"ROLE OF ULTRASOUND IMAGING IN ASSESSMENT OF GROWTH PLATE AND IT'S CLINICAL APPLICATIONS – A ONE YEAR HOSPITAL BASED OBSERVATIONAL STUDY"

BY

REG. NO. BS0120014

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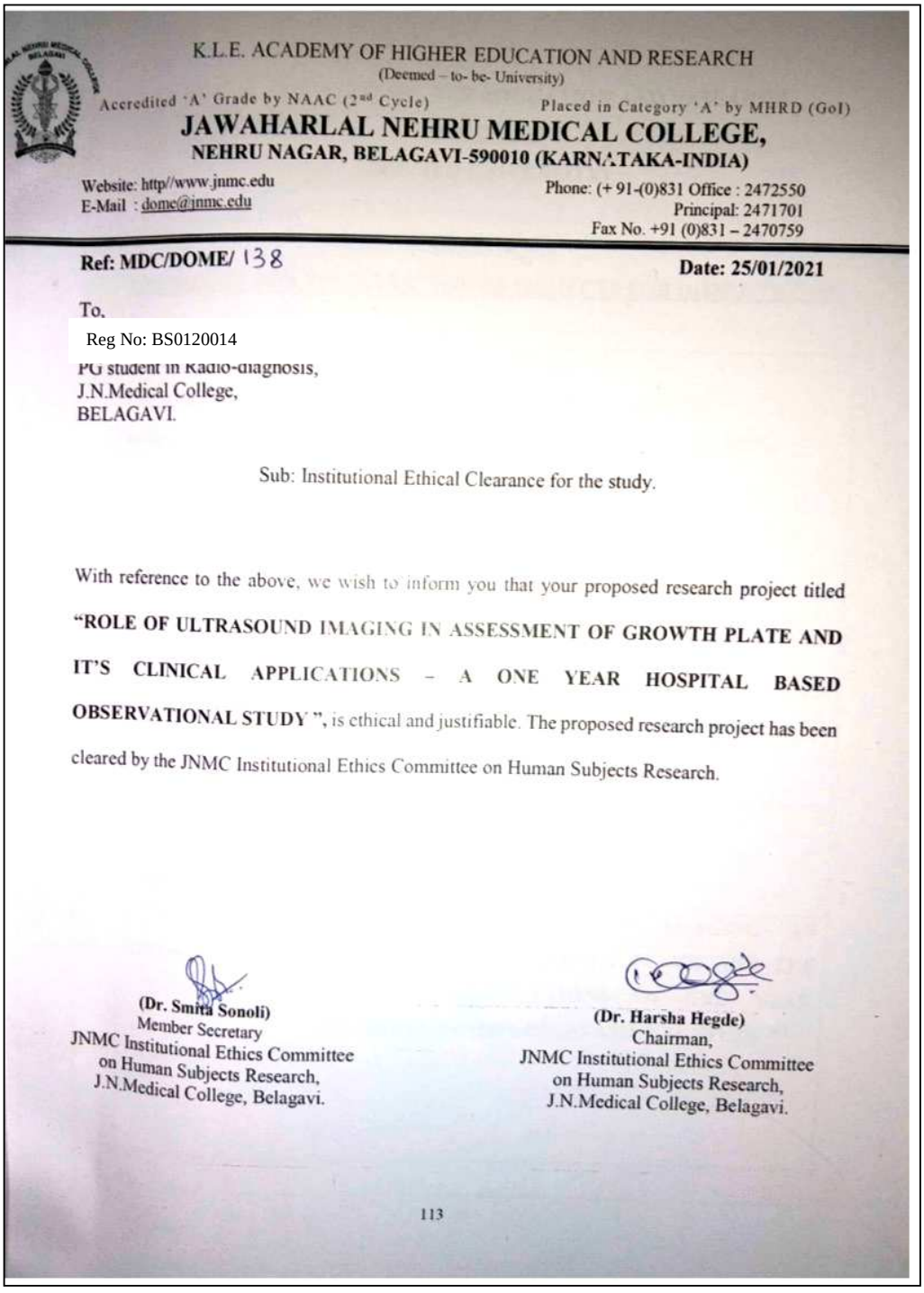

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With reference to the above, we wish to inform you that your proposed research project titled **"ROLE OF ULTRASOUND IMAGING IN ASSESSMENT OF GROWTH PLATE AND IT'S CLINICAL APPLICATIONS – A ONE YEAR HOSPITAL BASED OBSERVATIONAL STUDY "**, is ethical and justifiable. The proposed research project has been cleared by the JNMC Institutional Ethics Committee on Human Subjects Research.

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LIST OF ABBREVIATIONS

USG	Ultrasonography
MRI	Magnetic resonance imaging
T1w	T1 weighted
T2 w	T2 weighted
STIR	Short tau inversion recovery
CT	Computed tomography
SH	Salter Harris
ZPC	Zone of provisional calcification
SOC	Secondary ossification centre
GRL	Growth recovery lines
mm	Millimeter

ABSTRACT

BACKGROUD & OBJECTIVES:

The cartilaginous primary physis, or growth plate is a critical component of the immature skeleton and is present at the end of long bones in children allowing for longitudinal bone growth. Sandwiched between the metaphysis and the epiphysis, these areas are susceptible to a variety of insults that can lead to growth disturbances. The most often-described growth disturbance is premature physeal closure with bone bridge formation. Physeal fractures accounts for 21 to 30% of all long bone fractures while the isolated Physeal fractures or fractures through the growth plate is commonly graded as grade I fracture according to the Salter-Harris classification accounts for 6.0%–8.5% of all growth plate fractures. Plain radiography is currently the standard imaging choice for fractures in children but isolated physeal fractures are easily missed on radiographs making Ultrasound a potential modality in detecting such fractures. However, there are no established sonographic criteria for normative, baseline measurements for pediatric physeal plate widths, making identification and diagnosis of SH-I fractures challenging and subjective.

This study mainly focuses on to determine the role of ultrasound in the assessment of normal physeal plate while determining the baseline measurements in physeal plate width in pediatric population and assessing variation in the measured widths among contralateral sides, age group, and sex in the pediatric population.

MATERIALS AND METHODS:

This is a hospital based observational study, conducted from 1st January 2021 to 31st December 2021 for a period of 1 year in children between 5 to 12 years referred for ultrasound imaging to the department of Radio-diagnosis, KLE'S Dr Prabhakar Kore Hospital.

A total of 96 patients were included in this study. After obtaining informed verbal assent from children aged 7-12 years and written consent from the parents of all subject, they were subjected to B-Mode ultrasonography of distal end of long bones-radius, ulna, tibia and fibula using a 7.5–12 MHz high frequency linear array transducer on GE VOLUSON machine (GE Healthcare, USA) and Philips HD-11Xe machine. The findings of ultrasonography were assessed and analyzed. Descriptive analysis was carried out for all the quantitative data.

RESULTS:

Out of the total 96 children all between 5 to 12 years, 54 (56.25%) were males outnumbering the number of females enrolled in the study who were 42 (43.75%).

The mean age of the enrolled children was 8.25 ± 2.17 years.

No significant statistical difference could be elicitated in physeal plate width measurement in children of different gender and similar age group.

The average physeal plate width found in distal end of fibula is 3.0 ± 0.22 mm with a mean difference of 0.11 ± 0.3 mm between contralateral sides

The average physeal plate width found in distal end of tibia is 3.5 ± 0.28 mm with a mean difference of 0.1 ± 0.31mm between contralateral sides

The average physeal plate width found in distal end of radius is 2.88 ± 0.25 mm with a mean difference of 0.08 ± 0.31mm between contralateral sides

The average physeal plate width found in distal end of ulna is 2.74 ± 0.24 mm with a mean difference of 0.1 ± 0.32 mm between contralateral sides

No statistical difference was found in the physeal plate width between the contralateral sides for the long bones which were imaged in the study - radius, ulna, fibula or tibia.

CONCLUSION:

This study is first of its kind in India to assess the normal physeal plate and determine sonographic baseline measurements of physeal plate widths This study demonstrates that there is no statistically significant difference in physeal plate widths between contralateral extremities and between the two genders. Also children of similar age group has no significant disparity in physeal plate width measurement.

The sonographic detection of significant disparities in physeal plate widths of injured children may have the potential for earlier detection of SH injuries with subsequent appropriate management.

Keywords : **Ultrasonography of physeal plate, physeal plate width, radius, ulna, tibia, fibula**

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INTRODUCTION

Skeletal fractures exhibit unique patterns in the pediatric population because of the properties of growing bone [(1)] , including longitudinal and radial growth of the bone, which occurs during childhood and adolescence [(2).]

Present at the end of long bones between the metaphysis and epiphysis, the cartilaginous primary physis or growth plate is the most critical component of the immature skeleton. It allows for longitudinal bone growth [(1)] but is also the weakest skeletal structure in children[(3)]. Injury to either the growth plate (direct injury) or the adjacent epiphysis and metaphysis (indirect injury) can cause growth plate dysfunction, ultimately leading to growth disturbances. The most common insult mechanism is trauma, which can directly or indirectly injure the growth plate.[(4)] Approximately eighteen percent of all fractures in children involve the growth plate and 5% to 10% of physeal fractures lead to growth disturbances [(5)].

Less common mechanisms of indirect causes of injury include vascular compromise, infection, inflammation, radiation and tumour. The most often-described growth disturbance is premature physeal closure with bone bridge formation [(4)]. Chronic repetitive physeal injuries can also cause physeal widening or physeal bridges [(6).]

The Salter-Harris classification system is currently used to grade the fractures involving the growth plate in children [(7)]. The physeal fractures are subdivided into five classes based on their radiographic appearance and causal mechanism [(4)].

Type I Salter-Harris fractures, accounting for 6.0%–8.5% of growth plate fractures, are transverse cleavages through the growth plate [(4)]. The physeal fractures account for 21 % to 30% of all long bone injuries.[(1)] Also, there is a greater propensity for

growth disturbance when injuries occur at the distal ends compared to the proximal ends of the long bones [8].

Plain radiography is currently the standard imaging choice for fractures in children, but isolated physeal fractures, i.e. Salter-Harris type I fracture are easily missed on radiographs. Due to the lack of any prominent radiographic signs on initial presentation, the diagnosis of an undisplaced Salter-Harris type I injury becomes more of a clinical diagnosis based on swelling and tenderness directly over the affected physis of long bones [9]

Ultrasound thereby has a potential role in detecting such fractures and in the prevention of future growth disturbances. It has the advantage of real-time assessment, ease of access, and cost-effectiveness with no radiation exposure at all, making it a superior and more convenient modality to use in paediatric emergencies and in follow-up cases where the use of radiography leads to repeated radiation exposure.

However, there are no established sonographic criteria for normative baseline measurements for pediatric physeal plate widths, making identification and diagnosis of SH-I fractures challenging and subjective.

OBJECTIVES

With the help of ultrasonography, we aim to diagnose radiographically silent fractures involving the paediatric physeal plate

OBJECTIVE OF THE STUDY:

1. To determine baseline measurements of physeal plate width and to assess variation in the measured widths among contralateral sides, age group, and sex in the pediatric population.
2. Ultrasound assessment of physeal plate in normal uninjured children in order to detect any variations from the normal anatomy if present including physeal plate fracture, bridge and premature closure of the physis

REVIEW OF LITERATURE

ANATOMY:

The human skeleton is divided into two major groups - the appendicular group comprising the long bones of the upper and lower extremities, including the shoulder girdle & pelvis and the axial group [10]

Anatomically, the long bones of the body are divided into three parts - hollow shaft or diaphysis which is primarily composed of dense cortical bone, the metaphysis below the growth plates and rounded epiphyses above the growth plates. Both the metaphysis and epiphysis are composed of trabecular meshwork bone surrounded by a relatively thin shell of dense cortical bone [2].

Based on the tissue composition and its contribution to growth, the developing ends of long bones can again be divided into the cartilaginous epiphyseal unit, osseous metaphysis and fibrous perichondrium. The epiphysis and the physis / growth plate are parts of the epiphyseal unit [11].

Sandwiched between the epiphysis and the metaphysis, the growth plate is made of a particular type of cartilage, bony and fibrous components with a unique metabolism as a result of its unique microcirculation and extracellular microenvironment [12,13] The periphery of the physis consists of two elements: The groove of Ranvier and the perichondrial ring of LaCroix, which is a dense fibrous structure that surrounds the groove of Ranvier and is continuous with the periosteum of the metaphysis providing stability to the growth plate. Being composed of vertical, horizontal and oblique collagen fibres, it is very resistant to shearing forces, thereby providing mechanical support to the otherwise weak chondro-osseous junction.

The perichondrial groove of Ranvier is a wedge-shaped band of osteoblasts, chondrocytes and fibrous cells at the periphery of the germinal zone and is responsible for latitudinal growth of the physis.[11]

The growth plate has two parts - primary discoid growth plate, which is responsible for the longitudinal growth of the bone and the secondary spherical growth plate or acrophysis, which is responsible for the enlargement of the secondary ossification center (SOC) within the cartilaginous epiphysis. [4]

The attachment of the growth plate to the metaphysis has reduced bone strength and is thus an important site of injury after musculoskeletal trauma. Damage to the growth plate at this point can disrupt future growth at that site [14].

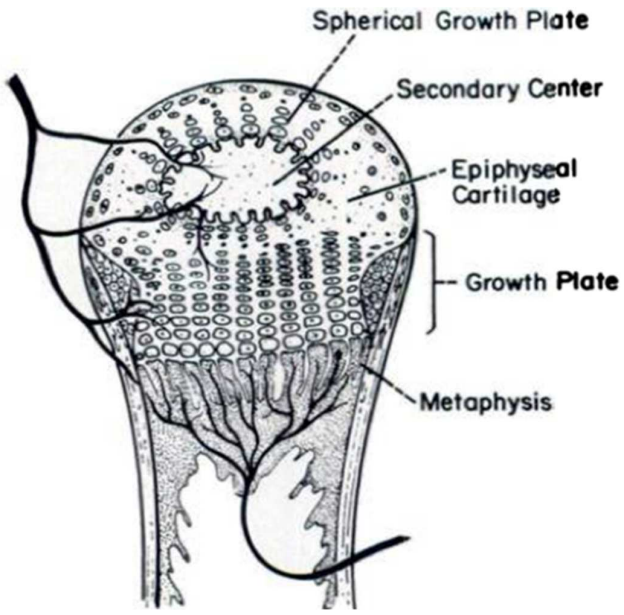

Fig. 1 Anatomy of epiphysis and the growth plate

HISTOLOGY:

The growth plate is a highly cellular structure with the chondrocytes maturing as they move toward the metaphysis from the epiphyseal side.

Based on their microscopic cellular morphology and function, there are three distinct histologic zones of chondrocytes recognised as reserve, proliferative, and hypertrophic zones (including zone of provisional calcification) [(4)].

Reserve Zone: The region of the physis adjacent to the epiphysis is the reserve or germinal zone containing abundant extracellular matrix and disorganised collagen fibrils with randomly distributed chondrocytes. These chondrocytes function as the stem cells of the physis and are responsible for storing nutrients (glycogen and lipids), dividing only sporadically. The oxygen tension in this region is also low compared to the other regions [(4,13).]

Proliferative Zone: Proliferative layer lies just deep to the germinal layer, where collagen fibrils are confined to longitudinal septa and chondrocytes are organised into columns. The chondrocytes rapidly divide in this region owing to the highest oxygen content allowing for longitudinal bone growth. This high oxygen supply comes from branches of the epiphyseal artery coursing within the vascular channels through the reserve zone to supply the upper proliferative zone. Hence, any insult to this zone will most likely result in growth disturbance [(4. 6)].

Hypertrophic zone: Closest to the metaphysis lies the hypertrophic layer of the physis which prepares the matrix for calcification and triggers organised apoptosis of

chondrocyte[6].This zone can be further subdivided into the zones of maturation, degeneration, and zone of provisional calcification (ZPC) [15].

In the metaphyseal side abutting the ZPC lies the primary spongiosa which is a highly vascularized structure that contains the newly formed metaphysis[16]. The metaphyseal arterial loops are found just short of the ZPC, leaving the hypertrophic zone avascular. The low oxygen tension leads to anaerobic metabolism with mitochondrial release of calcium, thereby facilitating matrix calcification. Progressive matrix calcification hinders the diffusion of nutrients and oxygen, ensuring apoptosis of the remaining chondrocytes [4, 6]

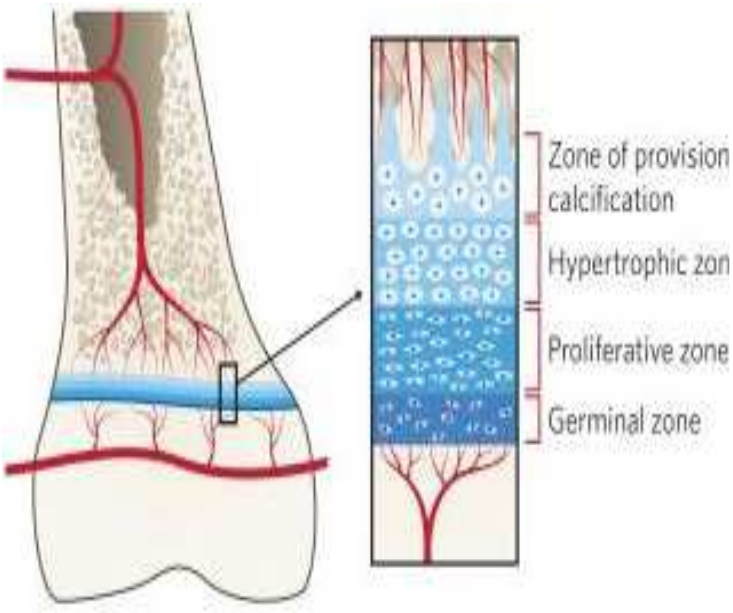

Fig 2. Histology of growth plate

VASCULAR SUPPLY:

The unique arrangement of vascularity at the distal end of developing bone allows for a coordinated balance between chondrocyte growth & division and endochondral bone formation [(6)].

Three different vascular systems supply the growth plate and the epiphyseal region of long bones: the epiphyseal, metaphyseal and perichondral arterial blood supply.

The epiphysis and the secondary ossification center are supplied by Epiphyseal arteries, which enter the epiphysis from different sides. The branches of the epiphyseal artery also supply the germinal zone and a portion of the proliferative zone [(6, 17)] .

The epiphyseal vasculature further subdivides into central arterioles coursing through blind-ended epiphyseal vascular canals where an epiphyseal vascular complex is formed. Arterioles within junctional canals branch into penetrating epiphyseal vessels that descend through the epiphyseal-physeal boundary to terminate as a penetrating vascular plexus supplying the parts of the growth plate [(18, 19)].

The physis thereby has a dual vascular supply - the epiphyseal vessels nurture the chondrocytes of the physis and the metaphyseal vessels regulate enchondral ossification by invading the physis and triggering cell death and bone synthesis [(11)].

Only the hypertrophic zone of the physis remains avascular as the metaphyseal and nutrient vessels loop back on themselves.

Metaphyseal arteries also supply the peripheral and central portions of the metaphysis. These metaphyseal arteries are primarily derived from the nutrient artery, which further divides in a tree-like fashion into several major branches and multiple smaller arteries and capillaries.

The perichondral vessels surround the growth plate by a circular vascular system sending anastomoses to both the metaphyseal and the epiphyseal arteries [6, 17].

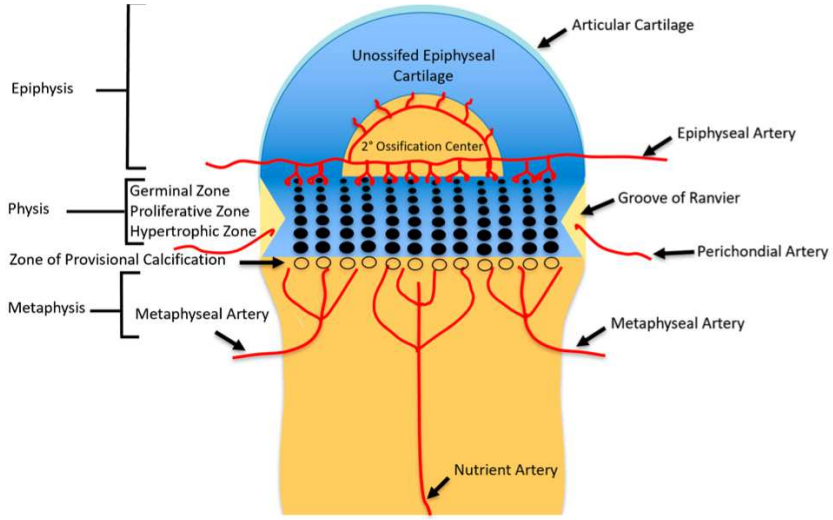

Fig 3. Vascular supply of growth plate

EMBRYOLOGY:

Formation of bone occurs in two ways - intramembranous and endochondral ossification. In general, flat bones develop through intramembranous ossification, which takes place mainly in the cranial vault, mid-clavicle, mandible and maxilla during the first few months of foetal development, occurring directly from the mesenchyme.

The long bones develop by means of endochondral growth, which is the overall dominant process in the skeleton and occurs in the skull base, vertebral column, pelvis, and extremities. This endochondral growth occurs on a cartilaginous framework at the growth plate [4, 19].

The cartilaginous extracellular matrix they construct is then invaded by blood vessels, osteoclasts, bone marrow cells and osteoblasts, the last of which deposit bone on remnants of cartilage matrix

During the 6th week of embryonic development, mesenchymal cells differentiate into chondrocytes which are responsible for the formation of a cartilaginous model of a future skeleton. As a part of endochondral ossification, chondrocytes proliferate and undergo hypertrophy while the matrix begins to calcify in the central portion of this cartilaginous anlage, i.e. the future diaphysis. During the 7th week of embryonic development, there is formation of the periosteal sleeve. Vascular invasion with mesenchymal cells differentiation into osteoblasts and osteoclasts occurs by the 8th week.

The primary ossification centre is produced by the osteoblasts, which manufacture an osteoid matrix on the calcified matrix. On the other hand, osteoclasts are responsible for bone remodelling and medullary cavity formation.

As the primary ossification centre grows toward the ends of the bone and expands bidirectionally, its leading edges become the primary growth plates.

Growth cartilage is found in two locations at each end of a developing long bone: the growth plate and the articular-epiphyseal growth cartilage, which drives expansion of the primary and secondary centres of ossification [4, 20].

During ossification, the condensation of the periphery of the mesenchymal model forms the double-layered periosteum [21].

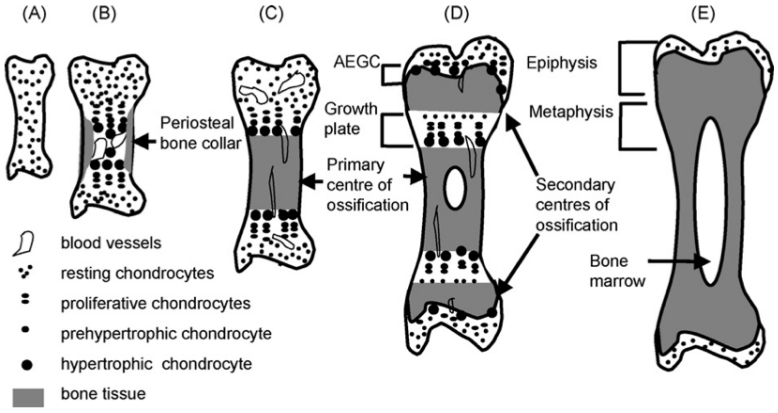

Fig 4. Embryology of bone

At birth, the primary growth plates are relatively smooth and flat assuming a more undulating configuration during childhood in response to physiologic dynamic biomechanical forces. However, the thickness of the growth plate remains relatively constant because of an intricate balance between chondrocyte proliferation and death. Any focal thickening is thereby suggestive of a disturbance in endochondral ossification. Narrowing across the growth plate signals its closure with impending skeletal maturation. The final conversion of chondrocytes into bone leaves behind a physeal scar representing a residual zone of provisional calcification (ZPC) that rarely persists into adulthood [(4,16)].

PHYSEAL INJURY:

Insults to immature skeletons, i.e., with an open growth plate may affect the bone growth resulting in growth arrest, angular deformities and limb shortening [(22)].

The most widely described type of growth disturbance is physeal arrest with bone bridge formation across the physis. Any physeal dysfunction without bridge formation occurs with resultant physeal irregularity or widening.

The mechanisms of growth disturbance include direct physeal injury, epiphyseal injury and metaphyseal injury [(11)].

Physeal insults and less commonly the epiphyseal insults may lead to physeal bridge formation, while the metaphyseal injuries typically lead to disruption of apoptosis and endochondral ossification resulting in widening of the physis [(6)].

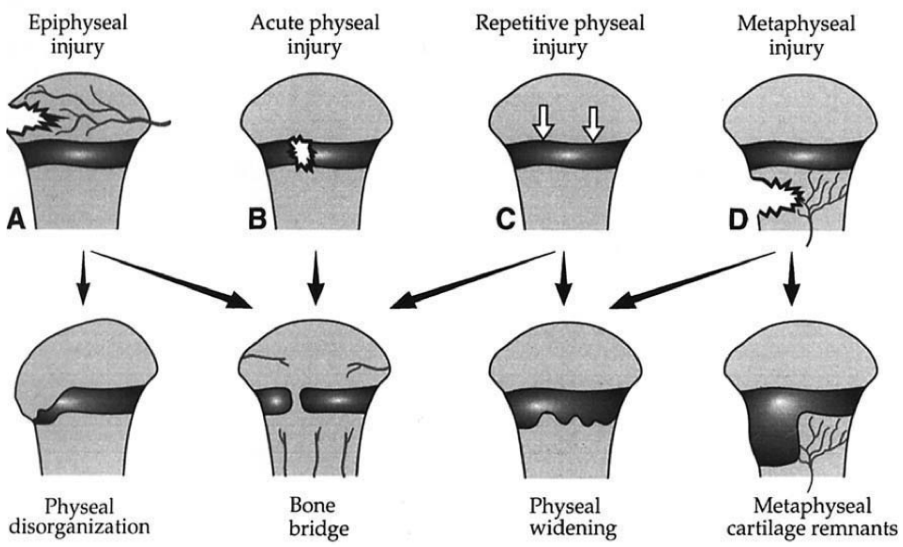

Fig 5. Types of physeal injury

Direct physeal injury: Direct injuries to the physis can occur from a fracture that extends across or into the physis (i.e. Salter–Harris-type fractures) or from chronic repetitive injuries to the physis. They are the most common cause of physeal bridges. When a fracture extends longitudinally across the physis, it allows for the formation of transphyseal vascularity with communication of epiphyseal and metaphyseal arteries. Osteoprogenitor cells can then deposit bone along these transphyseal vessels forming a bridge [(6)].

Following a physeal fracture, the risk of growth disturbance is dependent on the severity of the injury, the patient's growth potential (age and skeletal maturity) and the anatomic site involved. The fracture pattern also plays a role and has a direct relation to premature physeal closure and the chance for angular deformity.

Fractures with significant comminution, displacement, or with loss of a segment of the germinal or proliferative physeal layers are at greatest risk. Younger patients have a poorer prognosis because there is more time for the deformity to develop. The importance of the anatomic site is related to the contour and size of the physis and its rate of growth.

The most common sites of physeal fracture are the phalanges and the distal radius, but they rarely result in growth arrest. Post-traumatic physeal bridge formation is much more common at the distal ends of long bones than at the proximal ends and in the lower extremities as compared to the upper extremities.

Most physeal bridges occur in areas of physeal undulation, such as the distal femoral physis and medial aspect of the distal tibial physis. The distal tibia is by far the most frequent site of post-traumatic bridge formation [11,16,23,24]

Indirect physeal injury: [11, 25]

Epiphyseal injury: Epiphyseal injury may lead to two types of growth disturbances. Any compromise of epiphyseal vascularity leads to focal ischemia of the germinal and proliferative zones of the physis resulting in the death of the chondrocyte, which may lead to bony bridge formation. Alternatively, if growth ceases in the ischemic portion of the physis and continues in the unaffected areas, there is a loss of its normal discoid shape with the area of slowed growth curving toward the metaphysis leading to angular deformity.

Metaphyseal injury: Injury to the metaphyseal vascularity has no effect on chondrogenesis or chondrocyte maturation, but rather blocks enchondral ossification. Thus disruption of the metaphyseal blood supply leads to a thickened physis, with an abundance of hypertrophic chondrocytes that have lost their signalling to die and ability to mineralise. This persistent metaphyseal cartilage may take the form of a tongue perpendicular to the physis or a broad band extending from the physis

SALTER HARRIS CLASSIFICATION:

Robert B. Salter and W. Robert Harris introduced a physeal fracture classification system in 1963, based on anatomy, fracture pattern and prognosis [26, 27]

Since Salter-Harris fractures or physeal fractures refer to fractures through a growth plate (physis), they are therefore described exclusively in children [7].

These fractures mainly occur at the ZPC, a transition point which is weaker than the surrounding structures and is thus more prone to trauma.

In general, upper extremity injuries are more common than lower extremity injuries. Of the five most common Salter-Harris fracture types, type II is the most common (75%), followed by types III (10%), IV (10%), type I (5%), and lastly, type V, which is very rare [7].

Salter-Harris types I and II fractures are horizontally oriented fractures that follow the plane of the physis resulting in less bone bridge formation than the Salter-Harris types III and IV fractures which are vertically oriented fractures traversing the physis resulting in breach of the reserve and proliferative layers.

Radiographic findings generally include a frank physeal fracture or a physeal bony bridge.[28]

Salter Harris fracture type I: Fracture lines extending through the physis or within the growth plate are deemed as Salter Harris type I fracture. In these fractures, there is absent involvement of both metaphysis and epiphyseal ossification centre, representing approximately 6.0% to 8.5% of all injuries [7 , 29]

These fractures are due to the longitudinal shearing and avulsion force applied through the physis resulting in splitting of the epiphysis from the metaphysis. However, the displacement of epiphysis is only momentarily at the time of injury and returns to its normal position on removal of the shearing and distracting forces. The periosteal attachments usually remain intact [27].

The most common sites of Salter-Harris type 1 fractures were the distal radius and phalanges [29] During childhood, an undisplaced Salter-Harris I physeal injury is more likely since tears or ruptures of major ligaments are uncommon [28]. Thereby, children with history of trauma and clinical signs of fracture but having a normal radiograph may be suspected for an undisplaced Salter-Harris I physeal injury.

Salter Harris fracture type II : Fracture line involving the physis and further extending through a margin of the metaphysis is referred to as Salter-Harris type II injury resulting in the separation of a variably sized triangular metaphyseal fragment referred to as the corner sign / Thurston- Holland fragment [29]. These fractures are the most common type of Salter-Harris fractures and occur away from the joint space [7]. During childhood, the periosteum extends along the primary center of ossification till the level of the physis where it is tightly attached. More proximally along a long bone its attachment to the bony cortex via Sharpey's fibres is more flimsy and loose. This is responsible for the production of Salter-Harris II fractures in which a fracture line

running through the physis that is unable to violate the tight periosteal attachment to the physis and thereby deviates into the metaphysis [30].

Salter Harris fracture type III : These fractures are intra-articular fractures which extend from the physis into the epiphysis. If the fracture line extends through the complete length of the physis, this type of fracture may form two epiphyseal segments**.** Normally the displacement is minimal, with no associated fracture of the metaphysis [29].

These fractures may also result in damage to the articular cartilage with a predisposition to stunted growth and premature osteoarthritis.

Salter Harris fracture type IV: These are vertically oriented intra-articular fractures with splitting compression force that extends through epiphysis, physis and adjacent metaphysis resulting in the separation of a portion consisting of both metaphysis and epiphysis.

Since the epiphysis is involved, like the Salter-Harris III fracture, the articular cartilage may be damaged. These fractures thus also carry a risk for altered joint mechanics, growth retardation and functional impairment [29].

Salter Harris fracture type V [7, 29]**:** Type V Salter-Harris fractures are rare fractures occurring due to a compression or crush injury of the growth plate with no immediate radiographic findings**.** The force is transmitted through the physis and epiphysis, potentially disrupting the germinal matrix, the hypertrophic region and the vascular supply. Such fractures tend to be seen in cases of severe injury or frostbite, electric shock and irradiation and typically have a poor prognosis leading to bone growth

arrest, which is detected only on follow-up examination as shortening of the bone with angular deformity**.**

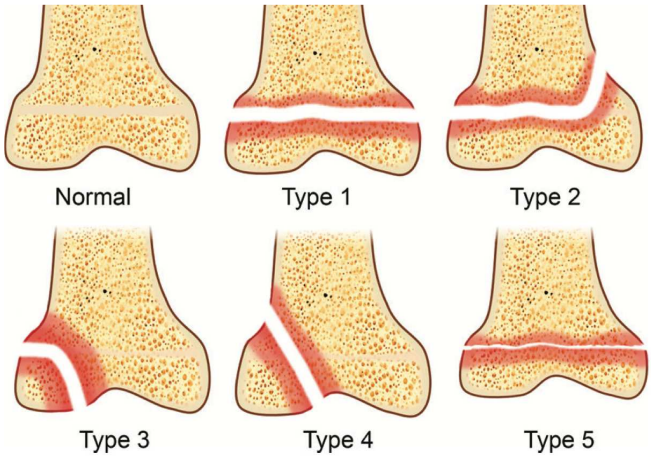

Fig 6. Salter Harris classification of physeal fracture

IMAGING IN PHYSEAL INJURIES:

For the evaluation of skeletal injuries, Plain radiography still remains the primary modality. Features indicative of physeal injuries are haziness or obliteration of normal sharply defined opposing margins of the epiphysis and metaphysis, epiphyseal displacement and widening / narrowing of the physis. [29]

Bone bridge formation can be visualised on radiographs after approximately three months following injury as foci of osteocondensation in the metaphyseal interface [10,22]. Other indirect findings on plain radiographs include angular deformities and ill-defined physeal lines [22].

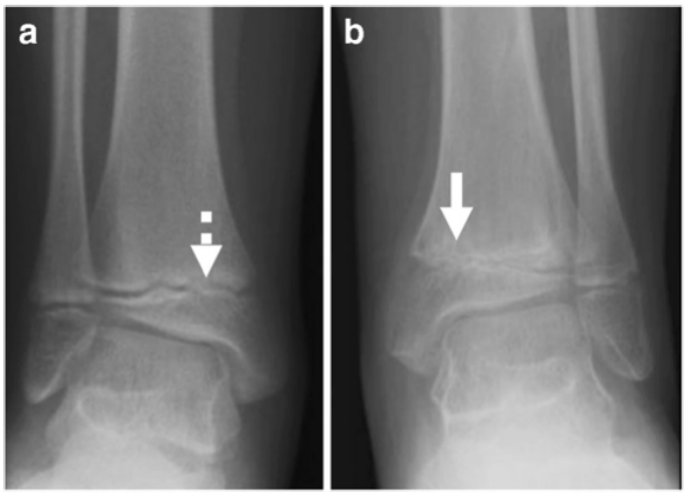

Fig 7. Narrowing of the distal tibial physis in left (image b) as compared to right (image a)

The use of plain CT is to more fully evaluate and classify injuries which are already identified on the plain radiographs and are particularly useful in Salter-Harris type 4 fractures to determine the alignment of the articular surface [(29)]

It can be used to identify physeal bridges and may identify the smaller ones missed on plain radiographs. CT allows evaluation of the interface between the epiphysis and metaphysis and thus is helpful in the localisation and dimension of the bone bridges**.** Smaller physeal bridges appear as a focal area of sclerosis on CT, while the larger physeal bridges appear as trabecular bone extending across the growth plate. The Coronal, sagittal and 3D reconstructions images acquired with CT are also helpful in preoperative planning [(6,22)]

In cases of subtle nondisplaced fractures, both plain radiographs and CT may require imaging of the contralateral side for comparison and identification [(16)].

However, CT has been mostly replaced by MRI for evaluation of the physeal bridges because of better visualisation of the physeal cartilage as well as the lack of

ionising radiation in MRI. For MR imaging of physeal pathology, coronal T1-weighted, sagittal fat-suppressed fast spin-echo proton density and T2-weighted images are acquired. T2- weighted images are used to differentiate physeal cartilage in young people, which appears bright compared to epiphyseal cartilage. T2-weighted images along with Proton density images, are also helpful for the identification of associated marrow and soft tissue edema, ligamentous or meniscal injury, persistent metaphyseal cartilage and avascular necrosis.

Growth recovery lines (GRL), also called Parks or Harris lines, can be visualised on radiographs and MR imaging and represents disks of transversely oriented bony trabecula. They are formed at the physis during slowed growth in view of injury or immobilisation. A GRL which appears angled or obliquely oriented when compared to the physis is indicative of growth tethered by a bone bridge and is typically best visualised on T1-weighted MR images [6,10].

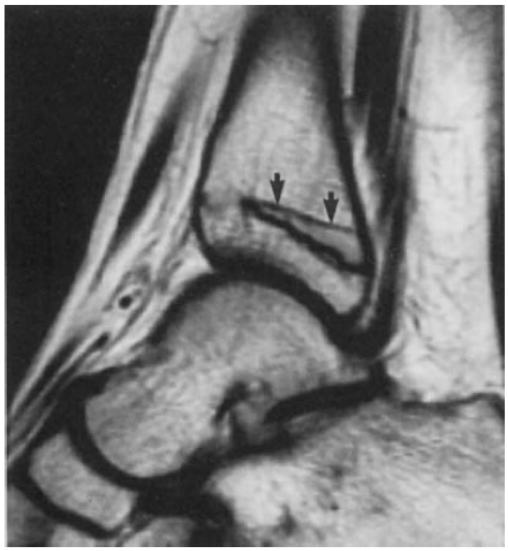

Fig 8. Sagittal MRI image of ankle showing the physis abutting the growth recovery line (arrows)

The signal intensity of physeal bridges on MRI depends upon the size of the bridge, sequence used as well as the presence or absence of bone marrow oedema. Chronic and larger bridges typically follow the bone marrow signal intensity on all sequences having increased signal intensity on T1-weighted MR images without fat saturation, and low signal intensity on T2-weighted fat-saturated or short tau inversion recovery (STIR) sequences On the other hand, smaller bridges may show low signal intensity on T1-weighted images due to either sclerosis or bone marrow oedema within and adjacent to the bridge [(6)].

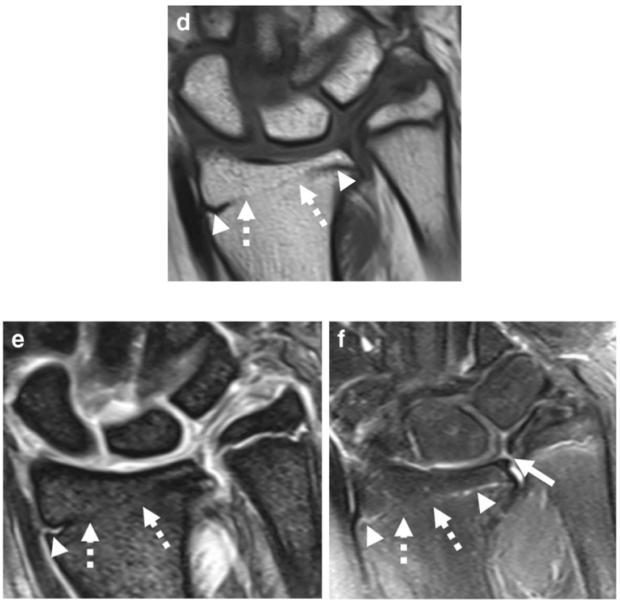

Fig 9. Coronal T1 weighted (d), 3-D gradient gradient recalled echo (e) and T2 weighted (f) images showing a large central bridge

On MRI, other indicative findings of growth plate injury are widening, irregularity and increased signal of physeal plate, adjacent bony marrow oedema and hypertrophy, and soft tissue oedema [(25)]

Ultrasonography provides excellent means to identify a fracture through the physeal plate, particularly in the paediatric age in whom the epiphyses are not ossified. It also allows for real-time imaging and comparison with the unaffected contralateral side within the same examination.

Evaluation of the unaffected side establishes the normal width of the growth plate, which adds certainty to the diagnosis of suspected physeal separation / fracture[1, 21,30]

The sonographic appearance of a normal cortex is bright or echogenic linear structure with hypoechoic shadowing posterior to the bone. The epiphyseal cartilage appears as a homogeneously hypoechoic pattern with scattered hyperechoic foci of calcification, while the ossified epiphyses appear similar to the diaphysis and are seen as a continuous echogenic line.

It is important to visualise the bone from all possible angles while searching for a fracture. An avulsion or metaphyseal fracture can be identified on sonography which is not seen on radiographs [31]

According to Davidson et al. and Markowitz et al., ultrasound could be very useful in the diagnosis of unossified medial epicondyle avulsion in young children presenting with elbow trauma. In young children, the injured unossified epiphysis can be easily missed on plain radiographs but can be visualised on sonography [14,32]

In a study done by M Burnier et al. and Simanovsky N, Hiller et al. ultrasonography was established as a sensitive imaging tool for the diagnosis of occult elbow and ankle fractures in children respectively. Negative ultrasound had negative radiograph establishing when both radiography and ultrasonography are normal, the possibility of fracture could be ruled out definitively, thereby reducing the need for unnecessary prolonged immobilisation [33, 34].

The ultrasonographic appearance of the fractures included subperiosteal haematoma, joint effusion, discontinuity of the echogenic cortical line, cortical depression, metaphyseal irregularity, a small echogenic fragment adjacent to the cortex, soft tissue swelling, periosteal elevation [34, 35].

Frances A. Farley et al. l, in their study, stated that extra-periosteal haemorrhage seen on sonography is more indicative of ligament injuries in contrast to physeal fractures which result in subperiosteal haemorrhage [35].

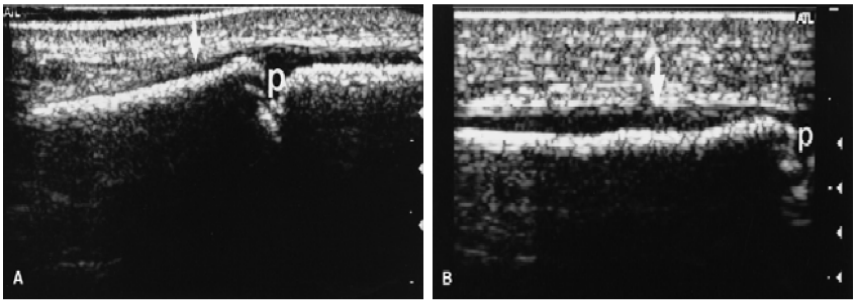

Fig 10 : Normal appearance of physis on USG

Fig 11 : Hypoechoic area along the bony cortex on USG – subperiosteal fluid consistent with Salter Harris type 1

The advantage of sonography is that it often provides the same information as radiography with no radiation to the patient. Also, musculoskeletal ultrasound is superior to radiography in identifying physeal separation, sub-periosteal hematomas, intra-articular bodies and ligamentous injuries. [31]

Compared to MRI imaging, ultrasound is less time-consuming, less expensive and gives the advantage of real-time imaging. However, there is a lack of studies directly comparing ultrasound to the gold standard MRI, and thus there is no evidence

establishing the specificity or sensitivity of ultrasound to diagnose physeal injuries when compared with MRI [36].

REVIEW OF STUDIES:

A recent study conducted by Lorraine N et al. in 2014 established baseline sonographic measurement of physeal plate width in uninjured and healthy children between the age group 0 to 12 years. The study also suggested that sonographic detection of significant disparities in the width of physeal plate of injured children may help in earlier detection of Salter-Harris injuries, thereby helping inappropriate referral and management [1].

SangHoo Kim et al. [37] in their research established a new imaging analysis algorithm for automatic detection of the size of growth plate via ultrasound. The ultrasonic images with measurement of growth plate in proximal tibiae, phalanges, and calcanei of 269 children of age 7 to 16 years and the X-ray showed high correlation. The advancements getting introduced in ultrasound thereby have a possibility to completely replace the existing X-ray method in order to measure the growth plate correctly, which can further help in the detection of growth plate fractures.

In a study conducted by Farley et al [35], 2 out of 14 children in USA who had ankle injuries with negative radiographs were found to have subperiosteal fluid adjacent to the distal fibula physis. The findings were consistent with Salter-Harris type I fracture which was confirmed after 2 weeks with X-rays.

Another case report by Taggart et al[38] established the role of sonography in radiographically silent fracture. In a 14- year-old boy with occult ankle injury,

diagnosis of Salter-Harris type I was made with the help of sonography which showed subperiosteal fluid at the metaphysis and distal fibula and widening of the physis as compared to the uninjured side. The findings were confirmed on subsequent X-rays which revealed a slight widening of the distal fibular physis with adjacent soft tissue swelling, thus being consistent with the diagnosis of Salter-Harris type I fracture.

Naum Simanovsky et al.[34] in their research suggested that with the use of only radiograph a high number of fractures are underdiagnosed and treated as simple sprains which further explains why a significant number of children have protracted pain and suffer from longer recovery period than others. The study concluded that the use of high-resolution ultrasonography is sensitive and specific in diagnosing occult pediatric fractures of ankle and thereby can be used as an adjunctive tool in evaluating pediatric injuries.

MATERIALS AND METHODS

Source of data: Children between the age group of 5-12years referred for Ultrasound imaging to the Department of Radio-Diagnosis at The KLE'S Dr. Prabhakar Kore hospital & MRC, Belgaum.

Method of collection of data:

(a) Study design: Hospital based observational study

(b) Sample size: Study comprised of 96 patients.

(c) Sample size formula:

The minimum sample size formula based on prevalence rate:

$$n = \frac{Z^2 p(1-p)}{d^2}$$

where P is the percentage of prevalence and d is the percentage likely difference in the prevalence.

Z is linked with z_α is linked with the level of significance. For 5% level of the significance $z_\alpha = 1.96$.

With P = 40% and d = 25% of P = 10.0%, the minimum sample size is 92.

(d) Study duration: January 2021-December 2021

(e) Sampling method: Random sampling

(f) Inclusion criteria:

1) Any child between the age group of 5–12 years referred to the Department of Radio-diagnosis at The KLE'S Dr. Prabhakar Kore hospital & MRC for ultrasound imaging.

(g) Exclusion criteria:

1) Any child having some known bony deformity.
2) Any child below the age of 12 years presenting with premature physeal closure.
3) Parental refusal of participation.

(h) Methodology:

Data was collected in patients referred for ultrasound imaging to the Department of Radio-Diagnosis at the KLE's Dr. Prabhakar Kore Hospital & MRC, Belagavi.

An informed verbal assent from children aged 7-12 years and written consent from the parents of all the subjects was obtained.

A pre-structured proforma was used for the collection of clinical data.

The above mentioned study population who met the inclusion criteria and did not get excluded were subjected to ultrasound of distal end of long bones on both sides mainly– radius, ulna, tibia and fibula. In a total of 96 children, the assessment of growth plate physeal width measurement was done on both sides using linear array transducer of 7.5-12 MHz on GE VOLUSON machine (GE Healthcare, USA) and Philips HD-11Xe. The transducer was placed along the long axis of ankle and wrist. After visualizing the metaphysis, the transducer was further slid distally to visualize the physeal plate which was seen as a smooth space between the epiphysis and metaphysis. To assess the physeal plate width, the measurement were taken on the dorsal surface of wrists, medial surface of tibia and lateral surface of fibula on both sides. All the children were examined on real-time two-dimensional greyscale and the images were stored securely.

Assessment of normal physeal plate with baseline measurements of physeal plate width along with assessment of variation in the measured widths among contralateral sides, age group, and sex in the study subjects were done.

Follow up: No

Ethical considerations: This research was accepted by an institutional human ethics committee. All research participants received informed written consent and only those participants willing to sign the informed consent were included in the research. The confidentiality of the participants in this research was preserved.

The data gathered was analyzed and presented where possible in the form of tables, graphs, figures, and diagrams.

STATISTICAL METHODS :

Descriptive analysis was carried out by mean and standard deviation for quantitative variables, frequency, and proportion for categorical variables. Non normally distributed quantitative variables were summarized by median and interquartile range (IQR). Data was also represented using appropriate diagrams like bar diagram, pie diagram and box plots.

All Quantitative variables were checked for normal distribution within each category of explanatory variable by using visual inspection of histograms and normality Q-Q plots. Shapiro- wilk test was also conducted to assess normal distribution. Shapiro wilk test p value of >0.05 was considered as normal distribution.

For normally distributed Quantitative parameters the mean values were compared between study groups using independent sample t-test (2 groups)

P value < 0.05 was considered statistically significant. IBM SPSS version 22 was used for statistical analysis.

IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp

RESULTS

Table 1: Descriptive analysis of age in study population (N=96)

Parameter	Mean ± SD	Median	Minimum	Maximum	95% C.I	
					Lower	Upper
Age	8.25 ± 2.17	8.00	5.00	12.00	7.81	8.69

The study had subjects between the age group 5 to 12 years. The average age of the population was 8.25 years in this study**.**

Table 2: Descriptive analysis of age group in the study population (N=96)

Age Group	Frequency	Percentages
5-8	56	58.33%
9-12	40	41.67%

The enrolled subjects were further grouped into two age groups and it was noticed that 58% of the study population were between the age of 5-8 years and almost 42% were between 9-12 years old.

Figure 1: Bar chart of age group in the study population (N=96)

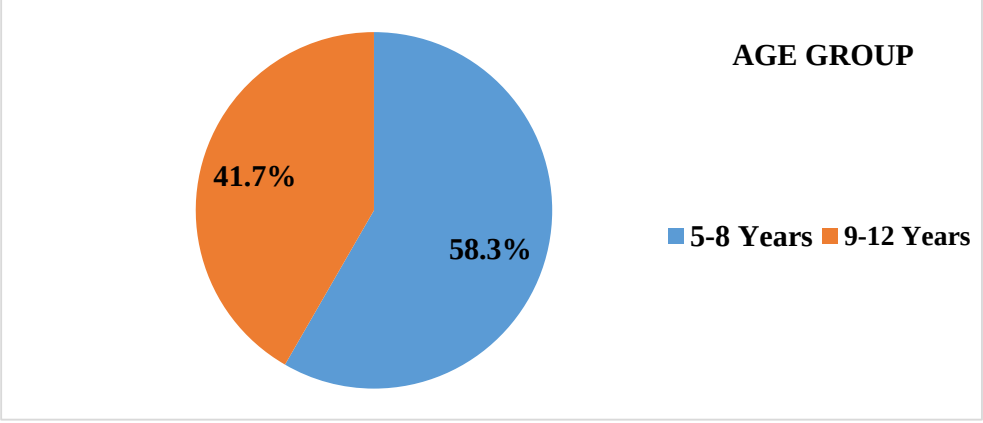

Table 3: Descriptive analysis of gender in the study population (N=96)

Gender	Frequency	Percentages
Male	54	56.25%
Female	42	43.75%

Out of the 96 study subjects enrolled in the study, 54 were male and 42 were females.

Figure 2: Bar chart of gender in the study population (N=96)

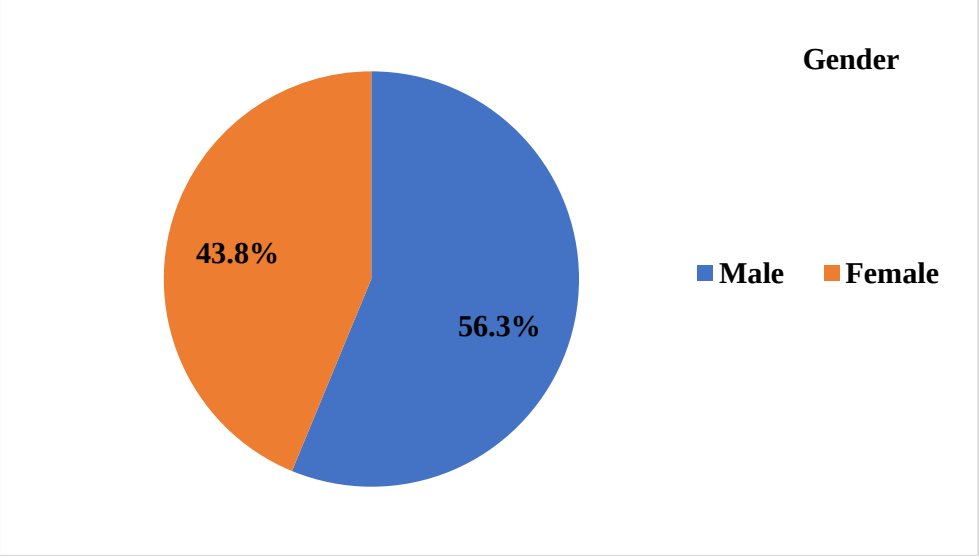

Table 4: Descriptive analysis of physeal plate width in study population Total (N= 96)

Parameter	Mean ± SD	Median	Minimum	Maximum	95% C.I	
					Lower	Upper
Physeal Plate Widths (mm)						
Right Radius	2.88 ± 0.25	2.9	2.3	3.5	2.8	2.9
Left Radius	2.96 ± 0.27	2.9	2.4	3.5	2.9	3.0
Right Ulna	2.74 ± 0.24	2.8	2.2	3.4	2.7	2.8
Left Ulna	2.84 ± 0.27	2.9	2.1	3.3	2.8	2.9
Right Fibula	3.0 ± 0.22	3.0	2.6	3.6	3.0	3.1
Left Fibula	3.11 ± 0.25	3.1	2.5	3.7	3.1	3.2
Right Tibia	3.5 ± 0.28	3.5	2.8	4.2	3.5	3.6
Left Tibia	3.6 ± 0.31	3.6	2.5	4.2	3.5	3.7
Difference Between Contralateral Side						
Radius	-0.08 ± 0.31	-0.1	-0.6	0.5	-0.1	0.0
Ulna	-0.1 ± 0.32	-0.2	-0.6	0.7	-0.2	0.0
Fibula	-0.11 ± 0.3	-0.2	-0.6	0.5	-0.2	0.0
Tibia	-0.1 ± 0.31	-0.2	-0.6	0.6	-0.2	0.0

The above table establishes that there is no statistical difference in the physeal plate width between the contralateral sides for all the long bones which were imaged in the study - radius, ulna, fibula or tibia.

The median value of physeal plate in right and left radius was same (2.9) whereas there was a difference of 0.1 while comparing the physeal plates of ulna (2.8 right and 2.9 left), fibula (3.0 right and 3.1 left) and tibia (3.5 on the right and 3.6 on the left).

Table 5: Comparison of mean of physeal plate width between age group (For Male) (N=54)

Parameter	Age Group (Mean± SD)	
	5-8 Years (N=33)	9-12 Years (N=21)
Physeal Plate Widths (mm)		
Right Radius	2.87 ± 0.28	2.91 ± 0.19
Left Radius	2.98 ± 0.27	3.03 ± 0.3
Right Ulna	2.75 ± 0.27	2.79 ± 0.16
Left Ulna	2.88 ± 0.22	2.9 ± 0.28
Right Fibula	2.99 ± 0.2	3 ± 0.17
Left Fibula	3.1 ± 0.23	3.14 ± 0.25
Right Tibia	3.47 ± 0.26	3.45 ± 0.28
Left Tibia	3.56 ± 0.32	3.55 ± 0.35
Difference Between Contralateral Side		
Radius	-0.11 ± 0.32	-0.12 ± 0.31
Ulna	-0.12 ± 0.35	-0.12 ± 0.32
Fibula	-0.11 ± 0.3	-0.14 ± 0.31
Tibia	-0.09 ± 0.31	-0.1 ± 0.33

The above table compares the differences in the mean width of contralateral physeal plate of the radius, ulna, fibula and tibia in the two age groups comprising of only males while proving there is no significant statistical difference seen in the two age groups.

Table 6: Comparison of mean of physeal plate widths between age group (For Female) (N=42)

Parameter	Age Group (Mean± SD)	
	5-8 Years (N=23)	**9-12 Years (N=19)**
Physeal Plate Widths (mm)		
Right Radius	2.83 ± 0.26	2.94 ± 0.25
Left Radius	2.95 ± 0.27	2.85 ± 0.23
Right Ulna	2.68 ± 0.23	2.74 ± 0.28
Left Ulna	2.77 ± 0.34	2.79 ± 0.25
Right Fibula	3.01 ± 0.23	3.02 ± 0.28
Left Fibula	3.1 ± 0.27	3.08 ± 0.27
Right Tibia	3.52 ± 0.29	3.59 ± 0.29
Left Tibia	3.62 ± 0.3	3.72 ± 0.26
Difference Between Contralateral Side		
Radius	-0.13 ± 0.3	0.09 ± 0.27
Ulna	-0.08 ± 0.35	-0.06 ± 0.25
Fibula	-0.1 ± 0.31	-0.07 ± 0.29
Tibia	-0.1 ± 0.3	-0.12 ± 0.29

The above table compares the differences in the mean width of contralateral physeal plate of the radius, ulna, fibula and tibia in the two age groups comprising of only females while proving there is no significant statistical difference seen in the two age groups.

Table 7: Descriptive analysis of any physeal plate abnormality detected in the study population (N=96)

Any Physical Plate Abnormality Detected	Frequency	Percentages
NIL	96	100.00%

Our study population comprised of healthy uninjured children and didn't show any incidental physeal plate abnormalities.

Table 8: Comparison of mean physeal plate widths and differences between the contralateral side between age group (N=96)

Parameter	Age Group (Mean± SD)		P value
	5-8 Years (N=56)	9-12 Years (N=40)	
Physeal Plate Widths (mm)			
Right Radius	2.85 ± 0.27	2.93 ± 0.22	0.174
Left Radius	2.97 ± 0.27	2.95 ± 0.28	0.667
Right Ulna	2.72 ± 0.26	2.76 ± 0.22	0.436
Left Ulna	2.83 ± 0.27	2.85 ± 0.27	0.695
Right Fibula	3 ± 0.21	3.01 ± 0.22	0.837
Left Fibula	3.1 ± 0.25	3.11 ± 0.26	0.864
Right Tibia	3.49 ± 0.27	3.52 ± 0.29	0.671
Left Tibia	3.59 ± 0.31	3.63 ± 0.32	0.493
Difference Between Contralateral Side			
Radius	-0.12 ± 0.31	-0.02 ± 0.31	0.137
Ulna	-0.11 ± 0.34	-0.09 ± 0.29	0.797
Fibula	-0.11 ± 0.3	-0.11 ± 0.3	0.995
Tibia	-0.09 ± 0.3	-0.11 ± 0.31	0.758

The above table did not show any statistical difference in the measured physeal plate width and their difference between the contralateral side be it radius, ulna, fibula or tibia between the two age groups under consideration in this study

Table 9: Comparison of mean physeal plate widths and differences between the contralateral side between gender (N=96)

Parameter	Gender (Mean± SD)		P value
	Male (N=54)	Female (N=42)	
Physeal Plate Widths (mm)			
Right Radius	2.89 ± 0.25	2.88 ± 0.26	0.872
Left Radius	3 ± 0.28	2.91 ± 0.26	0.100
Right Ulna	2.76 ± 0.23	2.71 ± 0.25	0.249
Left Ulna	2.89 ± 0.24	2.78 ± 0.3	0.051
Right Fibula	2.99 ± 0.19	3.01 ± 0.25	0.696
Left Fibula	3.12 ± 0.24	3.1 ± 0.27	0.678
Right Tibia	3.46 ± 0.27	3.55 ± 0.29	0.109
Left Tibia	3.56 ± 0.33	3.66 ± 0.28	0.094
Difference Between Contralateral Side			
Radius	-0.11 ± 0.31	-0.03 ± 0.31	0.190
Ulna	-0.12 ± 0.33	-0.07 ± 0.31	0.443
Fibula	-0.12 ± 0.3	-0.08 ± 0.3	0.531
Tibia	-0.09 ± 0.32	-0.11 ± 0.29	0.812

The above table proves that the differences in the physeal plate width and its variation between the contralateral sides in radius, ulna, tibia and fibula is statistically insignificant between the two genders.

DISCUSSION

Ultrasound being a non-invasive and cost-effective imaging modality can play a vital role in diagnosis of radiographically occult or isolated physeal fracture i.e., Salter-Harris type I fracture. This study conducted over a period of 12 months in the Department of Radiodiagnosis, Jawaharlal Nehru Medical College, Belagavi is thereby done with the purpose of establishing the importance of ultrasonography in diagnosis of pediatric physeal plate fractures.

In the current study, after considering the inclusion and exclusion criteria, sample size was taken as 96 being almost similar to the sample size of 95 used by Lorraine et al. [(1)] in his study.

In this study we tried to successfully compile a database of baseline measurements of the physeal widths of the four long bones - radius, ulna, fibula and tibia with further comparison of the width between the contralateral side, gender and age. This database would aid to detect any disparity further helping in diagnosis of physeal plate fracture.

It has been researched that a variety of pathological conditions including fractures in patients with immature skeleton may affect the physis resulting in complications like growth arrest, limb shortening, development of bone bridges and angular deformities.[(39)]

The study was done on healthy children between age 5 to 12 years further divided into two age groups mainly 5 to 8 years and 9 to 12 years with no history trauma or skeletal abnormality. The maximum age of the included subject was capped at 12 years in order to avoid cases with closed physeal plate.

The number of males included in the study were 54 (56.25 %) outnumbering the number of females which were 42 (43.75%).

Maximum number of children enrolled in the present study were between the age group of 5-8 years (58.33%) with a mean of 8.25 years and a standard deviation of 2.17 whereas the mean age in the study done by Lorraine et al [(1)] was 6 years 3 months.

Shari T et al. in his study compared three imaging modalities namely radiographs, computed tomography and magnetic resonance imaging, and found MRI to be the most sensitive of all to visualize the physis [(40)]. However recent studies like that of Lorraine et al [(1)] and Crystal C Wang et al [(31)] stated sonography to be effective in accurately determining physeal plate width and thereby help in diagnosing physeal injuries.

Naum simanovsky et al. [(34)], in their study established that sonography is more sensitive in detecting fractures when compared to radiographs.

Since there is a lack of a sonography data regarding the physeal plate fractures, we chose ultrasonography as the modality to evaluate the physeal plate in our study.

Our study is the first in the nation to evaluate, measure and compare physeal plate widths among pediatric population with respect to contralateral side, gender and age.

The average physeal plate width, in our study population, found in distal end of fibula, radius, ulna and tibia have been compiled in the results along with the differences seen in contralateral sides of each.

Sonography of none of the children in the study revealed any kind of incidental physeal abnormalities or variations.

Also, in our study we could not establish any statistically significant disparity in physeal plate width measurement between contralateral sides.

Lorraine et al. [(1)], found in their study that there was minimal variation in the physeal plate widths of pediatric patients regardless of age or sex, and the same result was seen in our study where there was very minimal variation in the widths seen in both age and sex.

Our study aids the study conducted by Lorraine et al.[(1)] in establishing baseline values of physeal plate width which can be used by all the radiologists to diagnose Salter Harris 1 fractures commonly missed over radiographs.

No intervention was observed in our study.

CONCLUSION

In this study on 96 patients, physeal plate widths of four long bones were measured and compared between contralateral sides, age and gender aiding in formulating a baseline of physeal plate width measurements that can be of use in emergency settings to diagnose fractures commonly missed over radiographs.

It can be concluded that a common baseline value for physeal plate can be used for the pediatric age group 5-12 years and in both sexes as no statistically significant difference was observed between them.

SUMMARY

- Physeal injuries can lead to growth disturbances in children with greater propensity for growth disturbance when injuries occur at the distal ends of the long bones. Even though radiograph is currently the gold standard to diagnose fractures, isolated physeal fractures or transverse cleavage through the growth plate commonly graded as grade I fracture according to the Salter-Harris (SH) classification system gets commonly missed on radiograph

- The sonographic detection of significant disparities in physeal plate widths of injured children or in suspected case of isolated physeal fracture may have the potential for earlier detection of Salter Harris type 1 injuries with subsequent appropriate management.

- This study is a hospital based observational study done on 96 children with no history of trauma or skeletal abnormality.

- The objective of the study was to determine baseline measurements of physeal plate width and to assess variation in the measured widths among contralateral sides, age group and sex in the pediatric population.
- Ultrasound assessment of physeal plate in normal uninjured children was also done in order to detect any variations from the normal anatomy if present

- This study is first of its kind in India to assess and determine sonographic baseline measurements of normal physeal plate widths and demonstrates no statistically significant difference in physeal plate widths between contralateral extremities and between the two genders.

- The study also demonstrates that children of similar age group have no significant disparity in physeal plate width measurement.

- Sonography has the advantage of being non-invasive, cost and real time imaging modality with no risk of any radiation making it a safe and a potential first line investigation for evaluation of pediatric fractures

LIMITATIONS

The present study is only a single-center observational study with a relatively small sample size. To establish a baseline measurement of physeal plate width, a larger sample would give more accurate data. The study results therefore cannot be generalized because of the small sample size and single center sampling.

Future multi-centric studies with a large sample size could increase the validity of the results and can further help in generating clinical and radiological evidence for making recommendations in the day-to-day practice.

Another limitation of our study is that the ultrasound technique largely depends on the skill of the examiner and hence the data regarding physeal plate width could face intra and inter-observer variations.

Also distal ends of only four long bones were assessed in the study. Further studies including more long bones with assessment of their physeal width at both proximal and distal ends would provide a better data further helping the radiologists in cases of occult pediatric fractures

Lastly, no radiograph or MRI was performed to corroborate the findings.

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ANNEXURE III: FIGURES

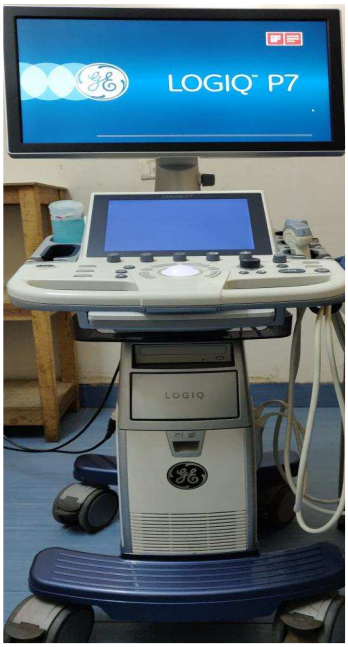

Fig 12: GE VOLUSON USG machine used for the study

Fig 13: PHILIPS HD – 11 Xe USG machine used for the study

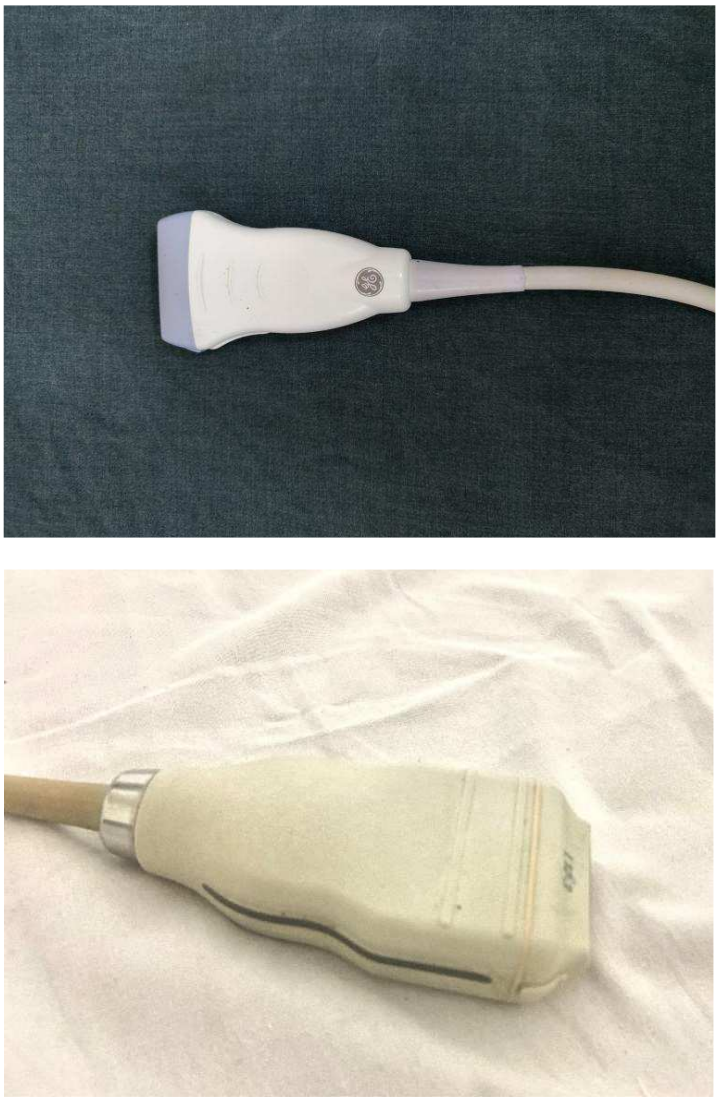

Fig 14: High frequency linear arrays transducers used for the study.

Fig 15: Image showing the position of the linear array transducer along the long axis of radius for measurement of physeal width

Fig 16: Image showing the position of the linear array transducer along the long axis of ulna for measurement of physeal width

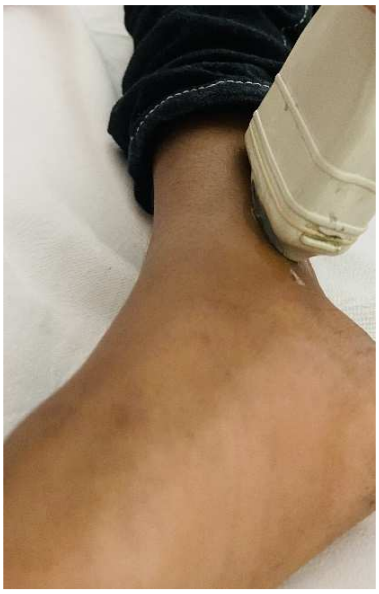

Fig17: image showing the position of the linear array transducer along the long axis of tibia for measurement of physeal width

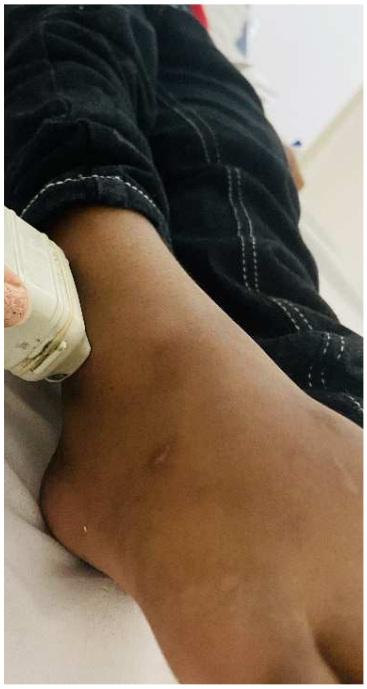

Fig18: image showing the position of the linear array transducer along the long axis of fibula for measurement of physeal width

PHOTOGRAPHS OF THE SUBJECTS INCLUDED IN THE STUDY

CASE 1 : 9 year old female

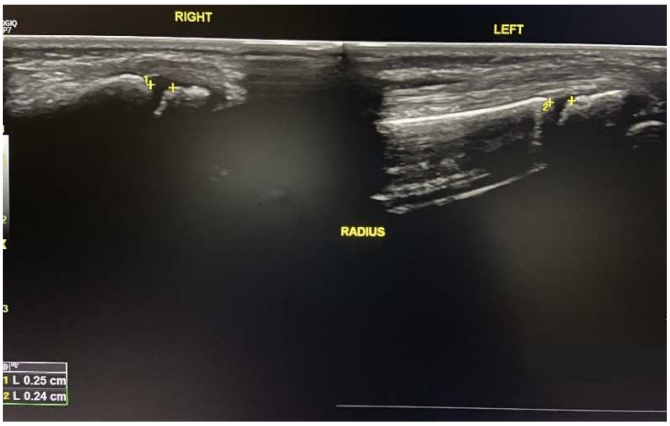

Fig 19: B mode USG image showing normal physeal plate width measurement in radius

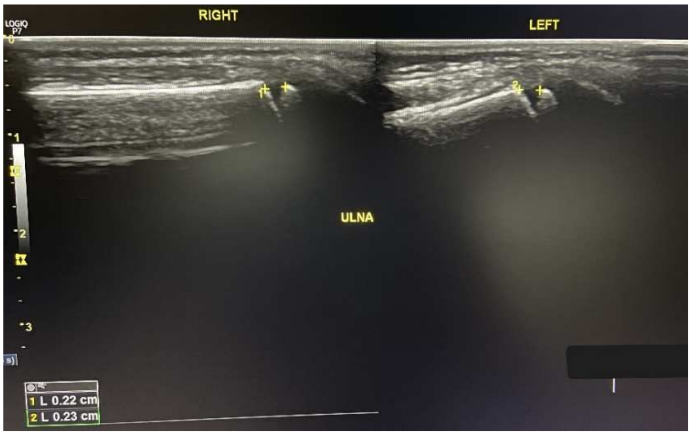

Fig 20: B mode USG image showing normal physeal plate width measurement in ulna

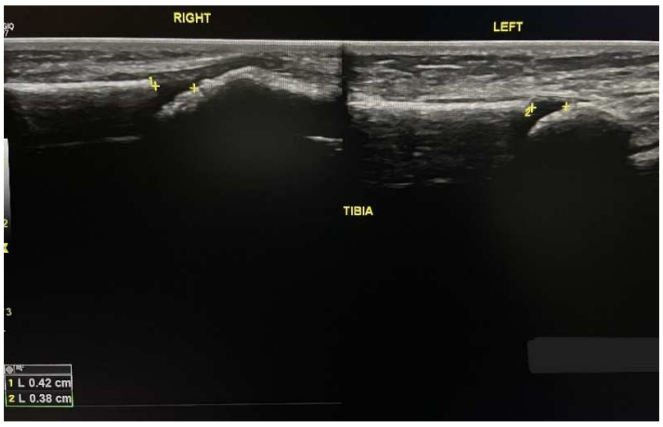

Fig 21: B mode USG image showing normal physeal plate width measurement in tibia

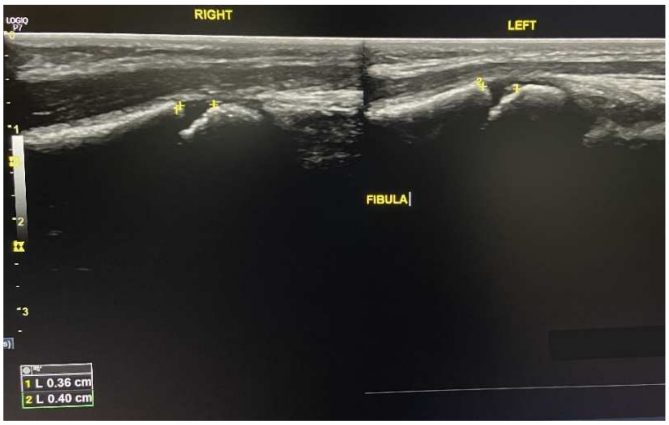

Fig 22: B mode USG image showing normal physeal plate width measurement in fibula

CASE 2 : 10 year old male

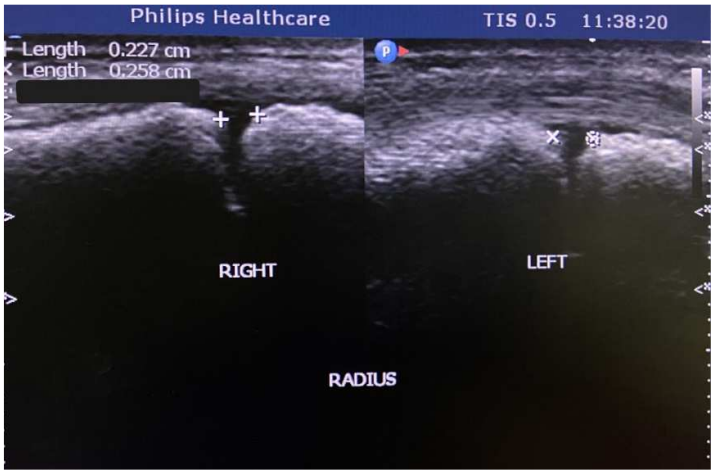

Fig 23: B mode USG image showing normal physeal plate width measurement in radius

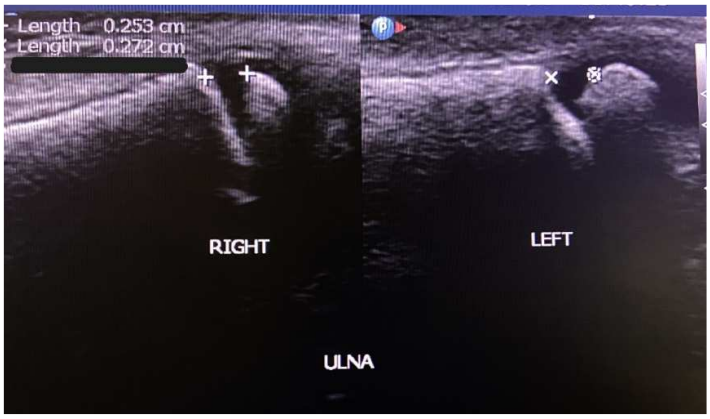

Fig 24: B mode USG image showing normal physeal plate width measurement in ulna

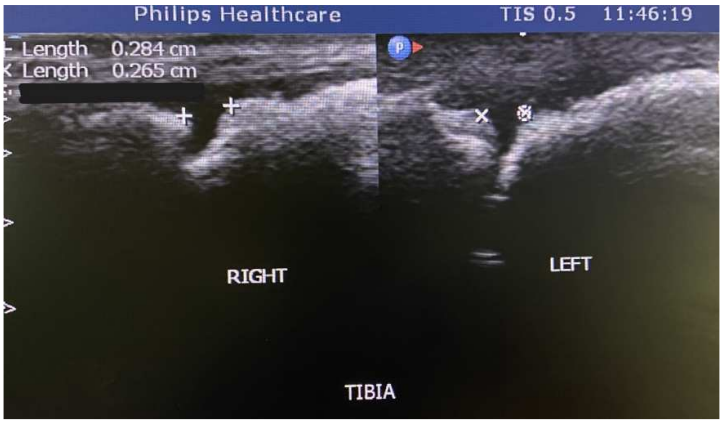

Fig 25: B mode USG image showing normal physeal plate width measurement in tibia

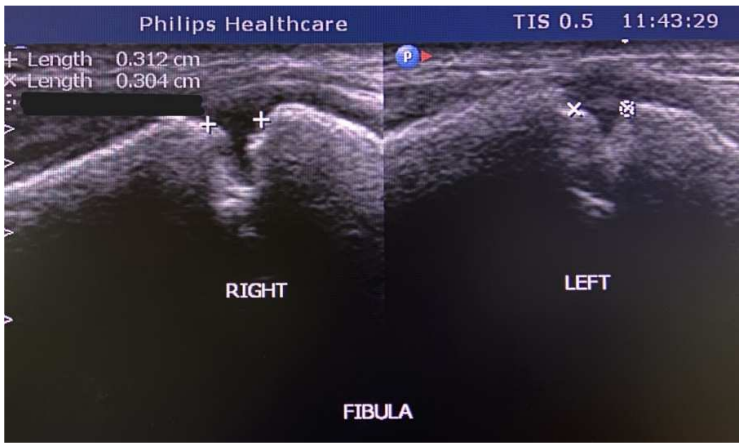

Fig 26: B mode USG image showing normal physeal plate width measurement in fibula

CASE 3 : 7 year old female

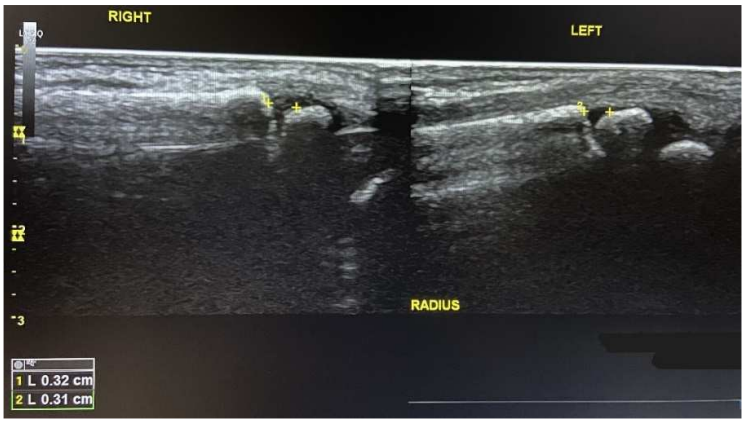

Fig 27 : B mode USG image showing normal physeal plate width measurement in radius

Fig 28: B mode USG image showing normal physeal plate width measurement in ulna

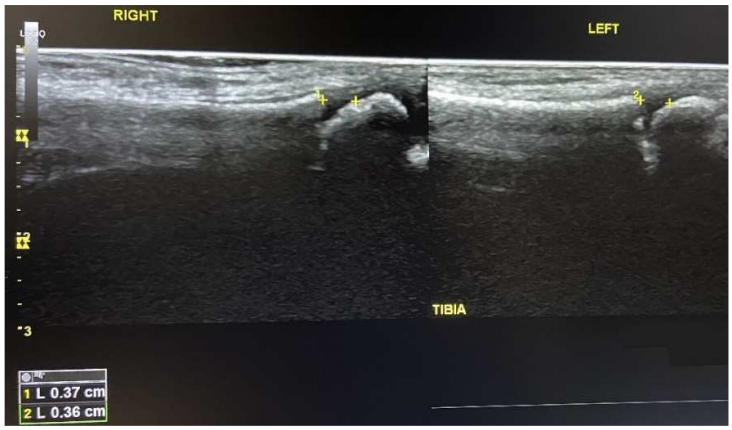

Fig 29: B mode USG image showing normal physeal plate width measurement in tibia

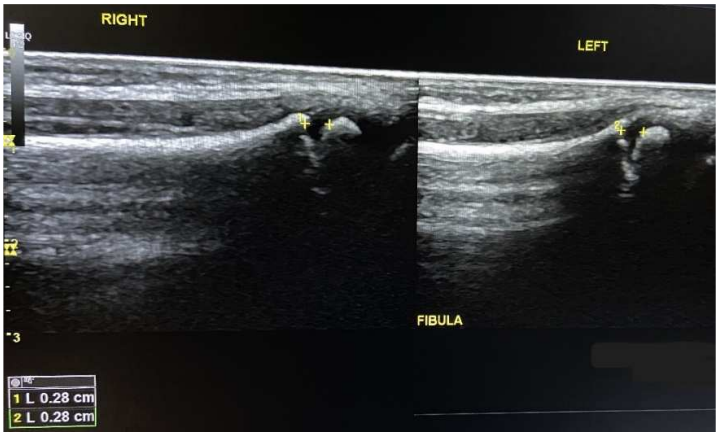

Fig 30: B mode USG image showing normal physeal plate width measurement in fibula

ANNEXURE I- INFORMED CONSENT FORM

CONSENT TO PARTICIPATE IN RESEARCH STUDY:

SIGNED CONSENT FROM THE PARENTS OF ALL THE SUBJECTS:

1. I understand that my child will be participating in the study, which includes ultrasound of the long bones.

2. I confirm that I have read and understood the information in the patient information sheet. Procedure is explained to me in detail along with information about the advantages and disadvantages of my child taking part in the study. I have been given the opportunity to discuss all aspects of the trial, to ask questions and hereby consent my child to participate in the trial outlined above.

3. I understand that the decision to take part in this study is completely voluntary and I am aware that I can choose to withdraw my child from the study at any point of time.

4. I consent to the photographing or recording of the procedure to be performed including appropriate portions of my child's body, for medical, scientific or educational purposes provided his/her identity is not revealed in the pictures or by the descriptive texts accompanying them.

5. I understand that there is no significant risk involved in the test that would be done in this study.

6. No guarantee or assurance has given by anyone as to the results that may be obtained.

7. My signature on this form signifies that I have willingly decided for my child's participation after understanding the above information.

Participant's Name/ legally authorized

Representative _____

Signature _____

Name and signature of witness _____

Name and signature of interviewer _____

Date:

Place:

VERBAL ASSENT FROM MINOR (7-12 years) ALONG WITH PARENTAL CONSENT:

I / my parent or legal guardian has read the previous page(s) of the consent form and the investigator has explained the details of the study. I/my parent or legal guardian understands that I am free to ask additional questions.

I/my parent or guardian understands that participation in this study entitled "ROLE OF ULTRASOUND IMAGING IN ASSESSMENT OF GROWTH PLATE AND IT'S CLINICAL APPLICATIONS– A ONE YEAR HOSPITAL BASED OBSERVATIONAL STUDY" is voluntary and I/my parent or legal guardian may refuse to participate or may discontinue participation at any time without penalty, loss of benefits, or prejudice to the quality of care which I will receive.

I/my parent or legal guardian, acknowledge that no guarantees have been made to me regarding the results of the treatment involved in this study, and I agree to participate in the study and have been given a copy of this form.

Name of the Parent	Signature of the parent
Name of Investigator	Signature of investigator
Name of Witness	Signature of Witness

ANNEXURE III- PROFORMA FOR DATA COLLECTION

NAME: _____

AGE: _____

SEX: _____ OP/IP NO: _____

USG NUMBER: _____

PAST HISTORY (INCLUDING ANY HISTORY OF TRAUMA OR BONY DEFECT) :

USG FINDINGS:

LONG BONE	**PHYSEAL PLATE WIDTH (in mm)**
1. RIGHT RADIUS	
2. LEFT RADIUS	
3. RIGHT ULNA	
4. LEFT ULNA	
5. RIGHT TIBIA	
6. LEFT TIBIA	
7. RIGHT FIBULA	
8. LEFT FIBULA	

Sr No.	USG No.	AGE	GENDER	PHYSEAL WIDTH (in mm)												ANY PHYSEAL PLATE ABNORMALITY DETECTED
				RIGHT RADIUS	LEFT RADIUS	DIFFERENCE BETWEEN CONTRALATERAL SIDE	RIGHT ULNA	LEFT ULNA	DIFFERENCE BETWEEN CONTRALATERAL SIDE	RIGHT FIBULA	LEFT FIBULA	DIFFERENCE BETWEEN CONTRALATERAL SIDE	RIGHT TIBIA	LEFT TIBIA	DIFFERENCE BETWEEN CONTRALATERAL SIDE	
1	29918	9	FEMALE	2.5	2.4	0.1	2.2	2.3	-0.1	3.6	3.7	-0.1	4.2	3.8	0.4	NIL
2	12685	7	FEMALE	3.2	3.1	0.1	2.3	2.1	0.2	2.8	2.8	0	3.7	3.6	0.1	NIL
3	12711	11	MALE	2.9	3.3	-0.4	2.9	2.6	0.3	2.8	3.1	-0.3	3.2	3.8	-0.6	NIL
4	12738	6	MALE	3.2	2.8	0.4	2.6	3	-0.4	3.2	3	0.2	3.7	4.1	-0.4	NIL
5	12767	7	MALE	3.4	3.4	0	2.8	2.5	0.3	3	3.4	-0.4	3	3.5	-0.5	NIL
6	30041	10	MALE	2.3	2.6	-0.3	2.5	2.7	-0.2	3.2	3.1	0.1	2.8	2.6	0.2	NIL
7	20313	6	FEMALE	3	2.8	0.2	2.8	2.3	0.5	3.3	2.9	0.4	3.1	3	0.1	NIL
8	30917	5	MALE	2.3	2.4	-0.1	3.4	2.7	0.7	3	3.3	-0.3	2.9	2.5	0.4	NIL
9	3452	5	FEMALE	2.6	2.8	-0.2	2.5	2.4	0.1	2.8	2.5	0.3	2.9	3.1	-0.2	NIL
10	3451	8	MALE	2.9	2.7	0.2	2.8	2.9	-0.1	3	3.2	-0.2	3.3	3.4	-0.1	NIL
11	3454	11	MALE	3.1	3.3	-0.2	2.9	3.2	-0.3	3.1	3.1	0	3.2	3.4	-0.2	NIL
12	3090	12	MALE	3	2.7	0.3	2.9	2.4	0.5	3.2	2.8	0.4	3.7	3.1	0.6	NIL
13	3277	8	FEMALE	2.8	3.4	-0.6	2.6	3.2	-0.6	2.9	3.3	-0.4	3.4	3.6	-0.2	NIL
14	4010	6	MALE	2.7	3.2	-0.5	2.5	2.8	-0.3	2.7	3	-0.3	3.2	3.6	-0.4	NIL
15	3453	8	FEMALE	3	2.9	0.1	2.8	3.2	-0.4	3	3.5	-0.5	3.4	3.8	-0.4	NIL
16	4012	7	MALE	2.6	3	-0.4	2.5	3	-0.5	2.9	3.1	-0.2	3.3	3.5	-0.2	NIL
17	4187	9	MALE	2.9	3.5	-0.6	2.8	3.1	-0.3	2.9	3.2	-0.3	3.3	3.4	-0.1	NIL
18	4189	12	FEMALE	2.8	2.9	-0.1	2.7	2.6	0.1	2.8	3	-0.2	3.5	3.9	-0.4	NIL
19	4190	5	MALE	2.7	3.1	-0.4	2.5	3	-0.5	2.7	3.3	-0.6	3.3	3.8	-0.5	NIL
20	4002	8	MALE	3.2	2.8	0.4	3	2.8	0.2	3.2	3.1	0.1	3.6	4	-0.4	NIL
21	3454	11	MALE	3.1	3	0.1	3	2.6	0.4	3.3	2.9	0.4	3.7	3.4	0.3	NIL
22	4006	10	FEMALE	2.9	2.7	0.2	2.5	2.7	-0.2	2.8	3.1	-0.3	3.6	3.9	-0.3	NIL
23	5278	6	MALE	2.5	2.9	-0.4	2.5	2.7	-0.2	2.7	3	-0.3	3.2	3.7	-0.5	NIL
24	4734	9	FEMALE	2.7	3	-0.3	2.6	3	-0.4	3	3.5	-0.5	3.8	4.1	-0.3	NIL
25	13278	7	FEMALE	2.4	2.5	-0.1	2.5	2.5	0	2.8	2.9	-0.1	3.6	3.5	0.1	NIL
26	4371	6	MALE	2.7	2.9	-0.2	2.6	3	-0.4	2.7	3.2	-0.5	3.3	3.7	-0.4	NIL
27	4917	12	FEMALE	3.4	3	0.4	2.9	3	-0.1	3.1	3.3	-0.2	3.8	4.1	-0.3	NIL
28	46303	11	FEMALE	3	3.1	-0.1	2.7	2.9	-0.2	3	3.2	-0.2	3.7	4	-0.3	NIL
29	5087	8	MALE	2.8	2.9	-0.1	2.7	2.9	-0.2	3	3.4	-0.4	3.5	3.8	-0.3	NIL
30	5090	5	MALE	2.4	2.8	-0.4	2.2	2.7	-0.5	2.6	2.9	-0.3	3.3	3.5	-0.2	NIL
31	13276	7	FEMALE	2.6	3	-0.4	2.5	3	-0.5	2.8	3.1	-0.3	3.4	3.8	-0.4	NIL
32	13105	10	MALE	2.9	2.5	0.4	2.8	2.7	0.1	3	3.4	-0.4	3.8	4	-0.2	NIL
33	7871	6	MALE	2.8	3.3	-0.5	2.6	3.1	-0.5	2.9	3.2	-0.3	3.5	3.8	-0.3	NIL
34	12374	7	MALE	2.5	2.9	-0.4	2.3	2.6	-0.3	2.8	2.9	-0.1	3.2	3.3	-0.1	NIL
35	6198	8	FEMALE	2.7	2.8	-0.1	2.7	2.7	0	2.9	3.1	-0.2	3.4	3.6	-0.2	NIL
36	14278	9	MALE	3	2.9	0.1	2.7	2.9	-0.2	2.8	3.2	-0.4	3.3	3.6	-0.3	NIL
37	13310	12	FEMALE	2.8	2.5	0.3	2.5	2.3	0.2	2.7	2.6	0.1	3.2	3.4	-0.2	NIL
38	7126	5	FEMALE	2.3	2.8	-0.5	2.3	2.6	-0.3	2.6	3	-0.4	3.1	3.7	-0.6	NIL
39	13115	8	FEMALE	2.5	2.7	-0.2	2.3	2.5	-0.2	2.8	3.1	-0.3	3.4	3.8	-0.4	NIL
40	7316	6	FEMALE	2.9	2.7	0.2	2.9	2.5	0.4	3.3	2.9	0.4	3.6	3.3	0.3	NIL
41	18190	10	FEMALE	2.6	3	-0.4	2.4	2.9	-0.5	2.6	3	-0.4	3.2	3.7	-0.5	NIL
42	16261	9	MALE	2.9	3.3	-0.4	2.8	3.3	-0.5	3	3.6	-0.6	3.4	3.7	-0.3	NIL
43	15113	7	FEMALE	2.8	2.8	0	2.7	2.4	0.3	3.3	3.1	0.2	4	3.8	0.2	NIL
44	6386	11	MALE	3.2	3	0.2	3.2	3.1	0.1	3.4	3.4	0	4.1	3.8	0.3	NIL
45	7125	5	MALE	2.5	2.8	-0.3	2.3	2.7	-0.4	2.8	2.9	-0.1	3.3	3.6	-0.3	NIL
46	12373	8	FEMALE	3.1	2.9	0.2	2.9	3	-0.1	3.2	3.5	-0.3	3.9	4	-0.1	NIL
47	14182	9	FEMALE	2.9	2.7	0.2	2.8	2.7	0.1	3	2.9	0.1	3.4	3.3	0.1	NIL
48	14179	12	FEMALE	3.3	3	0.3	3.2	3.1	0.1	3	3.3	-0.3	3.6	3.9	-0.3	NIL
49	40314	6	FEMALE	2.7	3.1	-0.4	2.5	3	-0.5	2.8	3.2	-0.4	3.3	3.9	-0.6	NIL
50	49014	7	MALE	2.7	2.9	-0.2	2.6	3	-0.4	2.9	3.1	-0.2	3.5	3.8	-0.3	NIL
51	14441	7	MALE	3	2.9	0.1	2.7	3	-0.3	3.1	2.9	0.2	3.7	3.4	0.3	NIL
52	12373	8	FEMALE	2.9	3.4	-0.5	2.8	3.2	-0.4	3	3.3	-0.3	3.6	3.9	-0.3	NIL
53	14106	10	FEMALE	3.3	3	0.3	3.2	3.1	0.1	3.5	3.2	0.3	4	3.6	0.4	NIL

54	20313	6	MALE	2.9	3.3	-0.4	3	3.2	-0.2	3.2	3.7	-0.5	3.7	4.1	-0.4	NIL
55	5099	12	MALE	2.8	2.7	0.1	2.6	2.5	0.1	2.9	2.6	0.3	3.3	3.2	0.1	NIL
56	21194	9	MALE	3.1	3.4	-0.3	2.9	3.3	-0.4	3	3.5	-0.5	3.5	3.8	-0.3	NIL
57	20625	7	FEMALE	2.8	3	-0.2	2.7	2.9	-0.2	3	3.3	-0.3	3.5	3.8	-0.3	NIL
58	21338	5	FEMALE	2.7	3.1	-0.4	2.5	3	-0.5	2.8	3.2	-0.4	3.4	3.6	-0.2	NIL
59	18526	8	MALE	3.2	3	0.2	3	2.7	0.3	3.2	3	0.2	3.7	3.4	0.3	NIL
60	19506	8	MALE	3	3.5	-0.5	2.8	3.2	-0.4	3	3.5	-0.5	3.6	4	-0.4	NIL
61	12208	11	FEMALE	3	2.8	0.2	2.9	2.8	0.1	3.1	2.9	0.2	3.4	3.6	-0.2	NIL
62	15034	10	MALE	3.1	2.6	0.5	2.9	2.7	0.2	3	2.9	0.1	3.6	3.5	0.1	NIL
63	14441	7	MALE	2.7	3.2	-0.5	2.5	3.1	-0.6	2.8	3.2	-0.4	3.3	3.3	0	NIL
64	38104	6	MALE	2.6	3.1	-0.5	2.6	3	-0.4	2.9	3.2	-0.3	3.2	3.4	-0.2	NIL
65	14279	12	FEMALE	2.9	2.8	0.1	2.5	2.7	-0.2	2.7	3	-0.3	3.1	3.5	-0.4	NIL
66	20488	9	MALE	3	3.3	-0.3	2.8	3.1	-0.3	3	3.3	-0.3	3.7	4.1	-0.4	NIL
67	20487	5	FEMALE	2.9	2.5	0.4	3	2.7	0.3	3.1	2.9	0.2	3.4	3.2	0.2	NIL
68	43777	6	MALE	3.5	3.3	0.2	3.1	3	0.1	3.3	3	0.3	3.8	3.3	0.5	NIL
69	21333	8	FEMALE	3.2	2.9	0.3	3	2.6	0.4	3.4	2.9	0.5	3.7	3.4	0.3	NIL
70	17845	10	MALE	2.9	2.8	0.1	2.8	2.6	0.2	3	2.9	0.1	3.6	3.1	0.5	NIL
71	13937	11	MALE	2.9	3.4	-0.5	2.7	3.2	-0.5	3.1	3.1	0	3.7	3.9	-0.2	NIL
72	20141	7	FEMALE	3	3.5	-0.5	2.9	3.3	-0.4	3.4	3.6	-0.2	4.1	3.8	0.3	NIL
73	15030	5	MALE	3.1	2.9	0.2	3.1	3	0.1	3.4	3.2	0.2	3.7	3.6	0.1	NIL
74	15514	8	MALE	3	2.7	0.3	2.9	2.7	0.2	3.1	3	0.1	3.8	3.5	0.3	NIL
75	15966	12	MALE	2.7	3	-0.3	2.6	3	-0.4	2.8	3.3	-0.5	3.3	3.7	-0.4	NIL
76	39389	9	MALE	2.9	3.3	-0.4	2.6	3.1	-0.5	2.9	3.1	-0.2	3.4	3.5	-0.1	NIL
77	17896	5	MALE	2.9	2.6	0.3	2.8	2.5	0.3	3	2.7	0.3	3.4	3.1	0.3	NIL
78	21336	8	FEMALE	2.6	2.8	-0.2	2.6	2.7	-0.1	2.9	2.8	0.1	3.5	3.3	0.2	NIL
79	21337	10	FEMALE	2.7	3.2	-0.5	2.5	3.1	-0.6	2.7	3.2	-0.5	3.6	4	-0.4	NIL
80	44832	9	MALE	2.9	3.1	-0.2	2.8	3.1	-0.3	2.9	3.4	-0.5	3.3	3.8	-0.5	NIL
81	17897	11	FEMALE	2.9	2.8	0.1	2.7	2.8	-0.1	3	3.2	-0.2	3.4	3.7	-0.3	NIL
82	49013	6	MALE	3.1	3.4	-0.3	3	3.2	-0.2	3.1	3.3	-0.2	3.6	3.8	-0.2	NIL
83	44899	9	MALE	2.7	3	-0.3	2.6	3	-0.4	2.8	3.1	-0.3	3.2	3.6	-0.4	NIL
84	21333	8	FEMALE	3.3	3	0.3	3	2.6	0.4	3.2	3	0.2	3.8	3.6	0.2	NIL
85	15285	12	FEMALE	2.8	2.4	0.4	2.7	2.4	0.3	2.9	2.6	0.3	3.4	3.3	0.1	NIL
86	39378	10	FEMALE	2.9	3	-0.1	2.8	2.9	-0.1	3.2	2.9	0.3	3.8	3.7	0.1	NIL
87	38421	7	MALE	3	3.1	-0.1	3	3	0	3.3	3.1	0.2	4.1	3.7	0.4	NIL
88	46293	9	FEMALE	3.2	3	0.2	3.1	3	0.1	3.4	3	0.4	3.7	3.4	0.3	NIL
89	40167	8	MALE	2.9	3.4	-0.5	2.6	3.2	-0.6	2.8	3.3	-0.5	3.4	3.6	-0.2	NIL
90	49027	7	MALE	3	2.7	0.3	3	2.6	0.4	3.1	2.9	0.2	3.6	3.5	0.1	NIL
91	38382	11	FEMALE	3.3	2.9	0.4	3.1	2.8	0.3	3.2	3	0.2	3.9	3.7	0.2	NIL
92	39315	5	MALE	3.1	3.2	-0.1	3	2.9	0.1	3.1	3	0.1	3.8	3.6	0.2	NIL
93	40479	8	MALE	3	2.7	0.3	3	2.7	0.3	3.2	2.8	0.4	3.7	3.5	0.2	NIL
94	38786	12	MALE	2.8	2.9	-0.1	2.7	2.8	-0.1	2.9	2.9	0	3.3	3.6	-0.3	NIL
95	44897	6	FEMALE	3	3.4	-0.4	2.9	3.2	-0.3	3.1	3.5	-0.4	3.8	4.2	-0.4	NIL
96	49053	8	MALE	2.9	2.6	0.3	2.8	2.5	0.3	3	2.6	0.4	3.4	3.1	0.3	NIL