ANATOMICAL VARIANTS OF THE TEMPORAL BONE AS DEPICTED BY HRCTS OF PATIENTS EVALUATED IN TWO RADIOLOGY CENTRES IN NAIROBI

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A dissertation submitted in part fulfillment of the requirements for the degree of Master of Medicine in Otorhinolaryngology, Head and Neck Surgery, University of Nairobi.

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STUDENT'S DECLARATION

I declare that this is my original work and it has not been presented for the award of any degree in any research institution or university.

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ACKNOWLEDGEMENT AND DEDICATION

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DEDICATION

I dedicate this thesis to my family for their immense support, patience and sacrifices. I look forward to spending quality time with you. Thank you.

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ABBREVIATIONS

AICA - Aberrant Internal Carotid Artery
ASS - Anterior Sigmoid Sinus
CSF - Cerebrospinal Fluid
DJB - Dehiscent Jugular Bulb
EAC - External Auditory Canal
ERC - Ethics and Research Committee
EVA - Enlarged Vestibular Aqueduct
FND - Facial Nerve Dehiscence
HJB - High Jugular Bulb
HRCT - High Resolution Computed Tomography
IAC - Internal Auditory Canal
ICA - Internal Carotid Artery
KNH - The Kenyatta National Hospital
LCA - Large Cochlear Aqueduct
LIAC - Large Internal Auditory Canal
LICA - Lateral Internal Carotid Artery
LLT - Low Lying Tegmen
LSCC - Lateral semicircular canal
LSS - Lateral Sigmoid Sinus
M:F - Male to Female ratio
PSA - Persistent Stapedial Artery
PSS - Prominent Sigmoid Sinus
SCC - Semicircular Canal
SSCCD- Superior Semicircular Canal Dehiscence
SNHL - Sensorineural Hearing Loss
SPSS - Statistical Package for Social Sciences
TBs - Temporal Bones
UoN - The University of Nairobi
WHO - World Health Organization

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OPERATIONAL DEFINITIONS (Diagnostic criteria)

AICA: Aberrant Internal Carotid Artery is an internal carotid artery that is laterally placed thus it is within the middle ear cavity without its bony covering/ it is outside the vertical carotid canal

ASS: Anterior Sigmoid Sinus is a sigmoid whose anterior sigmoid plate is ≤9mm from the posterior EAC bony wall when seen in axial view

Cochlear cleft is a hypodense region within the cochlear bony labyrinth seen especially anterior to the oval window best seen in axial view

DJB: Dehiscent jugular bulb is the absence of bony covering on the lateral aspect of the jugular bulb with its direct exposure to the middle ear cavity when seen in axial and coronal views

EVA: Enlarged Vestibular Aqueduct is one with a midpoint girth of ≥1mm or operculum girth of ≥2mm (Cincinnati criteria) or the width is wider than that of the ipsilateral posterior SCC

FND: Facial Nerve Dehiscence is the absence of bony covering over the facial nerve when seen in axial and coronal views, with or without oval window obstruction

HJB: High Jugular Bulb is a jugular bulb that is seen at the same level as the IAC in axial view

LCA: Large Cochlear Aqueduct is one whose width is ≥4.5mm at the medial operculum or ≥1mm at the midpoint when seen in axial view

Large Mastoid Emissary Vein is a prominent mastoid emissary vein with a width ≥33.3% of sigmoid diameter in axial cuts

LIAC: Large Internal Auditory Canal is one with a width of ≥9mm or a width difference of ≥2mm when compared to the contralateral IAC in axial view

LICA: Lateral Internal Carotid Artery is one with a dehiscent lateral bone cover with or without lateral protrusion into the middle ear cavity in axial and coronal views (orthogonal planes)

LLT: Low lying tegmen is significant tegmen sloping laterally below the level of the crista pyramidis and lateral to the attic and tympanum best seen in coronal view

LSS: Lateral Sigmoid Sinus is one laterally placed compared to the contralateral side or lateral distance to the outer cortex is less than the thickness of the cranium taken at the ipsilateral occipitomastoid suture in axial scan taken at the level of EAC

PSA: Persistent Stapedial Artery is noted as an expansion of the tympanic facial canal with obliteration of the stapes obturator foramen and the absence of the foramen spinosum in axial view

PSS: Prominent Sigmoid Sinus is a significant lateral indentation of the sigmoid plate of relative to the contralateral sigmoid or ≥33.3% protrusion of the sigmoid sinus diameter into the mastoid seen in axial view

Sigmoid Sinus Dehiscence is a defect in the sigmoid plate with direct exposure of the sigmoid to the mastoid airspaces

Sinus tympani types are seen on axial scans where:

Type A- The depth does not exceed the anterior aspect of the mastoid facial nerve segment

Type B- The depth exceeds the anterior but not the posterior limit of the mastoid facial nerve

Type C- The depth exceeds the posterior limit of the mastoid facial nerve

SSCCD: Superior Semicircular Canal Dehiscence- is where there is deficient bony labyrinth over the superior semicircular canal thus directly exposing it to the intracranial space

ABSTRACT

Background: The temporal bone is the centre of otology practice thus understanding its anatomy and variations is important for diagnosis, treatment and surgical planning in ear pathology.

Aim: To determine the patterns and prevalence of anatomical variations in temporal bone anatomy as depicted on high resolution computed tomography (HRCT) scans.

Methodology

Study Sites: The Kenyatta National Hospital and Plaza Imaging Solutions.

Study duration: 12 months

Study Sample Size: 100 participants were recruited where 82 paired temporal bones (TBs) and 18 unpaired TBs totaling 182 TBs were assessed.

Study Design and Procedure: This was a descriptive cross-sectional study. The study population included patients who had undergone HRCT of the temporal bone at the two radiology centres. Their demographic data was collected and their scans were evaluated by the principal researcher in conjunction with a consultant radiologist in the respective study site. Variations of the temporal bone were recorded in a data collection sheet.

Data analysis and Results: Data analysis was done using SPSS version 22. The age range was 2-74 years with a mean of 31.6±16.5 years and a male to female ratio of 1:1.1. Anatomical variations were observed in 99% of participants. The most prevalent variants were type B sinus tympani (73.1%), prominent sigmoid sinus (70.3%), Korner's septum (57.1%), petrous pneumatization (56.5%) and Hans type 4 mastoid pneumatization (47.8%). The least prevalent variants included large cochlea aqueduct (0.6%), enlarged vestibular aqueduct (1.1%), petrosquamous sinus (1.1%) and sclerosed petrous (3.3%). Correlation by Fisher's exact test showed significant correspondence between mastoid and petrous pneumatization patterns ($p < 0.001$), male preponderance to large internal auditory canal ($p=0.03$) and Hans 1 mastoid pneumatization ($p=0.003$), and female preponderance to low lying tegmen ($p=0.02$). Paediatric petrous pneumatization pattern was predominantly diploe (80%) compared to adults' aerated petrous in 62.4% ($p < 0.003$). No observations of aberrant internal carotid artery, persistent stapedial artery or jugular diverticulum were made.

Conclusion and Recommendation: There is a high prevalence rate of temporal bone anatomical variants in this study, with significant disparity between gender, age groups and individuals. These variants must thus be actively sought on case to case basis.

1.0 CHAPTER ONE: BACKGROUND

1.1 Introduction

Anatomical variations are the normal flexibilities or differences in topography and morphology of body structures usually of embryonic or genetic origin[1]. They encompass a range of anatomy that may be less frequent and not primarily considered pathology. The differences may be morphometric (size and shape), consistency (present, absent or multiple) and or spatial/positional (anterior/posterior, proximal/distal)[2]. The variations clinically influence predisposition to certain illnesses, symptomatology, clinical findings, investigation findings and patient management especially surgical procedures[3]. Anatomical variants in the temporal bone may clinically simulate known pathologies, for example, an aberrant ICA or a jugular diverticulum may be seen on otoscopy as a bluish or reddish mass behind the tympanic membrane and this may be mistaken for a glomus tumour. Similarly, variations of the temporal bone can be misdiagnosed as pathology on temporal bone HRCT, for example, cochlear cleft simulates otic capsule otosclerosis and temporal bone fracture. Temporal bone variants may also predispose patients to certain pathologies, for example, Korner's septum may predispose individuals to chronic ear disease including chronic otitis media and tympanosclerosis.

The variations of temporal bone anatomy modify planned surgeries and may pose a great challenge during major operations and even during basic procedures like taking biopsies and myringotomy. The vascular variants significantly increase the risk of intraoperative haemorrhage during otology procedures. Other increased surgical risks posed by variant anatomy include facial nerve injury in facial nerve dehiscence (FND), perilymphatic gusher in large cochlear aqueduct (LCA) or enlarged vestibular aqueduct (EVA) and dural breach in low lying tegmen (LLT).

1.2 Gross Anatomy

The temporal bone, also called *Os temporale*, is grossly located in the *Norma Lateralis* of the skull. It has five parts which are *squama temporalis* (squamous temporal bone), *pars tympani* (tympanic temporal bone), *pars petrosa* (petrous bone), *pars mastoidea* (mastoid bone) and *processus styloideus* (styloid process)[4]. **The *squama temporalis*** is a flat bone like the other main calvaria bones with an inner and outer cortex and interposed diploe. The ***processus styloideus*** is a needle-like or conical bony projection at the base of the temporal bone.

Pars mastoidea is posterior to the EAC and lateral to the petrous bone. It is usually pneumatized with several aerated aircells where the largest aircell is the antrum. The antrum communicates with the epitympanic middle ear cleft via the aditus forming the main conduit for mastoid ventilation. The mastoid pneumatization and aeration pattern is radiologically classified using the Han's method, in relation to the sigmoid sinus, into 4 types. Hans 1 is poor pneumatization that is anterior to the sigmoid sulcus, Hans 2 is moderate pneumatization that is up to the anterior half of the sigmoid sulcus, Hans 3 is good pneumatization that is up to the posterior half of the sigmoid and Hans 4 is very good pneumatization that is beyond the posterior end of the sigmoid sulcus[5]. Hans 2-4 are considered well pneumatized mastoid and is seen in approximately 42.9- 90.7% of population[5-7]. The non-pneumatized types of mastoid include diploe type seen in 8.7- 31.4% and sclerosed type seen in 0.7- 25.7% of population[5-7]. The mastoid has great significance in ear and intracranial surgery as it acts as a gateway to the middle ear, the inner ear and even to the posterior cranial fossa. It may be involved in ear disease hence requiring its removal, that is, mastoidectomy. Mastoidectomy is a common but fairly complex temporal bone surgery that is usually aimed at making the ear safe, dry and to preserve or restore hearing and vestibular functions[8]. Its landmarks include the tegmen superiorly, mastoid tip inferiorly, posterior EAC wall anteriorly and sigmoid sinus posteriorly[9]. The *pars tympani* is a bony canal that extends from the tympanic sulcus medially to the osteocartilaginous junction of EAC laterally. It serves as the bony part of the EAC. The *pars petrosa* is also called *pars pyramis*. It houses the middle ear and inner ear.

The middle ear is the middle ear cleft (*tympanum)* which contains the following; three ear ossicles (malleus, incus and stapes) and their associated ligaments; the stapedius muscle and tendon (which exits at the pyramidal eminence); the tensor tympani muscle and its tendon; and the horizontal course of the facial nerve[10]. There are several middle ear recesses, however, the most notable of these recess are the epitympanum, the facial recess and sinus tympani**.** The sinus tympani is the space between the cochlear promontory medially and facial canal and

pyramidal eminence laterally: It is bounded superiorly by the ponticulum and inferiorly by subiculum which are bony ridges from the lateral wall to the cochlear oval and round windows respectively.

The inner ear comprises of the cochlear and vestibular systems organized into an outer bony labyrinth and an inner membranous labyrinth that is surrounded by perilymph and contains endolymph. The vestibular system forms the balance apparatus organized into a vestibule and three semicircular canals. The cochlea is connected to the vestibular system via the ductus reuniens of Hansen and also has an outpouching called the **perilymphatic duct/ periotic duct** from the cochlear to the subarachnoid space[11]. This duct is carried in a bony canal called the **cochlear aqueduct (CA),** also called *the aqueductus cochleae,* which commences anteroinferior to the round window, traverses the petrous bone to open into the subarachnoid space just anteromedial to the jugular foramen. The vestibule has an endolymphatic outpouching that arises from the posterior wall of the saccule and is joined by *ductus utriculosaccularis* from the utricle ending in a blind pouch called the *saccus endolymphaticus* or **endolymphatic sac**[12]. This sac is on the posteromedial side of the semicircular canal thus in the posterior margin of the petrous bone. It is housed within a bony canal, **vestibular aqueduct,** and runs a posteromedial course away from the jugular foramen.

The Internal Acoustic/Auditory Canal (IAC) is in the medial aspect of *pars pyramis*. It has an anteromedial course and opens intracranially at the cerebelopontine angle. It is traversed by the facial nerve, vestibulocochlear nerve and the labyrinthine artery. The medial opening of the IAC is called the ***porus acusticus*.** The IAC and porus acusticus can be variably widened as an anatomical variation but they can also be widened by pathologies like acoustic neuromas and facial nerve schwannomas[13].

The facial nerve traverses the petrous bone from the IAC (entry) to its exit at the stylomastoid foramen. Facial nerve has an initial intracranial course from the cerebellopontine angle to the IAC then traverses the IAC exiting to the geniculate ganglion via a labyrinthine canal. It turns posterolaterally to take a horizontal/ tympanic course usually within a bony canal (fallopian canal) and it runs below the lateral SCC. It then turns downwards, distal to the pyramidal eminence and descends through the mastoid as the mastoid segment exiting at the base of skull through the stylomastoid foramen[14].

The sigmoid sinus commences as the distal continuation of the transverse venous sinus. It makes an indentation on the posterior mastoid plate as it descends posterior to the mastoid and at the inferior base of the petrous bone drains into the jugular bulb. The jugular bulb continues distally as the internal jugular vein that traverses the jugular foramen. **The petrous apex** is a

pyramid-shaped structure that is formed by the medial portions of the temporal bone and runs within the skull base with its apex pointing anteromedially and its base located posterolaterally bound by the bony inner ear labyrinth[15].

The internal carotid artery (ICA) is the main arterial structure traversing the temporal bone entering it inferiorly into carotid canal. It has an inferior vertical course that is anterior to the middle ear cavity, and a superior horizontal course parallel to the petrous apex up to the foramen lacerum where it enters the cavernous sinus.

1.3 Radiology and Anatomy of Temporal Bone Variants

Temporal bone HRTCs are a good imaging modality for assessing the temporal bone anatomy and its associated pathologies. The air and bone predominance in the temporal bone provides good contrast for delineating the temporal bone anatomy. The basic temporal bone views are taken in axial profile at 30^0 angles to the anthropometric horizontal plane and cuts through the vestibule and lateral SCC representing it radiologically as a signet ring. Scans are taken in axial profile at 0.6-1 mm slice thickness and subsequent coronal reconstructions are usually done at a 105^0 angle to the anthropometric horizontal plane at 1.5-2mm slice thickness[16,17]. Poschl and Stenvers views are considered special view to assess targeted anatomy, for example, Poschl view to examine the entire superior SCC arc and Stenvers to examine the full labyrinthine and ossicular chain architecture. Several temporal bone variants can be detected by HRCT. In Table 1 below are the radiological diagnostic criteria for some of the variants as described by Pawel[18].

Table 1: Diagnostic criteria for some of the temporal bone variants on HRTC by Pawel[18]

Serial	Structures	Imaging criteria
1.	High jugular bulb	Highest point of the jugular bulb is over the plane of the bottom portion of the IAC at the standard axial scan and perpendicular to the plane of the lateral SCC
2.	Prominent jugular bulb	Significantly larger jugular bulb compared to the opposite side
3.	Dehiscent jugular bulb	Absence of hyperdense bony septa between tympanic cavity and jugular bulb
4.	Jugular bulb diverticulum	Isolated finger like projection extending from jugular bulb to the middle ear
5.	Lateralized/ Dehiscent ICA	Dehiscent bony wall of petrous ICA with or without artery protrusion into the middle ear
6.	Aberrant ICA	Displaced ICA running through the middle ear
7.	Persistent stapedial artery	Foramen spinosum is absent and there is an artery running parallel to the cochlea promontorium through the stapes foot plate
8.	Prominent sigmoid sinus	Prominent sigmoid sinus compared to opposite side
9.	Lateral sigmoid sinus	Protrusive sigmoid sinus placed laterally with a reduced distance between sigmoid sinus and mastoid cortex
10.	Anterior sigmoid sinus	Protrusive sigmoid sinus placed anteriorly with a reduced distance between Henle's spine and sigmoid sinus
11.	Petrosquamous sinus	Occurrence and diameter of petrosquamosal sinus, aberrant vascular channel in the bony canal in the mastoid roof draining to the sigmoid sinus running in an anteroposterior direction
12.	Jugular bulb-vestibular aqueduct dehiscence	Dehiscence of vestibular aqueduct caused by jugular bulb

Other variants include Korner's septum, low lying tympani, cochlear cleft, enlarged vestibular aqueduct, large IAC, facial nerve dehiscence, large cochlear aqueduct, pneumatized petrous bone and deep sinus tympani.

Lateral ICA (LICA) is radiologically diagnosed by dehiscence in the lateral wall of the petrous part of the ICA. It may protrude into the middle ear cavity in the anteromedial region of the vertical course usually near the basal cochlear turn. On contrast, an enhancing ICA may protrude into the middle ear cavity.[19]

Aberrant ICA (AICA) is a vascular variant where ICA passes through the middle ear cavity instead of its usual carotid canal. It enters the middle ear cavity through an expanded inferior tympanic canaliculus that's posterolateral to the carotid foramen, goes over the cochlear promontory and enters the horizontal portion of the carotid canal through a dehiscence in its lateral wall. Radiologically, on axial cuts, it is identified as a tubular structure in the middle ear cavity moving from the posterolateral aspect to the anteromedial aspect of middle ear cavity, over the cochlear promontory with an empty carotid canal. On coronal view, it is seen as a

solitary round soft tissue density at the cochlear promontory mimicking a glomus tympanicum tumour. It avidly enhances in contrast scans. AICA coexists with PSA in 30% cases and rarely occurs bilaterally[20].

Persistent stapedial artery (PSA) occurs due to persistence of the embryological stapedial artery. It passes through the caroticotympanic canaliculus into the middle ear cleft, then passes over the cochlear promontory, into the stapedial obturator foramen and superiorly joins the anterior tympanic segment of the facial nerve and finally proceeds intracranially around the geniculate ganglion to become the middle meningeal artery[21]. It is seen on HRCT as a small linear hypodense structure in the middle ear, it enlarges the anterior tympanic segment of the facial nerve with an absent foramen spinosum and exits into the cranium around the geniculate ganglion. AICA may be present as PSA is seen in 30% of AICA cases[20].

Korner's septum is also called persistent petrosquamous suture/ lamina. This bony septum can run from the posterior aspect of the glenoid fossa through the antrum to the inferolateral aspect of the facial canal down to the mastoid tip. Radiologically, it is seen as a bony thickening in the mastoid antrum in axial view, dividing the antrum into a superficial and deep part. There may be concurrent tympanosclerosis and otomastoiditis as Korner's septum is associated with chronic ear disease and attic obstruction hence opacification of the mastoid air cells[22,23].

Low lying tegmen (LLT) is also called a low hanging dura or low tegmen tympani. It is seen where the tegmen is depressed especially on the lateral aspect i.e. lateral to the attic and labyrinth. The floor of the middle cranial fossa deepens to form a groove lateral to the attic and labyrinth. The low hanging dura may cover the roof of the external auditory canal[24].

Cochlear cleft is defined as a narrow curved radiolucency extending from the cochlear towards the promontory. It is of congenital origin where after the 14 cochlear ossification centres form and fuse in-utero between weeks 15-21, the primitive cochlear architecture is preserved and not converted to classical artesian system. In so doing, 3 layers of bony otic capsule form, these are the outer periosteal layer, the inner endosteal layer and the middle layer that's of endochondrial origin. The endochondrial layer initially consists of cartilage islands that coalesce and finally ossify. The regions in the endochondrial layer, usually those closer to the outer periosteal layer, that remain as spaces or unossified cartilage islands become the cochlear cleft. The cleft is seen in HRCT as a radiolucent area or an area of low attenuation with its upper part lying in the region of fissula ante fenestram anterior to the oval window and medial to the cochleariform process while its inferior part is in the inferolateral aspect of the cochlear capsule[25].

Enlarged vestibular aqueduct (EVA) is the congenital enlargement of the bony canal which houses an enlarged endolymphatic duct and sac. This enlargement is the commonest inner ear variant and is associated with sensorineural hearing loss (SNHL) from cochlear anomalies especially cochlear hypoplasia (in 75% cases) seen as 1.5 turns and thought to be a result of developmental arrest of the cochlear in the 7th week of gestation. In 90 % of cases, there is an associated absence of the bony modiolus[26]. Other associations include vestibular and/or SCC anomalies in 50% of cases of EVA and rarely renal tubular acidosis, branchio-oto-renal syndrome and Pendred syndrome[27]. On HRCT it is seen as an enlarged vestibular bony aqueduct whose diameter size is larger than that of the posterior SCC or has a diameter of ≥1.5mm (Valvassori Criteria) at the midpoint or ≥4.0mm at the operculum[26,28,29].

Facial nerve dehiscence (FND) is the breach or segmental absence in the bony wall of the facial canal with exposure of the facial nerve whereas **facial nerve prolapse** is the protrusion of facial nerve through a dehisced wall or absent facial canal such that the facial nerve crosses/ strands through the middle ear cavity uncovered. FND may be seen in >50% of population without middle ear disease while protrusion occurs in <1% of normal population[28]. FND is identified on HRCT as the partial/ segmental absence of bony wall covering of facial nerve especially in the tympanic cavity while facial nerve prolapse is seen in axial view as "hammocking" of the facial nerve spanning the middle ear cavity until it's under the Lateral SCC and in coronal view as a soft tissue density around the oval window niche and along the undersurface of the Lateral SCC with loss of Lateral SCC notch[28].

Large IAC (LIAC) is also called a patulous IAC. This is an IAC that is ≥9mm or it is wider than the contralateral side by 2mm[30]. The enlargement may be at the porus acusticus, the isthmus or the lateral fundus as the general shape of IAC changes from medial to the lateral aspect. On average, the normal vertical (cephalocaudal) and anteroposterior (horizontal) diameters range from 3-7mm[31]. In the absence of pathology, LIAC is seen especially in the mid portion[31]. The shapes of IAC observed in children and adults are funnel-shaped (74% and 58.3%, respectively), cylindrical (22% and 30.9%, respectively) and bud-shaped (4% and 10.8%, respectively)[32]. There are no differences in the IAC diameters between gender[33].

Large cochlear aqueduct (LCA) is a result of embryologic arrest during calcification of the cochlear aqueduct during gestational weeks 16-26 thus preventing the 6 fold reduction in diameter usually achieved by complete ossification. It has four segments namely the lateral orifice, otic, petrous and medial orifice (operculum) segments. The normal diameter of the cochlear aqueduct is variable at its 4 segments but generally the mean of its otic portion is 0.2mm (but normal is up to 0.8mm) and 4.5mm at the medial orifice (operculum) portion. Only

31% of axial scans show the aqueducts complete course while the medial orifice segment is seen in 97% of axial scans[34]. On HRCT, the LCA is best seen on axial cuts as a hypodensity from the cochlear to the medial aspect of the jugular foramen with a diameter of ≥1mm at the mid-otic portion or ≥4.5mm at the medial operculum[34,35].

Deep sinus tympani is one that extends beyond the posterior wall of the mastoid facial canal. The sinus tympani is best seen on axial HRCT view and it is identified as the space bounded by the cochlear promontory medially and pyramidal eminence/ facial nerve laterally where further laterally is the facial recess. It is then classified by its posterior extension/ depth in relation then mastoid facial nerve. There are generally 3 types of sinus tympani; Type A is shallow and doesn't reach the anterior border of the facial canal; Type B reaches the facial canal and; Type C extends beyond the facial canal[36]. Type A is considered as the shallow sinus tympani, type B is of normal depth and type C is considered the deep sinus tympani.

1.4 The clinical significance of anatomical variants of the temporal bone

Anatomical variants have been found to significantly complicate temporal bone surgeries. Deep sinus tympani may hide cholesteatoma resulting in recurrence after cholesteatoma surgery. Surgical approach to this region is challenging by open (retrofacial) technique or endoscopy approach only[37]. To achieve good cholesteatoma clearance, both open and endoscopic techniques may be employed in cases of deep sinus tympani. In some cases, deep sinus tympani penetrate around the facial canal up to 2/3 of canal's circumference increasing the risk of the iatrogenic facial nerve damage[38]. Low lying tegmen (LLT) and anterior sigmoid sinus (ASS) are directly associated with difficult mastoidectomy where they result in a contracted surgical field during saucerization of the mastoid[39]. The risk of dural breach is significantly increased in LLT especially where the meningeal height from the temporal lobe/ superior pole of the petrous bone, to the tegmen tympani is ≥7mm best seen in coronal cuts. ASS increases risk of sigmoid injury especially when the distance from the anterior border of the posterior bony EAC wall to the anterior border of the sigmoid plate is ≤9mm[39]. Thick and long Korner's septum may be mistaken for the medial extent of the mastoid antrum during mastoidectomy or it may increase surgical difficulty by limiting mastoid antrum exposure, thus ear disease like cholesteatoma may possibly be left medial to it resulting in disease persistence or recurrence[40,41]. High jugular bulb (HJB) and ASS pose major haemorrhagic risks during temporal bone surgery[26]. Enlarged vestibular aqueduct (EVA) and large cochlear aqueduct (LCA) have been associated with perilymphatic gusher especially in patients undergoing

cochlear implant[42]. In skull base surgery, petrous pneumatization is a risk factor for postoperative CSF leaks leading to CSF rhinorrhea[43]. Facial nerve dehiscence predisposes to iatrogenic facial nerve injury with resultant palsy during temporal bone surgery/ middle ear exploration[44].

There are several anatomical variants that simulate or are associated with clinical and radiological pathology. Korner's septum is highly associated with chronic middle ear disease and tympanosclerosis[22,23,45]. Cochlear cleft seen radiologically could be mistaken for otosclerosis, temporal bone fracture or fissula ante fenestrum[26,46]. EVA is associated with SNHL, cochlear hypoplasia, vestibular system anomalies and congenital syndromes[26,27]. Prominent petromastoid canal and LCA simulate temporal bone fracture[26]. Radiologically, lateral ICA and aberrant ICA could easily be mistaken for each other or for glomus tumor, ICA aneurysm or for dehiscent jugular bulb, and clinically they present with objective tinnitus and conductive hearing loss while on otoscopy, a retrotympanic mass may be seen which is usually characteristic of glomus tumours[19,20]. HJB and jugular diverticulum may also be seen as retrotympanic masses that are characteristic of glomus tumour. Persistent stapedial artery (PSA) is mainly asymptomatic but may rarely present as a pulsatile retrotympanic mass with pulsatile tinnitus and radiologically it may be mistaken for a facial nerve haemangioma, facial nerve schwannoma, herpetic facial neuritis or facial perineural carcinoma[21]. Facial nerve prolapse may radiologically be mistaken for a congenital cholesteatoma, oval window atresia, glomus tympanicum or facial nerve schwannoma[29]. Pneumatized petrous apex has been associated with apical mucocele, petrous apicitis, Gradenigo syndrome and effusion of petrous apical air-cell mainly seen in the background of chronic ear disease[47]. The mastoid pneumatization patterns can change drastically in presence of chronic ear disease from the well pneumatized type prevalence of (42.9-90.7%) to predominantly sclerotic type (78.9%)[6,7]. Large IAC is associated with Goldenhar syndrome, Apert syndrome, Patau syndrome and CHARGE syndrome and it may be mistaken for an intrameatal tumour[30].

2.0 CHAPTER TWO: LITERATURE REVIEW

2.1 Literature Review

Tomura et al (Japan) described six (6) groups of anatomical variants depicted by HRCT of temporal bones, however, these groups do not exhaustively incorporate the multitude of temporal bone anatomical variants thus similar variants will be discussed in tandem[48]. Group I described jugular bulb dehiscence at a 2.4% prevalence rate. This resonated with Visvanathan et al (Scotland) who described a 2.8% rate[49]. Slightly lower rates were described by Koesling et al (Germany) at 1% and higher rates by Pawel et al (Poland) at 4%[18,50]. Koesling and Pawel also described the prevalence of high jugular bulb (HJB) at 6% and 11.9% respectively[18,50]. Cigdem et al (Turkey) described the highest rate of HJB prevalence at 32% with 40.6% bilaterality[51]. The noted differences in prevalence in these studies may be due to geographical variation as the study methodology and sample size were fairly similar.

Group II described asymmetrical jugular foramen at a prevalence rate of 4% but Koesling found a much higher rate at 42%[48,50]. Group III included anterior sigmoid sinus (ASS) at a 1.6% prevalence. This low prevalence was in tandem with Pawel's, Visvanathan's and Koesling's studies where ASS was seen in 1.1%, 2.9% and 5% TBs respectively[18,49, 50]. However, Junior and Cigdem reported significantly higher rates at 10% and 34% respectively with bilateral ASS in 50%[39,51]. Lateral sigmoid sinus (LSS) prevalence was at 8.3- 28%[18,50].

Group IV observed deep sinus tympani in 5.9% cases which resonated with Visvanathan's 5.0% and Marchioni et al (Italy) 4.4% rates[48,49,52]. Nitek et al (Poland) reported a 33% prevalence of deep sinus tympani with its occurrence increasingly related to prominent facial canal, prominent pyramidal eminence and partial or absent ponticulum but no gender or side disparities were noted[38]. Nitek's figures are significantly higher probably due to the comparatively small sample size and also his study procedure was on dissection of cadaveric temporal bone whereas the other studies were HRCT evaluations.

Group V described large internal acoustic canal (LIAC) at a 2.3% prevalence. Visvanathan (USA) and Lela et al (Israel) reported 1.8% and 0.3% prevalence rates respectively[31,49]. Lela found that in the absence of inner ear pathology, the patulous IAC segment was predominantly in the mid portion[31].

Group VI included large cochlear aqueduct (LCA) at a 3.0% prevalence while Visvanathan found a significantly lower prevalence rate of 0.6%[48,49]. Giovanni et al (Italy) found a 2.2% prevalence in patients exclusively undergoing cochlear implantation[42]. Unlike enlarged

vestibular aqueduct (EVA), LCA was not associated with inner ear deformities or congenital syndromes[46].

EVA was seen in 2.9% of patient undergoing cochlear implant[42]. Valvassori et al (USA) noted a 1.4% prevalence in patients referred for inner ear evaluations and, of these, 60% had concurrent inner ear malformations, 66.7% had bilateral EVA and there was a 3:2 female preponderance[29]. Despite the widely accepted diagnosis of EVA as midpoint diameter ≥1.5mm (Valvassori criteria) and ≥4.0mm at the operculum, others have sought to prove lower values of ≥1.0mm at midpoint and ≥2.0mm at the operculum (Cincinnati criteria) are statistically and clinically significant[29,53]. Karuna et al (USA) compared the two criteria in preoperative HRCTs of 130 paediatric cochlear implant recipients (260 TBs) with SNHL and diagnosed 44% TBs with EVA by Cincinnati versus 16% with Valvassori criteria, where 70 TBs that were classed as normal by Valvassori criteria were reclassified as EVA by Cincinnati criteria[54]. Controversy over which criteria is more preferable still persists.

Arterial variants in the temporal bone are extremely uncommon. Persistent stapedial artery (PSA) and aberrant internal carotid artery (AICA) were not observed in several temporal bone studies that actively evaluated for them[18,48,49]. Cigdem, after assessment of 356 temporal bone HRCTs, found AICA prevalence at 0.3% (n=1/356) and 1% by Koesling[50,51]. Lateral ICA (LICA) prevalence is also low at 2% - 3.4%[18,50,51]. PSA prevalence was found to be 0.5% by Moreano et al (USA), that is 5/1045 temporal bones[55]. PSA incidence is so rare that its occurrence is mainly limited to case reports[31,56].

Pawel evaluated 276 temporal bones by HRCTs from 138 patients for anatomical variation.[18] No AICA or PSA was detected. The patterns and prevalence of anatomical variations in diseased and normal TBs were summarized as in the table 2 below[18].

Table 2: Summary of anatomical variants seen in Pawel's study[18]

	Structure	All Temporal bones n= 256	RCOM temporal bones n= 110	No RCOM temporal bones n= 166
1	HJB	33 (11.9%)	19 (17.3%)	14 (8.4%)
2	Pro-JB	37 (13.4%)	20 (18.2%)	17 (10.2%)
3	DJB	5 (1.8%)	3 (2.7%)	2 (1.2%)
4	JBD	11 (4%)	6 (5.5%)	5 (3.0%)
5	DCN7	4 (1.5%)	4 (3.6%)	00
6	Lat- ICA	9 (3.4%)	5 (4.6%)	4 (2.4%)
7	Pro-SS	43 (15.6%)	26 (23.6%)	17 (10.2%)
8	Lat- SS	23 (8.3%)	16 (14.6%)	7 (4.2%)
9	Ant- SS	3 (1.1%)	2 (1.8%)	1 (0.6%)
10	PSS	19 (6.9%)	16 (14.6%)	3 (1.8%)
11	JBVAD	19 (6.9%)	10 (9.1%)	9 (5.4%)

RCOM – temporal bones with radiological features of chronic otitis media; HJB – high jugular bulb; Pro-JB – prominent jugular bulb; DJB – dehiscent jugular bulb; JBD – jugular bulb diverticulum; DCN7 – dehiscent facial nerve canal; Lat-ICA – lateralized or dehiscent internal carotid artery; Pro-SS – prominent sigmoid sinus, Lat-SS – laterally located sigmoid sinus; Ant-SS – anteriorly located sigmoid sinus; PSS – petrosquamosal sinus; JBVAD – jugular bulb-vestibular aqueduct dehiscence

Pawel noted that the prevalence of anatomical variants was higher in temporal bone that had chronic ear disease than those that were normal. FND specifically was not seen in the normal ears but was seen in 3.6% of chronic ear disease and thus 1.5% of the study population[18].

Sertac et al (Turkey) evaluated 144 cases for FND where 11% had dehisced segment noted as follows: at second genu 31.3%, horizontal segment 25%, round window 18.8%, combined horizontal segment and second genu 18.8%; and combined vertical segment and second genu 6.3%[57]. He further found an 81.3% radiosurgical correlation between the preoperative HRCT and intraoperative findings of FND. Sertac's FND prevalence of 11% resonates with Cigdem who found 12% rate with 25% bilaterality[51].

Pre-operative temporal bone HRCT were evaluated by Chee et al (Singapore) who found a 2.8% prevalence of LLT[58]. This correlates with Thripthi (India) who also found a low prevalence of 2% seen in both HRCT and X-ray- Schullers view[24]. Cigdem found a significantly higher rate at 26% with 14 % bilaterality on HRCT[51]. Cigdem (Turkey) had a large study population of n=178 patients, compared to Chee n=36 and Thripthi n=50 patients, that may account for the variance, although geographical variation may have been a factor.

Hentona et al (Japan) evaluated petrous bone pneumatization by HRCT and found a 32.7% prevalence of petrous pneumatization[59]. Higher degrees of pneumatization occurred concurrently with larger pneumatized mastoid cavities suggesting correlated regional pneumatization but no gender disparity was noted. In those with pneumatized petrous apex, 40% had complete petrous apex pneumatization and 60 % had partial/ segmental pneumatization. In partial pneumatization, higher rates occurred in the inferior region rather than the superior region[59].

The cochlear cleft is a variant commoner in children and decreases with age. It is easily mistaken for a demineralized focus in the region of the fissula ante fenestram[46]. Chadwell et al (USA) evaluated 200 temporal bones of 100 paediatric patients with SNHL and found 41% had cochlear cleft with 26% being bilateral[25].

Korner's septum prevalence by Cigdem was 28% with 53% bilaterality[51]. Korner's septum is postulated to result in blockage of the atticoantral drainage predisposing one to chronic ear disease[22]. Lower prevalence of Korner's septum was seen in individuals with normal ears at 6.6% as compared to patients with chronic ear disease as follows: tympanic membrane retraction with adhesion at 30.4% and 17.4% in chronic ear disease but no retraction or tympanic membrane adhesions[22].

In Kenya, Koima in 2014 studied the "Spectrum of findings of HRCT of temporal bone in KNH and Plaza Imaging Solutions" over a 5 month study period while undertaking her thesis for M.Med in Diagnostic Imaging and Radiation Medicine (UoN). The thesis focused on the clinicoradiological correlation of pathological conditions that were noted in the temporal bone HRCTs. Patients and their scans were evaluated where 37% (n=19/52) scans were found to be normal, and the rest had pathologies. The bulk of the pathological group had inflammatory conditions at 51.9%, with otomastoiditis being the commonest inflammatory condition. In the study, no mention or emphasis was made to document the anatomical variations seen in the evaluated temporal bone HRCT scans despite mention of vascular variants like AICA and dehiscent jugular bulb in the literature review[60].

2.2 Study Justification

There is significant geographical variation in the prevalence of temporal bone variants, that is, high jugular bulb (HJB) prevalence is 2.4% in Japan and 33% in Turkey while anterior sigmoid sinus (ASS) prevalence is 1.1% in Poland and 34% in Turkey, whereas there is limited local data on these variants. These variants significantly influence disease predisposition, symptomatology, clinical evaluations, investigations and surgical procedures.

Knowledge of the presence, patterns and prevalence of temporal bone variants, will refine patient management especially in planning for surgical procedures. It may further sensitize clinicians on predisposing factors of ear pathology and differential diagnosis thus avoiding clinical and radiological diagnostic pitfalls.

3.0 CHAPTER THREE: METHODOLOGY

3.1 Research question

What are the patterns and prevalence of anatomical variants of the temporal bone in Nairobi?

3.2 Objectives of the Study

3.2.1 General Objective

To determine the patterns and prevalence of anatomical variations of the temporal bone in patients evaluated by temporal bone HRCT in Nairobi.

3.2.2 Specific Objectives

a) To describe radiologic variants in temporal bone anatomy in patients evaluated by temporal bone HRCT
b) To determine prevalence of the various anatomical variants of temporal bone in patients evaluated by temporal bone HRCT

3.3 Study Site

This was a multisite study involving the departments of Radiology and ENT at the KNH which is Kenya's largest and highest public referral facility, and Plaza Imaging Solutions which is a private imaging centre and both facilities are based in Nairobi, Kenya.

3.4 Study Population

The study population comprised of all the patients who had undergone/ were to undergo temporal bone HRCT at the KNH and Plaza Imaging Solutions. Temporal bone HRCTs done in the KNH and Plaza Imaging Solutions, and held in custody, were also included.

3.4.1 Inclusion Criteria

1. Patients who consented to have their temporal bone HRCT scans included in this study.
2. Temporal bone HRCTs retained/ held in custody at the respective study sites.

3.4.1 Exclusion Criteria.

1. Patients who were unwilling to participate in the study.
2. Temporal bone HRCT that had bilateral pathology obscuring visualization of and/ or erosion of major landmarks and anatomical features.
3. Patients who had undergone bilateral temporal bone surgery
4. HRCTs with evident bilateral temporal bone fracture/s following head injury

3.5 Study Design

This was a descriptive cross-sectional study.

3.6 Sample size

The sample size was calculated using a WHO formulae extracted from WHO's Sample size determination in health studies[61]. There were no loco-regional or international studies that alluded to the overall prevalence of anatomical variants yet the temporal bone anatomical variants were many with varied individual prevalence of <1% as in aberrant internal carotid artery (AICA) to 34% as in anterior sigmoid sinus (ASS)[50,51]. In such cases, the WHO formulae provides for use of the "safest choice" of prevalence as 50%[61]. The sample size formula is:

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

Where:

n= minimum sample size required

Z= normal standard deviation at 95% confidence level=1.96

p= the anticipated population proportion with anatomical variations in temporal bone anatomy estimated at the "safest choice" of 50% prevalence for uncertified/ unknown prevalence thus p= 0.5[61]

d= standard margin of absolute precision or error at 10% given to be 0.1

Therefore:

$$n = \frac{1.96^2 \times 0.5(1-0.5)}{0.1^2}$$

$$n = 96.04$$

This was rounded off to 96 participants plus 5% (n=4) to cater for possible exit from study hence totaling **100 participants.**

3.7 Sampling Procedure

The patients who were to undergo/ had undergone temporal bone HRCT at the respective study sites were recruited into the study by convenience sampling. Temporal bone HRCTs held in custody at the study sites were also included by convenience sampling.

3.8 Study Procedures and Instruments/ Equipment

Patients were recruited at the reception areas of the department of radiology in KNH and Plaza Imaging Solutions prior to undergoing HRCT of the temporal bone. Patients seen in the KNH ENT clinic, who had undergone temporal bone HRCT at KNH or Plaza Imaging Solutions, were also recruited. The study was explained to all patients/ guardians of patients who met the

inclusion criteria and then informed consent/ assent was taken, as per Appendix 1, for collection of their demographic data and use of their temporal bone HRCT scans in this study. The temporal bone HRCT scans held in custody at the study sites were also included in the study. Patients' demographic data was entered into the data collection sheet when getting consent or as per the available records as in cases of retained scans. All collected scans were evaluated by the principal researcher in conjunction with a consultant radiologist at the respective study sites and verified by the consultant radiologist study supervisor. Temporal bones (TBs) with pathology obscuring visualization of and/ or erosion of major landmarks and anatomical features were excluded from the study but the contralateral ear was included as an unpaired TB: These totaled 18 unpaired TBs while 82 paired TBs were also included totaling 182 TBs studied. Anatomical variations in the HRCT temporal bone were recorded in the data collection sheet (Appendix 2). Measurements that were taken included; distance of anterior boundary of sigmoid sinus from the anterior border of the posterior bony EAC wall as seen in axial view to diagnose anterior sigmoid sinus (ASS); depth of low lying tegmen (LLT) from a tangent crossing the superior border of the petrous bone as seen in coronal view; width of the IAC at the porus acusticus as seen on axial scans; the distance of lateral sigmoid boundary to the adjacent outer cortex at the level of EAC on axial view to diagnose lateral sigmoid sinus (LSS); the width of the vestibular aqueduct at it midpoint and operculum to diagnose enlarged vestibular aqueduct (EVA); and the width of the cochlear aqueduct at the mid-otic segment and medial orifice to diagnose large cochlear aqueduct (LCA). Two research assistants from the department of radiology KNH and Plaza Imaging Solution, who are qualified radiographers, were recruited and trained to facilitate consent/ assent taking, image collection and demographic data collection.

The computed tomography scan machine employed at KNH was a Philips 16 slice Brilliance machine model 45356702331, manufactured by Philips Medical Systems taking standard axial scans by helical technique (140kV, 250mA, rotation time of 0.75 seconds, section thickness of 0.6mm with 1mm reconstructions). The computed tomography scan machine at Plaza Imaging Solutions was Aquilion One Toshiba 320 slice machine manufactured by Toshiba, performing standard axial plane scans by helical technique (135kv, 200mA, rotation time of 1.5 seconds, slice thickness of 0.5mm with 1mm reconstructions). To standardize image viewing and measurements, RadiAnt Dicom viewer version 5.5.0 was utilized to view all the scans, do reconstructions from axial cuts and take measurements.

3.9 Data Management

Upon assessment of the temporal bone HRCTs, findings were entered into a preformed data sheet (Appendix 2). All requisite forms and signed consents were stored securely in a lockable drawer in the Department of Surgery (ENT Section), UoN. Soft copy versions of the data were stored in a password protected computer. The data was only accessible to the principal investigator, supervisors and the site radiology consultants.

3.10 Data Analysis

Findings of the study are presented below in text, percentages, charts and tables. The primary outcome was the count of patients with variant anatomy calculated by counting any type of variation seen on temporal bone HRCT. Percentages were obtained by counting specific types of variants per TB as the numerator and using total evaluated TBs as the denominator. Descriptive analysis was conducted using univariate analysis methods where specifically, mean, standard deviation, mode and median were calculated for age of patients (continuous variable). Multivariate cross-tabulations were used to examine the distribution of variant anatomy according to gender and age group and their statistical significance calculated using Fisher's exact test where significance was given by a p value of ≤ 0.05. The data analysis was performed using IBM SPSS statistical software (Version22).

3.11 Quality Assurance

All the temporal bone scans were evaluated by the principal researcher in conjunction with a consultant radiologist in the respective study site. These scans were similarly reassessed by the study supervisor who is also a Consultant Radiologist. RadiAnt Dicom viewer version 5.5.0 was utilized to view all the scans, do reconstructions from axial cuts and take any requisite measurements.

3.12 Ethical Considerations

The study was carried out only after approval by the KNH/UoN as study number P577/10/2017 (Appendix 3). Participation in the study was voluntary and consented both verbally and written. Approval was given for use of temporal bone HRCTs held in custody by the study sites. Patients were not subjected to additional procedures/ expenses/ risk by participating in this study. No victimization or preferential treatment was experienced by refusal or participation in this study. Sensitive patient information that was obtained was kept confidential and no names were recorded in the study data collection sheet.

3.13 Study limitations

The study limitations experienced in this research included

a) The subjective classification of petrous pneumatization as fully and partially (supralabyrinthine and infralabyrinthine) pneumatized and aerated with no available standardized classification without volumetric studies.
b) Controversy over the use of Cincinnati criteria over Valvassori criteria for diagnosis of enlarged vestibular aqueduct with no consensus on the preferred criteria.
c) Arbitrary criteria were established for radiological diagnosis of lateral sigmoid sinus (LSS), prominent sigmoid sinus (PSS) and large mastoid emissary vein as no standardized objective protocol for their diagnosis was noted in literature other than subjective measures such as right to left comparison.
d) Depiction of soft tissue on HRCT is not as good as on MRI thus certain inference are made with reservation, for example, that no pathology was noted as a cause of the expansion or size asymmetry of the internal acoustic canal.
e) Data on the indications for the studies HRCTs was not collected thus clinicoradiological correlation could not be undertaken

3.14 Study Results Dissemination Plan

The study result will be disseminated to the medical fraternity through publication made in at least one peer review journal and scientific meetings. The dissertation hard copies will be available at the UoN Library (KNH) and Libraries at the Departments of Surgery (UoN) and ENT (KNH). A soft copy of the dissertation will be available at the UoN e-repository on the UoN website (**http://erepository.uonbi.ac.ke**).

4.0 CHAPTER FOUR: RESULTS

Temporal bone HRCT scans of 100 participants were examined totaling 200 temporal bones (TBs). Gross pathology that distorted temporal bone anatomy was observed in 18 TBs which were then excluded. Therefore, 182 TBs were included in the study and evaluated, that is, 82 paired TBs and 18 unpaired TBs.

4.1 Demography

The participants' ages ranged from 2 years to 74 years. The mean age was 31.8±16.5 years while the median age was 32 years and the mode 48 years. The overall gender distribution was male n=47 (47%) and female n=53 (53%) giving a 1:1.1 male to female ratio.

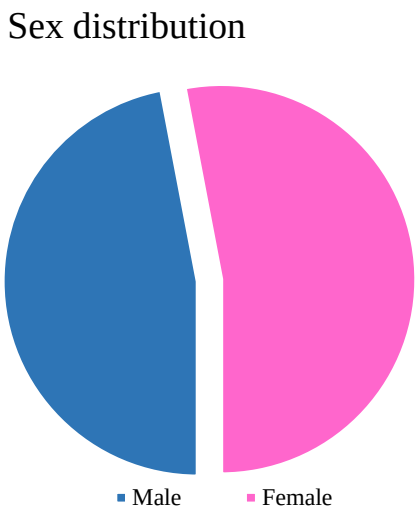

Figure 1: Sex distribution chart

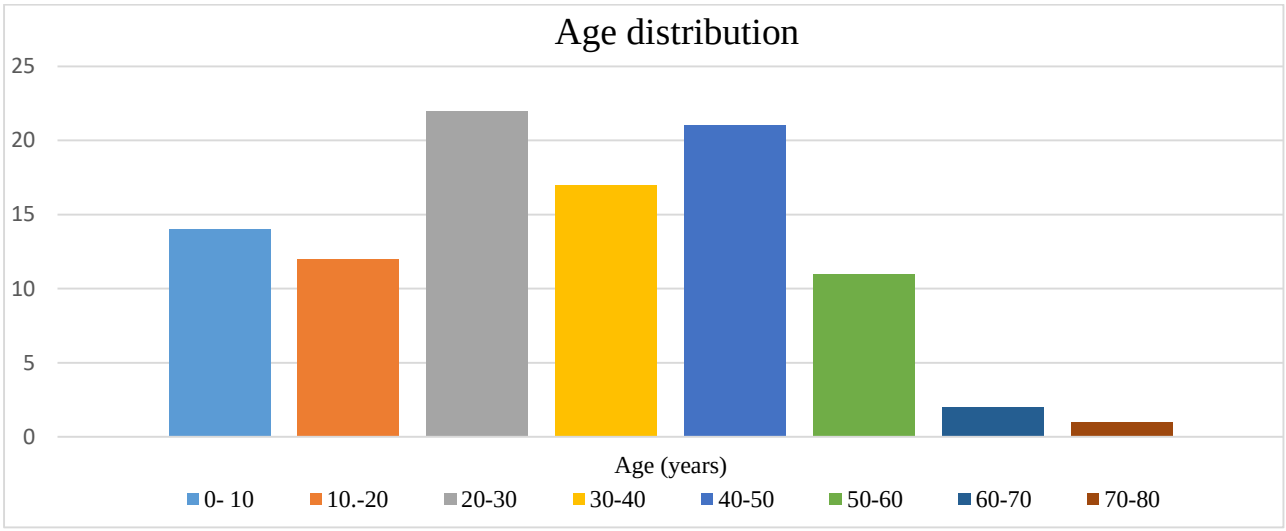

Figure 2: Age distribution chart

4.2 Variant Anatomy of Temporal Bone

Various types and degrees of anatomical variation were noted in 99% of the participants with only 1 participant (1%) free of significant variation (type B sinus tympani with Hans 3 mastoid).

Variants with highest prevalence included type B sinus tympani (73.1%), prominent sigmoid sinus (70.3%), Korner's septum (57.1%), petrous aeration (56.5%) and Hans type 4 mastoid (47.8%). Variants with the lowest prevalence included large cochlear aqueduct (0.6%), enlarged vestibular aqueduct (1.1%), petrosquamous sinus (1.1%) and sclerosed petrous (3.3%). No observations were made of the following variations: aberrant internal carotid artery (AICA), persistent stapedial artery (PSA) and jugular diverticulum. Vestibular and cochlear aqueducts were seen in 100% of TBs and the full course of cochlear aqueduct was appreciated in 32.4% of TBs (n=59). Lateral internal carotid artery (LICA) was the only arterial variant observed in this study with a prevalence of 12.6% and 38.5% bilaterality.

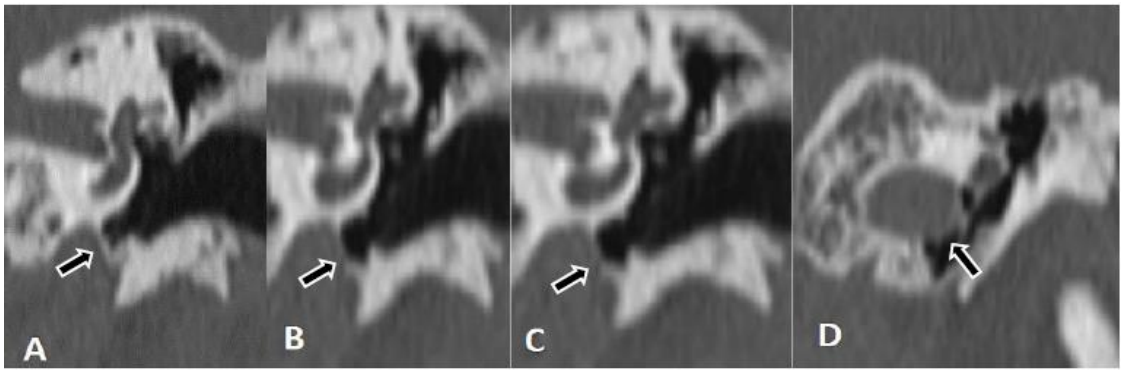

Figure 3: LICA: Left ICA taken serially as it moves caudocranially (A-D) revealing dehiscence (follow the arrows)

The overall prevalence of variants are summarized in table 3 below.

Table 3: Summary of anatomical variations in temporal bone HRCTs

Variations		Rt n=89 (48.9%)	Lt n=93 (51.1%)	Total n=182 (100%)	Comments
1.	Aberrant ICA	00	00	00	
2.	Lateral ICA	13	10	23 (12.6%)	1 case LICA protrusion
3.	Persistent stapedius artery	00	00	00	
4.	Sinus tympani types				
	A	15	4	19 (10.4%)	
	B	67	66	133 (73.1%)	
	C	7	23	30 (16.5%)	
5.	Anterior sigmoid sinus	6	10	16 (8.8%)	
6.	Lateral sigmoid sinus	21	20	41 (22.5%)	
7.	Prominent sigmoid sinus	68	60	128 (70.3%)	
8.	Sigmoid sinus dehiscence	12	7	19 (10.4%)	3 cases sigmoid diverticula
9.	Korner's septum	50	54	104 (57.1%)	
10.	Petrous type				
	Fully aerated	27	29	56 (30.8%)	
	Supralabyrinthine aeration	00	00	00	
	Infralabyrinthine aeration	12	13	25 (13.7%)	
	Supra. and infralabyrinthine aeration	11	11	22 (12.1%)	
	Diploe	36	37	73 (40.1%)	
	Sclerosed	3	3	6 (3.3%)	
11.	High jugular bulb	14	7	21 (11.5%)	
12.	Dehiscent jugular bulb	7	5	12 (6.6%)	
13.	Jugular diverticulum	00	00	00	
14.	Enlarge vestibular aqueduct	1	1	2 (1.1%)	
15.	Large cochlea aqueduct	1	00	1 (0.6%)	
16.	Cochlear cleft	24	23	47 (25.8%)	
17.	Large internal acoustic canal	8	13	21 (11.5%)	
18.	Low lying tegmen	28	25	53 (29.1%)	
19.	Facial nerve dehiscence	6	7	13 (7.1%)	1 FND obstructing oval window
20.	Mastoid type				
	Hans 1	10	13	23 (12.6%)	
	Hans 2	19	11	30 (16.5%)	
	Hans 3	12	13	25 (13.7%)	
	Hans 4	40	47	87 (47.8%)	
	Sclerosed	8	9	17 (9.3%)	
21.	SSCCD	8	8	16 (8.8%)	2 posterior limb dehiscence
22.	Large Emissary Vein	5	5	10 (5.5%)	
23.	Tegmen tympani dehiscence	10	15	25 (13.7%)	No case of herniation
24.	Foramen of Huschke	24	24	48 (26.4%)	
25.	Petrosquamous sinus	1	1	2 (1.1%)	

Sigmoid sinus had several variants with the prominent sigmoid sinus as the commonest variant at 70.3%, then lateral sigmoid sinus (LSS) 22.5%, sigmoid sinus dehiscence at 10.4% and anterior sigmoid sinus (ASS) as the least common sigmoid variation at 8.8% %. 3 cases of sigmoid sinus diverticula were observed. Jugular bulb variants were high jugular bulb (HJB) at 11.5% and dehiscent jugular bulb (DJB) at 6.6%. Large emissary vein was noted in 5.5% TBs with no bilaterality.

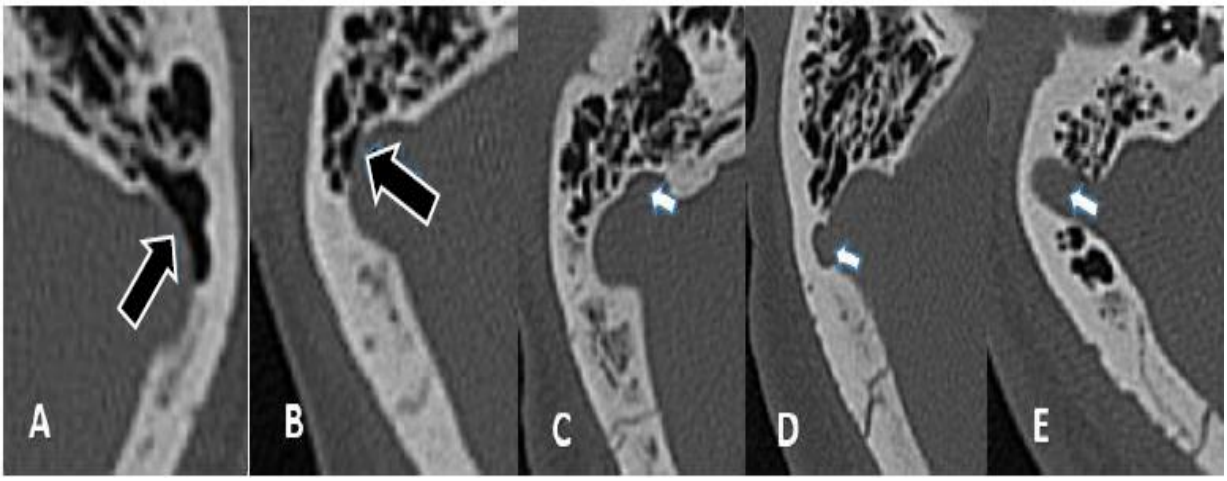

Figure 4: Sigmoid dehiscence (white hollow arrows)-A/B and Sigmoid diverticula (white solid arrows)-C/D/E

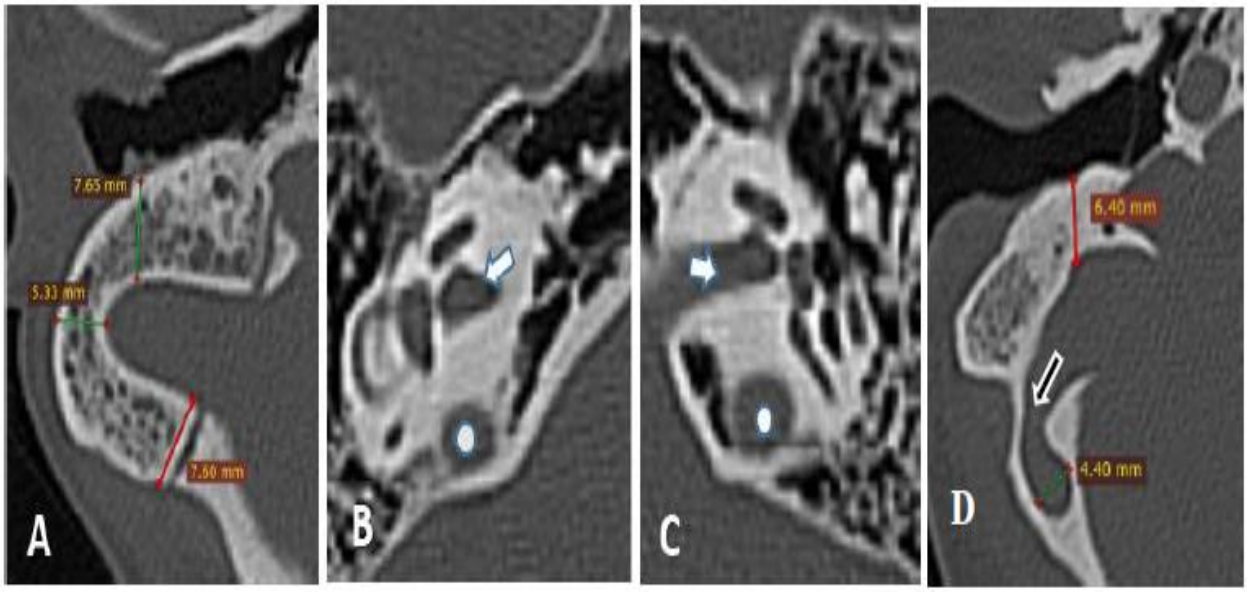

Figure 5: Concurrent ASS/ LSS/ PSS-A, bilateral HJB-B/C (white spots- jugular / white solid arrows- IAC) and Rt ASS/LSS with a large emissary vein-D (white hollow arrow)

The petrous pneumatization pattern was diploe in 40.1% of TBs, fully aerated in 30.8%, partial infralabyrinthine aeration 13.7%, combined supralabyrinthine and infralabyrinthine aeration 12.1% and sclerosed in 3.3%. Partial and full petrous pneumatization and aeration totaled 56.6%.

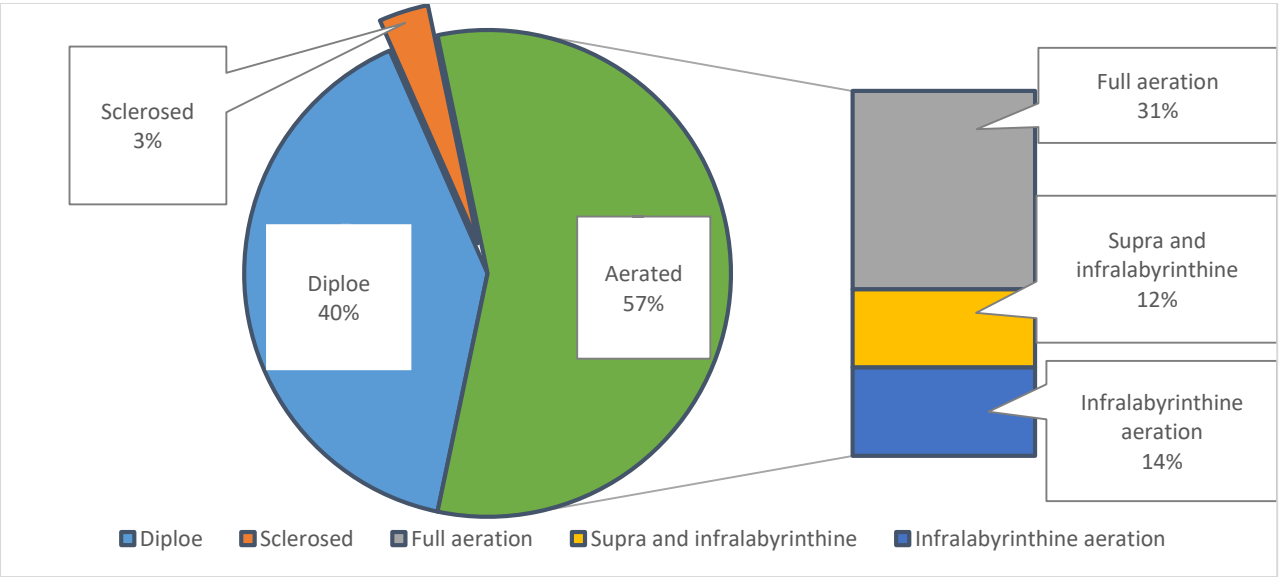

Figure 6: Petrous pneumatization pattern

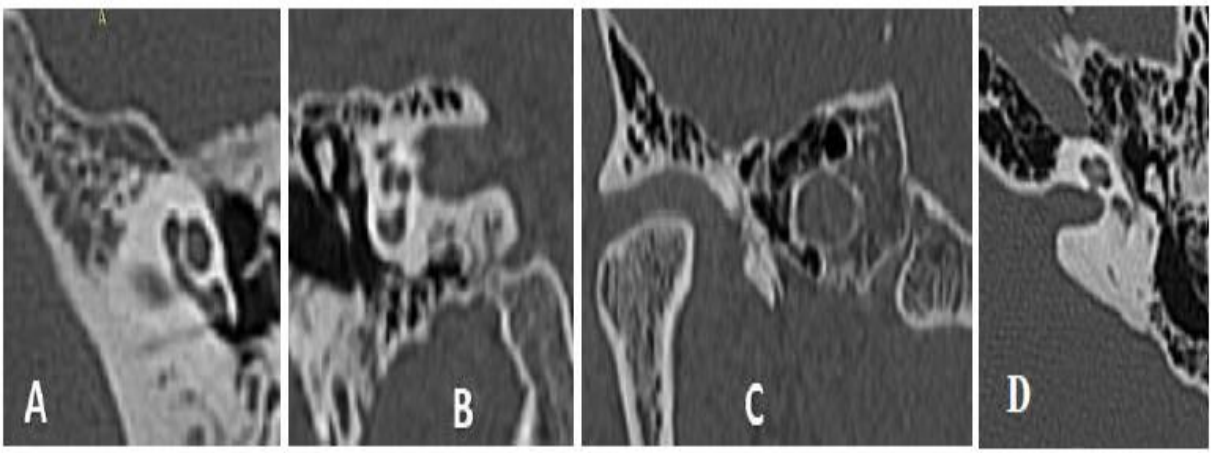

Figure 7: Scans of petrous pneumatization. Diploe (axial)-A, supralabyrinthine and infralabyrinthine aeration (coronal) -B/C and full aeration (axial)-D

Mastoid pneumatization was classified as sclerosed (9.3%) and pneumatized according to Han's classification into Hans 1= poor pneumatization (12.6%), 2= moderate pneumatization (16.5%), Hans 3= good pneumatization (13.7%) and Hans 4= very good pneumatization (47.8%).

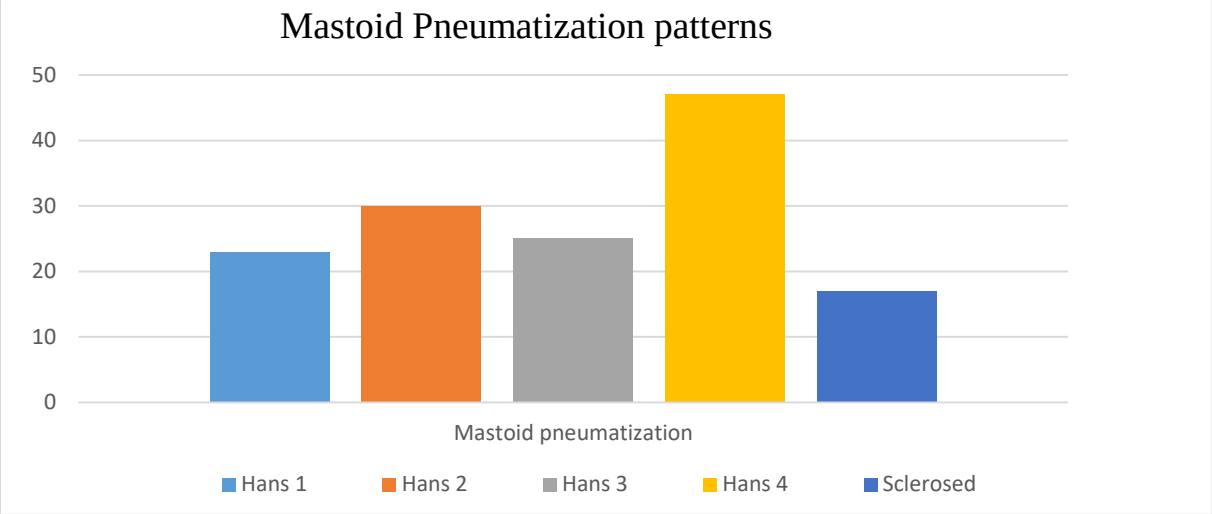

Figure 8: Chart on mastoid pneumatization patterns

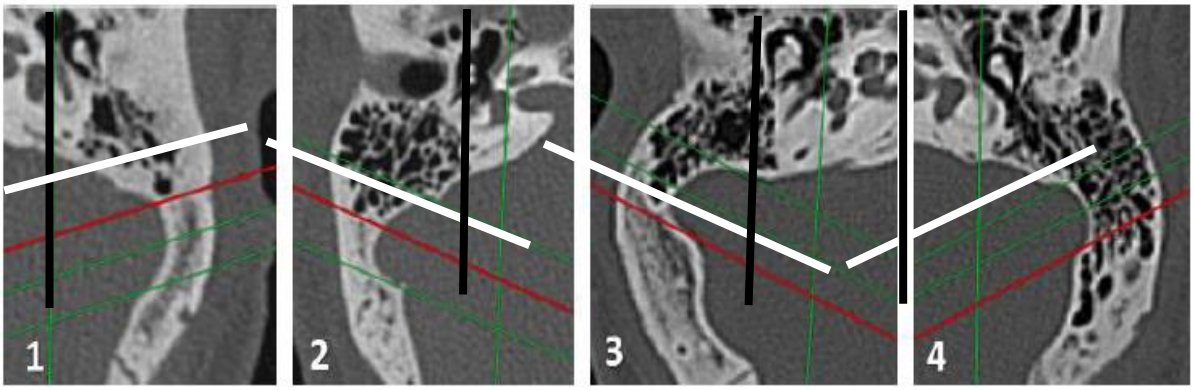

Figure 9: Scans showing mastoid pneumatization Hans types 1-4 respectively (axial cut at level of incudomalleor joint with black lines in the anteroposterior plane while white and green lines are at 40-45^0 consistent with Hans classification)

Korner's septum was noted in 57.1% of TBs with 77.8% bilaterality.

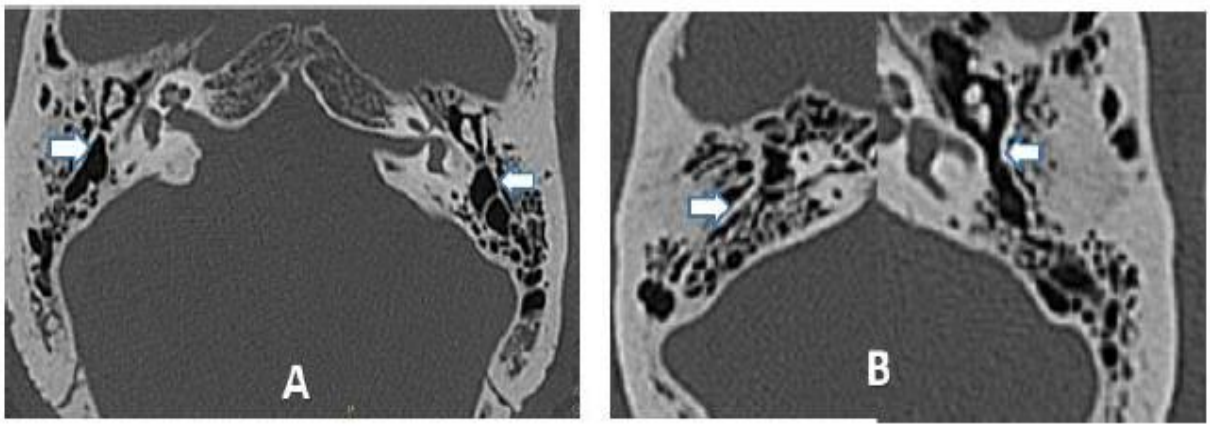

Figure 10: Scans of bilateral Korner's Septum (white arrow) in 2 participants.

The prevalence of the types of sinus tympani was as follows, type B was the commonest at 73.1%, type C was 16.5% with only 26.1% bilaterality and type A was the rarest at 10.4%.

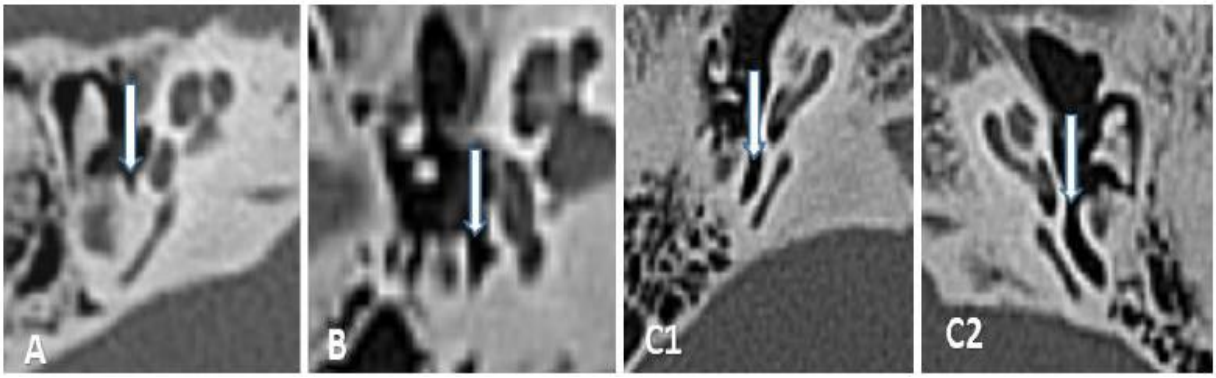

Figure 11: Scans of types of sinus tympani in axial view (white arrows): Types A, B, and 2Cs

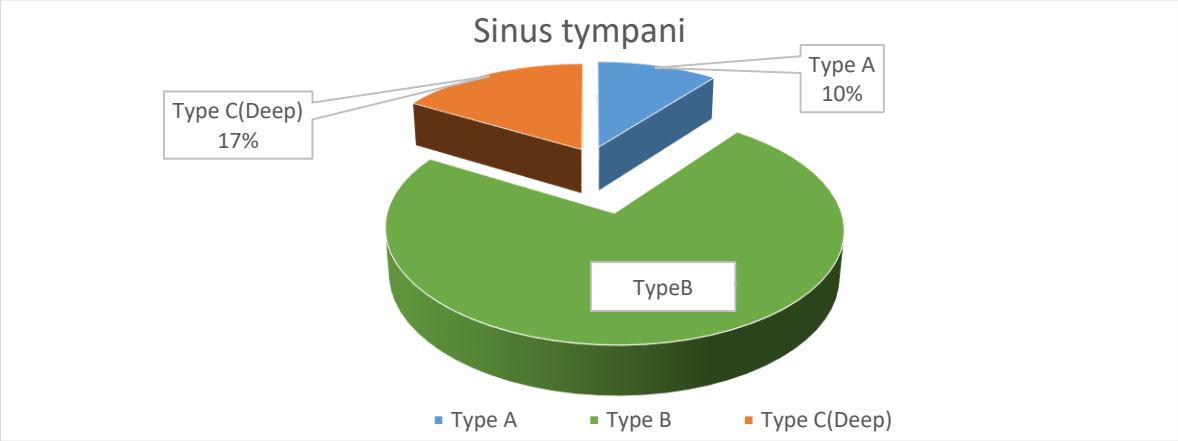

Figure 12: Chart on types of Sinus tympani

Variations in the labyrinth by frequency included cochlear cleft at 25.8% with 70.8% bilaterality and 1 case of a large right cochlear aqueduct. SSCCD was observed in 8.8% TBs with 50% bilaterality and 2 cases were noted to have dehiscence in the posterior limb of the superior SCC.

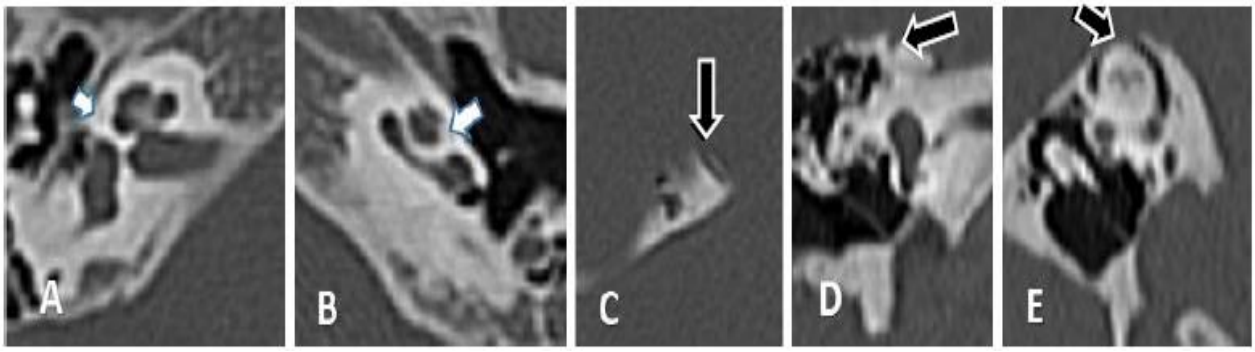

Figure 13:Scans of bilateral cochlear cleft (axial)-A/B (white solid arrows) and Right SSCCD (white hollow arrows) in axial- C, coronal- D and poschl- E views

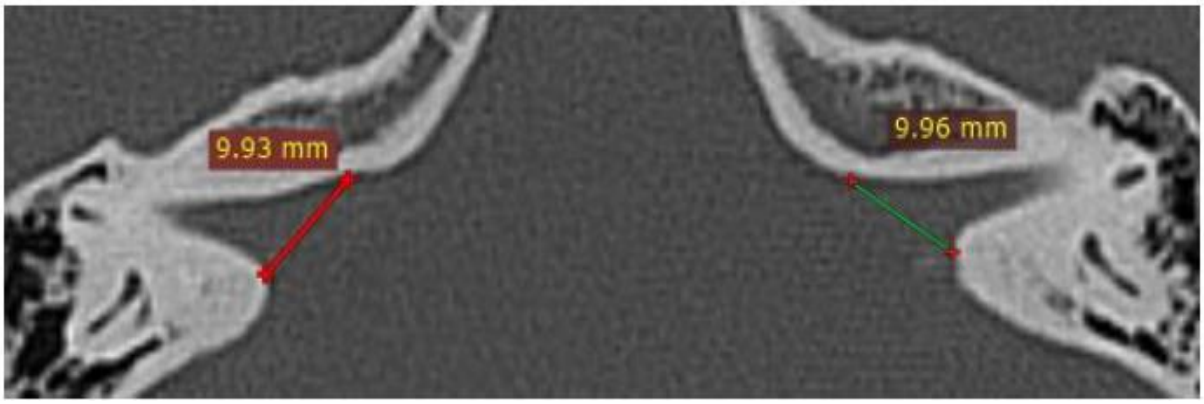

Figure 14: Scan of bilateral LIAC porus acusticus width is >9mm

Large internal auditory canal (LIAC) was noted in 11.5% TBs with 38.5% bilaterality (Figure 14 above). The shape of IAC was also evaluated and four different shapes were observed. Their prevalence are given in the table 4 below noting that the funnel and bud shapes were the commonest shapes.

Table 4: Frequency table of IAC shape

IAC shape	Rt	Lt	Total
Funnel shaped	47	44	91 (50%)
Bud shaped	25	25	50 (27.5%)
Cylindrical	11	20	31 (17.0%)
S- shaped	6	4	10 (5.5%)
Total	89 (48.9%)	93 (51.1%)	182 (100%)

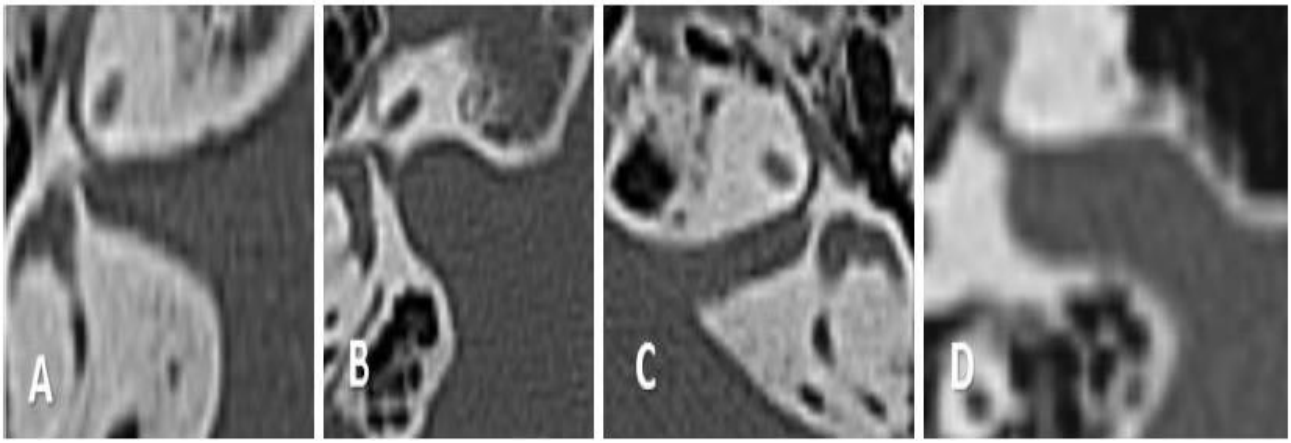

Figure 15: IAC shapes (axial views): Funnel- A, Bud- B, Cylindrical- C and S-shaped – D

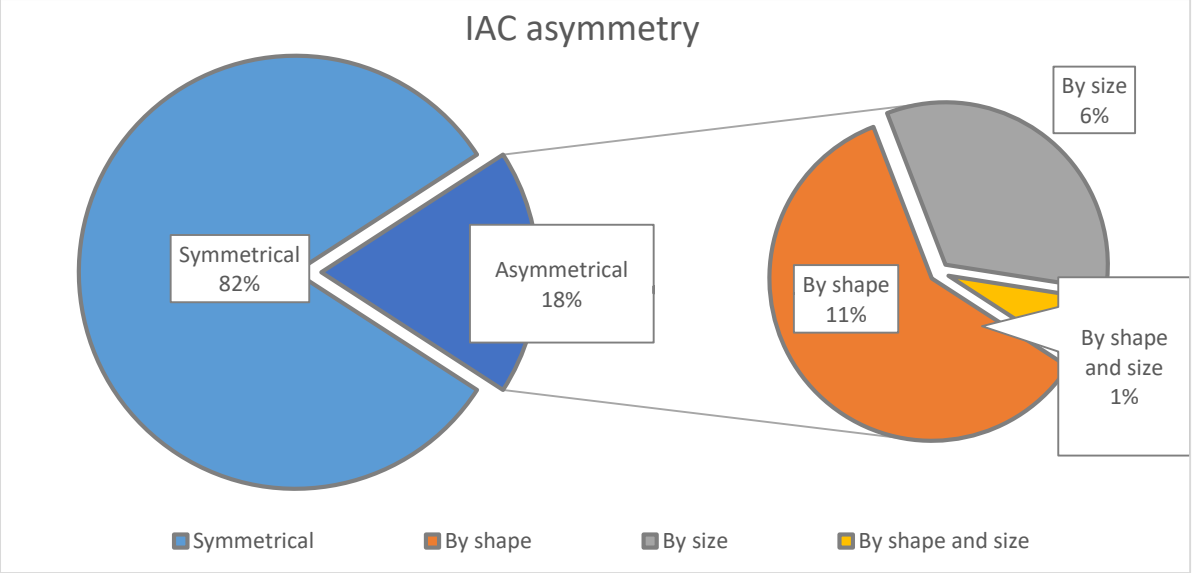

Figure 16: IAC asymmetry

Asymmetry in the IAC by shape was noted in n=9/82 (10.9 % of paired TBs) and by size, that is a difference of ≥2mm in the porus acusticus width, in 5/82 (6.1% of paired TBs) with n=1/82 (1.2%) case having both size and shape asymmetry. Therefore, n= 15/82 (18.3% of paired TBs) had IAC asymmetry.

Tegmen variations observed included low lying tegmen at 29.1% (n=53/182) where 27.3% (n=15/53) were ≥7mm deep and tegmen tympani dehiscence at 13.7% with 46.7% bilaterality but no meningeal herniation noted.

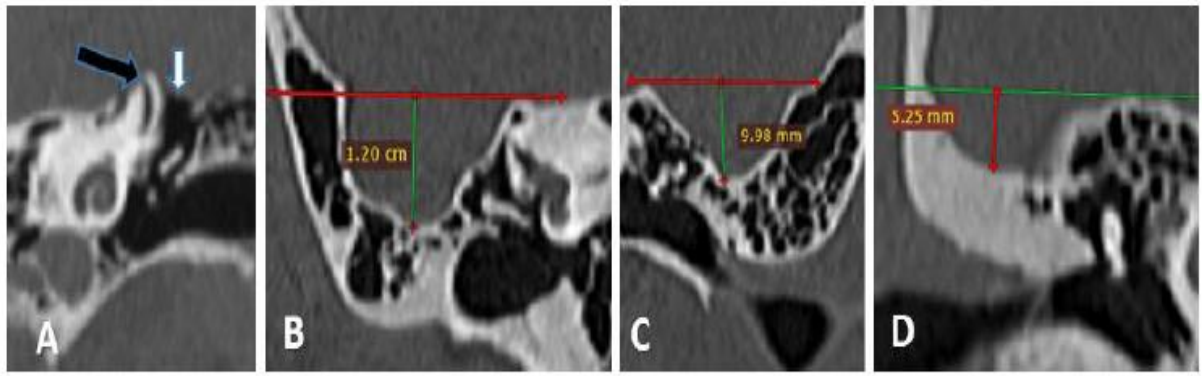

Figure 17: Scans of concurrent dehiscent tegmen tympani (black arrow) with SSCCD (white arrow)- A and coronal scans of low lying dura- B/C/D (All in coronal plane)

Foramen of Huschke was noted in 26.4% of TBs with 79.2% bilaterality. Facial nerve variations were facial nerve dehiscence in 7.1% of TBs with 71.4% bilaterality, and 1 case of FND with significant oval window obstruction.

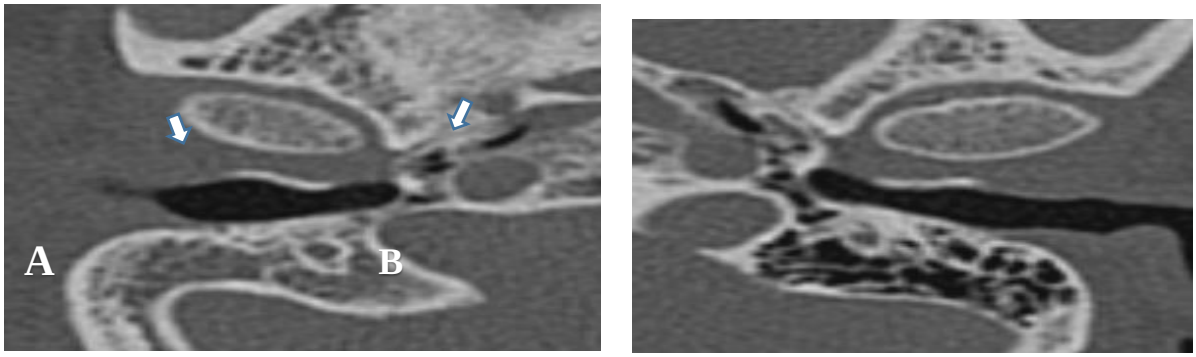

Figure 18: Scans of bilateral Foramen of Huschke A/B (white arrows)

Subarcuate canal was seen in n=122/182 (67.0%) of TBs with 71.4% bilaterality. The subarcuate canals that were prominent totaled n=13/122 (10.7%). Jugular foramen symmetry was also assessed in the 82 paired TBs. Asymmetrical jugular foramen was seen in n=33/82 (40.2%) of paired TBs against n=49/82 (59.8%) with symmetrical foramina.

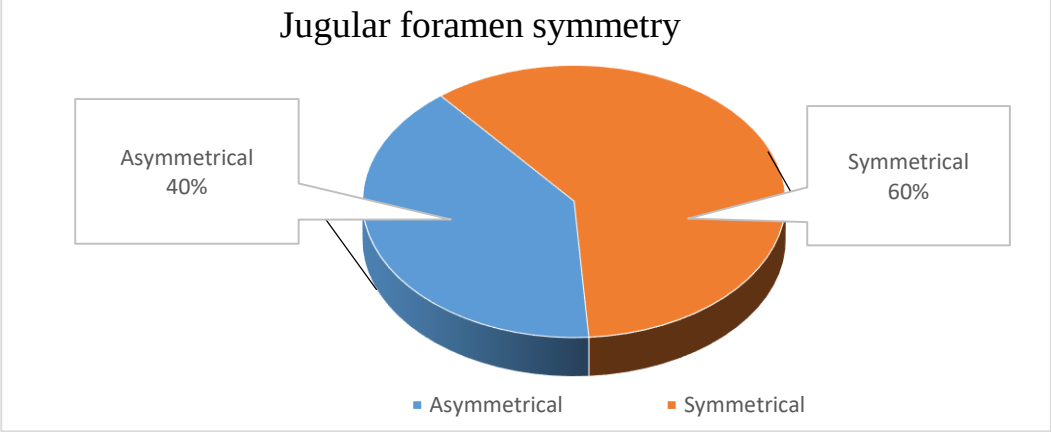

Figure 19: Jugular foramen symmetry

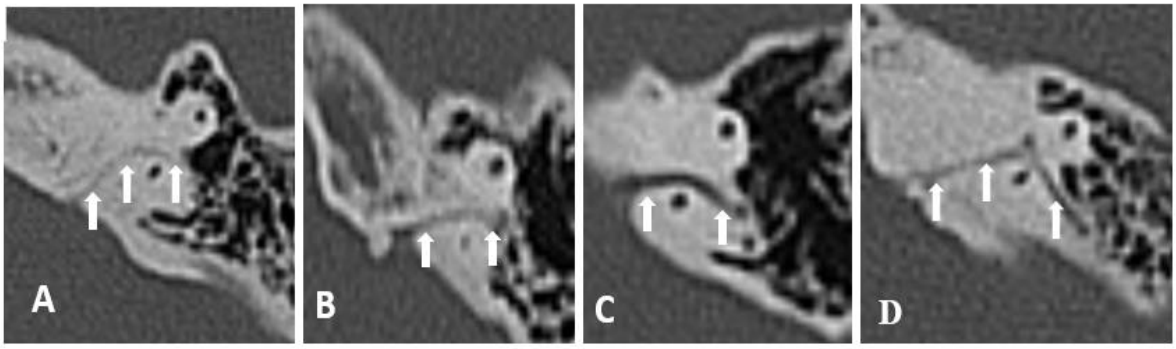

Figure 20: Scan of subarcuate canal barely visible in A/B and very prominent in C/D

Aberrant soft tissue density, possibly an anomalous venous channel, was observed in three TBs. The channel was anterior to the superior SCC running in an anteroposterior course to drain into the superior petrosal sinus.

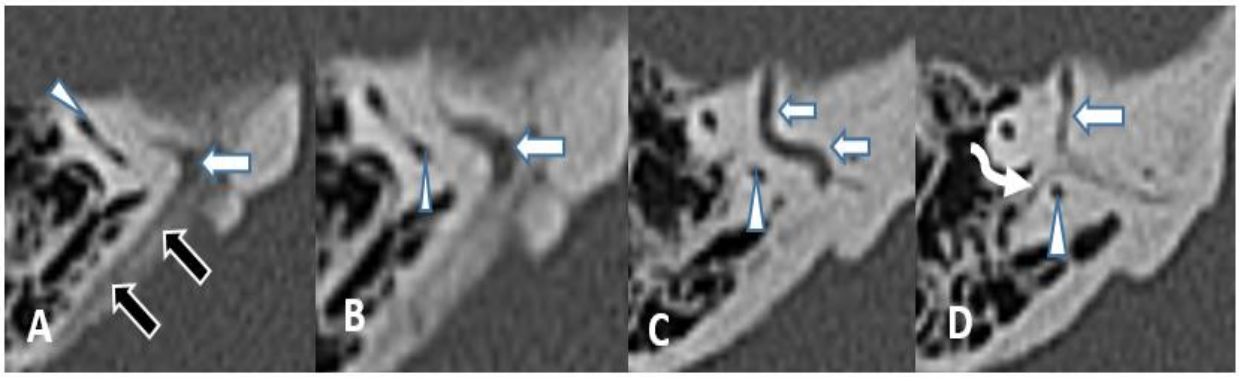

Figure 21: Anomalous venous channel(white solid arrow) from middle cranial fossa to the superior petrosal sinus is seen craniocaudally from A-D. Superior petrosal sinus(white hollow arrows, Superior SCC (white arrow head) and subarcuate canal (curved white arrow) are seen

4.3 Correlations and their analysis

There is significant difference in temporal bone maturation where age above 11 years is considered the cutoff for adult- type temporal bone in terms of pneumatization, aeration and ossification/ bone density with minimal further development occurring beyond 10.8 years[62]. Based on this, analysis of the participants aged below 11 years (paediatric group) against the ≥11 year olds (adult group) was undertaken. The paediatric group consisted of 14 participants (14% of study group) where 25 TBs were evaluated. The comparative central tendencies were contrasted in the table 5 below.

Table 5: Age ranges, central tendencies and M: F by age groups

Tendencies → / **Group** ↓	**Study size**	**Range (years)**	**Mean age**	**Median age**	**Mode**	**M:F**
Paediatric group	14(14%)	2-10	6.4	7.5	2	1.3: 1
Adult group	86(86%)	12-74	35.9	36	48	1: 1.2
Overall group	100(100%)	2-74	31.8	32	48	1: 1.1

It is significant to note that the M:F ratio in the paediatric group is male dominate and yet in the adult group is female dominated. The mean and median ages in both groups are highly in tandem pointing to the normality of their distribution. The paediatric temporal bone pneumatization differed from the adult group in that the paediatric petrous was predominantly diploe n=20 (80%) and aerated n=5 (20%) against the adult group of aerated petrous in 62.4% (n=98), diploe 33.8% and sclerosed 3.8% (p= 0.03). No petrous sclerosis was seen in the paediatric group (p=0.001).

Other anatomical variants with significant statistical difference between the age groups included higher paediatric rates of LSS at 60% versus adults'16.6% (p= 0.001), nearly similar rates of sigmoid sinus dehiscence at 12% versus adults'10.2% (p= 0.02) and higher HJB at 16% versus adults' 10.8% (p=0.048). Mastoid pneumatization pattern in the paediatric group was fairly distributed between Hans types 1, 2 and 4 whereas in the adult group was predominantly Hans type 4.

The prevalence of variations by age group are compared and summarized in table 6 below.

Table 6: Prevalence of temporal bone variation by age groups

Variations		Paediatric group n=25(100%)	Adult group n=157(100%)	Overall group n=182(100%)	p value
1.	Aberrant ICA	00	00	00	-
2.	Lateral ICA	00	23(14.6%)	23(12.6%)	0.54
3.	Persistent stapedius artery	00	00	00	-
4.	Sinus tympani types				
	A	1(4%)	18(11.5%)	19(10.4%)	0.45
	B	22(88%)	111(70.7%)	133(73.1%)	0.35
	C	2(8%)	28(17.8%)	30(16.5%)	0.5
5.	Anterior sigmoid sinus	4(16%)	14(8.9%)	16(8.8%)	0.27
6.	Lateral sigmoid sinus	15(60%)	26(16.6%)	41(22.5%)	0.001
7.	Prominent sigmoid sinus	17(68%)	111(70.7%)	128(70.3%)	0.62
8.	Sigmoid sinus dehiscence	3(12%)	16(10.2%)	19(10.4%)	0.02
9.	Korner's septum	18(72%)	86(54.8%)	104(57.1%)	0.35
10.	Petrous type				
	Fully aerated	3(12%)	53(33.8%)	56(30.8%)	0.03
	Supralabyrinthine aeration	00	00	00	
	Infralabyrinthine aeration	1(4%)	24(15.9%)	25(13.7%)	
	Supra and infralabyrinthine aeration	1(4%)	21(13.4%)	22(12.1%)	
	Diploe	20(80%)	53(33.8%)	73(40.1%)	0.001
	Sclerosed	00	6(3.8%)	6(3.3%)	0.001
11.	High jugular bulb	4(16%)	17(10.8%)	21(11.5%)	0.048
12.	Dehiscent jugular bulb	00	12(7.6%)	12(6.6%)	1.00
13.	Jugular diverticulum	00	00	00	-
14.	Enlarge vestibular aqueduct	00	2(1.3%)	2(1.1%)	1.00
15.	Large cochlea aqueduct	00	1(0.6%)	1(0.6%)	1.00
16.	Cochlear cleft	11(44%)	36(22.9%)	47(25.8%)	0.14
17.	Large internal acoustic canal	2(8%)	19(12.1%)	21(11.5%)	0.64
18.	Low lying tegmen	8(32%)	45(28.7%)	53(29.1%)	0.95
19.	Facial nerve dehiscence	1(4%)	12(7.6%)	13(7.1%)	0.33
20.	Mastoid type				
	Hans 1	7(28%)	16(10.2%)	23(12.6%)	0.11
	Hans 2	6(24%)	24(15.9%)	30(16.5%)	0.31
	Hans 3	3(12%)	22(14.0%)	25(13.7%)	1.00
	Hans 4	7(28%)	80(50.9%)	87(47.8%)	0.35
	Sclerosed	2(8%)	15(9.6%)	17(9.3%)	1.00
21.	SSCCD	4(16%)	12(7.64%)	16(8.8%)	0.56
22.	Large Emissary Vein	00	10(6.4%)	10(5.5%)	0.42
23.	Tegmen tympani dehiscence	3(12%)	22(14.0%)	25(13.7%)	1.00
24.	Foramen of Huschke	5(20%)	43(27.4%)	48(26.4%)	0.84
25.	Petrosquamous sinus	1(4%)	1(0.6%)	2(1.1%)	0.14

Correlation of the temporal bone anatomical variants by gender revealed higher prevalence of LIAC (p=0.03) and Hans 1 mastoid pneumatization (p=0.003) in the males and female preponderance for LLT (p=0.02) as shown below.

Table 7: Gender correlation of LIAC

Gender	Absent	Left	Right	Bilateral	Total	p-value
Female	46	1	3	3	**53**	**0.03**
Male	38	7	0	2	**47**	
Total	**84**	**8**	**3**	**5**	**100**	

Table 8: Gender correlation of low lying tegmen tympani

Gender	Absent	Left	Right	Bilateral	Total	p-value
Female	32	7	2	12	**53**	**0.02**
Male	35	0	5	7	**47**	
Total	**67**	**7**	**7**	**19**	**100**	

There was significant correlation between the mastoid pneumatization pattern and petrous pneumatization pattern where the rates of petrous pneumatization were higher in higher degrees of mastoid pneumatization with up to 74.8% (n= 77/103) of petrous pneumatization being associated with Hans 3 and 4 mastoid pneumatization (p=0.001). Hans 4 mastoid pneumatization was significantly associated with PSS (p= 0.001) and sclerosed mastoid significantly associated with both ASS (p= <0.04) and LSS (p= <0.005). LSS was associated with both sclerosed and lower mastoid pneumatization (Hans 1 and 2) than higher mastoid pneumatization (p=<0.005).

No association was noted between petrous pneumatization and LICA (p=0.98) or LLT (p= 0.09). Only one case of concurrent HJB with DJB was observed and no significant association was noted (p= 0.43). Similarly no association was made between SSCCD and the tegmen variations, which are LLT and tegmen dehiscence (p= >0.4).

5.0 CHAPTER FIVE: DISCUSSION

5.1 Demography

This study reveals that the overall prevalence of anatomical variations of temporal bone as depicted by HRCTs is high at 99%. With exception of the dominant variants, such as Korner's septum, PSS, temporal bone pneumatization patterns and sinus tympani types A and B, n=32/ 182 TBs (17.6% of TBs) with 52.4% bilaterality making n=11/82 paired TBs (13.4% of paired TBs) would have been classified as variation free. Most studies preferred to itemize the prevalence of individual variants as opposed to the overall prevalence thus the overall prevalence of variants is not comparable to other studies. The gender distribution between the paediatric age group and adult group is reversed pointing to a male predominated bias in the paediatric group. In the adult and overall groups, there was a female predominance in anatomical variant prevalence although only low lying tegmen (LLT) reflected statistical significance whereas large internal acoustic canal (LIAC) and Hans 1 mastoid show male preponderance.

5.2 Arterial Variants (AICA, LICA And PSA)

Arterial variants in the temporal bone especially the aberrant ICA (AICA) and persistent stapedial artery (PSA) are extremely rare. These variants were not observed in this study and several others[18,48,49]. However, 1% and 0.3% prevalence for AICA and 0.5% prevalence for PSA have been observed but the low rates still point to their rarity [50,51,55]. Lateral ICA (LICA) was noted to be the highest occurring arterial variant with a prevalence of 12.6% in this study and 2% - 3.4% in others[18,51]. This may be due to the lower threshold utilized to diagnose LICA where dehiscence of the lateral wall in one axial scans and one orthogonal reformat was considered diagnostic. Only one case of LICA with lateral protrusion of the ICA was observed. Injury to the LICA and other arterial variants can result in catastrophic intraoperative haemorrhage[18]. This may occur while probing and manipulating the protympanum thus the need to have a cautiously lower diagnostic threshold. Despite the low prevalence of arterial variants, their surgical implication of catastrophic haemorrhage is so significant that they should be actively looked for preoperatively and even intraoperatively in case they were missed or unreported.

5.3 Venous Variants (Sigmoid, Jugular Bulb and Mastoid Emissary Vein)

The sigmoid sinus, jugular bulb and mastoid emissary vein comprise the most significant venous structures in the temporal bone. The anterior sigmoid sinus (ASS) prevalence was 8.8% in this study, falling within the range of 1.1-34% prevalence by other studies[18, 39, 48-51]. The lateral sigmoid sinus (LSS) prevalence of 22.5% in this study resonates with Koesling's 28% but contrasts with Pawel's 8.3%[18,50]. There is marked resonance in the methodologies of these studies and even the study population, comparing ASS in Pawel (1.1%) and Cigdem (34%), was in patients with chronic ear disease yet there is inexplicably significant difference in prevalence. Anteriorly and laterally placed sigmoid significantly increases the difficulty of mastoidectomy, risk of haemorrhage and the overall operative time especially if concurrent with other variants for example low lying tegmen[13,18,39]. Sigmoid sinus dehiscence was noted in 10.4% TBs differing from Koesling's 1%[50].

High jugular bulb (HJB) prevalence was 11.5% in this study which is in tandem with prevalence of 6-32% given by other studies[18,50,51]. Jugular bulb dehiscence was noted in 6.6% of TBs which is higher than the 1- 4% prevalence reported in other studies[18,48-50]. HJB and dehiscence have been associated with significant haemorrhage during middle ear exploration and manipulation and can similarly be confused for a glomus tumor radiologically and during otoscopy especially in jugular diverticulum occurs[20,50].

The mastoid emissary veins are usually <1mm but higher mean sizes have been reported[63,64]. In this study, the prevalence of large emissary vein was 5.5% without bilaterality and the veins ranged 2.3- 4.7mm in diameter where all the sizes were ≥33.3% of the source sigmoid sinus diameter. Large emissary veins may result in significant venous haemorrhage in extended mastoidectomies and retrosigmoid approach procedures[65]. Mastoid emissary can also be a source of retrograde infection from the neck to the sigmoid, transverse, superior petrosal and even to the cavernous sinus[65]. In cases of sigmoid thrombosis/ dural sinus occlusive disease, Greisinger's sign may be present, this is erythema, oedema and tenderness in the postauricular region due to thrombosis of the mastoid emissary vein.

5.4 Petrous Pneumatization

In this study, full petrous pneumatization and aeration was seen in 30.8% TBs which is higher than Hentona's 12.8% prevalence[59]. Partial and full petrous pneumatization and aeration totaled 56.6% which was higher than Hentona's 32.7% but lower than Yamakami who observed 89% aerated and 11% sclerosed[42,59]. Petrous aeration was directly related to mastoid aeration as 74.8% of aerated petrous had Hans 3 and 4 mastoid pneumatization (p=0.001). This association has been replicated in other studies[42,59].

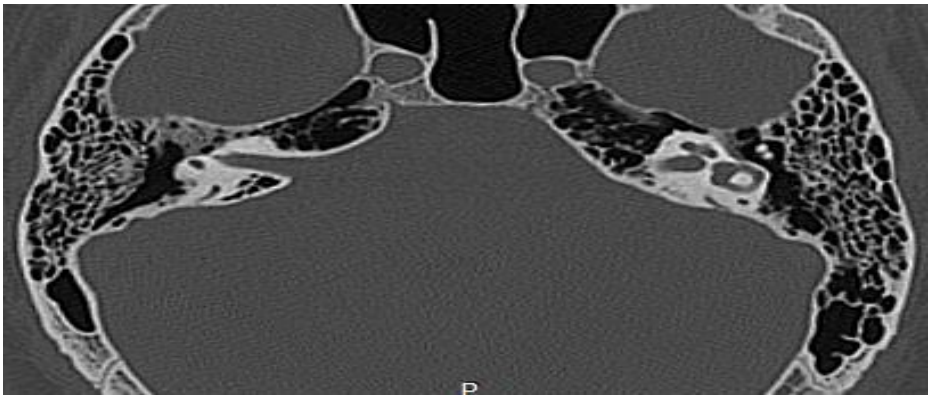

Figure 22: Concurrence of Hans 4 mastoid and full petrous pneumatization bilaterally.

Partial pneumatization comprised 45.6% of pneumatized petrous while full pneumatization was 54.4% differing from Hentona's 60% partial versus 40% full pneumatization pattern. Higher rates of inferior than superior pneumatization were noted in the partially pneumatized petrous resonating with Hentona's observation. Petrous pneumatization is important because it has been associated with higher incidence of apical mucocele, petrous apicitis, Gradenigo's syndrome and petrous air-cell effusion in the background of chronic ear disease as opposed to diploic and sclerotic apices[47]. Petrous pneumatization is also a risk factor for CSF rhinorrhea in skull base surgery[43].

5.5 Mastoid Pneumatization and Korner's Septum

Korner's septum prevalence in this study was higher at 57.1% with 77.8% bilaterality compared to Goksu's 6.6% prevalence in normal TBs, 30.4% in retracted TM, 17.4% in chronic otitis media without adhesions and Cigdem's 28% prevalence with 58% bilaterality[22,51]. Korner's septum has been associated with increased surgical time, poor surgical penetration to the aditus ad antrum with high disease recurrence or persistence, tympanosclerosis and chronic ear disease[22,23,40,41,45].

Well pneumatized mastoid which would comprise Hans types 2, 3 and 4 totaled n=142(78%) falling within the range of 42-90.7% by other studies.[6, 7] Mastoid pneumatization of Hans 3 and 4 patterns, which comprises 61.5% TBs in this study, has been associated with protective cushioning against otic capsule violation in temporal bone trauma, that is, up to 100% otic capsule sparing in temporal bone trauma [5].

5.6 Canals, foramina and recesses (EVA, LCA, LIAC, foramen of Huschke, Sinus tympani, jugular foramen and subarcuate canal)

The enlarged vestibular aqueduct (EVA) prevalence by this study was 1.1% TBs (n=2). This diagnosis was made using the Cincinnati criteria, however, if the Valvassori criteria was employed, the dimensions of the vestibular aqueduct would have been classified as normal hence highlighting the controversy of which criteria should prevail in diagnosis of EVA[28,53]. The 1.1% EVA prevalence resonates with prevalence by other studies at 1.4-2.9%[28,42]. Higher incidences of 16% (Valvassori criteria) and 44% (Cincinnati criteria) have been reported by Karuna where Karuna's study was exclusively conducted on paediatric patients with SNHL awaiting cochlear implant while this study/thesis was conducted on the general otology patients[54]. EVA has been associated with SNHL, third window syndrome (atypical conductive hearing loss), perilymphatic gusher during ear surgery, cochlear anomalies (in up to 90%), vestibular system anomalies (in up to 50%) and other congenital syndromes[26,27,42].

The large cochlear aqueduct (LCA) prevalence is very low at 0.6- 3% resonating with 0.6% finding in this study[42,48,49]. Its association with SNHL is disputed but its presence may form a conduit for infection tracking from the inner ear to the subarachnoid space and vice versa or it may result in a perilymphatic gusher during stapedectomy[42,46]. The rates of perilymphatic gusher are higher with LCA (83.3%) than EVA (12.5%) as noted during cochlear implant surgery[42]. The full course of the cochlear aqueduct was seen as in 32.4% of TBs resonating with Suresh et al at 31%[11]. The full course of the cochlear aqueduct may easily be confused for temporal bone fracture[26].

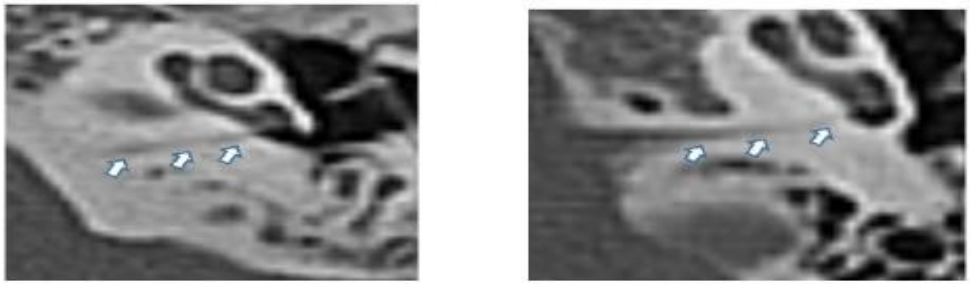

Figure 23: Scans of cochlear aqueduct showing long courses resembling fracture lines (white arrows)

Large internal acoustic canal (LIAC) was seen in 11.5% of TBs as opposed to 0.3- 6.1% by other studies[30,31,48,49]. The IAC significantly varied in shape where the funnel (50%) and bud (27.5%) types were the most prevalent. Sergio found a different distribution in the shape of adult IAC, that is, 58.3% funnel, 30.9% cylindrical and 10% bud but the S-shaped IAC was not observed like it was in 5.5% of TBs in this thesis[32]. LIAC can be associated with congenital syndrome like Goldenhar syndrome, CSF leak during cochleostomy, vestibular anomalies and higher rates of meningitis[30]. Asymmetry in the IAC, as seen in 18.3% paired TBs in this study, and especially size disparity observed in 6.1% of paired TBs, may point to a normal variant or pathology. Pathological asymmetry, unilateral or bilateral expansion of IAC may be the result of intrameatal pressure effect from facial schwannoma, vestibulocochlear schwannoma, dural ectasia and chronic hydrocephalus, inter alia, none of which was noted in this study. Lela reported the midpoint expansion of IAC as a patulous IAC which was a common variant in absence of IAC pathology but this variant was reported as the bud shaped IAC, rather than a patulous IAC, by Sergio and in this thesis[31,32].

Foramen of Huschke, which is also called foramen tympanicum, was seen in 26.4% of TBs with 79.2% bilaterality thus higher than the prevalence reported by other studies at 14.9-17.9%[66, 67]. It is reported to be commoner in paediatric age group, an observation not replicated in this study. This foramen has been associated with ease of spread of ear disease into the temporomandibular joint and vice versa. It may also predispose to fistula formation between parotid salivary gland and EAC[66,67].

Deep sinus tympani which is the type C sinus tympani was seen in 16.5% of TBs with low bilaterality at 26.1%. This prevalence is significantly higher than 4.4-5.9% reported by other studies[48,49,52]. Deep sinus tympani is associated with residual and recurrence of middle ear cholesteatoma as it is a recess that is difficult to fully access and clear disease[37]. Presence of disease in the deep sinus tympani may require additional employment of intratympanic mirrors, endoscopes, blind probing or mastoidectomy with retrofacial approach thus adding to the complexity, duration and possible complications of surgery[37,38]. Marchioni et al reported 94.2% endoscopic clearance of cholesteatoma in types A and B sinus tympani, where excessive bleeding limited surgery in the 5.8% cases. However only 40% clearance was achieved endoscopically for type C sinus tympani with mastoidectomy and retrofacial approach being employed to clear the remaining 60% of type C cases[37].

Jugular foramen was asymmetrical in 40.2% paired TBs resonating with Koesling's 42% prevalence but contrasting Tomura's 4%[48,50]. Asymmetrical jugular foramen could be a normal variant but it could also indicate lesions causing expansion of the foramen. No lesion was noted

as the cause of jugular foramen asymmetry in this study. Subarcuate canal was noted in 67.0% of TBs whereas Koesling noted it in 93% of cases[50]. Subarcuate canal in is also called the petromastoid canal and runs from the medial anteromedial margin of the cephalad petrous and passes between the limbs of the superior SCC. It was very prominent in 10.7% of cases and could easily be mistaken for a temporal bone fracture[26].

5.7 Labyrinthine variants (Cochlear cleft and SSCCD)

Cochlear cleft was seen in 25.8% of TBs with 70.8% bilaterality as compared to Chadwell's 41% prevalence with 26% bilaterality[25]. The cochlear cleft is especially prevalent in the paediatric age group, an observation reflected in this study with a paediatric prevalence of 44% versus 22.9% in the adult group[25]. It is considered a marker for the fissula ante fenestrum but it can be confused for otospongiotic phase of otosclerosis or a fracture line[26,46].

Superior semicircular canal dehiscence (SSCCD) was noted in 8.8% of TBs compared to prevalence rates as low as 2% in asymptomatic patients to 13.6% in symptomatic patients[68]. SSCCD is significant as symptomatic cases may present with chronic disequilibrium, atypical conductive hearing loss due to third window effect, autophony, pulsatile tinnitus, Tullio phenomenon and Hennebert sign[68,69].

5.8 Tegmen variations (Tegmen dehiscence and LLT)

Low lying tegmen (LLT) was observed in 29.1% of TBs with 69% bilaterality fairly resonating with prevalence of 26% by Cigdem and 26.7% by Junior but contrasts with others who reported 2-2.8%[24,39,51,58]. The depth of tegmen was variable where 60% of the LLT TBs had a depth of <7mm while 40% had ≥7 mm depth with the deepest recording being 12.3mm. A depth of ≥7mm has significant surgical implications where difficulty of surgery, duration and complications of surgery especially dural breach are increased due to contracted field of operation especially when concurrent with other variants like ASS[39].

Tegmen tympani dehiscence was noted in 13.7% of TBs but no dural herniation, meningocele or meningomeningocele were noted. No pathologies were observed as causes for the dehiscence. Tegmen dehiscence is seen in 15- 34% of the population[70]. When symptomatic, tegmen dehiscence may present as CSF effusion, CSF otorrhoea, serous otitis media, CSF rhinorrhoea, conductive hearing loss, meningitis, aural pain, headache, epilepsy, and other neurological complications. It could also increase the likelihood of intracranial extension of ear disease, increase risk of dural breach with CSF leak and meningocele/ meningoencephalocele[70].

5.9 Facial Nerve Dehiscence

Facial nerve dehiscence (FND) had a prevalence of 7.1% compared to 1.5-12% by others[18,51,57]. These results would be comparable except Pawel, who noted 1.5% prevalence in the overall study group, observed that all FNDs had concurrent chronic ear disease and no FND was noted in the normal TBs whereby this thesis was conducted in participants/ TBs with no chronic disease[18]. The other studies were similarly conducted in patient with chronic ear disease[51,57]. FND predisposes to facial nerve injury during middle ear examination and manipulation.

5.10 Other Variants

Petrosquamous sinus was observed in 1.1% of TBs resonating with Koesling's low prevalence of 1.4% but these significantly differ from Pawel's 6.9% observation[18,50]. This sinus is the persistence of embryonic vascular channel, possibly the lateral capital vein, that runs in an anteroposterior direction usually on the bony roof of the mastoid cavity and drains into the sigmoid sinus[18,71]. It is directly associated with mastoidectomy related bleeding which could be profuse and confused for sigmoid sinus bleeding[18,71].

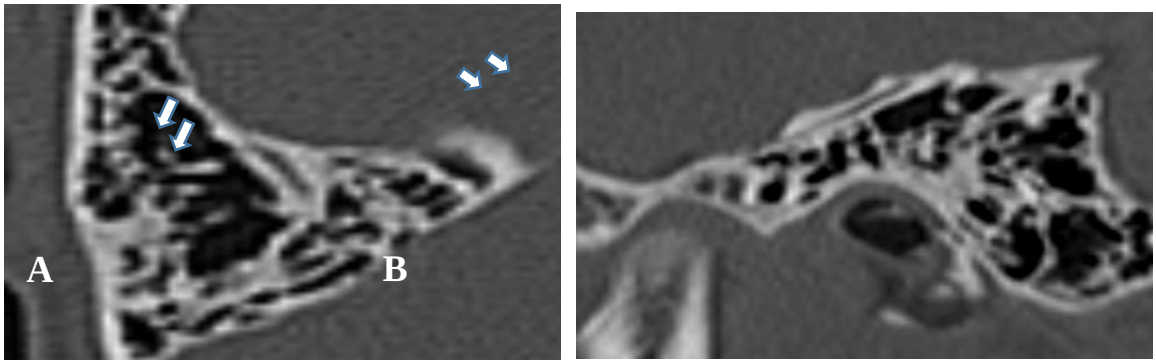

Figure 24: Petrosquamous sinus in axial- A and sagittal- B views

Several anomalous and aberrant venous channels in the temporal bone have been described[70,72]. These have been attributed to persistence of embryonic vasculature especially of the lateral capital vein also called the primary head sinus[71,73]. The anomalous channel seen in the 3 case were consistently anterior to the SCC thus may be an aberrance, persistent lateral capital vein or a transpetrous vein[71,72].

6.0 CHAPTER SIX: CONCLUSION AND RECOMMENDATION

6.1 Conclusion

There is a high prevalence rate of temporal bone variations in this study and possibly in the geographical area. The relatively high prevalence of vascular variants especially the known venous and aberrant variants alludes to the increased risk of intraoperative haemorrhage. Additionally, the relatively high rates of low lying tegmen, Korner's septum and type C sinus tympani would imply possibly longer and more complex temporal bone operations. The high rate of Korner's septum may also imply a correspondingly high rate of chronic otitis media whereas the low rates of aqueduct variants may resonate with low rates of perilymphatic gusher in stapedectomy and cochlear implant surgery. The mastoid and petrous are predominantly aerated in the adult group than in the paediatric group whereas the paediatric group generally has higher rates of variants possibly due to the immaturity of the temporal bone.

There are considerable differences in the prevalence of anatomical variants of temporal bone between age groups, gender and individuals. Furthermore, the differences in the prevalence rates of the anatomical variants between this study and others, suggests variants differ based on geographical region and may have a genetic element.

6.2 Recommendations

Considering the high prevalence of anatomical variants of the temporal bone in this study, it is prudent for the otolaryngologist and radiologists to actively seek them on case by case basis during temporal bone HRCT evaluation as the variants may result in significant pitfalls in establishing diagnosis of ear pathology and in undertaking surgical procedures. Additionally, clinicoradiological studies may be undertaken to correlate the anatomical variants to ear pathologies and/ or surgical impact.

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TIME FRAME

Table 9: Time frame

PERIOD	ACTIVITY
April- August, 2017	Proposal writing
October 2017	Proposal presentation
October 2017 - February 2018	Ethics approval (KNH UoN ERC)
March 2018 – March 2019	Data collection
April – October 2019	Data analysis and report writing
November 2019	Review and supervisors' approval
January 2020	Departmental presentation and defense
January 2020	Submission for marking
November 2020	Marked and returned with corrections
November 2020	Corrections and Final submission

BUDGET AND FUNDING

Table 10: Budget

ITEM	**AMOUNT (Kenya shillings)**
STATIONERY, PRINTING & BINDING	20,000
TRANSPORT	20,000
RESEARCH ASSISTANTS (Radiographers)	50,000
BIOSTATISTICIAN	40,000
MISCELLANEOUS	20,000
DISSEMINATION COSTS	30,000
TOTAL	**180,000**

Funding for this study was self-sponsored, that is, sponsored by the principal researcher.

APPENDICES

Appendix I: Consent/ Assent Form

ANATOMICAL VARIANTS OF THE TEMPORAL BONE AS DEPICTED BY HRCTS OF PATIENTS EVALUATED IN TWO RADIOLOGY CENTRES IN NAIROBI

English version

This Informed Consent/ Assent form is for Patients and Parents or Guardians with children who are undergoing HRCTS of temporal bone at KNH and Plaza imaging solutions.

Principal Investigator: Dr. Onyango M Stephen

I**nstitution**: School of Medicine, Department of Surgery (Otolaryngology, Head and Neck)
University of Nairobi

Supervisors: Dr. Peter Mugwe - Consultant ENT
Dr. Jane Thinwa - Consultant Radiologist

This form has three parts:

I. Information sheet
II. Consent/ Assent statement
III. Research statement

Part I: Information sheet

My name is **Dr. Stephen M. Onyango**, I am a postgraduate student at the Department of Surgery (ENT) in The School of Medicine, University of Nairobi. I am the principal researcher, carrying out a study to determine the "**ANATOMICAL VARIANTS OF THE TEMPORAL BONE AS DEPICTED BY HRCTS OF PATIENTS EVALUATED IN TWO DIAGNOSTIC CENTRES IN NAIROBI**". This will be determined by evaluation of the temporal bone scan that you have/ your child has undergone/ will undergo as independently requested by your primary clinician. I am inviting you to participate in my study at your free will. You will be given the opportunity to ask questions before you accept and you may talk to anyone you are comfortable with about the research before making your decision. You may seek any further clarification from me or my supervisors through the contacts given below.

Study background

There are several variations in the structure of the ear bone. These anatomical variations impact on ear symptoms and also procedures conducted on the ears. They may complicate surgeries or be mistaken for disease.

Broad objective

The study aims to describe the anatomical variations and their prevalence in our set up by using scans taken of the ear bone

Voluntariness and role of participation

Your/ Your child's participation is voluntary and no coercion or inducement will be experienced. If you agree to participate, your main role in this study is to consent to the use of the scans of the temporal/ ear bone. These scans will be examined for the structural differences also known as anatomical variants. You will also be asked to provide some minimal information about you/ your child.

Confidentiality

Your name/ your child's name will not appear in data collection sheet. You/ your child will only be identified by a number and only the principal researcher and supervisors can relate the number to you/ your child as a person. This information will not be shared with anyone outside the study unless authorized by the Kenyatta National Hospital/University of Nairobi - Ethics and Research Committee (KNH/UoN-ERC).

Costs and compensation

There will be no extra cost incurred for participating in this study. The scans you will undergo/ have undergone are independently requested by your primary physician at his/her discretion and not by the researcher. No inducement or compensation will be provided.

Benefits of the study

The results of this research will be beneficial as they may reduce risks of undergoing temporal bone surgeries and mismanagement of temporal bone disease by describing the variant anatomy of temporal bone in our local setup.

Risks

You/Your child will not be exposed to any risks if you consent to participate. The main requirement will be the temporal bone scan that you have undergone/ will undergo as requested independently by your clinician.

Right to withdraw

You/your child will not be denied medical care in case you refuse to participate in or withdraw from the study. You may stop participating at any time with no consequences whatsoever.

Ethical issues

All the information that you give us will be used for this research study only. Only the researcher and the supervisors are privy to your raw information. Confidentiality will be maintained as no names will appear in the data collection sheet. All hard copy data will be stored safely in a lockable cabinet in the Department of Surgery, UoN. All soft copy data will be password protected.

This proposal has been reviewed and approved by the KNH/UoN-ERC for the duration of one year. It was submitted to them through the Chairman of the Department of Surgery at the School of Medicine of the University after approval by my university supervisors.

Part II: Consent/ Assent Statement

I …….. give consent for me/my child …… to take part in the study conducted by Dr. Stephen Onyango, the nature of which has been explained to me. I have been informed and have understood that my/my child's participation is entirely voluntary and I understand that I am free to withdraw my consent at any time if I so wish and that my withdrawal will not compromise the care given to me/my child.

……

Signature (Self/Parent/Guardian)

Date……

Day/Month/Year

Study Number…….

X-ray Number……..

Left Thumb Print

Statement by the witness (where applicable)

I have witnessed the accurate reading of the consent form to the participant/guardian, and the participant has had the opportunity to ask questions. I confirm that the consent has been given freely.

Name of witness……

Signature of witness……..

Date……..

Day/Month/Year

Please feel free to seek additional information through the contacts given below;

Secretary, KNH/UoN-ERC

P.O. Box 20723 KNH, Nairobi 00202

Tel 020726300-9

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School of Medicine, UoN
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Mobile phone 0724588338
E-mail; dronyango@gmail.com

Part III: Researcher's Statement

I, the undersigned, have fully explained the relevant details of this research study to the aforementioned participant. The participant/ guardian has understood what the research study entails and has willingly given consent. I confirm that no coercion or inducement for participation was undertaken.

Name ……..

Signature ……Date…….

IDHINI KWA KISWAHILI

FOMU YA IDHINI

Fomu hili lina sehemu tatu

I. Maelezo ya Mtafiti Mkuu na utafiti
II. Fomu ya Idhini
III. Kiapo cha Mtafiti

(i) Sehemu ya kwanza –Maelezo ya Mtafiti Mkuu na utafiti.

Mimi ni **Dkt. Stephen M. Onyango**, kutoka chuo kikuu cha Nairobi, Shule ya Utabibu, Idara ya upasuaji, sehemu ya ENT. Ninafanya utafiti wa kubainisha "**ANATOMICAL VARIANTS OF THE TEMPORAL BONE AS DEPICTED BY HRCTS OF PATIENTS EVALUATED IN TWO RADIOLOGY CENTRES IN NAIROBI** yani, kubainasha maumbile zisio za kawaida katika mfupa wa sikio kulingana na picha spesheli aina ya Xray. Utafiti huu unaangalia umbo la mfupa wa skio na kudhibitisha tofauti zinazopatikana katika mfupa huu bila tofauti hizi kuwa magonjwa haswa. Tofauti hizi mara nyingi hufanya upasuaji wa mfupa huu wa skio kuwa mgumu zaidi. Kujua tofauti hizi kutasaidia katika.kupanga upasuaji wa mfupa huu na kupunguza madhara ya upasuaji ambayo yanaweza kuletwa na tofauti hizi. Ningependa kukuchagua / kuchagua mtoto wako katika utafiti huu.

Kukubali kwako ni kwa hiari yako na sio kwa kulazimishwa. Kukataa kwako hakutadhuru matibabu unayopata/ mtoto wako anafaa kupata, hautakatazwa matibabu kwa sababu ya kukataa kujiunga na utafiti huu.

Kujiunga na utafiti huu hakutakudhuru au kudhuru mtoto wako kwa njia yoyote kwani kile kinachohitajika ni picha ya Xray ya mfupa wa skio ambao umefanywa au utafanywa kulingana na maagizo ya daktari wako.

Habari zozote zitakazokusanywa kutoka kwako zitashughulikiwa kwa usiri na hazitasambazwa kwa yeyote ila tu kwa ruhusa kutoka kwa kamiti kuu ya utafiti ya chuo kikuu cha Nairobi na hospitali kuu ya Kenyatta (KNH/UON ERC).

(ii) Sehemu ya pili– Idhini ya mgonjwa

Mimi (Jina)……. / Mzazi

wa…….. kwa hiari yangu, nimekubali kushiriki/ kushirikisha mtoto wangu katika utafiti huu ambao unafanywa na Daktari Stephen Onyango. Nimeelezewa manufaa na madhara ya utafiti huu kwa undani na nimeyaelewa.

Jina la Mgonjwa/ Mzazi……

Sahihi……...

Tarehe……..

Siku/Mwezi/Mwaka

Nambari ya utafiti……..

Nambari ya picha(Xray)……

Jina la Shahidi……

Sahihi……..…….

Tarehe…….

(Siku/Mwezi/Mwaka)

Kidole Gumba- Mkono wa Kushoto

Unaweza kupata uchambuzi wa utafiti huu na maelezo zaidi kutokakwa:

Katibu wa utafiti,

Hospitali kuu ya Kenyatta na Chuo kikuu cha Nairobi (KNH/UON ERC).

Sanduku la Posta 20723 00202.

KNH, Nairobi, Kenya

Nambari ya simu: 020726300-9.

Dkt. Peter Mugwe

Sanduku la Posta 19676- 00202

Nairobi, Kenya

Nambari ya simu: 0202726300

Dkt. Jane Thinwa

Sanduku la Posta 19676-00202

Nairobi, Kenya

Nambari ya simu: 0202726300

Mtafiti Mkuu: Dkt Stephen M. Onyango

Sanduku la Posta 19676-00202

Nairobi, Kenya

Nambari ya simu ya rununu: 0724588338

Barua pepe: dronyango@gmail.com

(iii) Sehemu ya tatu – Kiapo cha mtafiti

Naapa ya kwamba nimeelezea mgonjwa/ mzazi wa mgonjwa manufaa na madhara yote yanayo husu kusajiliwa katika utafiti huu. Mgonjwa/ mzazi ameelewa yote yanayo hitajika na yanayo husu utafiti huu na usajili wake. Idhini yake imepewa kwa hiari yake bila kulazimishwa au kuahidiwa pesa, zawadi au matibabu ya ziada.

Jina la mtafiti/ Msimamizi……

Sahihi…… Tarehe……

(Siku/Mwezi/Mwaka)

Appendix II: Data Collection Sheet

STUDY NUMBER …… X-RAY No…… STUDY SITE- KNH/ PLAZA

BIODATA: Age (Years)…….. Sex- Male/ Female

Variant Anatomy (Mark Yes-√ or No- X)

Variations	**Rt**	**Lt**	**Comments/ Measurements (Where applicable)**
1. Aberrant ICA			
2. Lateral ICA			
3. Persistent stapedius artery			
4. Deep sinus tympani			
5. Anterior sigmoid sinus			
6. Lateral sigmoid sinus			
7. Prominent sigmoid sinus			
8. Sigmoid sinus dehiscence			
9. Korner's septum			
10. Petrous pneumatization			
11. High jugular bulb			
12. Dehiscent jugular bulb			
13. Jugular diverticulum			
14. Enlarge vestibular aqueduct			
15. Large cochlea aqueduct			
16. Cochlear cleft			
17. Large internal acoustic canal			
18. Low tegmen tympani			
19. Facial nerve dehiscence			
20. Other variants			

Appendix III: KNH/UON ERC Approval

21 MAR 2018

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KENYATTA NATIONAL HOSPITAL
P O BOX 20723 Code 00202
Tel: 726300-9
Fax: 725272
Telegrams: MEDSUP, Nairobi

Ref: KNH-ERC/A/111

21st March, 2018

Dr. Stephen Mugambi Onyango
Reg. No.H58/70092/2013
Dept.of Surgery
School of Medicine
College of Health Sciences
University of Nairobi

Dear Dr. Onyango

RESEARCH PROPOSAL - ANATOMICAL VARIANTS OF THE TEMPORAL BONE AS DEPICTED BY HRCS OF PATIENTS EVALUATED IN TWO RADIOLOGY CENTERS IN NAIROBI (P577/10/2017)

This is to inform you that the KNH- UoN Ethics & Research Committee (KNH- UoN ERC) has reviewed and **approved** your above revised proposal. The approval period is from 21st March 2018 – 20th March 2019.

This approval is subject to compliance with the following requirements:

a) Only approved documents (informed consents, study instruments, advertising materials etc) will be used.
b) All changes (amendments, deviations, violations etc) are submitted for review and approval by KNH-UoN ERC before implementation.
c) Death and life threatening problems and serious adverse events (SAEs) or unexpected adverse events whether related or unrelated to the study must be reported to the KNH-UoN ERC within 72 hours of notification.
d) Any changes, anticipated or otherwise that may increase the risks or affect safety or welfare of study participants and others or affect the integrity of the research must be reported to KNH- UoN ERC within 72 hours.
e) Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. (*Attach a comprehensive progress report to support the renewal*).
f) Submission of an *executive summary* report within 90 days upon completion of the study. This information will form part of the data base that will be consulted in future when processing related research studies so as to minimize chances of study duplication and/ or plagiarism.

For more details consult the KNH- UoN ERC website **http://www.erc.uonbi.ac.ke**

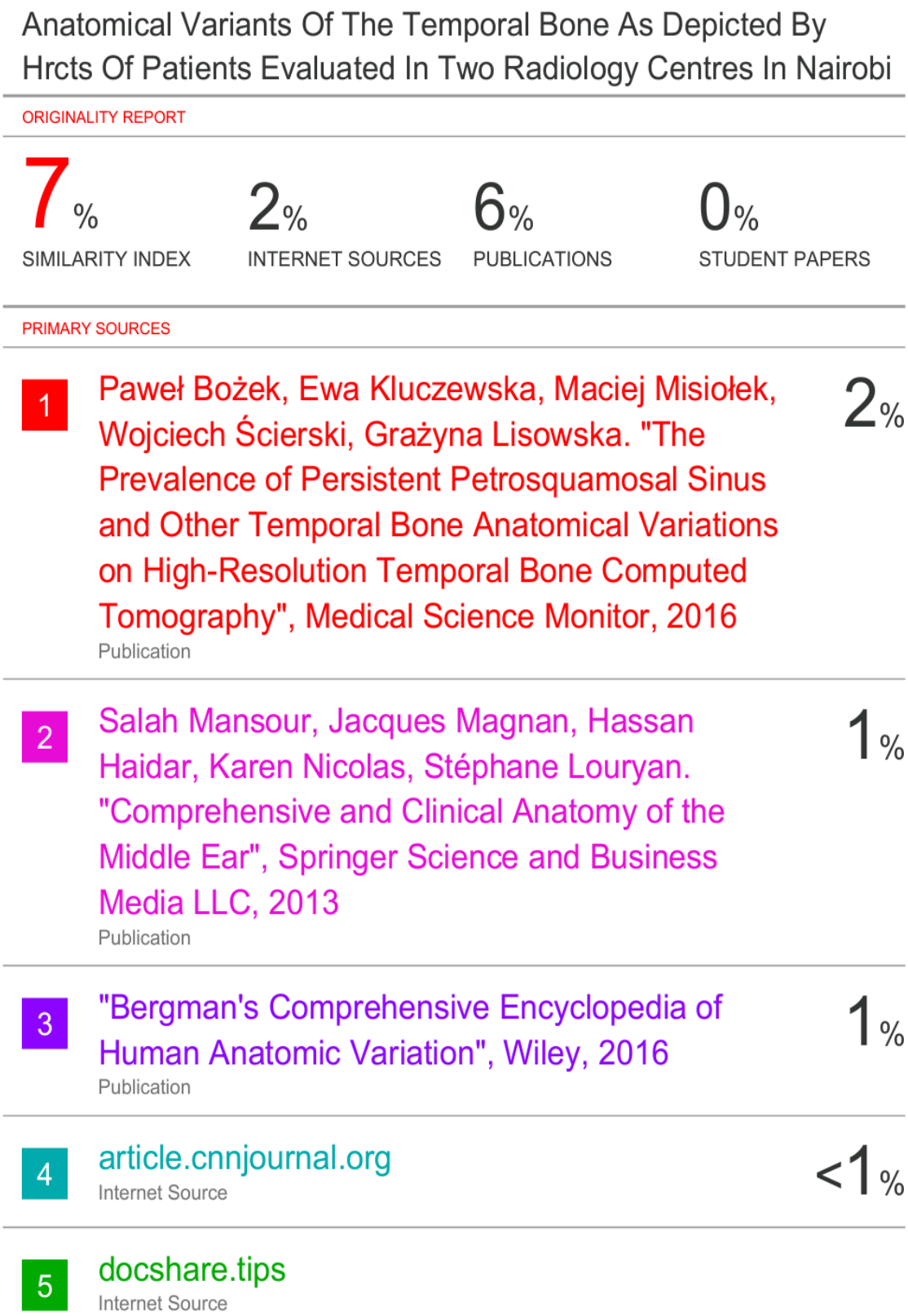
Yours sincerely,

PROF. M. L. CHINDIA
SECRETARY, KNH-UoN ERC

c.c. The Principal, College of Health Sciences, UoN
The Deputy Director, CS, KNH
The Chairperson, KNH-UON ERC
The Assistant Director, Health Information, KNH
The Dean, School of Medicine, UoN
The Chair, Dept. of Surgery, UoN
Supervisors: Dr. Peter Mugwe,Dr. Jane Thinwa

Protect to discover

Appendix IV: Antiplagiarism Certificate



Anatomical Variants Of The Temporal Bone As Depicted By Hrcts Of Patients Evaluated In Two Radiology Centres In Nairobi

ORIGINALITY REPORT

7%	2%	6%	0%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Paweł Bożek, Ewa Kluczewska, Maciej Misiołek, Wojciech Ścierski, Grażyna Lisowska. "The Prevalence of Persistent Petrosquamosal Sinus and Other Temporal Bone Anatomical Variations on High-Resolution Temporal Bone Computed Tomography", Medical Science Monitor, 2016 Publication	2%
2	Salah Mansour, Jacques Magnan, Hassan Haidar, Karen Nicolas, Stéphane Louryan. "Comprehensive and Clinical Anatomy of the Middle Ear", Springer Science and Business Media LLC, 2013 Publication	1%
3	"Bergman's Comprehensive Encyclopedia of Human Anatomic Variation", Wiley, 2016 Publication	1%
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