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Main Article

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Semicircular canals are long in patients with benign paroxysmal positional vertigo

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Abstract

Objective. To search for any morphological variation contributing to aetiopathogenesis and the diagnosis of benign paroxysmal positional vertigo, we measured the sizes of the semicircular canals in patients with and without benign paroxysmal positional vertigo using multidetector computed tomography.

Methods. Cranial bone computed tomography images of 30 benign paroxysmal positional vertigo patients and 30 control patients were acquired with a 128-slice computed tomography scanner and a transverse plane with a thickness of 0.67 mm. The inner diameter, height and width of the canals were measured.

Results. The width of the anterior semicircular canals, and the width and height of the posterior semicircular canals of the affected ears in benign paroxysmal positional vertigo patients ($n = 30$) were significantly greater than in the control patients ($n = 90$; $p = 0.001$, $p = 0.023$, $p = 0.003$, respectively).

Conclusion. In benign paroxysmal positional vertigo patients, the posterior and anterior semicircular canals are longer than those in people without benign paroxysmal positional vertigo. These morphological changes may contribute to elucidating the aetiopathogenesis and be used as a radiological sign for diagnosis of benign paroxysmal positional vertigo disease.

Introduction

The cochlea and vestibular system are housed in the bony labyrinth, located in the petrous region of the temporal bone. The vestibular system includes semicircular canals, which are responsible for balance. They are arranged over three orthogonal planes: anterior (superior), posterior and lateral (horizontal). The anterior and contralateral posterior canals act as a push–pull pair, with one working while the other is blocked.[1] Push–pull pairs of lateral canals on both sides function together.[2] Consequently, they maintain balance. Acute vertigo attacks occur when the inputs from each side of the vestibular system are asymmetric.[3] Benign paroxysmal positional vertigo (BPPV) is the most prevalent type of vertigo. It has a prevalence of 10.7 to 64 out of 100 000 people. The aetiology is unclear, but it is idiopathic in 50–70 per cent of cases.[4,5] In pathophysiology, it is claimed that calcium sequestering scaffold protein complexes called otoliths adhere to the cupula in the ampulla of semicircular canals or float free in semicircular canals.[6,7] The pathognomonic sign of BPPV is positional nystagmus. In diagnosis, some manoeuvres are used to detect the affected canal. To our knowledge, no radiological sign diagnoses BPPV.

The sizes of semicircular canals were previously measured in the temporal bones of cadavers.[8] Because formaldehyde causes tissue specimens to shrink, the measurements were smaller than the actual sizes.[9,10] The three-dimensional structure of the inner ear can be visualised in detail using computed tomography (CT).[11,12] Using multidetector CT, Daocai *et al.* evaluated the sizes of semicircular canals in different age groups of healthy people and stated that, unlike other human organs, semicircular canal sizes are not different in children compared with older people.[13] Until now, there has been no BPPV disease-specific study on the sizes of semicircular canals. This study aimed to compare the diameters of semicircular canals in BPPV patients with those in healthy people using multidetector CT and thus contribute to elucidating the aetiopathogenesis of BPPV disease and the radiological diagnosis of BPPV.

Materials and methods

This retrospective clinical study was performed in a tertiary referral centre. Cranial bone CT images of 30 patients with BPPV diagnosed by Dix–Hallpike and Pagnini–McClure manoeuvres using videonystagmography (ICS Charter EP, GN Otometrics, Schaumburg, IL, USA) and 30 control patients who underwent septoplasty surgery without ear pathology were examined. The group members were between 18 and 45 years old.

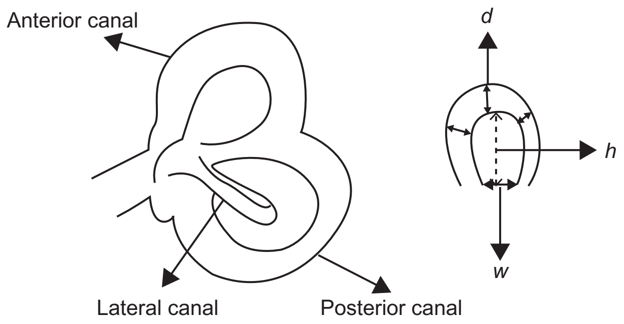

Figure 1. Illustration of semicircular canals and the dimensions of one of the canals: d = inner diameter; h = height; w = width

Patients who presented with multiple-canal BPPV, central nervous system pathology, head trauma or other vestibular diseases were excluded.

Study group patients were informed about the study and asked to sign the clinical trial informed consent form. The present study was approved by the local ethics committee and designed according to the Helsinki Declaration.

Radiological evaluation of semicircular canals

Measurements were performed by two neuroradiologists based on consensus. All the images were acquired using a 128-slice CT scanner and a transverse plane with a thickness of 0.67 mm, and were reconstructed using a bone algorithm. A window width of 1600 Hounsfield units and a window centre of 400 Hounsfield units on a picture archiving and communication system (Infinitt Healthcare, Seoul, South Korea) were used to display the images. Axial, sagittal and coronal planes were reformatted in an orthogonal plane using the multiplanar reformation software system. The reconstruction matrix size was 0.2 mm. After visualising the optimal images, the best images of all three semicircular canals (anterior, posterior and lateral) were chosen, and the inner diameter, height and width of the canals were measured as previously described by Daocai *et al.*[13] The inner diameter was calculated using the average of three measurements taken at three separate locations in the canal apices, the width was defined as the longest distance between the medial walls of the two bony crura of each semicircular canal and the height was defined as the maximum longitudinal extension from the medial vestibule wall proximate to the apices of the canals (Figures 1 and 2).

Statistical analysis

Descriptive statistical methods (mean, median, standard deviation, frequency, percentage, minimum and maximum) were used to evaluate the data. The normal distribution of quantitative variables was analysed using the Shapiro–Wilk test and graphics. In comparing two groups with normally distributed quantitative variables, the student's t-test was used, but with distributions that deviated from the normal, the Mann–Whitney U-test was used. The paired samples t-test was used for normally distributed quantitative variables in the internal comparison of each group. Pearson's chi-squared test was used to compare the qualitative variables. Statistical significance was accepted as $p < 0.05$.

Results and analysis

In this study, CT images of 120 ears were analysed for two groups: BPPV cases and control. The mean age was 40.63 ± 11.10 years in the BPPV group and 38.56 ± 9.84 years in the control group. The BPPV group contained 30 patients (18 female and 12 male) and the control group also contained 30 patients (14 female and 16 male). In descriptive analyses, no statistical difference in age or gender was found between the two groups ($p = 0.447$ and $p = 0.301$, respectively; Table 1).

BPPV was observed in patients with ratios of 70 per cent in the right ear, 60 per cent at the posterior semicircular canal and 43.3 per cent at the right posterior semicircular canal. The case group contained no patients with anterior-canal BPPV who had CT images (Table 1).

The canal sizes of the affected ears ($n = 30$) and others ($n = 90$, both contralateral ears of BPPV patients and control ears) were compared. The width of the anterior semicircular canals and the width and height of the posterior semicircular canals of the affected ears were significantly greater than others ($p = 0.001$, $p = 0.023$, $p = 0.003$, respectively).

The BPPV group was divided into two groups according to the canal affected: lateral-canal BPPV ($n = 12$) and posterior-canal BPPV ($n = 18$) patients. No statistical difference in size was found between these two groups. Compared with the

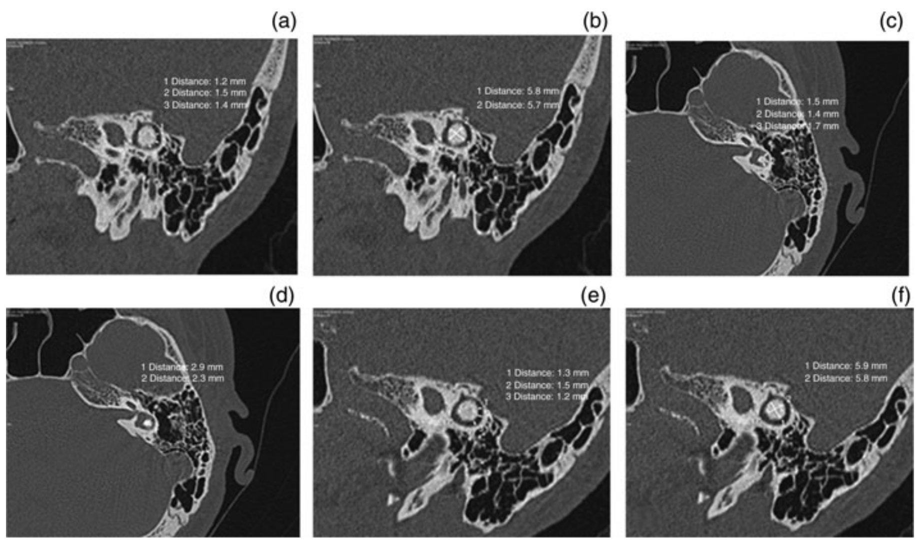

Figure 2. In the plane with a panoramic view of the three semicircular canals, the inner diameter, height and width were measured: (a) distance numbers 1, 2 and 3 for the inner diameter of the anterior semicircular canal; (b) distance number 1 for the height and distance number 2 for the width of the anterior semicircular canal; (c) distance numbers 1, 2 and 3 for the inner diameter of the lateral semicircular canal; (d) distance number 1 for the height and distance number 2 for the width of the lateral semicircular canal; (e) distance numbers 1, 2 and 3 for the inner diameter of the posterior semicircular canal; (f) distance number 1 for the height and distance number 2 for the width of the posterior semicircular canal.

Table 1. Descriptive data

Characteristic	BPPV group ($n = 30$)	Control group ($n = 30$)	p-value
Age (years)	40.63 ± 11.10	38.56 ± 9.84	0.447*
Gender (n (%))			0.301**
Female	18 (60)	14 (46.7)	
Male	12 (40)	16 (53.3)	
Affected side of BPPV (n (%))			
Right	21 (70)		
Left	9 (30)		
Affected canal of BPPV (n (%))			
Posterior semicircular canals	18 (60)		
Lateral semicircular canals	12 (40)		

*Student's t-test. **Pearson chi-square test. BPPV = benign paroxysmal positional vertigo

control group ($n = 30$), in both lateral- and posterior-canal BPPV patients, the widths of the right and left anterior semicircular canals (w-anterior) and the widths of the right and left posterior semicircular canals (w-posterior) were significantly greater (for lateral-canal BPPV patients, right $p_{w\text{-anterior}} = 0.027$, left $p_{w\text{-anterior}} = 0.003$ and right $p_{w\text{-posterior}} = 0.001$, left $p_{w\text{-posterior}} = 0.014$; for posterior-canal BPPV patients, right $p_{w\text{-anterior}} = 0.010$, left $p_{w\text{-anterior}} = 0.001$ and right $p_{w\text{-posterior}} = 0.001$, left $p_{w\text{-posterior}} = 0.002$, where $p_{w\text{-anterior}} = p$ value for width of anterior semicircular canal and $p_{w\text{-posterior}} = p$ value for width of posterior semicircular canal). In both lateral- and posterior-canal BPPV patients, the inner diameter of almost all the semicircular canals was observed as narrower than in control patients, but this was statistically approved for only the inner diameter of right posterior semicircular canals in lateral-canal BPPV patients (Table 2).

No statistical difference in size between semicircular canals in affected ($n = 30$) and unaffected ($n = 30$) ears was found in the BPPV group. Moreover, no statistical difference in size between semicircular canals in the right ($n = 30$) and left ($n = 30$) ears was found in the control group.

Table 3 shows the reference values for each semicircular canal measurement using the control group data within the 90 per cent range.

Discussion

The current study determined the sizes of semicircular canals in patients with BPPV measured using multidetector CT images. To our knowledge, no study has been published on this subject before. We measured the inner diameter separately using an average of three different points for the height and width of all three canals. Based on the normal reference values of the dimensions of semicircular canals in the study by Daocai *et al.*,[13] we visualised that the lateral semicircular canal had the largest inner diameter, and the anterior semicircular canal had the largest height and width in the control group.

Table 2. Comparison of sizes of the semicircular canals in the two groups studied

Semicircular canal		BPPV (mean ± SD) ($n = 30$)		Control (mean ± SD) ($n = 30$)	p-value (Lateral BPPV-control)	p-value (Posterior BPPV-control)
		Lateral BPPV (n = 12)	Posterior BPPV (n = 18)			
Anterior						
Inner diameter	Right	0.99 ± 0.08	1.00 ± 0.09	0.99 ± 0.07	0.999	0.670
	Left	0.97 ± 0.07	0.99 ± 0.07	0.99 ± 0.05	0.184	0.693
Height	Right	5.38 ± 0.60	5.37 ± 0.37	5.00 ± 0.57	0.064	0.019*
	Left	5.49 ± 0.42	5.54 ± 0.45	5.19 ± 0.49	0.071	0.016*
Width	Right	5.72 ± 0.44	5.69 ± 0.29	5.38 ± 0.43	0.027*	0.010*
	Left	5.77 ± 0.43	5.68 ± 0.34	5.36 ± 0.36	0.003*	0.003*
Posterior						
Inner diameter	Right	1.17 ± 0.09	1.21 ± 0.07	1.26 ± 0.11	0.021*	0.095
	Left	1.22 ± 0.08	1.23 ± 0.09	1.24 ± 0.08	0.348	0.573
Height	Right	5.49 ± 0.34	5.32 ± 0.60	5.13 ± 0.57	0.062	0.279
	Left	5.51 ± 0.28	5.39 ± 0.44	5.11 ± 0.48	0.010*	0.056
Width	Right	5.15 ± 0.34	5.02 ± 0.66	4.35 ± 0.56	0.001**	0.001**
	Left	4.93 ± 0.50	4.98 ± 0.48	4.30 ± 0.79	0.014*	0.002**
Lateral						
Inner diameter	Right	1.22 ± 0.11	1.23 ± 0.13	1.24 ± 0.14	0.666	0.810
	Left	1.22 ± 0.14	1.22 ± 0.12	1.25 ± 0.13	0.601	0.446
Height	Right	3.88 ± 0.40	5.85 ± 8.63	3.78 ± 0.40	0.463	0.193
	Left	3.82 ± 0.34	3.98 ± 0.42	3.73 ± 0.39	0.515	0.045*
Width	Right	3.37 ± 0.25	3.33 ± 0.42	3.26 ± 0.38	0.335	0.564
	Left	3.22 ± 0.36	3.37 ± 0.39	3.27 ± 0.43	0.711	0.421

*Student's t-test. **Mann–Whitney U-test. BPPV = benign positional paroxysmal vertigo; SD = standard deviation

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Table 3. The usual reference values for the measurements of each semicircular canal using the data of the control group

Semicircular canal	Inner diameter (mean ± SD, mm)	Height (mean ± SD, mm)	Width (mean ± SD, mm)
Anterior	0.975 ± 0.064	5.096 ± 0.530	5.319 ± 0.394
Posterior	1.25 ± 0.095	4.42 ± 0.814	4.32 ± 0.67
Lateral	1.253 ± 0.134	3.755 ± 0.392	3.262 ± 0.397

SD = standard deviation

BPPV is characterised as posterior-, anterior- or lateral-canal BPPV, depending on which canal the otoliths move through. The most common type of BPPV is posterior-canal BPPV, which accounts for 80 per cent of all BPPV cases, while anterior-canal BPPV accounts for only 3 per cent of cases.[14–16] In the present study, 60 per cent of patients with CT images had posterior-canal BPPV and no patients with CT images had anterior-canal BPPV.

In the study by Daocai *et al.*, the sizes of all the semicircular canals in four different age groups were compared using multi-detector CT. These authors claimed that the sizes of semicircular canals did not change as patients aged.[13] However, Klopp-Dutote *et al.* only considered the diameters of superior (anterior) semicircular canals.[17] Contrary to Daocai *et al.*, they asserted that a straight ratio existed between age and superior semicircular canal diameter. Another study, by Nomura and Kobayashi, compared only the sizes of cross-sections of the right and left posterior semicircular canals using coloured pixels on CT scans.[18] They stated that no difference existed in the sizes of posterior semicircular canals based on gender. In our study, no difference existed based on age and gender between the two groups, indicating that neither age nor gender affected the results.

Although several anatomical and radiological studies have been published on semicircular canal measurements,[8,19] only a few are disease specific. Krombach *et al.* used CT to examine the temporal bones of patients with Ménière's disease.[20] They assessed the length and width of the inner-ear structures and found that patients with Ménière's disease had a short and narrow vestibular aqueduct, but observed no difference in the sizes of the semicircular canals. They claimed that these morphological variants could play an important role in the endolymph balance. In our study, we used multidetector CT to determine the sizes of three semicircular canals in BPPV patients. The width of the anterior semicircular canals and the width and height of the posterior semicircular canals of the affected ears were greater in the ears of patients with BPPV than in unaffected ears (Figure 3). In mathematics, according to the Pythagorean theorem, the arc length of a parabolic curve is calculated by the following formula:

$$\sqrt{a^2 + b^2}$$

According to the formula, any change in the variables of the formula changes the result in direct proportion.[21,22] The length of a semicircular canal is $\sqrt{h^2 + w^2}$, where h is the height and w is the width. If the width or height of the semicircular canals increases, the length of the canal increases (Figure 4). Thus, patients with BPPV had long anterior and posterior semicircular canals in their affected ears. These morphological changes may be used as a radiological sign in

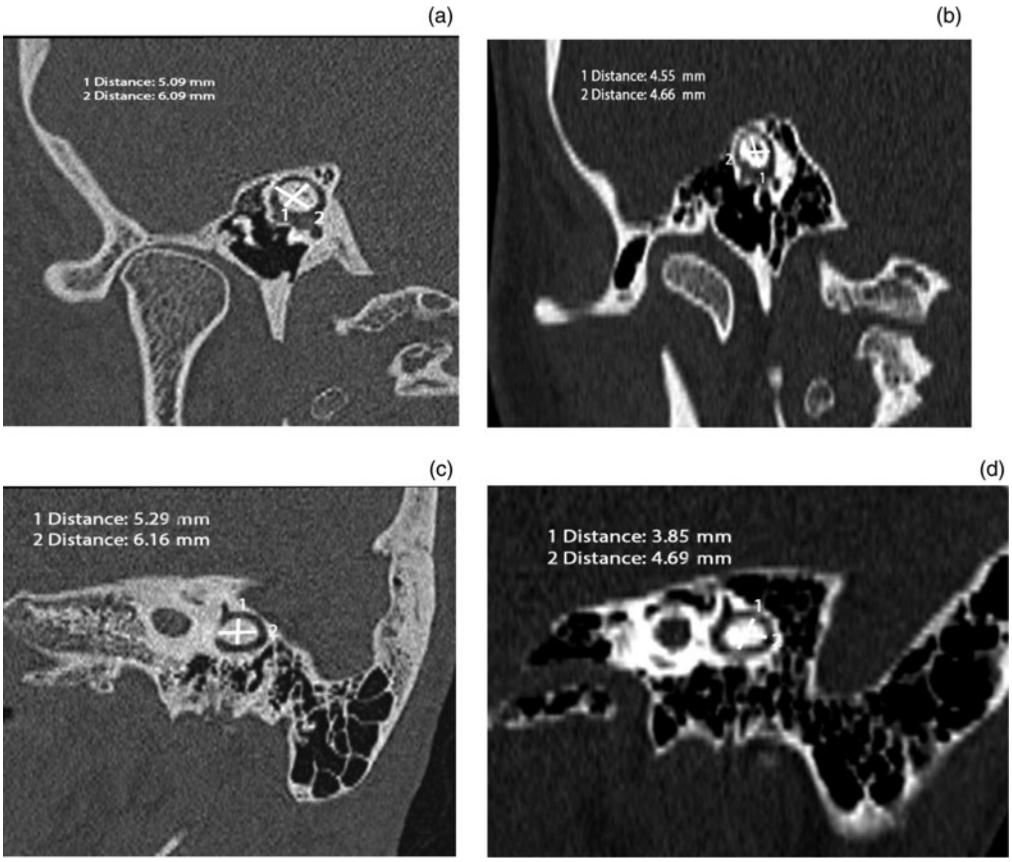

Figure 3. Sample images of findings from the benign positional paroxysmal vertigo (BPPV) group and control group (1 = height; 2 = width): (a) anterior semicircular canal in the BPPV group; (b) anterior semicircular canal in the control group; (c) posterior semicircular canal in the BPPV group; (d) posterior semicircular canal in the control group.

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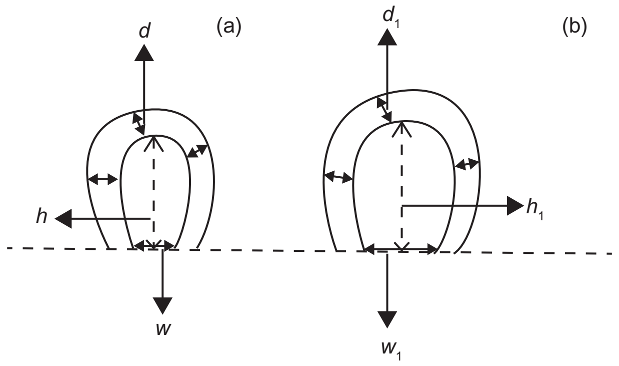

Figure 4. The increase in the length of the semicircular canals accompanying increases in the height and width of the canals. h_1 is greater than h and w_1 is greater than w, therefore the length of the canal in (b) is longer than that in (a). d = inner diameter; h = height; w = width

diagnosis of BPPV disease. In addition, in future studies, measurements of the volumes of the semicircular canals using multidetector CT may also contribute to the diagnosis of BPPV disease.

In another study, Lee *et al.* measured the size of the superior semicircular canal in ephrin-binding receptor-deficient mice with vertigo.[23] They discovered that the lumen diameters of the left and right superior semicircular canals were asymmetric and that this was unrelated to the direction of vertigo. In our study, the inner diameters of almost all the semicircular canals of BPPV patients were observed as narrow, regardless of the affected canal. These morphological changes in BPPV patients may cause otoliths to remain in the canal for an extended period, leading to canalolithiasis.

This study's main limitation was the small size of the sample. Many more participants are required to compare BPPV patients based on the affected canal and side. Moreover, we could measure only linear lengths using our software. The length of the semicircular canals might be measured directly using a different software system that includes an application to measure parabolic lengths. In addition, because semicircular canals with narrow diameters are slightly longer, they may still have the same volume of endolymph. Volumetric measurements of semicircular canals could therefore be added to the methodology, thus allowing much more data to be obtained about the volume of endolymph in semicircular canals to elucidate the aetiopathogenesis of BPPV disease.

- There is no difference in the sizes of semicircular canals by age
- Morphological variation of semicircular canals in patients with benign positional paroxysmal vertigo (BPPV) is unknown
- There are laboratory tests to diagnose BPPV, but no radiological tests
- The aetiopathogenesis of BPPV is still unclear
- The posterior and anterior semicircular canals are long in BPPV patients
- This morphological variation may contribute to the diagnosis of BPPV using multidetector computed tomography and to elucidating the aetiopathogenesis of BPPV

In conclusion, the posterior and anterior semicircular canals are longer in BPPV patients than in healthy people. In addition, the inner diameter of almost all the semicircular canals is narrow. These morphological changes may contribute to elucidating the aetiopathogenesis and can be used as a radiological sign for diagnosis of BPPV disease.

Competing interests. None declared

References

1 Graf W. Motion detection in physical space and its peripheral and central representation. *Ann N Y Acad Sci* 1998;**545**:154–69
2 Anson BJ, Donaldson JA. *Surgical Anatomy of the Temporal Bone*, 3rd edn. Philadelphia: WB Saunders, 1981
3 Hotson JR, Baloh RW. Acute vestibular syndrome. *N Engl J Med* 1998;**339**:680–5
4 Bhattacharyya N, Baugh RF, Orvidas L, Barrs D, Bronston LJ, Cass S *et al.* Clinical practice guideline: benign paroxysmal positional vertigo. *Otolaryngol Head Neck Surg* 2008;**139**:47–81
5 Kim JS, Zee DS. Clinical practice. Benign paroxysmal positional vertigo. *N Engl J Med* 2014;**370**:1138–47
6 Hall SF, Ruby RR, McClure JA. The mechanics of benign paroxysmal vertigo. *J Otolaryngol* 1979;**8**:151–8
7 Schuknecht HF, Ruby RR. Cupulolithiasis. *Adv Otorhinolaryngol* 1973;**20**:434–43
8 Spoor F, Zonneveld F. Comparative review of the human bony labyrinth. *Am J Phys Anthropol* 1998;**27**:211–51
9 Buytaert J, Goyens J, De Greef D, Aerts P, Dirckx J. Volume shrinkage of bone, brain and muscle tissue in sample preparation for micro-CT and light sheet fluorescence microscopy (LSFM). *Microsc Microanal* 2014;**20**:1208–17
10 Lane J, Rális ZA. Changes in dimensions of large cancellous bone specimens during histological preparation as measured on slabs from human femoral heads. *Calcif Tissue Int* 1983;**35**:1–4
11 Harada T, Ishii S, Tayama N, Sugasawa M. Computer-aided three-dimensional reconstruction of the osseous and membranous labyrinths. *Eur Arch Otorhinolaryngol* 1990;**247**:348–51
12 Purcell D, Johnson J, Fischbein N, Lalwani AK. Establishment of normative cochlear and vestibular measurements to aid in the diagnosis of inner ear malformations. *Otolaryngol Head Neck Surg* 2003;**128**:78–87
13 Daocai W, Qing W, Ximing W, Jingzhen H, Cheng L, Xiangxing M. Size of the semicircular canals measured by multidetector computed tomography in different age groups. *J Comput Assist Tomogr* 2014;**38**:196–9
14 Parnes LS, McClure JA. Free-floating endolymph particles: a new operative finding during posterior semicircular canal occlusion. *Laryngoscope* 1992;**102**:988–92
15 von Brevern M, Radtke A, Lezius F, Feldmann M, Ziese T, Lempert T *et al.* Epidemiology of benign paroxysmal positional vertigo: a population based study. *J Neurol Neurosurg Psychiatry* 2007;**78**:710–15
16 Anagnostou E, Kouzi I, Spengos K. Diagnosis and treatment of anterior-canal benign paroxysmal positional vertigo: a systematic review. *J Clin Neurol* 2015;**11**:262–7
17 Klopp-Dutote N, Kolski C, Biet A, Strunski V, Page C. A radiologic and anatomic study of the superior semicircular canal. *Eur Ann Otorhinolaryngol Head Neck Dis* 2016;**133**:91–4
18 Nomura Y, Kobayashi H. Laser irradiation of the semicircular canal: occlusion of the canal or duct. *Acta Otolaryngol* 2012;**132**:106–11
19 Lee JY, Shin KJ, Kim JN, Yoo JY, Song WC, Koh KS. A morphometric study of the semicircular canals using micro-CT images in three-dimensional reconstruction. *Anat Rec* (*Hoboken*) 2013;**296**:834–9
20 Krombach GA, van den Boom M, Di Martino E, Schmitz-Rode T, Westhofen M, Prescher A *et al.* Computed tomography of the inner ear: size of anatomical structures in the normal temporal bone and in the temporal bone of patients with Menière's disease. *Eur Radiol* 2005;**15**:1505–13
21 Law H. *Corollary 5 of Proposition XLVII (Pythagoras's Theorem)*. Part 1. The Elements of Euclid: with many additional propositions, and explanatory notes, to which is prefixed an introductory essay on logic. London: John Weale, 1853;**49**
22 Computing the arc length of a differentiable function on a closed interval. https://www.math.ucdavis.edu/~kouba/CalcTwoDIRECTORY/arclengthdirectory/ArcLength.html [7 July 2023]
23 Lee KH, Lee J, Shao D, Dravis C, Henkemeyer M. Asymmetry in semicircular canal diameters may account for circling behavior in EphB-deficient mice. *Laryngoscope* 2014;**124**:278–82