammillary bodies, tongue in groove morphology, collinearity of the sacrum with the iliac crest cranially, non-cylindrical neural foramina, acute alar slope and residual sacral disk space(19). These features were found to preclude a straight intraosseous trajectory between both sacroiliac joints and thus would have an implication on the safe insertion of a percutaneous sacroiliac screw. Below we highlight each of the qualitative features of sacral dysmorphism as described by Routt in 1996(17). Of note is the challenge associated with the subjective nature of qualitative findings. Hence current research is in looking for quantitative techniques that are more objective.

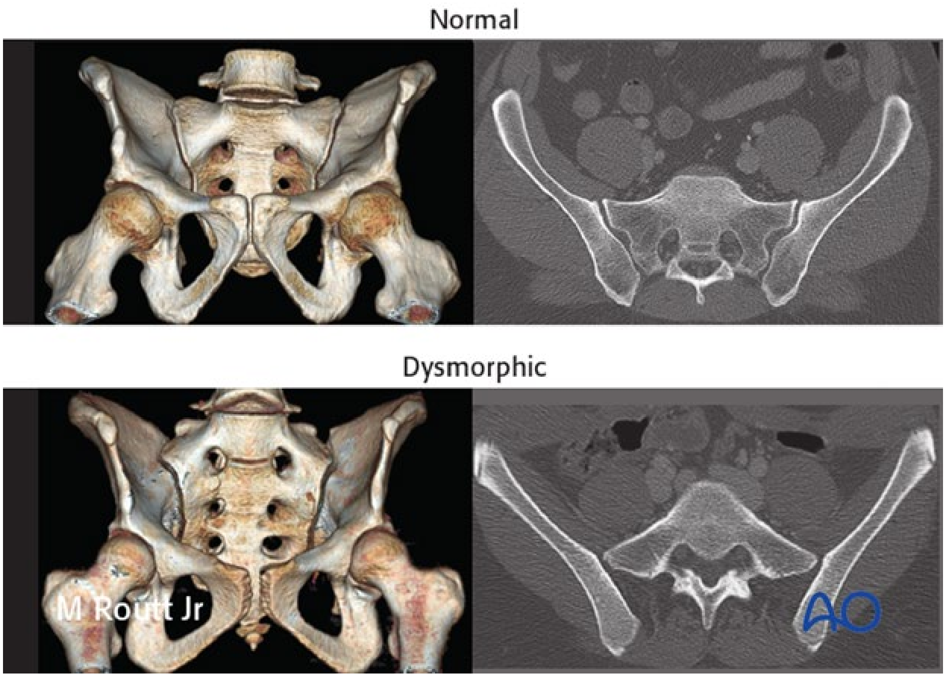

Figure 2: AO Surgery Reference-Normal versus Dysmorphic sacrum (16)

2.2.1.1 Lack of recession of the first sacral segment

The lumbosacral region is one of the most variable areas of the spine with most variation occurring in the first lumbosacral segment(34).On a normal standard outlet radiograph of a pelvis, the sacrum is usually recessed when compared to the position of the iliac crest. However, in a dysmorphic sacrum the sacrum fuses in a more cranial position creating *"sacralisation"* of L5. Sacralisation refers to the incorporation of the lumbar vertebrae into the sacrum thus having 4 lumbar vertebrae(35). These kind of transitional vertebrae are found in about 20 percent of the human skeleton(30). It may occur unilateral or bilateral and may also be classified as complete or incomplete. A higher presentation of the upper sacral vertebrae limits the safe insertion of a horizontal screw(36).It has been found that the anatomical changes in sacralisation of L5 reduced the pedicle height of S1 and is associated with an acute alar slope in the sagittal plane(37). It has been found that in dysplastic sacrum there is more than 50 percent of the height of the vertebral body over the iliac cortical density(37). This limits the safe area for screw insertion.

2.2.1.2 Irregular sacral foramina

In comparison to the normal sacrum, the upper segment anterior sacral neural foramina of the dysmorphic sacrum are larger, noncircular, and irregular(38). These foramina are optimally viewed on pelvic outlet plain radiographs. In the normal sacrum the neural foramina are usually circular and regular. In such cases the trajectory of the screw may cause injury to sacral nerve roots. On a true lateral view the screw trajectory should be caudal and posterior to the sacral ala to avoid injury to the L5 nerve root(38).

2.2.1.3 Acute alar slope

The sacral ala are wing shaped bones found on the lateral aspect of the S1 vertebral body. The alar anatomy is obliquely oriented; this will present limitations for sacral iliac screws insertion. It slopes from central cranial to peripheral lateral and from cranial posterior to caudal anterior. This is evident on a true lateral radiograph. In dysmorphic cases the alar slope is acutely positioned in both the coronal plane seen in a pelvic outlet radiograph and the sagittal plane seen on the true lateral(38). This may cause narrowing of the sacral vestibule leading to impediment in safe passage of sacral iliac screws. The L5 nerve root with the sacral ala form the superior border of the sacral vestibule whereas the inferior border is formed by the S1 foramen and its accompanying nerve root. These structures are at high risk of injury in cases of sacral dysmorphism(39).

2.2.1.4 Mamillary bodies

The dysmorphic upper sacral segment has mammillary processes which are found in the alar region; these processes can be visualized on pelvic outlet plain radiographs. The mammillary processes are deformed or remnants of transverse processes from the sacralized L5 vertebral body that were involved in the extended fusion process during development. These have a strong correlation with the critical sacral angle which may be used as a quantitative measure for adequacy of the safe sacral vestibule. Mamillary bodies have been found to reduce the trajectory of the sacral screw which may predispose to injury of the neurovascular structures(1).

2.2.1.5 Lack of fusion of sacral disc segments

Fusion of the sacral vertebrae mostly occurs through childhood. It is usually a direct result of ambulation or weight bearing such that in non-ambulant children then fusion does not occur. The first sacral vertebrae to fuse are S3-S4 and S4-S5in late adolescence; whereas S1-S2and S2-S3fuse by the third decade of life (40). In dysmorphic situations, then fusion does not occur, and residual disk space may be visualized between S1 sacral segment and S2 best seen on a pelvic outlet radiograph. This has been found to be associated with lumbo-sacral transitional vertebrae and therefore has an implication on the safe trajectory of the screw(35).

2.2.1.6 Tongue in groove morphology

Tongue in groove articular morphology is best seen in axial CT scans. It is seen as a highly interdigitated sacral iliac articulation, more than in the normal population. This increases the surface area of the sacral iliac joint(19). This may affect part of the preoperative planning as the sacral iliac joint is displaced more distally than normal (41). Here more than 50 percent of the body is found proximal to the iliac cortical density. Therefore, as the screw passes through S1 it occupies less than 50 percent of the sacral iliac joint articular surface.

2.2.2 Quantitative Description

Newer descriptions for a quantitative analysis of sacral dysmorphism have recently been formulated. The hallmark of the quantitative description of sacral dysmorphism is based on the CT determination of the diameter of the safe trans sacral corridor which should have a minimum diameter of 8 – 10mm(42). This had been earlier described by Carlson in 2000 as the *"sacral vestibule"* bounded inferiorly by the S1 foramen through which the S1 nerve passes and the sacral alae superiorly where the L5 nerve passes(39).

Sacral dysmorphism has also been described as when a trans sacral screw cannot be safely passed through S1 but can be safely passed through S2. In a study carried out by Conflitti in 2000 the S2 intraosseous pathways were wider in diameter than in the dysmorphic S1 segment(43).

Some of the quantitative techniques that have recently been used in various studies include measurements of sacral dysmorphism score, sacroiliac joint line length, safe zone cross sectional area, critical sacral iliac angle, and lateral sacral triangle method. The quantitative descriptions allow for a more objective evaluation of sacral dysmorphism. However, due to the scarcity in research, these techniques have not been validated.

2.2.2.1 Safe Zone for Sacral Fixation in a Normal Sacrum

Knowledge of the sacral anatomy is important in fixation of sacroiliac screws. The procedure is very technically demanding and it has been found that even deviations of as few as four degrees may result in cortical perforation and damage of critical structures(16). This occurs by orienting the screw towards the foramen of S1 or the anterior sacral wall(44). The sacral anatomy shows not much difference with age, however in regard to gender, there have been reports of narrower intraosseous corridors in the female pelvis(28).

The safe zone for fixation of sacral iliac screws consists of an intraosseous tunnel which ensures safe passage of the screw without risk of iatrogenic damage to neurovascular structures. Dysmorphic sacra have narrow and angled upper osseous corridors hence in these cases the risk is high. Carlson in his study in 2000 developed parameters to determine a safe sacroiliac corridor(39). The aim is to have the screw at the center of S1 and S2 vertebrae to avoid risk to neurovascular structures. Hence a safe bony corridor of 7 mm away from any neurovascular structures is achieved (45).

2.2.2.2 Quantitative Measures of Sacral Dysmorphism

As described previously, researchers have tried to find objective measures of sacral dysmorphism. This is in part due to the high prevalence of sacral dysmorphism whenever the qualitative aspects are considered exclusively(19). It has led to the question of how each morphological factor contributes to the safe placement of sacral iliac screws intra-op. Research is still ongoing in this area; however, the consensus is that all the qualitative factors create limitations to safe passage of a sacral iliac screw in the *"sacral vestibule"*.

We will have a look at the various quantitative techniques that have been used recently to objectively assess for sacral dysmorphism.

2.2.2.3 Sacral Iliac Joint length

Sacral dysmorphism leads to location of the sacroiliac joint more distally than in normal pelvises this affects the entry points and screw lengths for sacroiliac fusion(41). A study by Weigelt in 2019 found males to have a slightly longer(8.46cm) than average (7.36cm) sacral iliac joint length as compared to females(6.11cm).The small surface length of sacroiliac joint had a strong correlation with residual upper sacral segment disc space; and was significantly increased where there was tongue in groove morphology(19).

2.2.2.4 "Safe zone" cross-sectional area

This was defined by Carlson in 2000 as the first sacral vestibule (Carlson et al., 2000). It is the narrowest point through which an iliosacral screw may pass. This is highlighted in the diagram below(Figure 3). The sacral vestibule is ovoid in shape and measures an average of 534mm^2 in males and 450 mm^2 in females; the size is much more reduced in the S2 segment. The minimum diameter of the trans sacral corridor is 8 – 10mm where anything less than that is considered dysmorphic as it would not allow the diameter of a 7.5 mm screw to pass(42). The safe zone to place the screw is within a 20 mm radius in the center of the vertebrae in any direction provided the 7mm diameter screw is being used(28).

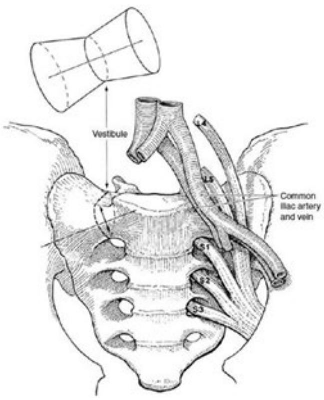

Figure 3: Safe zone cross sectional area

Measurement of the cross sectional area as carried out by (28) was done by getting a sagittal cut and measuring the quadrilateral surface area by either dividing it into two triangles or by inscribing a circumference on the margins of the quadrilateral surface and getting what the area of the sacral vestibule is.

2.2.2.5 Critical sacral iliac angle

The critical sacral iliac angle has been found to have a strong correlation with presence of mammillary bodies and intraarticular vacuum phenomenon(1). The intraarticular vacuum phenomenon is thought to be due to accumulation of intraarticular gas following degenerative changes due to overload of sacroiliac joints in sacral dysplasia.

The angle is drawn by a parallel line to the S1 vertebral end plate and another from its center to the most lateral part of the sacral ala. Alternative approaches to stabilization should be sought when a far negative value less than -14 degrees is found.

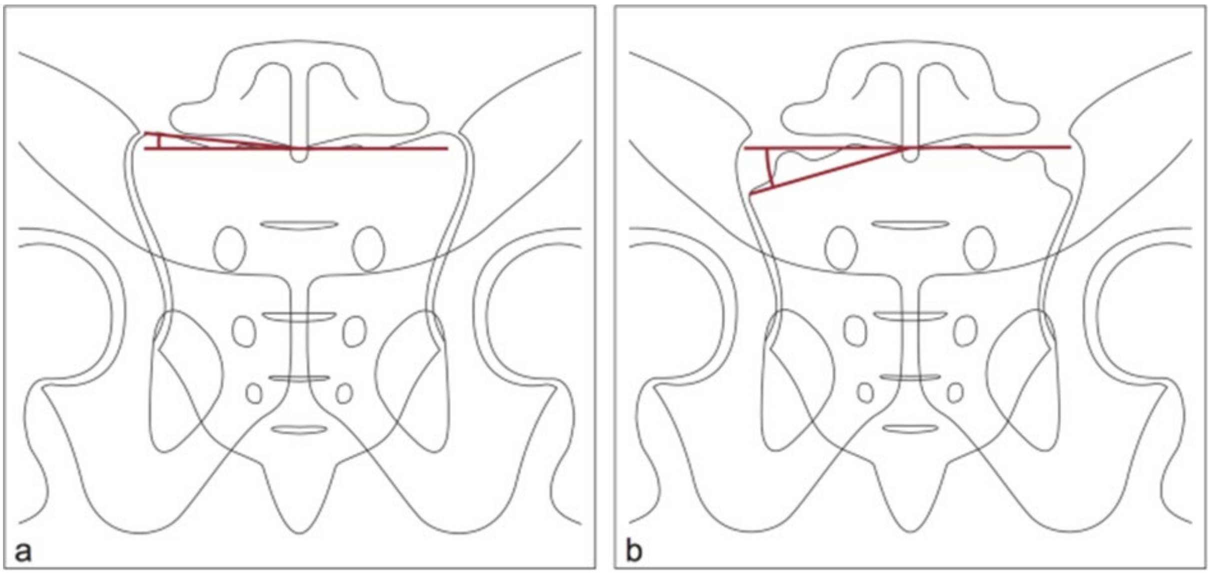

Figure 4: Images showing critical sacral angle. Adapted from (Laux et al., 2019) normal sacrum (a) and dysplastic sacrum (b)

2.2.2.6 Lateral sacral triangle method

This technique was developed by Mendel in 2011 and it is based on a triangle formed by the anterior height and superior width of the S1 as well as the iliac cortical density viewed on a true lateral projection image (Mendel et al., 2011). A triangle ratio is then calculated as superior width divided by the anterior height and if found to be less than 1.5 then the sacrum is dysmorphic, and the sacral vestibule will not allow for safe passage of a 7.3mm screw. This method makes use of only one radiological view and can be quickly done preoperatively using basic radiography or intraoperatively using fluoroscopy. It provides a quick objective assessment for sacral dysmorphism. Its use is limited to fractures that are undisplaced or well reduced as the formation of the *"triangle"* is dependent on a relatively intact anatomy.

2.2.2.7 Sacral Dysmorphism Score

Using the sacral dysmorphism criteria as described by Routt et al in 2000(10) in pre-operative planning can achieve low rates of neurovascular injury up to one percent (46). The sacral dysmorphism score was developed by Kaiser et al in 2014 as a means of quantifying the degree of sacral dysmorphism(16). Sacral dysmorphism was calculated and when found to be more than 70 then these patients had no safe transverse osseous corridor on the S1 vertebral segment. It is calculated as the sum of coronal angulation plus twice the axial angulation of the first sacral segment. The coronal angle is drawn on a coronal cut where there is a line along the axis of the osseous corridor and a line connecting the iliac spines. The axial angulation is drawn with a line connecting both posterior iliac spine and one parallel to axis of the osseous corridor (25).

2.3 Prevalence of Sacral Dysmorphism

The prevalence of sacral dysmorphism has been varied in different populations(18). Sacral dysmorphism is a congenital anomaly that has been found to have a relatively high prevalence of up to 70 percent in some populations(19). It has not been documented for the African population in existing literature.

2.4 Factors Associated with Sacral Dysmorphism

2.4.1 Gender

A few recent studies have shown the increased rate of sacral dysmorphism in female pelvises with resultant narrow intraosseous corridors(20)(16)(47). Some studies have however found no gender differences, hence the need for further detailed research in this topic. A more recent level two, retrospective radio anatomic cohort study; published findings that showed that sacral dysmorphism prevalence is irrespective of gender(42).

2.4.2 Ethnicity

There have been publications showing ethnic differences in the prevalence of sacral dysmorphism such as a study that showed the limited sacroiliac corridor in the Japanese versus European populations(26). There have been other studies that have shown increased dysmorphic prevalence in the Asian population as compared to Caucasian population(48).

2.5 Reasons why fixation is preferred through S1 segment

It is recommended that where the S1 segment cannot be utilized due to dysmorphism then a trans sacral fixation in S2 is preferred to ensure a more stable fixation(49). The S1 segment is however preferable due to the relative osteopenia in the S2 segment(50). The S1 segment is the largest sacral vertebrae, with great density of trabeculae arranged in a cruciate pattern.

In a study by (51)where the cortical thickness and bone density of the sacrum in a young healthy population was analyzed the findings showed that the strongest bone was found to be between the S1 and S2 foramen and the weakest was at the lateral sacral ala of S1 and at the junction of S2 and S3(52). The S1 has higher bone mineral density than S2 and is strongest in the posterior lateral and anterior lateral corners. The average bone density is less in the S2 segment compared to the S1 both in normal and dysmorphic sacrum.

Preliminary studies indicate that fixation in the S1 segment would confer better screw purchase for this reason(53). In the elderly where fragility fracture patterns occur and screw loosening is a big concern; augmentation with cement has been found to increase stability of fixations(24).

Studies have shown that when using conventional fluoroscopy, surgeons prefer to place the sacral iliac screws through the pedicles of S1 as those of S2 are narrow and difficult to visualize(27).

2.6 Impact on Practice

2.6.1 Radiological Guidance

Sacral iliac fixation as we have described is a technologically demanding technique. Use of image guidance is required. However, this may be fraught with difficulties in interpretation due to the presence of sacral dysmorphism. Intraoperatively, a qualified technician is required to get the necessary views and the surgeon must be able to interpret the images. The surgeon, to be successful needs to be prepared for any of these eventualities in the case of sacral dysplasia. These procedures when complicated due to dysmorphism are associated with increased radiological exposure to both the patient and the surgeon(27). This is usually performed under C –arm fluoroscopy in emergency set ups (54); but can still be associated with high degree of screw malposition even in the hand of experienced surgeons. When using conventional fluoroscopy drilling can only be controlled in one plane at a time and positions and adjustments must be made in AP, lateral, inlet and outlet views which also result in increased radiation exposure for both surgeon and patient(27).

There have also been challenges in use of fluoroscopy in obese patients where abdominal fat may obstruct inlet and outlet views and lateral pelvic flank obesity will impact lateral views. Prior CT guidance will be invaluable in such cases to allow for effective preoperative planning. The other challenge in these types of cases are need for extra-long instruments.

It has been recommended that better image guidance technology should be used such as CT controlled and navigated screw fixation techniques; however, these are technically demanding and may not be found readily available beyond advanced trauma centers.

Plain radiography has been found to provide inadequate imaging due to poor projections and visualization due to poor patient positioning and foreign body shadowing. As a result, CT images have been found to be adequate for analysis of sacral dysmorphism features.

3.0 CHAPTER 3: METHODOLOGY

3.1 Study Design

This was a retrospective cross sectional study. It involved radiographic evaluation of lumbo-sacral and pelvic helical CT scans (T12-L5) of patients without any factors that would distort the pelvic anatomy as highlighted in inclusion and exclusion criteria. Landmarks were from the lowermost thoracic vertebrae to the lesser trochanter. Direction of the scanning was cranio-caudal; no contrast given, and the respiratory phase was suspended. Patients were lying supine with hips and knee joints extended. Original axial images were presented in different presets including bone window and converted to multiplanar reconstruction (MPR) and three dimensional rendering. The CT was conducted with a NEOSOFT–64 slice scanner at Kenyatta National Hospital. Images taken were reformatted to 2mm thickness to allow for better definition of features.

3.2 Study Setting

The study was conducted at Kenyatta National Hospital (KNH). The hospital is a national referral hospital, Kenya Essential Package for Health (KEPH) level six, in Nairobi County. The institution is a tertiary referral facility with specialized radiologic and orthopaedic services and staff. The Orthopaedic Department at KNH handles a wide array of orthopaedic cases; most of which are due to trauma. The Radiology Department at KNH offers diagnostic and imaging services ranging which include plain radiography, ultrasound, CT scanning as well as interventional radiology services. The study used stored data within the CT repository which is an online database that houses CT images taken in the hospital.

3.3 Study Population

The study used digital repositories of stored pelvic CT scan images in Radiology Department at KNH for a period of 12 months from March 2020 to March 2021. The scans were randomly selected.

3.4 Inclusion and Exclusion Criteria

Inclusion criteria

- age between 18 and 70 years
- CT imaging that has the lowest rib-bearing vertebra and the entire pelvis.

Exclusion criteria

- unstable pelvic ring injury
- implants obscuring the lumbosacral junction
- sacral tumors or infection
- lumbar scoliosis of more than 20 degrees, or spina bifida (16)

Any study participant, scan, who did not meet the above criteria, was replaced by selecting the next randomized participant.

3.5 Sample Size Determination

Since was cross sectional survey, sample size of 283 was calculated using the OpenEpi online sample size calculator (*Epi Calc*, 2021.)using the sampling equation for a finite population: *sample size n = [DEFF*Np(1-p)]/ [($d^2/Z^2_{1-\alpha/2}$*(N-1) +p*(1-p)].*

The population size, *N*, was 1200 pelvic CT scans, these are from the CT scan repository in KNH for the duration of the study period. The anticipated frequency of sacral dysmorphia*, p,*was 40 percent (16). The confidence interval was 95 percent and the design effect (DEFF) was one. The value of standard normal distribution corresponding to a 95 percent significant level, $Z^2_{1-\alpha}$. Finally, the study had a power,d^2, of 80 percent. In our final data collection 303 CT scans were sampled and analysed; this figure was easily distributed amongst three radiologists. This was to take into account any scans that would be excluded from the study.

3.6 Sampling Procedure

Simple random sampling technique was used in this study because it offered an equal chance of selection in the study population. The study population was extracted on Microsoft Excel in a tabular format and randomized using the random function.

3.7 Variable Definition and Assessment

3.7.1 Exposure Variables

Exposure variables were divided into two broad groups, quantitative measurements, and qualitative features. For quantitative measurements, various assessments were recollected.

3.7.1.1 Quantitative measurements

3.7.1.1.1 Sacral Dysmorphism Score

Each CT scan was reformatted along the axis of the sacrum to obtain cross-sectional imaging of the S1 and S2 sacral osseous corridor, or *''safe zone''* for iliosacral screw placement(25). For standardization and reproducibility; the scans were reformatted in true coronal and axial planes by defining the sagittal axis as the posterior border of the sacrum and the axial reformats along the upper end plate of the S2 vertebrae(9).

Coronal angulation was measured by an angle formed by a line drawn along the axis of the osseous corridor and a line connecting the top of the iliac crests(25). The top of the iliac crest was found by correlating the axial and sagittal view on MPR reconstruction.

Axial angulation was measured as the angle formed by a line drawn on the axis of the osseous corridor and a line connecting the posterior iliac spines. The tip of the posterior superior iliac spine was found by correlating the axial and sagittal view on MPR reconstruction.

The outcome variable is sacral dysmorphism, which was defined as a dysmorphic score of more than 70 on quantitative analysis(16). The sacral dysmorphism score = (first sacral coronal angle) + 2 (first sacral axial angle)(25).

Figure 5: Coronal angulation is measured as the angle subtended by a line drawn along the axis of the osseous corridor and a line connecting the top of the iliac crests(25)

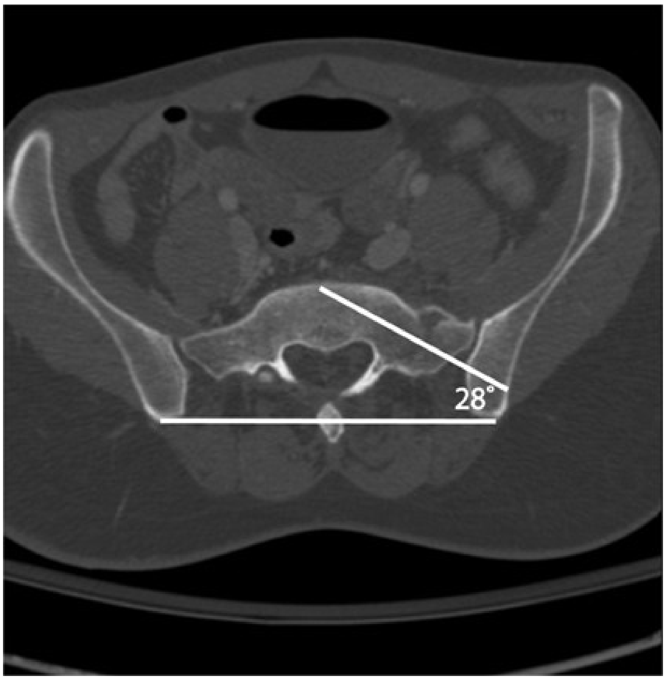

Figure 6: Axial angulation is measured as the angle formed by a line drawn on the axis of the osseous corridor and a line connecting the posterior iliac spines(25).

3.7.1.1.2 Sacral iliac joint area

Sacral iliac joint line was measured by a coloured line on axial CT scan given a slice thickness of 2 mm. The lines were then merged to a plane corresponding to the SIJ surface. This allowed for SIJ area to be calculated(1).

3.7.1.1.3 "Safe zone" cross-sectional area

Measurement of the cross sectional area was done by getting a sagittal cut and measuring the quadrilateral surface area of S1 by either dividing it into two triangles or by inscribing a circumference on the margins of the quadrilateral surface and getting what the diameter of the sacral vestibule shown below(28).

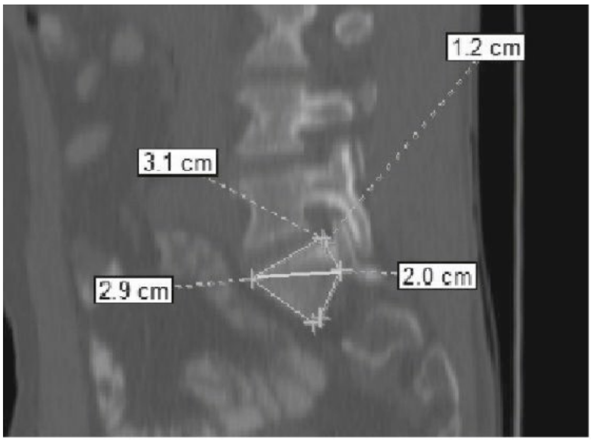

Figure 7: Images showing the quadrilateral surface of S1 image below adapted from (27)

3.7.1.1.4 Acetabular version

The acetabular version angle on all the evaluated scans is measured to find out if sacral dysmorphism may be associated with other anomalies in the pelvis. However to the best of our knowledge no studies have proved this correlation. Acetabular version was calculated based on axial CT scans extending through the center of a best fit circle on the central coronal reconstructed cut. Where a line connecting the anterior and posterior acetabular margins and a transverse line through the femoral head center normal is (12-20) degrees(56).

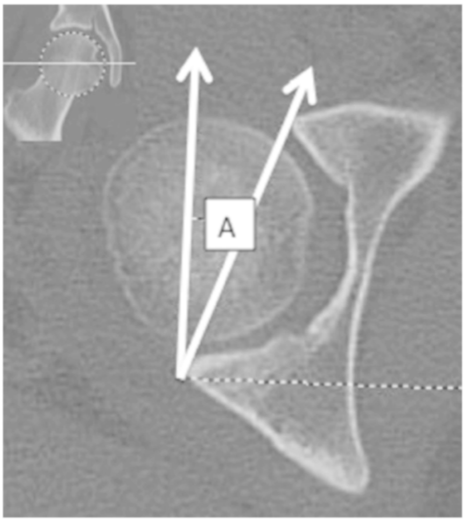

Figure 8: Acetabular version angle (58)

3.7.1.2 Qualitative Measurements

With regards to qualitative features, the study created pelvic outlet reconstruction in which neutral horizontal rotation was corrected by aligning lumbar spinous processes with the symphysis pubis. The vertical rotation was adjusted to align the superior cortex of the pubis with the second sacral segment body(25). Each outlet reconstruction was reviewed and the presence or absence of each of the radiographic qualitative characteristics of sacral dysmorphism that included: (i) an upper sacral segment not recessed in the pelvis; (ii) the presence of mammillary processes; (iii) an acute alar slope; (iv) a residual disc between the first and second sacral segments; and (v) noncircular upper sacral neural foramina determined. In addition, axial CT scans was reviewed for the presence or absence of a *''tongue-in-groove''* sacroiliac morphology(17).

3.7.2 Outcome Variables

The outcome variable was sacral dysmorphism, which was defined as a dysmorphic score of more than 70 on quantitative analysis (16). In addition, demographic data collected included age (years) and gender (male/ female).

3.8 Quality Assurance Procedures

In optimal minimizing of errors and biases, a pilot study was carried out in the Radiology Department at KNH with use of data extraction tool on pelvic CT scans done for the period January to March 2021. Three radiologists ably assisted the researcher.

3.9 Ethical Considerations

Approval to conduct the study was sought from the unit of Orthopaedic Surgery, and Kenyatta National Hospital-University of Nairobi Ethics and Research Committee (KNH-UON ERC) and a copy is annexed. The data collected was identified and anonymized to ensure confidentiality. The researcher cited sources of information gathered to avoid plagiarism.

3.10 Data Management

Data collected was collected using KoBoCollect®, this is a mobile application on Android® phones and downloaded as a comma-separated values (CSV) file. The dataset underwent univariate analysis using Stata 14 ® to produce proportions, tables, charts, and graphs. In addition, regression analysis was used to measure if there is any correlation between various exposure variables and the outcome variable, sacral dysmorphism.

3.11 Study Results Dissemination Plan

Results from the study will be disseminated to the UON-department of Orthopaedic Surgery and the University of Nairobi Library followed with a wider audience through a peer reviewed publication.

3.12 Study Limitations

Limitations are negative impacts that would influence the research in giving inaccurate findings and the researcher has little or no control over managing those. Since this is a retrospective cross sectional study, there was no evidence of a temporal relationship between independent and dependent variables. Another limitation is correlation of findings to race, due to the lack of racial data in the CT scan reports.

3.13 Delimitation measures

There is an inherent weakness of the cross-sectional study. However, data once drawn may be used to generate hypothesis that will be instrumental in designing a case control or cohort study; which are more robust study types. Randomization of the data improved external validity of the study.

4.0 CHAPTER 4: RESULTS

This study evaluated both qualitative and quantitative features amongst randomly selected 303 pelvic CT scans over the month of December 2021. The collected data was cleaned and this is highlighted in the result tables**.**

4.1 Age and Gender Distribution

Out of the 303 randomly selected CT scans the larger proportion, a majority, 52 percent were male with the rest, 48 percent female. The average age was 44.44 years with 95 percent confidence interval of 42.91-45.98 years.

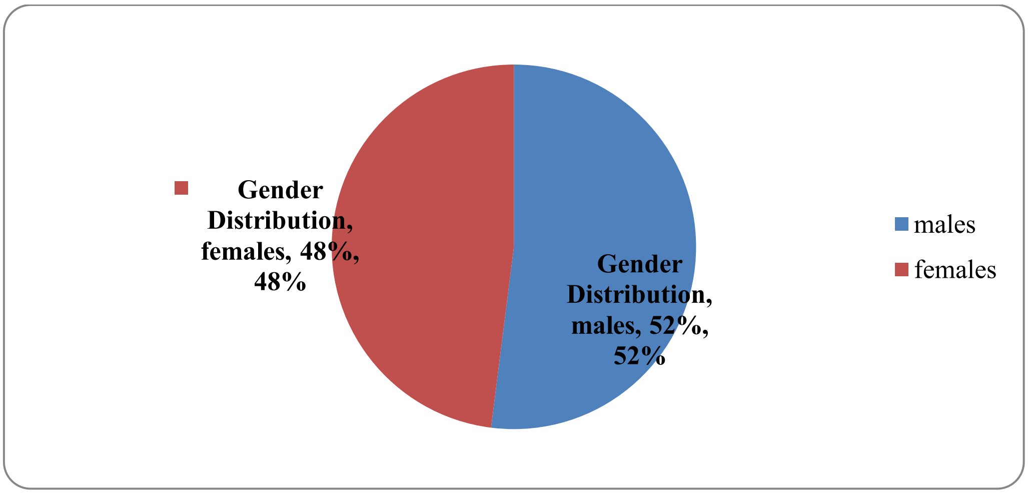

Figure 9: Gender Distribution of Cases

Table 1: Age – Sex Distribution of Study Participants

Variable	**Female 145** **Male 158**	**N = 303** **n (%)**
Sex	Female	145 (48)
	Male	158 (52)
Age	Mean (95% CI)	44.44 (42.91 – 45.98)

4.2 Qualitative Measures of Sacral Dysmorphism

4.2.1 Lack of Recession of the S1 Sacral Segment

The normal sacrum is usually *"recessed"* in relation to the level of the iliac crest. This is well described in Chapter 2. In our study 82 percent of the entire sample exhibited lack of recession of the S1 segment. The S1 segments here were positioned cranial to the level of the iliac crest and this was visible. This was visualized on three dimensional outlet views of the pelvic CT scans. It was also noted to be more in the male population at 84 percent compared to females at 79 percent.

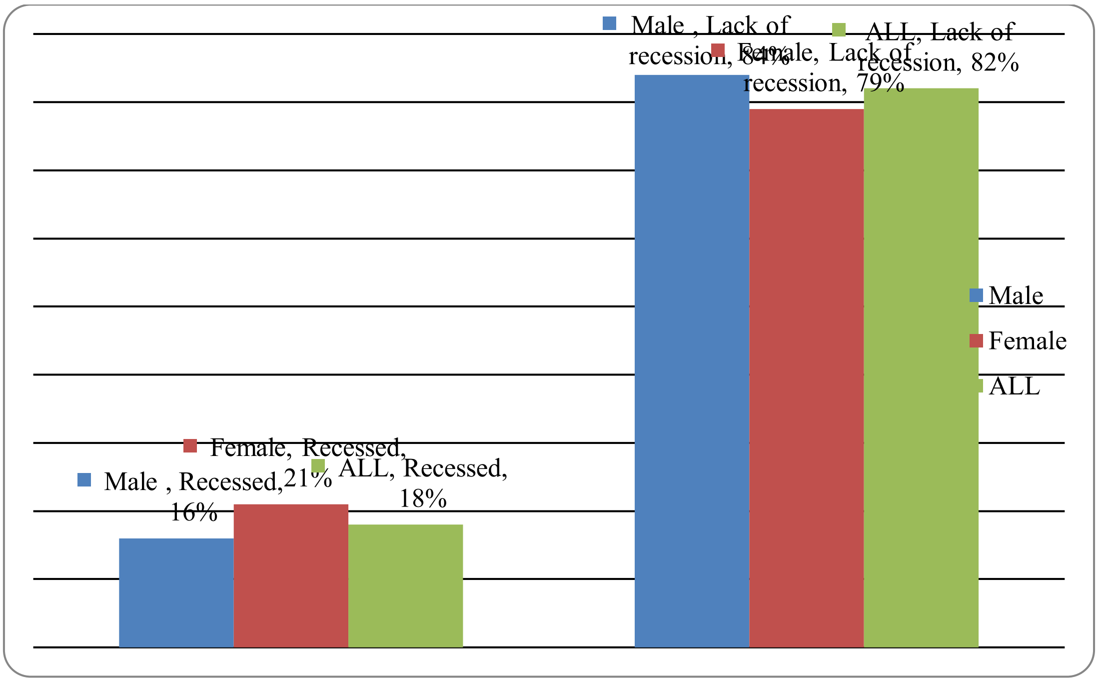

Figure 10: Proportion of Recession of S1 Segment Disaggregated by Gender

4.2.2 Presence of Irregular Sacral Foramen

In this aspect the results show that presence of irregular sacral foramina was 36 percent of the entire sample size. Disaggregated by gender, there was a similar distribution between males and females of 35 percent and 37 percent respectively. No significant gender variation was noted here.

4.2.3 Acute Alar Slope

Twenty – seven percent had an acute alar slope. Disaggregated by gender, both males and females had similar proportion of 27 percent.

4.2.4 Presence Of Mamillary Bodies

Mamillary bodies were present in one quarter (25 percent) of the sample population. This was almost evenly distributed amongst males and female with a slightly higher preponderance for females, 30 percent of sacra showed presence of mammillary bodies compared to 22 percent of the male population.

4.2.5 Unfused Sacral Segments

Unfused sacral segments as visualized on sagittal cuts was the most prevalent sacral dysmorphic feature affecting 77 percent of all scans. This formed about 83 percent in males and 71 percent in females.

4.2.6 Tongue in Groove Morphology

This was visualized on axial cuts and was found to be present in 30 percent of the scans. It was persistent in 32 percent of females and 27 percent of males.

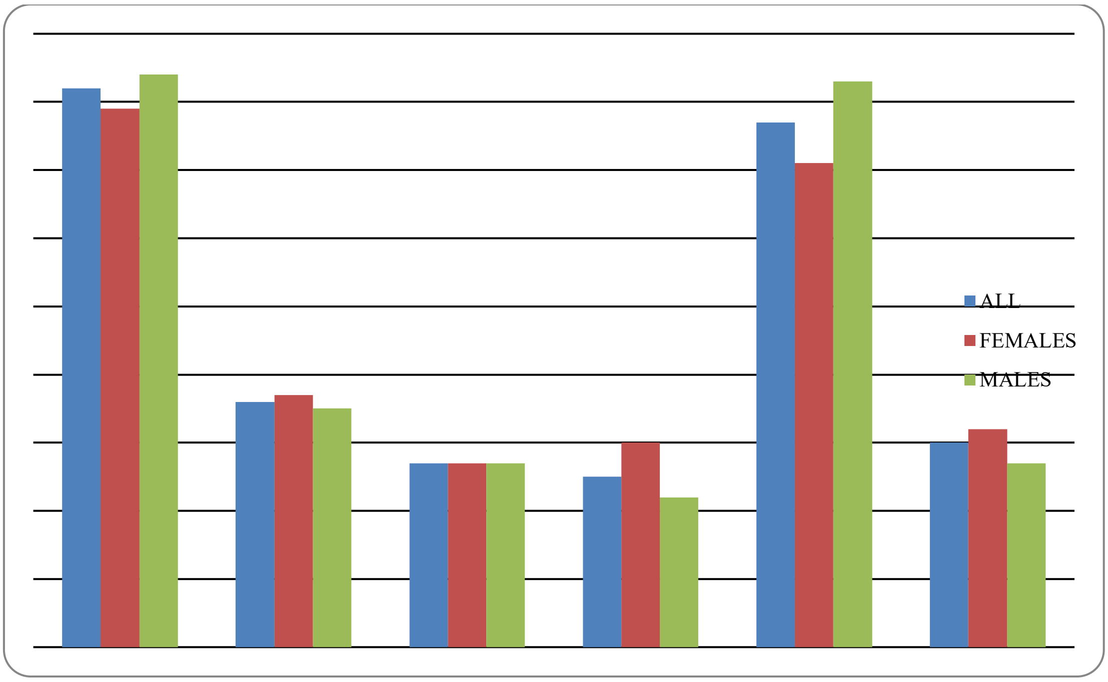

Figure 11: Prevalence of Qualitative Sacral Dysmorphism Features

In summary, lack of recession of the S1 segment was the most prevalent feature, followed by presence of unfused sacral segments at 82 percent and 77 percent respectively. There was no difference by gender amongst most of the qualitative dysmorphic features. Acute alar slope, presence of mammillary bodies and tongue in groove phenomenon were seen in less than a third of the entire study population.

Table 2: Qualitative Measures of Sacro – Iliac Dysmorphism

Variable		**N = 303** **n (%)**
Recession of S1 on outlet pelvic CT view, **ALL**	Lack of recession of S1	247 (82)
	Recession of S1	56 (18)
Recession of S1 on outlet pelvic CT view, **Female**	Lack of recession of S1	115 (79)
	Recession of S1	30 (21)
Recession of S1 on outlet pelvic CT view, **Male**	Lack of recession of S1	132 (84)
	Recession of S1	26 (16)
Irregular sacral foramina on outlet pelvic CT view, **ALL**	Regular sacral foramina	193 (64)
	Irregular sacral foramina	110 (36)
Irregular sacral foramina on outlet pelvic CT view, **Female**	Regular sacral foramina	91 (63)
	Irregular sacral foramina	54 (37)
Irregular sacral foramina on outlet pelvic CT view, **Male**	Regular sacral foramina	102 (65)
	Irregular sacral foramina	56 (35)
Acute alar slope on outlet pelvic CT view, **ALL**	Not acute alar slope	221 (73)
	Acute alar slope	82 (27)
Acute alar slope on outlet pelvic CT view, **Female**	Not acute alar slope	106 (73)
	Acute alar slope	39 (27)
Acute alar slope on outlet pelvic CT view, **Male**	Not acute alar slope	115 (73)
	Acute alar slope	43 (27)
Presence of mammillary bodies on outlet pelvic CT view, **ALL**	Absent	226 (75)
	Present	77 (25)

Variable		**N = 303** **n (%)**
Presence of mammillary bodies on outlet pelvic CT view, **Female**	Absent	102 (70)
	Present	43 (30)
Presence of mammillary bodies on outlet pelvic CT view, **Male**	Absent	124 (78)
	Present	34 (22)
Unfused sacral disc segments on sagittal pelvic CT view, **ALL**	Unfused	234 (77)
	Fused	69 (23)
Unfused sacral disc segments on sagittal pelvic CT view, **Female**	Unfused	103 (71)
	Fused	42 (29)
Unfused sacral disc segments on sagittal pelvic CT view, **Male**	Unfused	131 (83)
	Fused	27 (17)
Presence of tongue in groove morphology on axial pelvic CT view, **ALL**	Absent	214 (70)
	Present	89 (30)
Presence of tongue in groove morphology on axial pelvic CT view, **Female**	Absent	98 (68)
	Present	47 (32)
Presence of tongue in groove morphology on axial pelvic CT view, **Male**	Absent	116 (73)
	Present	42 (27)

4.3 Quantitative Measures Of Sacral Dysmorphism

4.3.1 Sacral Dysmorphism Score

The sacral dysmorphism score of more than 70 was found in 63 percent, with it being more prevalent among males compared to females, 68percent and 57 percent respectively. Mean sacral dysmorphism score among those who had dysmorphic sacra was 81, whereas in those with non - dysmorphic sacra, the mean was 56. This showed a positive correlation between high sacral dysmorphism score in those scans categorized as dysmorphic. A Chi square test for heterogeneity was done and the p value was 0.078; indicating that there is no significant difference between males and females.

4.3.2 Safe Zone Cross- Sectional Area

The cross-sectional area for the S1 segment was found to be 379mm^2 for females and 417mm^2 for males. Males generally reported higher cross-sectional areas as compared to females. Regression analysis shows that the smaller cross-sectional areas are associated with a higher rate of dysmorphism. There is an inverse relationship between sacral dysmorphism score with the cross sectional area with the regression equation being: *sacral dysmorphism score (y) = 79.2-0.02(cross sectional area)*

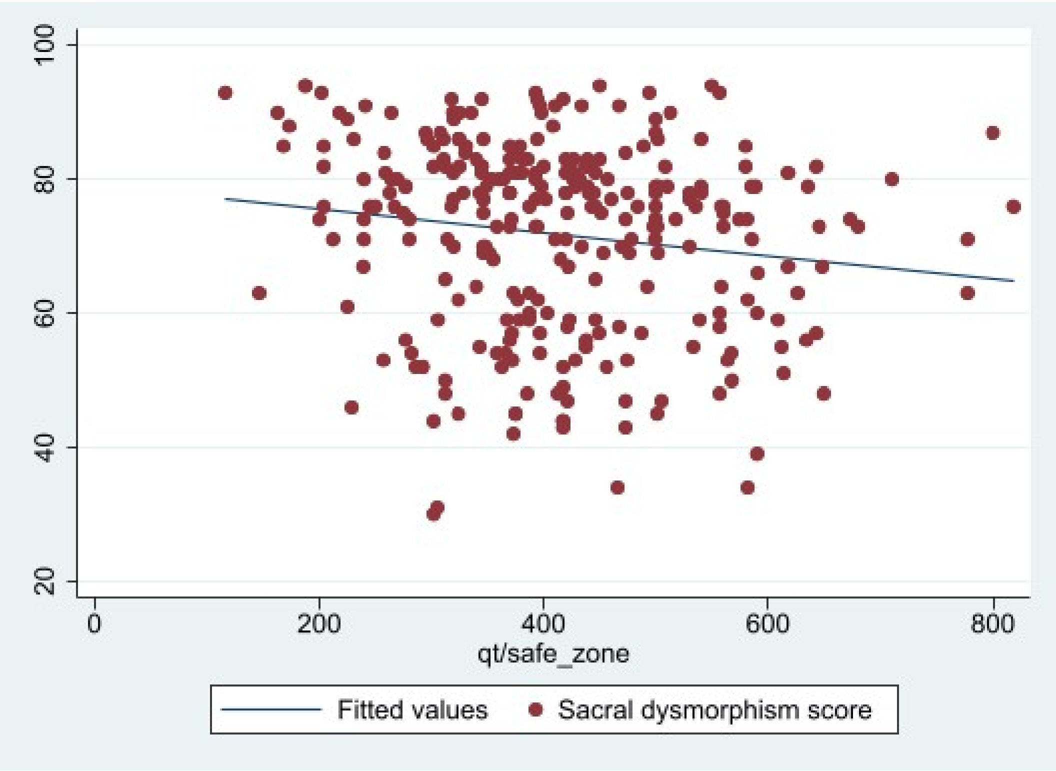

Figure 12: Regression Graph Between Sacral Dysmorphism Score and Cross Sectional Area

4.3.3 Acetabular Version Angle

The acetabular version angle was evaluated on all scans bilaterally with a recording of the average measurement. Acetabular version was found to be an average of 14 degrees amongst all subjects. There was no gender differences noted as the confidence intervals here overlap and the midpoints are similar. Hence no statistically significant gender intervals.

Based on the regression analysis done there is a positive correlation between acetabular version and sacral dysmorphism score. This is evidenced by this equation: *sacral dysmorphism score (y) =0.28(acetabular version) + 67.6*

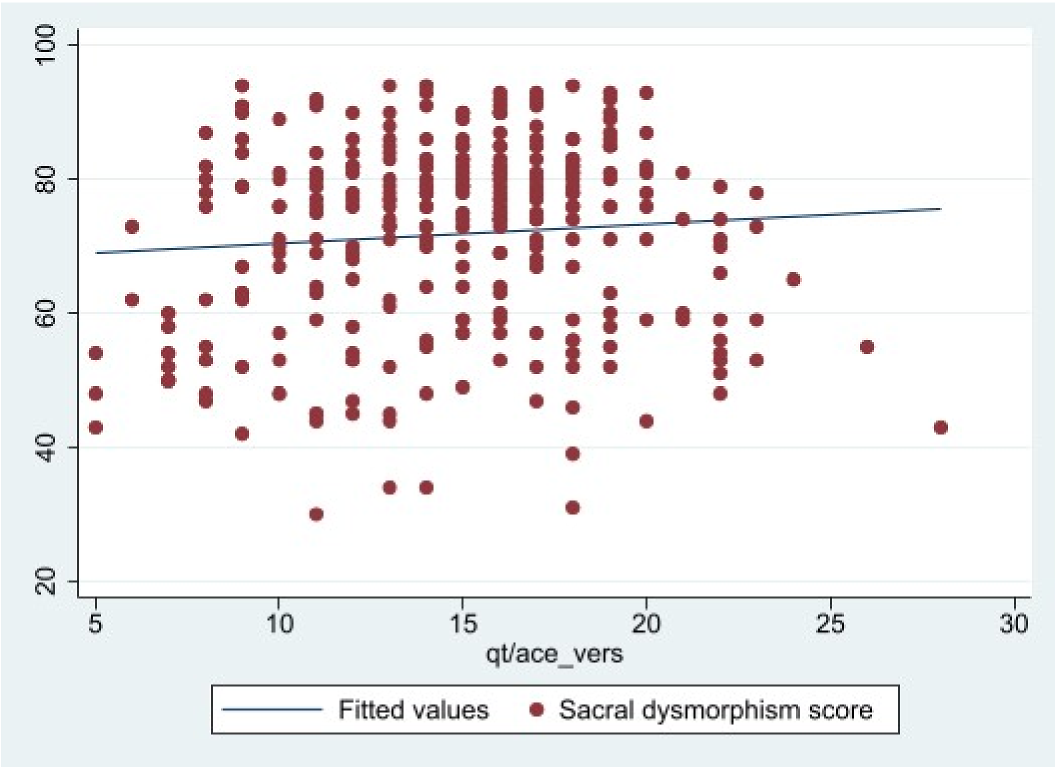

Figure 13: Regression Graph Between Sacral Dysmorphism Score and Acetabular Version

Table 3: Quantitative Measurements of Sacral Dysmorphism

Variable	**Female 145** **Male 158**	**N = 303** **n (%)**
Sacro-iliac dysmorphism score (Kaiser, 2013), **All**	> 70	193 (64)
	≤ 70	110 (36)
Sacro-iliac dysmorphism score (Kaiser, 2013) **Female**	> 70	85 (59)
	≤ 70	60 (41)
Sacro-iliacdysmorphism score (Kaiser, 2013) **Male**	> 70	108 (68)
	≤ 70	50 (32)
Safe zone cross – sectional area (mean, SD)	Female(143 obs)	395.52 (112.75)
	Male(156 obs)	426.18 (128.79)
	All	411.52 (122.15)
Acetabular version angle (mean, SD)	Female	14.57 (4.25)
	Male	14.87 (3.88)
	All	14.73 (4.06)

5.0 CHAPTER 5: DISCUSSION

The burden of trauma has been documented to be rising in lower and middle income countries (57). Pelvic trauma has been associated with significant morbidity and mortality(58). Life saving strategies need to be employed fast in order to save lives. Percutaneous sacral iliac screws have filled this gap and are aptly referred to as "resuscitation screws"(2).Posterior pelvic disruption contributes to significant morbidity and mortality; this has been mitigated in part, due to the use of percutaneous sacral iliac screws(5). Percutaneous sacral iliac screws are the current gold standard for fixation of posterior pelvic ring disruptions(1). These screws provide both stability and haemorrhage control. In experienced hands, these screws have been found to offer significant advantages such as minimal bleeding while offering stability. However, the main risk that is associated with the use of these screws is screw misplacement and subsequent damage to adjacent neurovascular structures(27). Sacral dysmorphism has been found to contribute to increase the likelihood of screw misplacement(21).

This study looked at almost an equal number of male versus female CT scans, 52percent and 48 percent respectively. Given the almost equal distribution we are able to make a rational comparison with regards to any gender differences in sacral dysmorphism. There was however no significant gender differences noted on dysmorphic versus non dysmorphic qualitative features. This is similar to other recent studies which note no gender differences in sacral dysmorphism(42).

We however note that pelvic trauma is predominantly in the younger population. Recent studies have found that pelvic trauma is common in the age group 37 to 47. The average age in our study was 44.44years with a range of (42.91-45.98); this was similar to other studies(59)(60).

Prevalence rates for sacral dysmorphism ranged between 20 – 80 percent. The highest was found in lack of recession of the s1 segments and presence of unfused sacral segments; this is similar to other studies that found the most common dysmorphic feature to be unfused sacral segment and lack of recession of the s1 segment in that order(19)(61).

However a direct correlation between these qualitative features and sacral dysmorphism score or cross- sectional area was not found in our study. This is similar to the Iranian study carried out in 2020 that was unable to find a reliable criteria for diagnosing sacral dysmorphism using qualitative features alone(62). However the high prevalence of these features in majority of the studies on qualitative features of sacral dysmorphism suggests that these highly prevalent features may be used as a screen for presence of sacral dysmorphism. This is important especially since these features are easily recognizable. This shows us that sacral dysmorphism is very prevalent and qualitative features alone may not be objective in determining the presence or absence of sacral dysmorphism.

With regards to quantitative features some significant differences were noted. Firstly, sacral dysmorphism score was found to be higher in males as well as the cross-sectional area of the s1 segment that was larger in males. Some previous studies which have shown high rates of sacral dysmorphism in females since they often present will narrower intra osseous S1 corridors(28) . It is also good to note that research is still ongoing in this area since there's been conflicting reports with regards to the role of gender in sacral dysmorphism(42).

The larger cross-sectional area in the s1 segment has been documented in several studies and may be attributed to the general larger stature of males(28). The increased rates of dysmorphism in the male population are contrary to the studies that show a higher female predilection(20)(16)(47). However it is good to note that other studies have not shown any gender differences. More studies need to be carried out in this area to evaluate gender differences and also rule out any role of ethnicity in the results found in our study. Sacral dysmorphism score of more than 70 in the original study by Kaiser et al was found to be 41 percent in the American population(16); and 37 percent in the Iranian population (62) whereas in our population it was found to be 63 percent. The role of ethnicity needs to be evaluated further in this case with similar studies being carried out in the African population. The dysmorphic sacra in our study had a sacral dysmorphism score of 81 which was comparable to 84 in the Iranian study(62).

Acetabular version angle has been found to range from 12 – 20degrees. Our study found acetabular version angle mean of 14degrees with a 95 percent confidence interval of 6 to 22 degrees, this is relatively normal given the variability that is expected in measurement of acetabular version due to pelvic tilt and obliquity among others(63). The positive correlation between acetabular version and sacral dysmorphism has not been studied before. A hypothesis can be generated from this data to evaluate whether the presence of sacral dysmorphism is associated with other pelvic abnormalities.

6.0 CHAPTER 6: CONCLUSION

In conclusion, sacral dysmorphism is highly prevalent within our study population. Care should be taken in screening patients for sacral dysmorphism as part of the pre-operative planning for sacral iliac screw fixation. Descriptive or qualitative features of sacral dysmorphism do not allow for a reliable way of predetermining sacral dysmorphism. Quantitative measurements of sacral dysmorphism offer a more objective way to evaluate sacral dysmorphism. There was no inferred gender influence on sacral dysmorphism.

6.1 Recommendations

Further studies need to evaluate gender and ethnic differences in sacral dysmorphism; size of osseous corridor in the first sacral segment compared to the second sacral segment; and role of unfused sacral segments as a screening feature for sacral dysmorphism. This feature (unfused sacral segment) is easily identifiable and has been found to have a very high prevalence globally based on available data. Alternatively a re-evaluation of these qualitative features of sacral dysmorphism may need to be done since there is such a high prevalence; future studies may need to consider this a normal feature if it is found not to have a direct correlation with narrowing of the safe osseous corridor in the S1 segment.

A recommendation of this study is that sacral dysmorphism score be requested in CT pelvises of trauma patients since this information is invaluable when planning to do percutaneous sacral iliac screw fixation. This offers new opportunities for further research to consolidate the role of sacral dysmorphism score in pre-operative screening for sacral dysmorphism.

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8.0 APPENDICES

A. Data Collection Sheet

Unique CT Study ID: ____________________

Date of Data Collection: ____________________

PART A: Demographic Data

	Variable	Unit of measurement	
1	Age of patient	Years	
2	Sex of patient	Male	Female

PART B: Quantitative Measurements

	Variable	Unit of measurement	Units
3	Coronal angulations of S1	Degrees	
4	Axial angulations of S1	Degrees	
5	Safe zone cross – sectional area	mm^2	
6	Acetabular version angle	Degrees	

PART B: Qualitative Features

	Variable	Pelvic CT View	Select one (Tick circle)	
7	Recession of S1	Outlet	**O**Presence	**O**Lack
8	Sacral foramina	Outlet	**O**Regular	**O**Irregular
9	Alar slope	Outlet	**O**Acute	**O**Notacute
10	Alar slope	Lateral	**O** Acute	**O** Not acute
11	Mamillary bodies	Outlet	**O** Present	**O** Absent
12	Sacral disc segments	Lateral	**O** Fused	**O**Unfused
13	Tongue in groove morphology	Axial	**O** Present	**O** Absent

B. Timeline

Table 4: Time Framework for the Project: April2020 to January 2022

Activity	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan ‘22
Developing Proposal										
Submitting proposal to supervisors for assessment										
Feedback from supervisors and corrections										
Submission to KNH-UoN ERC for perusal and approval										
Feedback from KNH-UoN ERC										
Resubmission to KNH-UoN ERC for approval										
Carry out pilot study at KNH Radiology Department										
Data collection at KNH										

Activity	Jan '22	Feb	March
Data analysis	■		
Writing results (Chapter 4), discussions and recommendations (Chapter 5)	■		
Submission of draft thesis to supervisors for feedback	■		
Corrections based on feedback from supervisors		■	
Final copy Submission to CHS – UoN		■	
Writing of manuscript for submission to peer reviewed journal			■
Submission to peer reviewed journal			■

C. Budget

Table 5: Budget

Particulars	Rate (KES)	No.	Days	Amount (KES)
Radiologist Consultant	5,000	2	15	150,000
Research Assistant	1000	1	10	10,000
Statistician	2000	1	10	20,000
KNH-UONERC fees	2,000	1	1	2,000
Final project writing, printing, and binding	-	-	-	26,550
Total Cost				**206,550**

Budget Justification

Two radiologist consultants were engaged in the study three hours a day for a period of 10 days each. In addition, the researcher enrolled the services of a research assistant over the same period of data collection to assist in populating the data set from the CT repository. This data set was randomized to create the sample. The research assistant was a radiographer based in the Radiology Department. The source of funds was from the researcher. The principle investigator coordinated data collection process working with both the research assist and the radiologists.