Value of magnetic resonance imaging measurement of lateral semicircular canal bone island in sensorineural hearing loss patients

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Objective
Dysplasia of lateral semicircular canal (LSCC) is a common inner ear anomaly that may exist in patients with sensorineural hearing loss (SNHL). The diagnosis of subtle anomaly is limited when depending on visual inspection alone to evaluate images. Our purpose is to prove that routine measurement of the bone island of LSCC can avoid missing subtle anomaly and to prove that MRI is a valuable tool in diagnosis.

Patients and methods
This is a retrospective study performed on 67 patients with severe to profound SNHL and on 12 patients with tinnitus. Patients were classified into the control group (46 ears of 34 patients), which had normal MRI findings by visual inspection (24 ears of the 12 patients with tinnitus and 22 normal ears of 22 patients with unilateral SNHL), and the SNHL group (116 ears of 67 patients), in whom inner ear structures were apparently normal in MRI. Patients with isolated vestibular aqueduct (VA) dilatation and patients with Mondini deformity were included in this group. We measured the transverse and the anteroposterior (AP) diameter of the LSCC bone island in two to three contiguous axial images. The width of VA at its midpoint and at its distal end was also measured. SPSS, 16.0, for windows, standardized Student's *t*-test and Pearson's correlation coefficient were used for statistical analysis.

Results
There was no statistical difference in the bone island width or AP diameter in correlation to the age ($P > 0.05$). In the SNHL group, the width of the bone island was less than 2.8 mm in 18 (15.5%) ears, whereas the AP diameter was less than 2.8 mm in 21 (18.1%) ears. The bone island width and AP diameter tend to be smaller in patients with dilated VA than in patients with normal VA ($P < 0.001$). Significant negative correlation was found between the VA width and the bone island width ($r = -0.41$) and the bone island AP diameter ($r = -0.42$).

Conclusion
Developing normative radiological measurements by each institute and routine measurement of the bone island of LSCC are essential to avoid missing subtle anomalies by visual inspection alone.

Keywords:
lateral semicircular canal bone island, magnetic resonance imaging, radiological measurement

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Introduction

Inner ear malformations are present in nearly 40% of patients with sensorineural hearing loss (SNHL) [1,2]. Dysplasia of semicircular canal (SCC) is a common inner ear malformation, and it is more common than aplasia [3]. Lateral semicircular canal (LSCC) dysplasia is more common than superior and posterior SCC dysplasia, as it is the last to be formed. Its anomalies may be associated with cochlear or vestibular malformations or may occur in isolation [2,4]. A malformed canal may be short and wide or it may be narrow [5]. Vestibular malformations rarely occur in isolation and are commonly seen in association with cochlea or SCC anomalies [5,6]. In extensive malformations, the vestibule becomes dilated forming a common lumen with the LSCC (LSCC-vestibule dysplasia) [7,8]. Enlargement of the vestibular aqueduct (VA) is a frequently encountered inner ear abnormality [5,8]. It may be isolated, unilateral or bilateral and is usually asymmetric [3,9]. It may be associated with cochlear and vestibular malformations [5], as well as with SCC dysplasia [3,10].

Interpretation of radiological images is highly dependent on experience. Most of the inner ear malformations such as Michel aplasia, aplasia of cochlea, common cavity anomaly and incomplete partitions are easily diagnosed. However, nearly one-third of mild dysplasias such as SCC dysplasia are

often missed when assessing images by visual inspection alone [11,12]. The use of radiographic measurements helps to increase sensitivity for detection of minimal abnormalities and to limit diagnostic errors [1,12].

Normal development of SCC is associated with the formation of a bone island in the central portion of the canal [12]. Measurement of the transverse diameter of the bone island of LSCC on axial images can identify the more prevalent, often missed, subtle LSCC abnormalities that may exist in patients with SNHL with normal-appearing inner ear anatomy on imaging. The VA is considered to be dilated when its diameter is wider than that of the adjacent limb of the posterior SCC [3]. Measurement of VA size greatly aided in the accurate diagnosis of a large VA syndrome [1]. It is regarded as enlarged if the size is greater than 1.5 mm at a point halfway between the crus communis and the intracranial opening of the aqueduct [4,7,13,14].

Aim

Dysplasia of LSCC is a common inner ear anomaly that may exist in patients with SNHL. The diagnosis of subtle anomaly is limited when depending on visual inspection alone to evaluate images. Our purpose is to prove that routine measurement of the bone island of LSCC can avoid missing subtle anomaly and to prove that MRI is a valuable tool in diagnosis.

Patients and methods

This is a retrospective study performed on patients with severe to profound SNHL and on patients with tinnitus who were referred from the Department of Otolaryngology to the Department of Diagnostic Radiology at Sohag University Hospital in the period from April 2014 to December 2015 for imaging assessment. MRI was performed for all patients using 1.5-T MRI unit (Philips-Achieva, Holland, the Netherlands).

Consent

Written consent was taken from the adult patients and from the parents of children in accordance with the ethics committee of our institution.

Magnetic resonance imaging technique

MRI was performed using a dedicated head coil with the patient in neutral supine position. The protocol included the following sequences – axial and coronal B_TFE sense on the inner ear, oblique sagittal T2W_3D_DRIVE CLEAR on the internal auditory canals and fluid-attenuated inversion recovery images on the brain. The following parameters were used: axial and coronal B_TFE sense (TR, 6 ms; TE, 3 ms; FOV, 180 mm; slice thickness, 1 mm; interslice gap, 0.5 mm; flip angle, 60°; and scan duration, 1.43 min for axial and 1.35 min for coronal), oblique sagittal T2W_3D_DRIVE CLEAR (TR, 1.5 s; TE, 250 ms; FOV, 130 mm; slice thickness, 1.4 mm; interslice gap, 0.7 mm; flip angle, 90°; scan duration, 2.26 min) and fluid-attenuated inversion recovery (TR, 9 s; TE, 140 ms; FOV, 230 mm; slice thickness, 4 mm; interslice gap, 1 mm; flip angle, 90°; scan duration, 3 min).

Light sedation was given for uncooperative children to ensure stability during the procedure.

The control group

The control group included 46 ears that had normal audiometry and normal inner ear imaging findings by visual inspection, 24 ears obtained from 12 patients who had tinnitus and 22 ears obtained from 22 patients who had unilateral SNHL, with a total of 34 patients. We used the control group to obtain normal data and measures that were applied to the SNHL group.

The sensorineural hearing loss group

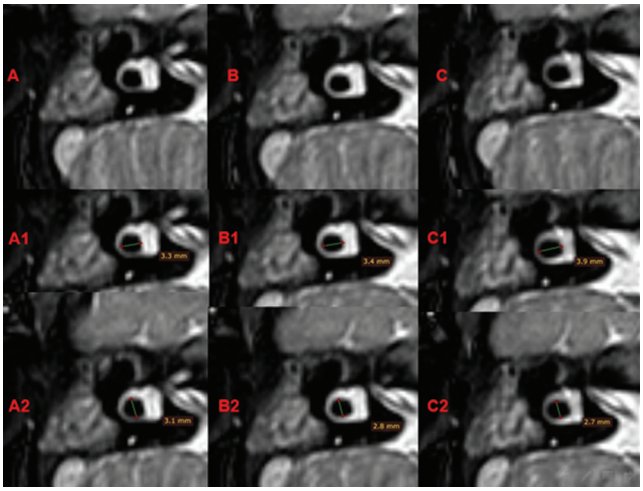
This group included 116 ears of 67 SNHL patients in whom inner ear structures were apparently normal in MRI. Patients with isolated VA dilatation and patients with Mondini deformity were included in this group. Patients with Michel aplasia, aplasia of cochlea, common cavity, incomplete partition type I and type III, patients with obvious SCC and vestibular malformations were excluded from the study.

Measurements methods

Images were obtained in a DICOM form, and after adequate image magnification using Radi (Medixant company, Poznan, Poland.) Ant DICOM Viewer 64 bit program, we used electronic calipers to precisely obtain the required measurements in millimetres.

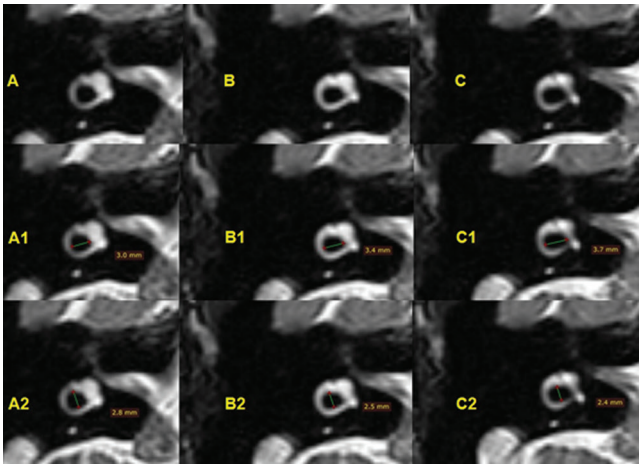
Using the aforementioned protocol, the LSCC and its bone island could be seen in at least two to three contiguous axial images. The bone island is imperfectly rounded and its dimensions vary from one image to another (Figs. 1 and 2). Authors used a line that extends from the apex of the canal's turn to the midpoint of the communication of the vestibule and the canal to measure the width of the LSCC bone island [1]. In our study, we measured the transverse diameter (width) and the anteroposterior (AP) diameter of the LSCC bone island in two or three levels, and the highest measurements only were recorded regardless of whether the ring formed by the vestibule and the limbs and arc of LSCC was completely seen in the image or

Figure 1



(C2–C2) is to be corrected by (A2-C2).

Figure 2



Normal right ear of a patient from the control group with bilateral tinnitus. (A-C) The lateral semicircular canal bone island in three contiguous axial images. The width (A1–C1) and the anteroposterior diameter (A2–C2) of the bone island differs from one level to another.

not. We also measured the width of VA at its midpoint and at its distal end.

Statistical analysis

We used statistical package for the social sciences (2007 SPSS, 16.0 for Windows, Chicago, USA) for statistical analysis. Bone island diameters were described with minimum, maximum and mean ± SD to measure the degree of dispersion of data around their mean. Student's *t*-test was applied to test the presence of significant differences between two comparable variables (bone island diameters in SNHL patients with and without dilated vestibular aqueduct and bone island diameters in normal paediatric and adult population). *P* value less than 0.05 was considered to indicate a significant difference.

The Pearson correlation coefficient (PCC), *r*, was used to measure the correlation between bone island diameters and width of vestibular aqueduct at its distal opening. The strength of the correlation was assessed using the guide that Evans suggests for the absolute value of *r*: 0.00–0.19, very weak; 0.20–0.39, weak; 0.40–0.59, moderate; 0.60–0.79, strong; and 0.80–1.0, very strong [15].

Results

The control group included 34 patients (46 normal ears). They included 19 female and 15 male patients. Their ages ranged from 2 years and 7 months to 50 years (mean age was 7 years and 4 months). Of the 34 patients, 23 patients (32 ears) were less than 18 years, and they were included in the paediatric group, whereas 11 patients (14 ears) were more than 18 years old and they were included in the adult group (Table 1).

The LSCC bone island width in the paediatric group ranged from 3 to 4.8 mm (mean ± SD: 3.709 ± 0.45), whereas in the adult group it ranged from 2.8 to 4.8 mm (mean ± SD: 3.777 ± 0.487), with a *P* value greater than 0.05 between the two groups, denoting that there is no significant difference in the bone island width in correlation to the age (Table 2).

The LSCC bone island AP diameter in the paediatric group ranged from 3 to 4.3 mm (mean ± SD: 3.444 ± 0.330), whereas in the adult group it ranged from 2.8 to 4.2 mm (mean ± SD: 3.346 ± 0.445), with *P* value greater than 0.05 between the two groups, denoting that there is no significant difference in the AP diameter of the bone island in correlation to the age (Table 3).

There was no significant difference as regards the width and the AP diameter of the bone island in relation to the sex ($P = 0.356$, which is statistically insignificant).

The SNHL group included 67 patients (116 ears): 49 patients with bilateral SNHL and 18 patients with unilateral SNHL. Of the 49 patients with bilateral SNHL, 36 patients had bilateral normal ear (72 ears), 11 patients had bilateral dilated VA (22 ears with bilateral dilated VA) with nine of them having bilateral Mondini and two having isolated bilateral dilated VA, whereas two patients had unilateral dilated VA (two normal ears and two ears with unilateral dilated VA). The 18 patients with unilateral SNHL were derived from the 22 patients used in the control group; four patients from the 22 were excluded as they had inner ear anomalies correlated to the mentioned exclusion criteria. The SNHL group included 36 female and 31 male patients. Their ages ranged from 1 year and

Table 1 Patient population in the control group

Patients presentation	*N*	Male	Female	Paediatric	Adult
Tinnitus	12 (24 ears)	5	7	9 (18 ears)	3 (6 ears)
Unilateral SNHL	22 (22 ears)	10	12	14 (14 ears)	8 (8 ears)
Total	34 (46 ears)	15	19	23 (32 ears)	11 (14 ears)

SNHL, sensorineural hearing loss.

Table 2 Age/lateral semicircular canal bone island width in the control group

	N	Minimum (mm)	Maximum (mm)	Mean (mm)	SD	*P*
Paediatric	32	3	4.8	3.709	0.45	0.658*
Adult	14	2.8	4.8	3.777	0.487	

P is statistically insignificant (*t*-test).

Table 3 Age/lateral semicircular canal bone island anteroposterior diameter in the control group

	N	Minimum (mm)	Maximum (mm)	Mean (mm)	SD	*P*
Paediatric	32	3	4.3	3.444	0.330	0.422*
Adult	14	2.8	4.2	3.346	0.445	

P is statistically insignificant (*t*-test).

5 months to 47 years (mean age was 3 years and 6 months) (Table 4).

The bone island width in the control group (46 ears) ranged from 2.8 to 4.8 mm, whereas in the SNHL group (116 ears) it ranged from 1.5 to 4.8 mm. The estimated *P* value was 0.462, which is statistically insignificant. However, we found that in the 116 ears with SNHL the width of the bone island was less than 2.8 in 18 (15.5%) ears.

The AP diameter of the bone island in the control group (46 ears) ranged from 2.8 to 4.3 mm, whereas in the SNHL group (116 ears) it ranged from 1.4 to 4.3 mm. The estimated *P* value was 0.576, which is statistically insignificant. However, we found that in the 116 ears with SNHL the AP diameter of the bone island was less than 2.8 mm in 21 (18.1%) ears.

In the 46 ears included in the control group, we found that six (13%) ears had central lucency of the LSCC bone island, whereas in the 116 ears included in the SNHL group it was found in 33 (28.4%) ears (Fig. 3).

The bone island width in SNHL patients with normal VA (92 ears) ranged from 2.5 to 4.8 mm (mean ± SD: 3.039 ± 0.383), whereas in the patients with dilated VA (24 ears) it ranged from 1.5 to 3.1 mm (mean ± SD: 3.767 ± 0.353). The estimated *P* value was greater than 0.001, which is statistically significant, denoting that the width of bone island of LSCC tends to be smaller in patients with dilated VA (Table 5).

The AP diameter of the bone island in the SNHL patients with normal VA (92 ears) ranged from 1.8 to 4.3 mm (mean ± SD: 3.462 ± 0.522), whereas in the patients with dilated VA (24 ears) it ranged from 1.4 to 3.3 mm (mean ± SD: 2.525 ± 0.452) (Figs. 4 and 5). The estimated *P* value was greater than 0.001, which is statistically significant, denoting that the AP diameter of the bone island of LSCC tends to be smaller in patients with dilated VA (Figs. 4 and 5 and Table 6).

Table 4 Patients population in the sensorineural hearing loss group

Patient population	*N*	Normal ear	Dilated VA
Bilateral SNHL with bilateral normal ear	36	72 ears	0
Bilateral SNHL with bilateral dilated VA.	11	0	22 ears
Bilateral SNHL with unilateral dilated VA	2	2 ears	2 ears
Unilateral SNHL with normal ear	18	18 ears	0
Total	67 patients	92 ears	24 ears

SNHL, sensorineural hearing loss; VA, vestibular aqueduct.

Estimation of the PCC in the 24 ears with dilated VA revealed a moderate negative correlation between the bone island width and the width of the VA at its distal end ($r = -0.41$) and also between the AP diameter of the bone island and the width of the VA at its distal end ($r = -0.42$). This means that the more the increase in the width of the VA the more the decrease in the width and in the AP diameter of the bone island of LSCC (Figs. 6 and 7).

Discussion

Visual inspection of radiological images can identify obvious morphogenetic malformations of the inner ear, but minor dysplasias may be missed [12]. It is reported that visual inspection alone can miss up to one-third of subtle inner ear anomalies [1].

The use of radiological measures increases the sensitivity to detect subtle abnormality and reduces diagnostic errors [1].

Table 5 Bone island transverse diameter in patients with sensorineural hearing loss

	N	Minimum (mm)	Maximum (mm)	Mean (mm)	SD	*P*
Normal VA	92 ears	2.5	4.8	3.039	0.383	>0.001*
Dilated VA	24 ears	1.5	3.1	3.767	0.353	

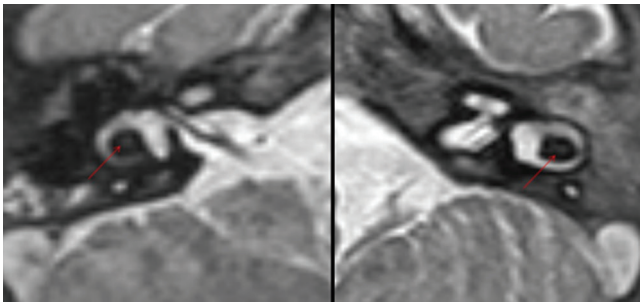
VA, vestibular aqueduct. *P=0.001, extremely statistically significant (t-test).

Table 6 Bone island anteroposterior diameter in patients with sensorineural hearing loss

	N	Minimum (mm)	Maximum (mm)	Mean (mm)	SD	*P*
Normal VA	92 ears	1.8	4.3	3.462	0.522	>0.001*
Dilated VA	24 ears	1.4	3.3	2.525	0.452	

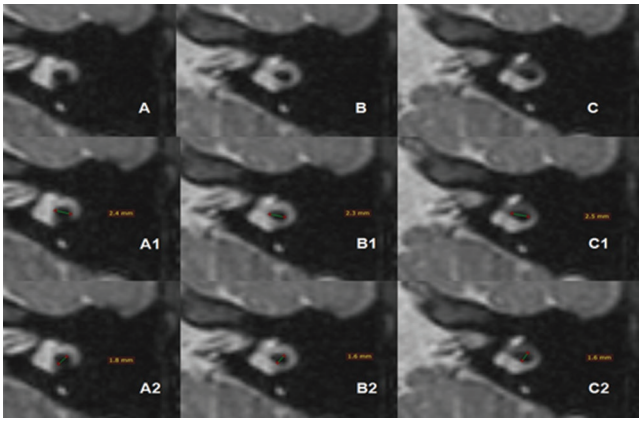
VA, vestibular aqueduct. *P>0.001, extremely statistically significant (t-test).

Figure 3



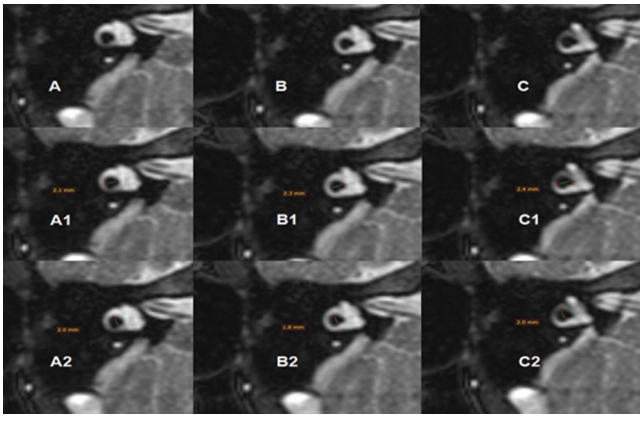
Central lucency of the bone island of lateral semicircular canal is seen in two different patients.

Figure 4



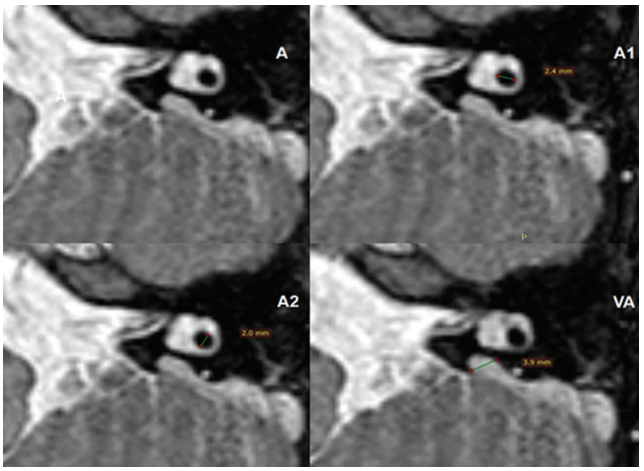
Patient with sensorineural hearing loss and normal width of vestibular aqueduct. (A-C) The lateral semicircular canal bone island in three contiguous axial images. The maximum width (A1–C1) of the bone island is 2.5 mm, whereas the maximum anteroposterior diameter (A2–C2) is 1.8 mm.

Figure 5



Sensorineural hearing loss patient with dilated vestibular aqueduct. (A-C) The lateral semicircular canal bone island in three contiguous axial images. The maximum width (A1–C1) of the bone island is 2.4 mm, whereas the maximum anteroposterior diameter (A2–C2) is 1.8 mm.

Figure 6



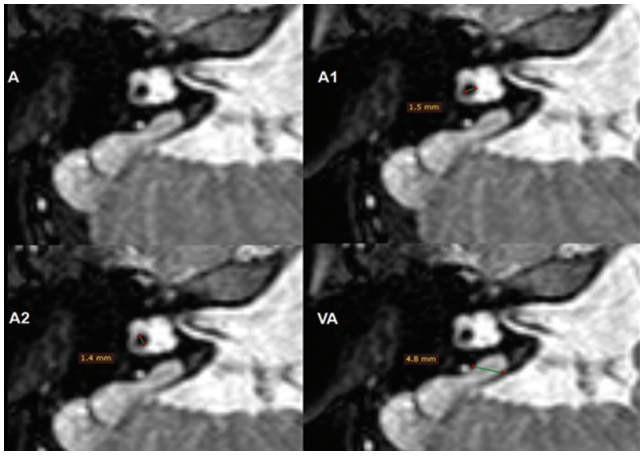
Left ear axial images of a sensorineural hearing loss patient with bilateral dilated vestibular aqueduct. (A) The lateral semicircular canal bone island and the dilated vestibular aqueduct. (A1) The maximum width of the bone island is 2.4 mm. (A2) the maximum anteroposterior diameter is 2 mm. (VA) The width of vestibular aqueduct is 3.9 mm.

Although evaluating the bone labyrinth by computed tomography scan is a convenient and cheap method, MRI offers further resolution and more data in SNHL patients [12].

The bone structures of the inner ear are fully developed at birth and do not change in size with age [11,12]. These results are in agreement with the current study, as we found that there is a statistically insignificant difference between the paediatric and adult patients in the control group as regards the LSCC bone island width (P = 0.658) and as regards its AP diameter (P = 0.422).

Also, there was an insignificant difference as regards the width and the AP diameter of the bone island in relation to the sex (P = 0.356).

Figure 7



Right ear axial images of the same patient at Fig. 6. (A) The lateral semicircular canal bone island and the dilated vestibular aqueduct. (A1) The maximum width of the bone island is 1.5 mm. (A2) the maximum anteroposterior diameter is 1.4 mm. (VA) The width of vestibular aqueduct is 4.8 mm.

Authors reported that the normal LSCC bone island width on axial images ranged from 2.6 to 4.8 mm. Consequently, a bone island width shorter than 2.6 mm or longer than 4.8 mm was called hypoplastic or hyperplastic, respectively [1,16]. In our study, the bone island width in the control group ranged from 2.8 to 4.8 mm. This can be attributed to the difference in the measurement method. Authors used a line that extends from the apex of the canal's turn to the midpoint of the communication of the vestibule and the canal to measure the LSCC bone island width [1]. In our study, we measured the width and the AP diameter in three levels and the highest measure only was recorded. Authors also suggested that racial difference may be responsible for the statistical differences [12].

Our study revealed that the AP diameter of the bone island in the control group (46 ears) ranged from 2.8 to 4.3 mm, and to our knowledge this is the first study dealing with that point.

Significant statistical differences as regards the LSCC bone island width were found between patients with and without SNHL [12]. In our study, we found that there was an insignificant statistical difference between the two groups ($P = 0.462$). Of the 116 ears included in the SNHL group, the bone island width of 98 (84.5%) ears was found to lie in the normal size range (2.8–4.8 mm), which led to statistically insignificant difference. However, we had bone island width less than 2.8 mm in 18 (15.5%) ears of the same group, which is a significant percentage that should not be overlooked.

Our study revealed that there was no statistically significant difference as regards the LSCC bone island AP diameter found between the control and SNHL groups ($P = 0.576$). Of the 116 ears included in the SNHL group, the bone island AP diameters of 95 (81.9%) ears were found to lie in the normal size range (2.8–4.3 mm), which led to a statistically insignificant difference. However, we had bone island AP diameter less than 2.8 mm in 21 (18.1%) ears of the same group, which is a significant percentage that should not be overlooked, and to our knowledge this is the first study dealing with that point.

Authors reported that LSCC bone island central lucency was frequently seen in the SNHL group in comparison with the control group [12]. In our study, the central lucency was seen in six (13%) ears of the control group, whereas it was seen in 33 (28.4%) ears of the SNHL group.

Enlargement of VA is a very common congenital inner ear anomaly in SNHL patients that is found by imaging [4,5]. It is commonly bilateral and may be asymmetric [3,7]. It is associated with cochlear incomplete partition type II but is also frequently associated with enlargement of the vestibule and with SCC dysplasia [7–10].

Of the 116 ears included in the SNHL group in our study, the bone island width and AP diameter in the patients with dilated VA (24 ears) were smaller than in patients with normal VA (92 ears), with the estimated *P* values for the width and AP diameter being greater than 0.001, which are statistically significant. The estimation of the PCC in the 24 ears with dilated VA revealed that there is moderate negative correlation between the width of the VA and the width and AP diameter of the bone island of LSCC, respectively. These findings mean that patients with VA dilatation tend to have smaller LSCC bone island and subsequently dysplastic LSCC and that the more wide the VA the more the degree of dysplasia.

Routine measurement of the transverse and AP diameter of the bone island of LSCC can detect subtle abnormality that may exist in patients with SNHL whose inner ear anatomy appears normal on imaging [1]. It is common to find the same structure to be normal when measured in a section, whereas it is abnormal when measured in another section. These findings can be related to the difference in the shape of structure from one section to another or related to a difference in angle of section and plane of measurement [11]. The detection of such subtle anomalies does not interfere with or contraindicate cochlear implantation; however, developing normative radiological measurements by each institute is essential in the imaging evaluation to reduce diagnostic errors.

To our knowledge, this is the first study that used MRI to measure the LSCC bone island and is the first study that is concerned with its AP diameter. We found that measurements can detect subtle inner anomalies that could be missed by visual inspection. We also found high association between VA dilatation and LSCC bone island hypoplasia, which is reflected as LSCC dysplasia.

Conclusion

Inner ear malformations, especially those of LSCC, are commonly found in SNHL patients. Visual inspection of radiological images can miss subtle anomalies. Routine measurement of the LSCC bone island is essential in diagnosis. Despite the fact that the detection of such subtle anomalies does not have an impact on cochlear implantation, developing normative radiological measurements by each institute is recommended to reduce diagnostic errors. MRI is a valuable imaging modality to diagnose inner ear anomalies.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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