

**DETERMINATION OF ACOUSTIC RADIATION
USING BONE CONDUCTOR RADIOEAR B71
AMONG MALAYSIAN HEALTHY ADULTS**

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UNIVERSITI SAINS MALAYSIA

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AMONG MALAYSIAN HEALTHY ADULTS**

by

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**Thesis submitted in fulfilment of the requirements
for the Bachelor of Sciences (HONOURS) Audiology**

July 2025

CERTIFICATION

This is to certify that the dissertation entitled ‘Determination of Acoustic Radiation using Bone Conductor RadioEar B71 Among Malaysian Healthy Adults’ is the project done by ‘ADLIN AMANIE BINTI MOHD KAMARULZAMAN from September 2024 to July 2025 under my supervision. We have read this dissertation, and, in our opinion, it fulfils the acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation to be submitted in partial fulfilment for the degree of Bachelor of Health Sciences (Honours) (Audiology). Research work and collection of data belongs to the Universiti Sains Malaysia.



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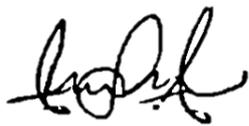


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DECLARATION

I hereby declare that the work has been done by myself, all the results are of my own investigation and my ideas or quotation from others' work are fully acknowledged according to the standard referring practices of the discipline. I also declare that it has not been submitted in previous or concurrently for any other degrees in any institutions. I acknowledge that the research work and collection of data belong to Universiti Sains Malaysia.



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LIST OF SYMBOLS

$<$	Less than
$>$	More than
$=$	Equal to
$-$	Minus
$<$	Less than
$>$	More than
\geq	Greater than or equal
\leq	Less than or equal
$\%$	Percentage
n	Sample size

LIST OF ABBREVIATIONS

ABG	Air-bone Gap
BC	Bone Conduction
AC	Air Conduction
dB	Decibel
dB HL	Decibels Hearing Level
kHz	kilohertz
PTA	Pure Tone Audiometry
HL	Hearing Loss
SNHL	Sensorineural Hearing Loss
CHL	Conductive Hearing Loss
USM	Universiti Sains Malaysia

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ABSTRAK

Audiometri Penghantaran Tulang (Bone Conduction, BC) merupakan komponen penting dalam penilaian pendengaran; namun begitu, ia terdedah kepada artifak seperti berlakunya fenomena radiasi akustik. Kejadian ini boleh menyebabkan ambang BC (*BC thresholds*) yang tidak tepat dan nilai perbezaan antara udara-tulang (*Air-Bone Gap, ABG*) yang mengelirukan, sekaligus berpotensi menjejaskan diagnosis klinikal akhir. Penyelidikan sedia ada mengenai radiasi akustik kebanyakannya dijalankan dalam kalangan populasi Barat, manakala data normatif dalam kalangan populasi Asia masih sangat terhad. Kajian ini bertujuan untuk (i) menentukan ambang penghantaran tulang dalam keadaan salur telinga terbuka dan ditutup pada frekuensi tinggi (2–8 kHz), (ii) membandingkan antara ambang BC antara dua keadaan salur telinga tersebut, dan (iii) membandingkan perbezaan nilai ABG antara kedua-dua keadaan dalam Audiometri Nada Tulen (*Pure Tone Audiometry*) dalam kalangan dewasa muda Malaysia yang mempunyai pendengaran normal. Seramai 35 peserta yang mempunyai pendengaran normal (70 telinga) berumur antara 20 hingga 25 tahun telah direkrut. Penilaian pendengaran merangkumi *otoscopy*, *tympanometry* dan audiometri nada tulen (*Pure Tone Audiometry*). Ambang BC diperoleh dalam kedua-dua keadaan salur telinga terbuka dan ditutup menggunakan pelindung telinga 3M, dan nilai ABG dikira. Analisis data menggunakan ujian Wilcoxon signed-rank menunjukkan bahawa ambang BC adalah lebih baik (rendah) dalam keadaan telinga terbuka dan perbezaan yang signifikan secara statistik ($p < .001$) didapati antara kedua-

dua keadaan telinga pada semua frekuensi yang diuji. Begitu juga nilai ABG menunjukkan nilai yang lebih tinggi secara signifikan dalam keadaan telinga terbuka ($p < .001$), yang mencadangkan pengaruh radiasi akustik terhadap pengukuran BC. Penemuan ini menyokong keperluan untuk menutup salur telinga semasa pengukuran ambang BC pada frekuensi tinggi apabila menggunakan alat konduksi tulang telinga RadioEar B71 bagi mengurangkan kesan radiasi akustik. Selain itu, kajian ini turut menekankan kepentingan untuk mendapatkan data normatif setempat, memandangkan perbezaan anatomi dan etnik mungkin mempengaruhi hasil ujian audiometri. Penetapan rujukan khusus populasi adalah penting untuk meningkatkan ketepatan diagnosis dalam bidang audiologi klinikal dalam kalangan populasi Asia.

Kata kunci: Konduksi tulang telinga, radiasi akustik, jurang udara-tulang (ABG), dewasa sihat Malaysia, RadioEar B71

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ABSTRACT

Bone Conduction (BC) audiometry is a critical component of hearing assessment; however, it is susceptible to artifacts such as the occurrence of acoustic radiation. This occurrence may lead to inaccurate BC thresholds and air-bone gap (ABG) values and potentially affecting final clinical interpretation. Existing research on acoustic radiation has primarily been conducted on Western populations, with limited normative data available for Asian populations. This study aimed to (i) determine the bone conduction thresholds in unoccluded and occluded ear canal conditions at high frequencies (2–8 kHz), (ii) to compare the difference of BC thresholds between unoccluded and occluded ear canal conditions, and (iii) to compare the difference of ABG between these two conditions in Pure Tone Audiometry among Malaysian young adults with normal hearing. A total of 35 normal-hearing participants (70 ears) aged 20–25 years were recruited. Hearing assessments included otoscopy, tympanometry, and pure-tone audiometry. BC thresholds were obtained under both unoccluded and occluded ear canal conditions using a 3M earmuff, and ABG values were calculated. Data analysis using the Wilcoxon signed-rank test showed that BC thresholds were consistently better (lower) under the unoccluded condition and statistically significant differences ($p < .001$) were observed between both testing conditions across all tested frequencies. Similarly, ABG values were significantly higher in the unoccluded condition ($p < .001$), suggesting the influence of acoustic

radiation on BC measurements. These findings support the need to occlude the ear canal during BC threshold measurements at high frequencies when using the RadioEar B71 bone conductor to minimize the effects of acoustic radiation. Furthermore, this study highlights the importance of developing localized normative data, as anatomical and ethnic differences may influence audiometric outcomes. Establishing population-specific references is essential for improving diagnostic accuracy in clinical audiology among Asian populations.

Keywords: Bone conduction, acoustic radiation, air-bone gap (ABG), Malaysian healthy adults, RadioEar B71.

CHAPTER 1 INTRODUCTION

1.1 Background of Study

Audiological assessments are the investigation of hearing loss that is conducted by experienced audiologist as to obtain diagnostic information that guides healthcare professionals toward appropriate treatment. Hearing loss is a widespread condition that affects millions of people regardless of age, ethnicity, and health status. Pure Tone Audiometry (PTA) is the gold standard of audiological assessment that conveyed the type, degree, and configuration of hearing loss information. Air Conduction (AC) testing and Bone Conduction (BC) testing are two pathways of hearing that are assessed through PTA testing. AC testing involves the sound waves to enter the external auditory canal and pass through the tympanic membrane, ossicular chain, and cochlea to reach the cochlear nerve and through the brainstem to the auditory cortex. Conversely, in BC testing sound waves are introduced directly to the cochlea through the vibration of a bone conduction oscillator on the mastoid process (Carl et al., 2023). AC and BC thresholds obtained from a PTA procedure are key components in establishing a valid diagnosis of the patient's hearing. The severity of the patient's hearing loss is dependent on their hearing levels which are obtained from the AC thresholds of the PTA testing. BC thresholds on other hand is also an important element in PTA testing as it helps audiologist to determine the type of the patient's hearing loss. Based on the measures of hearing thresholds obtained from the AC and BC testing, it is possible to establish the first topodiagnosis in audiology.

Therefore, it is critical for the examiner to avoid any errors and artifacts that

may jeopardize the accuracy and reliability of the result. Technical limits of the transducers used may affect the result obtained such as the pressure and placement of the bone vibrator, phenomenon of occlusion effect, and acoustic radiation (de Merces et al., 2010). False air-bone gap (ABG) is one of the potential sources of confusion or even misdiagnosis in audiological field. One clinical concern that may lead to false ABG is the phenomenon of acoustic radiation which is the acoustic energy radiating from the BC vibrator through AC into the external auditory canal (EAC) during BC testing (de Merces et al., 2010). Acoustic radiation is an occurrence that happened when the signal that is emitted by the bone vibrator is transmitted through the AC from the sound leakage of the bone vibrator causing patients to respond to the acoustic radiation produced by the bone vibrator instead of their true BC thresholds. As a result, patient's BC thresholds would thus misrepresent as better than they actually are as they are responding to the additional cue of AC signal from the acoustic radiation which should be by BC alone during the testing (Harkrider and Martin, 1998). Consequently, patient's bone thresholds may be corrupted as they are responding via AC to the acoustic radiation produced by the bone vibrator at a lower level than their true bone conduction thresholds, thus causing an invalid ABG in patients who do not persists of any conductive pathology (Harkrider and Martin, 1998). An invalid ABG may compromise the diagnosis obtained particularly on the type of hearing loss.

Standard clinical BC transducers that are used in clinical settings are RadioEar B-71 and B-81. However, in this study, it will be discussed regarding the determination of acoustic radiation using bone conduction RadioEar B-71 among Malaysian healthy adults. Malaysian healthy adults are generally

characterized by a well-functioning hearing system which is referring to the effective operation of the auditory system that encompasses both peripheral and central components involved in hearing. Auditory system consists of different parts which are outer ear, middle ear, inner ear, and the auditory nervous system. The efficiency of the transmission of sound through outer, middle, and inner ear is dependent on the integrity of ear structures, proper functioning of auditory nerves, and the absence of hearing impairments thus allowing individuals to detect and interpret sounds across a wide range of frequencies and intensities (Dobie and Van Hemel, 2005). Normal hearing level is generally defined from their AC thresholds of PTA which are equal or better than 20 dB HL. Standard clinical BC transducers that are used in clinical settings are RadioEar B-71 and B-81. However, in the study of acoustic radiation, RadioEar B-71 BC transducer is mostly reported in the study of acoustic radiation.

1.2 Problem Statement

Studies on acoustic radiation had been conducted in estimating the influence of acoustic radiation on behavioural thresholds by obtaining unoccluded and occluded bone conduction thresholds especially at high frequencies especially at 2000Hz, 3000Hz, and 4000Hz among normal hearing participants using BC transducer RadioEar B-71 based on the study by de Merces et al. (2010). The result of the study has shown significant acoustic radiation effect that it is recommended for BC thresholds in the frequencies of 3000Hz and 4000Hz to be obtained with the ear canal occluded to eliminate the possibility of acoustic radiation enabling more accurate BC measurements. The impact of acoustic radiation emitted by the bone vibrator used in BC audiometry

has been recognized in many years with various universal studies published especially with the use of RadioEar B-71 BC transducer.

Although existing studies have explored on the effects of acoustic radiation on BC thresholds using RadioEar B-71 among Caucasian populations, no studies have specifically addressed these thresholds among Malaysian subjects. Acoustic radiation effects may vary due to genetic, anatomical, or physiological differences between populations. Variations in lifestyle and dietary patterns between Asians and Caucasians could influence bone density, potentially resulting in different acoustic radiation effects during bone conduction audiometry. For instance, in a study by Nam et al. (2013) in comparing lifestyles between different ethnic and racial populations have shown a significant racial and ethnic differences in bone mineral density among non-Asians and Asian women. These differences were influenced by factors such as estrogen use and body weight differences. Additionally, anatomical difference particularly in bone size, play a role in bone mineral content and density differences between Asians and Caucasians. Asians generally have smaller bone sizes, which result in lower bone mass and contribute to observed differences in bone mineral content and density (Bhudhikanok et al., 1996). Therefore, it is critical to establish normative data specific to this demographic. Without localized data, the application of findings from Caucasian studies may lead to inaccurate audiological management in Malaysian patients particularly in determining the type of hearing loss.

The purpose of this study is to investigate further the presence of acoustic radiation produced by bone vibrators RadioEar B-71 among Malaysian healthy adults specifically at the frequencies of 2000Hz, 3000Hz, 4000Hz, 6000Hz, and

8000Hz. The findings of this study will be valuable in estimating the extent of acoustic radiation in local populations and establishing population-specific reference values to enhance the diagnostic accuracy and precision of BC threshold measurements in routine audiological assessments.

1.3 Research Questions

- i. Is there a significant difference in bone conduction thresholds obtained using the RadioEar B71 bone vibrator between unoccluded and occluded ear canal conditions?
- ii. Is there a significant difference in air-bone gap obtained using the RadioEar B71 bone vibrator between unoccluded and occluded ear canal conditions?

1.4 Research Objectives

1.4.1 General Objective

To determine the effect of acoustic radiation using RadioEar B-71 bone conduction transducer in Pure Tone Audiometry (PTA).

1.4.2 Specific Objectives

- i. To determine the bone conduction thresholds in unoccluded and occluded ear canal at high frequencies specifically at 2 kHz, 3 kHz, 4 kHz, 6 kHz, and 8 kHz in Pure Tone Audiometry.
- ii. To compare bone conduction thresholds between unoccluded and occluded ear canal conditions at high frequencies specifically at 2 kHz, 3 kHz, 4 kHz, 6 kHz, and 8 kHz in Pure

Tone Audiometry.

- iii. To compare air-bone gap between unoccluded and occluded ear canal conditions at high frequencies specifically at 2 kHz, 3 kHz, 4 kHz, 6 kHz, and 8 kHz in Pure Tone Audiometry.

1.5 Research Hypothesis

1.5.1 Hypothesis 1

Null hypothesis, H_0

There is no significant difference of bone conduction thresholds between unoccluded and occluded ear canal conditions at high frequencies in Pure Tone Audiometry.

Alternative hypothesis, H_1

There is a significant difference of bone conduction thresholds between unoccluded and occluded ear canal conditions at high frequencies in Pure Tone Audiometry.

1.5.2 Hypothesis 2

Null hypothesis, H_0

There is no significant difference in the air-bone gap between unoccluded and occluded ear canal conditions at high frequencies in Pure Tone Audiometry.

Alternative hypothesis, H_1

There is a significant difference in the air-bone gap between unoccluded and occluded ear canal conditions at high frequencies in Pure Tone Audiometry.

CHAPTER 2 LITERATURE REVIEW

2.1 Pure Tone Audiometry

Pure tone audiometry (PTA) is the gold standard behavioural test used to evaluate an individual's hearing sensitivity across a range of frequencies. It measures the softest level of sound (threshold) a person can hear through two main pathways: air conduction (AC) and bone conduction (BC). Pure tone audiometry (PTA) is performed by producing a tone with a controlled frequency and recording the lowest sound intensity in decibels (dB), at which the tone can be perceived half of time (Brandt and Winters, 2023). In air conduction testing, sound waves will enter the external auditory canal and pass through the tympanic membrane, ossicular chain and cochlea to reach the cochlear nerve and thus through the brainstem to the auditory cortex. Meanwhile, in bone conduction testing, sound waves are introduced directly to the cochlea through the vibration of a bone vibrator on the mastoid process. (Carl et al., 2023). The comparison between air and bone conduction thresholds is essential in differentiating types of hearing loss: conductive, sensorineural, or mixed. Accurate interpretation of BC thresholds requires an understanding of the underlying bone conduction transmission mechanisms, which involve multiple pathways contributing to cochlear stimulation.

2.2 Bone Conduction Mechanisms in Audiology

Bone conduction (BC) is a crucial mechanism in audiology that allows sound to reach the cochlea through the vibration of cranial bones, bypassing the outer and middle ear structures. Bone conduction is important in both clinical diagnostics like tuning fork tests and bone conduction audiometry along with hearing device technologies like bone-anchored hearing aids. The pathways through which bone-conducted sound is

transmitted to the cochlea can be categorized into three main mechanisms which are osseotympanic, inertial, and compressional (Dauman, 2013).

2.2.1 Osseotympanic Pathway

The osseotympanic pathway involves vibrations of the bony walls of the external auditory canal. These vibrations generate sound waves within the air of the ear canal, which in turn stimulate the tympanic membrane and the ossicular chain, resembling an air conduction process (Henry and Letowski, 2007). This pathway becomes more significant when the ear canal is occluded, such as with an earplug or during the use of supra-aural headphones, leading to the well-documented of occlusion effect. The occlusion effect is the phenomenon that enhances the perception of low-frequency bone-conducted sounds due to increased acoustic energy in the sealed ear canal (Carillo et al., 2021).

2.2.2 Inertial Motion of the Ossicles

The inertial component of bone conduction arises from the principle of inertia. When the skull vibrates, the ossicles which are malleus, incus, and stapes will lag due to their inertia, especially at lower frequencies. Thus, this will lead to stimulation of the cochlea via the oval window. This mechanism becomes significant in the mid-frequency range and is affected by the condition of the middle ear that tends to lag slightly behind due to their mass. This relative motion results in movement of the stapes footplate within the oval window, producing fluid displacement in the cochlea (Stenfelt and Goode, 2005). This pathway is sensitive to conditions that will affect the ossicular chain mobility, such as ossicular chain discontinuity or stapes fixation in otosclerosis, which can attenuate this form of sound conduction.

2.2.3 Compressional Mechanisms Pathway

Another mechanism involved in bone conduction hearing is the compressional pathway, also referred to as the distortional pathway. This mechanism becomes especially significant at higher frequencies, typically above 1500 Hz, where the skull no longer vibrates as a rigid body but instead undergoes segmental deformation. These vibrations cause mechanical distortions in the bony labyrinth of the cochlea, particularly in the petrous portion of the temporal bone, which houses the cochlear structures. As a result of this deformation, fluid displacement occurs within the cochlea, leading to movement of the basilar membrane and stimulation of the hair cells in the organ of Corti (Stenfelt and Goode, 2005). Unlike the inertial or osseotympanic pathways, the compressional mechanism does not rely on the middle or outer ear structures, making it particularly relevant in assessing sensorineural hearing. It provides a direct representation of cochlear function, which is critical in bone conduction threshold measurements, especially at high frequencies. Finite element models and studies on cadaver heads have confirmed the dominance of this pathway in cochlear stimulation at higher frequencies (Stenfelt and Goode, 2005). Understanding the compressional pathway is essential in interpreting bone conduction results accurately, particularly when considering variables such as transducer placement, frequency effects, and interference from acoustic radiation.

2.3 Acoustic Radiation

One clinical concern in conducting Pure Tone Audiometry (PTA) is when there is involvement of the phenomenon of acoustic radiation during bone conduction audiometry. The effect of the radiation of the acoustic energy emitted

by the bone vibrator to the external ear canal might affect the bone conduction thresholds obtained during PTA testing. Inaccuracy in the bone conduction thresholds obtained might affect the diagnosis of the patient's type of the hearing loss. The signal of the bone conduction is now transmitted through air conduction can be sufficiently intense to serve as an additional clue to patients when they are supposed to only response to the stimuli presented on the bone pathway. Consequently, the patient's bone conduction thresholds of this patient may appear to be better than they really are and probably would produce invalid air-bone gaps, especially in the higher frequencies.

2.4 Effects of Acoustic Radiation on Bone Conduction Thresholds

From a study by de Merces et al. (2010) on Acoustic Radiation Effects on Bone Conduction Threshold Measurement, the author had conducted a study on Acoustic radiation on the bone conduction tonal threshold audiometry in the frequencies of 2000Hz, 3000Hz and 4000Hz. The study was conducted with the sample of 101 individuals, 11 ears from females and 130 from males with age ranging between 20 and 70 years which had included participants with no external ear canal obstruction or foreign body and air bone gap higher than 10 dB on the frequencies of 2000, 3000 and 4000Hz. The participants were put into inspections of their external ear canal, air conduction tonal audiometry with supra-aural phones and bone conduction threshold tonal audiometry using RadioEar B-71 bone vibrator. Participants who have a gap between the air and bone conduction thresholds in the frequencies of 2000, 3000, and 4000Hz was reassessed with the occlusion of the external ear canal using the participant's own index finger. The results showed that occluding the external ear canal effectively eliminated the artificial ABG, thereby supporting the existence of acoustic radiation. The authors concluded that energy from the bone vibrator could not escape and reach the cochlea once the external auditory canal was occluded, validating that acoustic radiation can influence BC threshold outcomes.

Supporting this, Harkrider and Martin (1998) conducted a study titled *Quantifying Air-Conducted Acoustic Radiation from the Bone-Conduction Vibrator*, where they assessed acoustic radiation by placing an earplug in the external auditory canal, with a lateral surface resting at the osseocartilaginous junction. This was done to eliminate sound pressure level (SPL) generated via

the osseotympanic mode of BC. In their methodology, BC thresholds were retested to determine the degree of attenuation provided by the earplug. A probe microphone was positioned laterally to the earplug inside the canal to record SPL. The aim of this study was to compare the effect of BC vibrator placement on the ipsilateral and contralateral mastoid and the forehead. The results revealed that excessive acoustic radiation from the RadioEar B-71 occurred primarily at 4000 Hz, especially when the vibrator was placed on the mastoid ipsilateral to the test ear. Forehead placement also produced notable radiation but to a lesser extent compared to ipsilateral mastoid placement, while no significant acoustic radiation was recorded when the vibrator was placed on the contralateral mastoid. The authors noted that 18% of participants demonstrated excessive acoustic radiation with a mean SPL of 90.0 dB SPL, indicating that although the phenomenon exists, its impact is limited to certain frequencies and placements. The authors concluded that the acoustic radiation from the RadioEar B-71 BC vibrator to the false air-bone gap is minimal and that other sources like various effects of skull vibration and the resonant frequency of the middle ear should also be considered.

Contrary to the conclusions drawn by de Merces et al. (2010) and Harkrider and Martin (1998), a study by Tate, Maltby, and Gaszczyk (2015) challenged the necessity of occluding the external ear canal during BC testing at 4000 Hz. Their findings suggested that occlusion may not significantly impact BC threshold results. Specifically, their study found no meaningful difference in results between open-ear and occluded-ear conditions when using an earplug, with the observed thresholds difference between the two conditions was only 5 dB. Based on these findings, the authors concluded that false ABGs are unlikely to be

caused by acoustic radiation, and therefore, routine occlusion during BC testing may be unnecessary. This stands in contrast to previous studies that advocate for ear canal occlusion to prevent artificial threshold shifts caused by acoustic radiation.

2.5 Effects of Acoustic Radiation on Air-Bone Gap

From Harkrider and Martin (1998) in quantifying air-conducted acoustic radiation from the bone conduction vibration, the study was conducted by measuring the sound pressure level at external auditory canal (EAC) at the frequency of 2kHz until 4kHz in 50 individuals by placing the bone vibrator (RadioEar B-71) on the mastoid and forehead. The study was resulted that a clinically significant ABG (>10 dB) was found due to the occurrence of acoustic radiation especially at high frequencies specifically at 3kHz and 4kHz. In another study by Margolis et al. (2013) also reported of difference between two conditions of open ear canal and closed ear canal evaluated especially at 4000Hz showed significant difference of with the mean of ABG (14.1 dB) using RadioEar B-71 among SNHL participants. Thus, the number of cases of sensorineural hearing loss that was misdiagnosed to mixed hearing loss was significant too.

In summary, while several studies support the existence of acoustic radiation contributes to artificially lowered BC thresholds, other research suggests that its impact may be clinically negligible. This contradiction highlights the ongoing debate within the field and emphasizes the need for further localized studies. Given that most existing research was conducted in Western populations, this study aims to contribute by investigating this

phenomenon among Malaysian healthy young adults as no previous research regarding this have been locally reported.

CHAPTER 3 METHODOLOGY

3.1 Study Design

This study used a cross-sectional design within a quantitative research framework. It involved the comparison of bone conduction (BC) threshold measurements under two testing conditions which are unoccluded and occluded ear canal within the same group of participants. The data obtained were analyzed to determine the effect of acoustic radiation under these testing conditions.

3.2 Study Location

The research was conducted in a sound-treated room at the Audiology Clinic, School of Health Sciences, Universiti Sains Malaysia (USM) Health Campus, Kubang Kerian, Kelantan.

3.3 Study Population

Participants were selected among normal-hearing young adults from within and outside the USM Health Campus who met the study's inclusion and exclusion criteria

3.4 Selection Criteria

3.4.1 Inclusion Criteria

- a) Malaysian youths aged from 18 to 30 years old (Malaysia Youth Policy, 2019) regardless of gender, race, and religion.
- b) Malaysian youths with normal middle ear function on both ears indicated by type A tympanogram bilaterally
- c) Malaysian youths with normal hearing on both ears indicated by Air Conduction (AC) thresholds are within normal limit which are less than or equal to 20 dB HL.

3.4.2 Exclusion Criteria

- a) Individuals with history of outer and middle ear problem
- b) Individuals with history of ear surgery or pathology

3.5 Sampling Size Calculation

The sample size was calculated using the MedCalc software based on the study by de Merces et al. (2010). By taking the alpha value of 0.05, power of study = 0.8, mean difference of 6.9 dB, standard deviation of difference 13.5, the sample size required is 32. However, by considering 10% dropout, so we aim to recruit 35 participants for this study.

3.6 Sampling Method and Recruitment

A convenience sampling method was used. Participants were recruited based on availability, accessibility, and willingness to participate. Recruitment was done through e-posters circulated on social media platforms, with an attached Google Form for expression of interest. Hearing screening sessions were conducted for respondents who filled out the form. Participants who met the inclusion criteria were selected for the study.

3.7 Research Instruments

i. Welch Allyn 3.5v Diagnostic Otoscope

Otoscope examination is a clinical procedure used to examine structures of the ear, particularly the external auditory canal and the tympanic membrane. Otoscope is used during routine wellness physical exams as to visualize the ear anatomy. The otoscope contains a light and a magnifying lens to illuminate and enlarge ear structures and accurately visualize the external ear canal and tympanic. This procedure is essential for identifying abnormalities in the external auditory canal and tympanic membrane, which may indicate underlying ear pathologies.

ii. Grason-Stadler Inc. (GSI) TymStar Pro Tympanometer

Tympanometer is a diagnostic tool that sets the clinical standard for performing a full range of middle ear measurements that provides the information about the presence of fluid in the middle ear, mobility of the middle ear system, and ear canal volume. It is a diagnostic tool in assessing the middle ear function of the participants by measuring how the eardrum moves when variations of air pressure are introduced in the

ear canal. A 226Hz tone will be presented in the external auditory canal by the loudspeaker and the pressure is altered within the sealed canal with a pump. During the pressure sweep, the sound is reflected from the eardrum and is measured by the microphone. The output is represented in the form of a graph, called a tympanogram.

iii. Grason-Stadler Inc. (GSI) 61 Audiometer

Pure Tone Audiometry (PTA) will be conducted using audiometer that will be used in evaluating hearing thresholds of a person between different pitches and frequencies. Audiometer will be used in presenting different pure tones at different volumes and frequencies through a transducer while the participant will press a button when a sound is perceived. The softest sound that the participant can hear, or their thresholds will be recorded at each frequency particularly at 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz, and 8000Hz. The pure tones will be presented through air and bone conduction thus determining the participant's air and bone conduction thresholds.

iv. TDH 50-P headphones

Headphone is an air conduction transducer that is used to deliver pure tone stimulus that is presented by the audiometer in evaluating the participant's air conduction thresholds. It is an important element in PTA in order to determine the participant's hearing level.

v. RadioEar B-71 bone vibrator

Bone vibrator is a bone conduction transducer that is used to deliver pure tone stimulus that is presented by the audiometer. Bone vibrator transducer is placed at the mastoid process and stimuli will be

transferred through vibrations of the bone to the inner ear. Bone conduction audiometric is an essential element in determining the participant's bone conduction thresholds to obtain their air-bone gaps values and type of hearing loss.

vi. 3M Earmuffs

3M earmuffs are designed for comfort and excellent noise reduction especially for workers that are exposed to frequent loud noise during working hours. In this study, this earmuff will be used to occlude the ear during ear canal testing condition. Earmuffs will be put on the test ear to block any AC sounds transmission from any probable phenomenon of acoustic radiation.

3.8 Research Protocols

Participants who expressed interest were briefed on the study and provided written informed consent. Each session lasted approximately one hour, beginning with a brief case history to identify any exclusion criteria. Data collected during history taking included:

- IC Number
- Date of Birth
- Age and Sex
- History of ear pathology or surgery
- Current ear health status
- Other relevant medical history

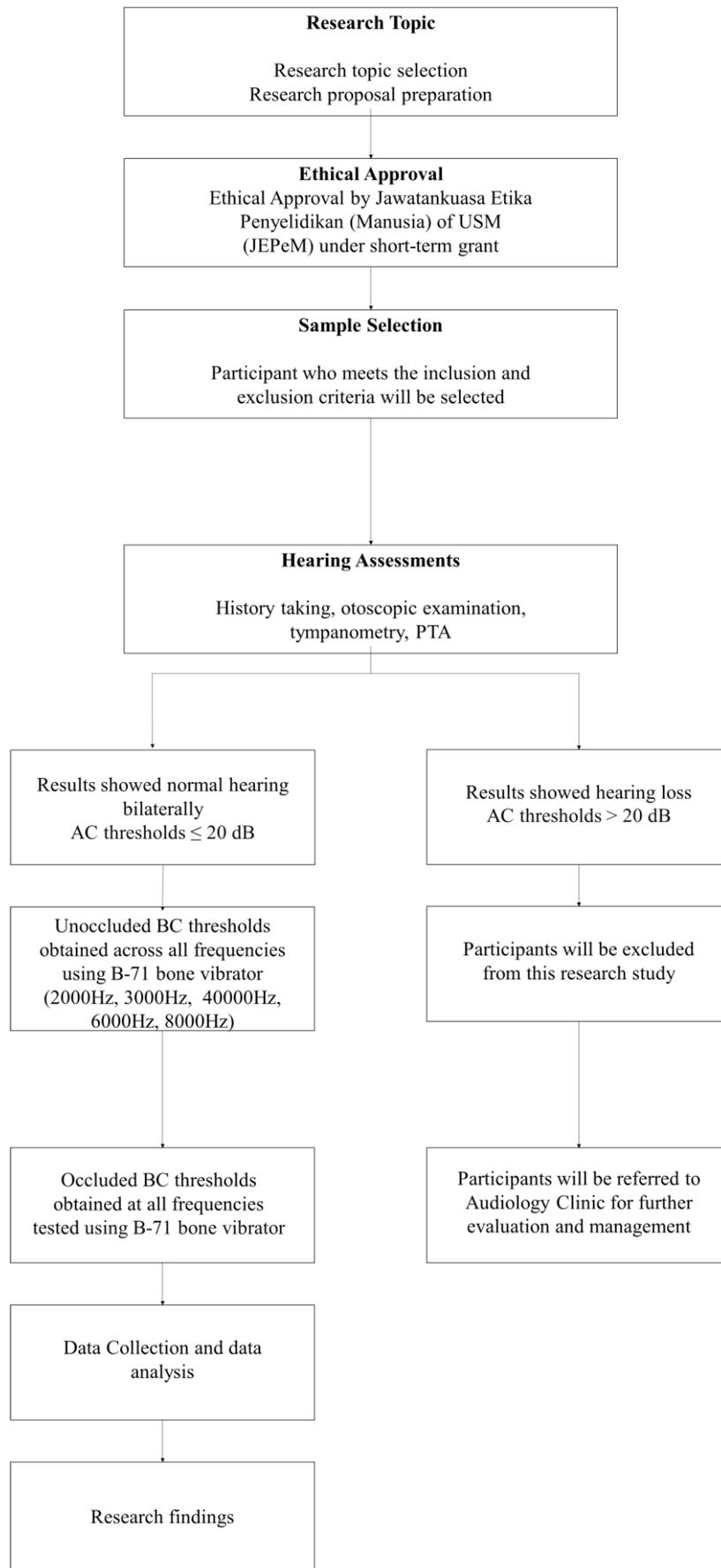
This was followed by otoscopic examination to visualize the external auditory canal and tympanic membrane. Participants with normal findings proceeded to tympanometry to assess middle ear status. Only those with Type A tympanograms bilaterally continued to pure tone audiometry (PTA).

PTA was conducted using TDH 50-P headphones and the GSI 61 audiometer. Air conduction thresholds were measured across 250 Hz to 8000 Hz using the Hughson-Westlake method. Thresholds were determined as the lowest intensity level at which the participant responded to at least two out of three ascending presentations. Normal hearing was defined as ≤ 20 dB HL across all frequencies. Participants who met these criteria bilaterally were included.

Bone conduction thresholds were then obtained using the RadioEar B-71 bone vibrator. Initial testing was conducted under unoccluded conditions at 2000 Hz, 3000 Hz, 4000 Hz, 6000 Hz, and 8000 Hz. BC thresholds were then re-evaluated under occluded conditions using 3M earmuffs on the test ear. Testing was repeated on the contralateral ear.

The difference in ABG values between the unoccluded and occluded conditions was analyzed to assess the potential effect of acoustic radiation on BC thresholds using the B-71 transducer.

3.9 Flow Chart of the Study



3.10 Statistical Analysis

The collected data were analyzed using JASP version 0.19.3. Prior to conducting inferential statistical tests, a Shapiro-Wilk test was performed to assess the normality of distribution for all continuous variables, including bone conduction (BC) thresholds and air-bone gap (ABG) values across both unoccluded and occluded ear canal conditions at high frequencies (2 kHz, 3 kHz, 4 kHz, 6 kHz, and 8 kHz). A significance level of $p < 0.05$ was used to determine deviations from normality. Wilcoxon signed-rank test, a non-parametric equivalent of the paired samples t-test, was used to compare BC thresholds and ABG values between unoccluded and occluded ear canal conditions within the same participants.

For each frequency, the following statistical values were reported:

- Median and Interquartile Range (IQR) for both conditions
- Z-value, which represents the standardized test statistic
- p -value, to assess the level of statistical significance

In addition, descriptive statistics such as mean, standard deviation (SD), range, and frequency percentages were calculated for participant demographics, including age, gender, and race. These values were used to summarize the characteristics of the study sample. The outcomes of the statistical analyses were interpreted to determine whether there were significant differences in BC thresholds and ABG values between the two testing conditions, thus addressing the study objectives related to the effect of acoustic radiation.

3.11 Ethical Consideration

The ethical approval from Jawatankuasa Etika Penyelidikan (Manusia) of USM (JEPeM) was obtained under the supervisor's grant prior to this study (USM/JEPeM/KK/24121127). Each participant included in this study was provided with participants information and consents forms (PIS) prior to the research session. There was no conflict of interest, including personal, financial, or proprietary interest, in the research results. There were no implications or consequences for those participants who refused to take part or withdraw from the study at any time. The personal details and data collected were kept confidential and not to be enclosed other than the supervisor unless the disclosure is required by law. All original records are only accessible to the researcher's authorized team members only.