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RESEARCH

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Relationship of cranial deformation with nasal obstruction and middle ear function in babies: cross-sectional study

Ana Jacinta Gomes[1], Angélica Tavares[1], Maria Sousa Silva[1], Cláudia Silva[1], Ana Alexandrino[1], Goreti Varela[1], António Mota[2*] and David Tomé[1]

Abstract

Purpose This study aimed to analyse the relationship between cranial deformations (CD), nasal obstruction, and middle ear function in infants up to 12 months of age.

Methods A cross-sectional analytical observational study was conducted with a sample of 10 babies (3 females, 7 males) aged between 1 and 7 months. The study utilized quantitative and qualitative methodologies, including the Pediatric Respiratory Severity Scale, tympanometry, and cranial anthropometry using a craniometer. Data were analysed using IBM SPSS Statistics 28, with a 95% confidence interval.

Results Of the 10 participants, 70% had cranial asymmetry index (CAI) alterations, and 60% had cephalic ratio (CR) alterations. Nasal obstruction was observed in 60% of the babies. A significant linear relationship was found between CAI and ear canal volume bilaterally, and between CAI and right ear compliance. Additionally, a significant relationship was observed between CR and ear canal volume. However, no statistically significant relationship was found between CD and nasal obstruction or middle ear pressure values.

Conclusion The study found no direct relationship between cranial deformities and nasal obstruction, although a tendency for nasal obstruction in babies with plagiocephaly and brachycephaly was noted. An increase in CAI was associated with a decrease in ear canal volume and right middle ear compliance, while an increase in CR was related to an increase in ear canal volume. These findings suggest that cranial deformities may impact middle ear function and structure, highlighting the importance of early referral to ENT specialists for infants with CD.

Keywords Cranial deformation, Nasal Obstruction, Middle ear function, Cephalic ratio

Introduction

Cranial deformation (CD) is an alteration in the shape of the skull, caused by mechanical forces that occur both prenatally and postnatally and is related to an increased risk of facial, auricular and mandibular asymmetry [1, 2].

It can be classified according to the type of deformity, namely: plagiocephaly, brachycephaly and dolichocephaly, in which severity is measured by the cranial asymmetry index (CAI) and the cephalic ratio (CR) [1, 3]. A study carried out in Alberta, Canada, showed that the incidence of CD in babies between 7 and 12 weeks was estimated at 46.60% in the 440 babies evaluated [4]. There are several factors that can influence the increased risk of CD, including: restricted intrauterine development, delivery using forceps or a vacuum extractor, a predominantly supine position, and it can also be associated with cases of congenital

*Correspondence:
António Mota
antoniopedromota95@gmail.com
[1] Polytechnic of Porto (E2S- P.Porto), Porto, Portugal
[2] Royal Berkshire NHS Foundation Trust, Reading, United Kingdom

muscular torticollis [3, 5]. Although CD is seen by many as a purely aesthetic problem, several studies have challenged this view [6–9].

According to Moon [2] cranial deformities can induce structural alterations in the Ears, Nose and Throat (ENT) sphere. Mandibular asymmetry and nasal deviation are common in infants with CD, displaying a deviation of the nose and mandible to the ipsilateral side, which is highly correlated with the severity of the deformation [2]. Nasal deviation refers to the convexity of the septum to one side which can lead to deformities of the midline and lateral nasal wall structures. This structural alteration causes changes in airflow dynamics, mucociliary function and obstruction in the osteomeatal complex, resulting in nasal blockage [10]. These aspects are considered risk factors for allergic and infectious diseases, related to symptoms that the physiotherapist can raise awareness of and educate early in the sense of correct nasal hygiene/unobstuction on the part of the parents, preventing or minimizing more severe infections, including lower tract infections [11, 12].

Babies with CD may also have structural and functional alterations of the middle ear. Cranial asymmetry can affect the temporomandibular joint (TMJ), where a posterior displacement of the condyle can interfere with drainage and negatively impact the baby´s middle ear ventilation, increasing the likelihood of developing an infection [3]. According to Purzycki [5] a higher level of severity of plagiocephaly is directly related to the incidence of otitis media. Infants are often referred for physiotherapy treatment for other reasons (such as congenital muscular torticollis), which are often related to CD [1].

Given the scarcity of information on this subject, this study aimed to analyze the relationship between cranial deformations, nasal obstruction, and middle ear function. For this purpose, we assessed the relationship between the cranial asymmetry index and nasal obstruction and middle ear function (compliance, middle ear pressure and ear canal volume), as well as the relationship between the cephalic ratio and nasal obstruction and middle ear function (compliance, middle ear pressure and ear canal volume) in infants up to 12 months of age.

Methods

Study design

To answer the research question, a cross-sectional analytical observational study was carried out, using quantitative and qualitative methodology, in accordance with the STROBE guideline [13].

Sample

The final sample included 10 babies, 3 female and 7 male.

The sample was selected non-probabilistically for convenience, on a voluntary basis, through direct and indirect contacts.

Babies who met the following inclusion criteria were considered: age up to 12 months and living in the Porto metropolitan area. Excluded from the sample were babies with: a medical diagnosis of chromosomal abnormalities, neurological, metabolic, or progressive diseases; an unstable health condition due to acute and infectious diseases [14]; failed Universal Neonatal Hearing Screening (UNHS) with a "refer" outcome; and a "moderate" or "severe" respiratory condition according to the classification of the "Pediatric Respiratory Severity Scale" [15].

Human ethics and consent to participate

The study was submitted for review on April 5th of 2022 and successfully approved by the Ethics Committee of Escola Superior de Saúde from Instituto Politécnico do Porto. Written informed consent was provided and obtained from each of the baby's parents.

All the procedures used for the assessment were non-invasive, painless, well tolerated by the baby and without contraindications [16–18]. A period of 10 to 15 min of discontinuous data collection was established during periods of quiescence [18, 19].

Instruments

Pediatric respiratory severity scale

The "Pediatric Respiratory Severity Scale" is the Portuguese version of the original scale *"Paramètres anamnestiques et cliniques utiles au suivi et à láchèvement de la toilette bronchopulmonaire du nourisson et de l`enfant".* It is a simple, valid (Cronbach´s $\alpha = 0.80$, good internal consistency) and reliable (ICC = 0.91, excellent test–retest reliability) measuring instrument [15].

KYARA pediatric digital scale (LTK630) and Seca 232n pedometer

A KYARA LTK630 digital scale was used to measure the participants´ weight. This instrument has a maximum load limit of 20 kg, with an accuracy of 5 g. A Seca 232n pedometer was used to measure length.

Littmann 3200 electronic stethoscope (3 M Health Care® USA)

A Littmann 3200 electronic stethoscope (3 M Health Care ® USA) was used to perform lung auscultation (inherent to the application of the "Pediatric Respiratory Severity Scale") and nasal auscultation.

At the same time, Zargis ® StethAssistTM software was used to record and store nasal sounds.

MI34 impendence meter (Maico®)

A Maico MI34 Impedance Meter (Maico ®), calibrated in 2019 according to Food and Drug Administration (FDA) parameters, was used to perform tympanometry. The test was carried out at a frequency of 1000 Hz since an infant's middle ear admittance is mass-dominated, owing to softer outer wall and less rigidity [20].

According to Margolis [21], compliance values for the 1000 Hz probe are between 0.6–4.3mmho and peak pressure between -133 and 113daPa. These values refer to babies between 2 and 4 weeks old, within a 95th percentile, and it would be expected that pressure and compliance values would be higher in older children [21].

Typical ear canal volume values for children between 3 and 5 years old are between 0.4–1.0 mL, and there are no normative values for the range of the sample under study [22, 23]. In a study carried out in [24], it was observed that the volume of the normal ear canal for both the 226 Hz and 1000 Hz frequencies showed no statistically significant differences. The average volume was 0.5 mL for 226 Hz and 0.4 mL for 1000 Hz.

Craniometer

The Mimos craniometer is a measuring instrument specially developed to measure cranial asymmetries in children up to the age of 2. It is a safe, quick and low-cost assessment method [25].

The craniometer is used to objectify cranial circumference asymmetries by measuring the CAI and CR [26]. The CR values were classified as "dolichocephaly" (less than 76%), "brachycephaly" (greater than 81%) and "no change" (between 76 and 81%), according to Graham [27]. CAI values are classified according to the plagiocephaly severity scale [28].

Plagiocephaly severity scale

The "Plagiocephaly Severity Scale" is a valid, efficient, and reproductible tool that allows this condition to be classified into 5 levels of severity, considering observational data (physical characteristics and traits commonly observed in each level) and quantitative data obtained through measurements with a craniometer. The higher the final score, the greater the asymmetry degree [28].

In this way, CAI values were classified as "level 1" when they were below 3.50, "level 2" if between 3.50 and 6.25, "level 3" if between 6.25 and 8.75, "level 4" between 8.75 and 11.00, "level 5" if higher than 11.00 [28].

Procedures

Collection protocol

Feeding and sleep hygiene conditions were met prior to the assessment, allowing for adjustments in the data collection periods, so that the baby was calm [18, 19].

To collect nasal auscultation sounds, the electronic stethoscope was used by 3 blinded experts, placing its diaphragm 5 cm away and parallel to the baby´s nostrils [19]. All assessors were duly qualified to use the respective assessment instruments appropriately, thus reducing potential measurement bias (Table 1). Finally, both cranial anthropometry using the craniometer and the "Plagiocephaly Respiratory Severity Scale" were carried out by the same evaluator, minimizing inter-observer error and observer bias.

Statistical procedures

For the statistic and descriptive analysis of the variables in this study, IBM ® SPSS® Statistics 28 for Windows 11 ® was used, with a 95% confidence interval (significance level $\alpha = 0.05$).

In order to analyze the relationship between the variables, simple linear regression calculations (between cranial asymmetry index (CAI) and ear canal volume, pressure and compliance of both middle ears), and Pearson´s coefficient of determination and correlation

Table 1 Nasal obstruction classification results

Nasal sound classification				
	Age (months)	**Expert 1**	**Expert 2**	**Expert 3**
Baby 1	7	Obstructed	Non-obstructed	Obstructed
Baby 2	2	Obstructed	Obstructed	Obstructed
Baby 3	1	Non-obstructed	Non-obstructed	Non-obstructed
Baby 4	5	Obstructed	Obstructed	Obstructed
Baby 5	6	Obstructed	Obstructed	Obstructed
Baby 6	4	Non-obstructed	Obstructed	Obstructed
Baby 7	5	Non-obstructed	Non-obstructed	Non-obstructed
Baby 8	5	Non-obstructed	Non-obstructed	Non-obstructed
Baby 9	1	Non-obstructed	Obstructed	Obstructed
Baby 10	1	Non-obstructed	Obstructed	Non-obstructed

were used, considering: "very strong" correlation when the value was between 0.9–1, "strong" between 0.6–0.9, "moderate" between 0.3–0.6, and "weak" between 0–0.3 [29].

Results

Characterization of the sample

Of the 13 initial participants, 3 were excluded (1 for having a medical diagnosis of bronchiolitis and the other 2 for not having completed the assessment). The data analyzed in this study therefore relates to the remaining 10 participants.

The final sample consisted of 10 participants, 3 females and 7 males, aged between 1 and 7 months (mean 3.7 months ± 2.263). All the babies (100%) had a "normal" classification on the Pediatric Respiratory Severity Scale, as well as no respiratory or ear infections within the last month. Table 2 summarizes the characteristics of the study sample.

Of the babies included in the study, 70% had CAI alterations and 60% had CR alterations, with 3 babies having both alterations simultaneously. Regarding nasal obstruction, at the time of the assessment, 60% were classified as "obstructed" and the remaining 40% as "non-obstructed". In the CD subgroups, 4 babies with plagiocephaly (57.1%) had nasal obstruction and of the babies with brachycephaly, 5 (83.3%) were also obstructed (Table 3).

In the participants analyzed, CD and middle ear pressure were not statistically related. Regarding the values for ear canal volume, pressure and compliance of both middle ears, within the group with plagiocephaly (level 2 and level 4), a lower median was observed in babies classified at level 4 on the plagiocephaly severity scale when compared to those ate level 2. In the classification of CD according to CR, the median values for pressure and compliance are lower in babies with brachycephaly. The opposite was observed when analyzing the median values for ear canal volume (Table 4).

Results regarding the cranial asymmetry index (CAI)

Regarding nasal obstruction, there were no statistically significant differences in the CAI between "obstructed"

Table 2 Characterization of the sample in terms of sociodemographic, anthropometric, and clinical data

		n (%)	Mean ± SD	Median [P25; P75]	Minimum	Maximum
Female		3 (30)	–	–	–	–
Male		7 (70)				
Age (months)		10 (100)	3,7 ± 2,263	4,5 [1,00; 5,25]	1	7
Gestational age (weeks)		10 (100)	38,3 ± 1,636	39 [38,00; 39,00]	34	40
Weight (grams)		10 (100)	6315,4 ± 1490,43	6630 [4561,25; 7525,00]	4190	8254
Length (centimeters)		10 (100)	62,44 ± 5,948	62,7 [57,73; 64,98]	64,5	76
Pediatric Respiratory Severity Scale		10 (100)	8,00 ± 0,00	8 [8,00; 8,00]	8	8
Respiratory or ear infections within the last month	**Yes**	0 (0)	–	–	–	–
	No	10 (100)	–	–	–	–

Table 3 Description of the results regarding cranial deformities and nasal obstruction

	Cranial Asymmetry Index	Severity Level of Plagiocephaly	Cephalic Ratio (%)	Classification to Cephalic Ratio	Nasal Obstruction
Baby 1	5,26	Level 2	88,36	Brachycephaly	Obstructed
Baby 2	3,1	Level 1	82,95	Brachycephaly	Obstructed
Baby 3	4,1	Level 2	79,37	Y/A	N.O
Baby 4	4,26	Level 2	87,94	Brachycephaly	Obstructed
Baby 5	2,24	Level 1	86,47	Brachycephaly	Obstructed
Baby 6	6,11	Level 2	86,13	Brachycephaly	Obstructed
Baby 7	3,65	Level 2	79,14	Y/A	N.O
Baby 8	0,7	Level 1	92,31	Brachycephaly	N.O
Baby 9	8,8	Level 4	77,95	Y/A	Obstructed
Baby 10	10,7	Level 4	79,1	Y/A	N.O

Table 4 Medians of tympanometry variables at different levels of plagiocephaly severity and classification of cranial deformation according to cephalic ratio

		Median				
		Level of severity of plagiocephaly			**Classification of CD according to cephalic ratio**	
		Level 1	**Level 2**	**Level 4**	**Without brachycephaly**	**With brachycephaly**
Right Ear	**Pressure (daPa)**	-51.000	15.000	-36.000	0.500	-29.000
	Volume of ear canal (mL)	0.600	0.7400	0.1550	0.415	0.670
	***Compliance* (mmho)**	1.780	1.290	0.665	1.465	1.290
Left Ear	**Pressure (daPa)**	-81.000	12.000	-139.500	-39.000	-40.500
	Volume of ear canal (mL)	0.580	0.650	0.160	0.350	0.640
	***Compliance* (mmho)**	1.730	1.910	1.250	1.880	1.650

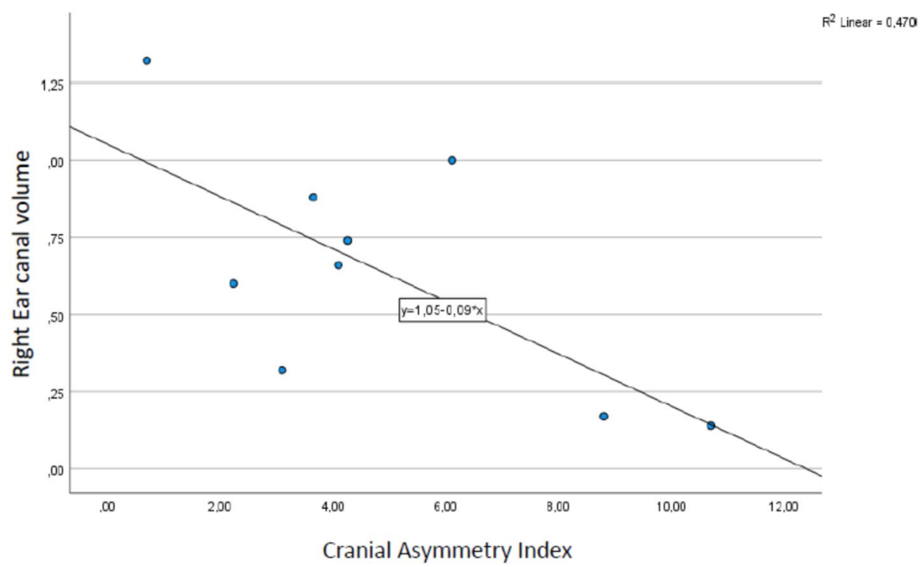

Fig. 1 Linear relationship between cranial asymmetry index and right ear canal volume

and "non-obstructed" individuals ($p = 0.762$). However, when the medians of the CAI were compared between the "obstructed" ($\hat{x}$=4.76) and "non-obstructed" groups ($\hat{x}$=3.87), the median was slightly higher in the "obstructed" group.

The data analyzed showed a significant linear relationship between CAI and ear canal volume bilaterally (Figs. 1 and 2), with both the right ear ($p = 0.03$; $R = 0.686$) and the left ear ($p = 0.008$; $R = 0.779$) ears showing a strong negative correlation.

Thus, the CAI explains 60.7% (R2 = 0.607) of the variation in the volume of the left ear canal and 47% (R2 = 0.470) of the variation in the volume of the right ear canal.

In addition, there was a significant linear relationship between CAI and right middle ear compliance (Fig. 3), $p = 0.009$, $R = -0.770$ (strong negative correlation). 59% of the variation in right ear compliance is explained by the CAI (R2 = 0.593).

There is no significant linear relationship between the CAI on the right ($p = 0.753$) and left ($p = 0.352$) middle ear pressure values in the region of the model´s validity, nor is there a significant linear relationship between the CAI and the left middle ear compliance values ($p = 0.478$).

Results relating to the level of severity of plagiocephaly

There was no statistically significant evidence of an association between the severity of plagiocephaly and the results of nasal obstruction or middle ear pressure values.

Cephalic ratio results

Regarding nasal obstruction, there were no statistically significant differences in CR between "obstructed" and "non-obstructed" individuals ($p = 0.610$). However, when

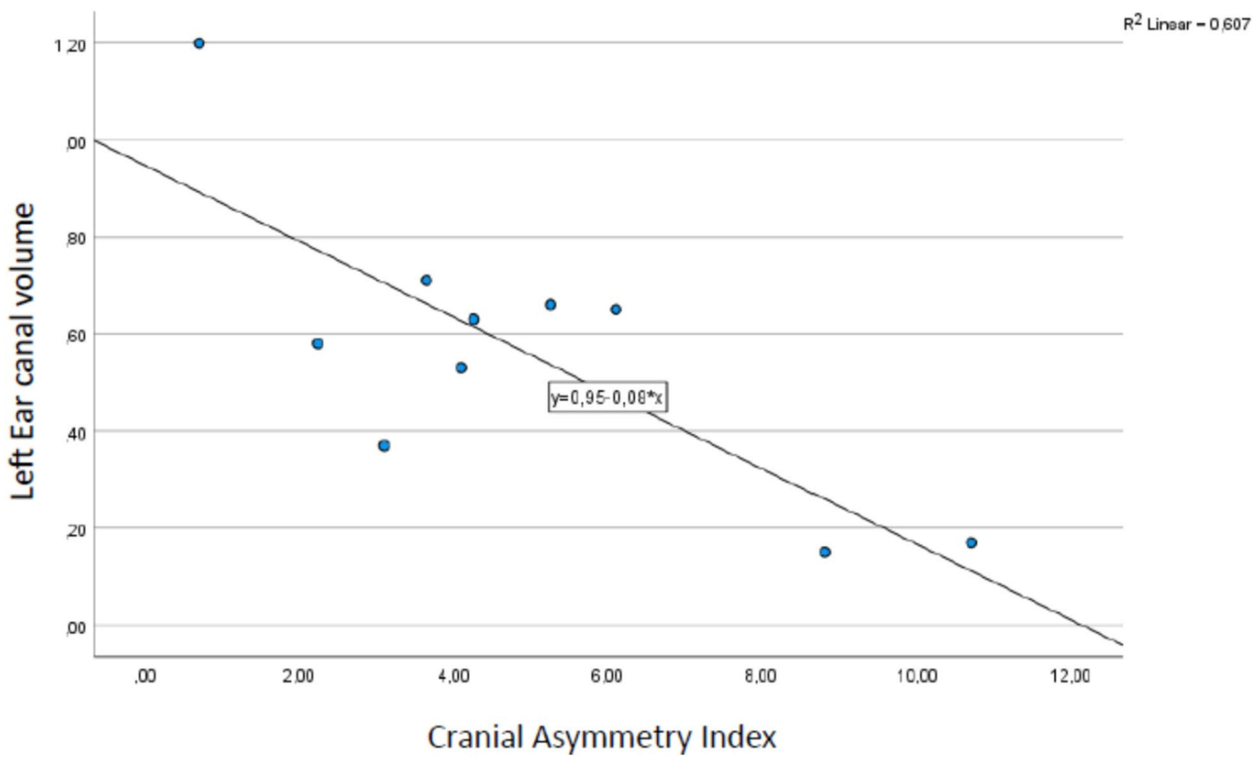

Fig. 2 Linear relationship between cranial asymmetry index and left ear canal volume

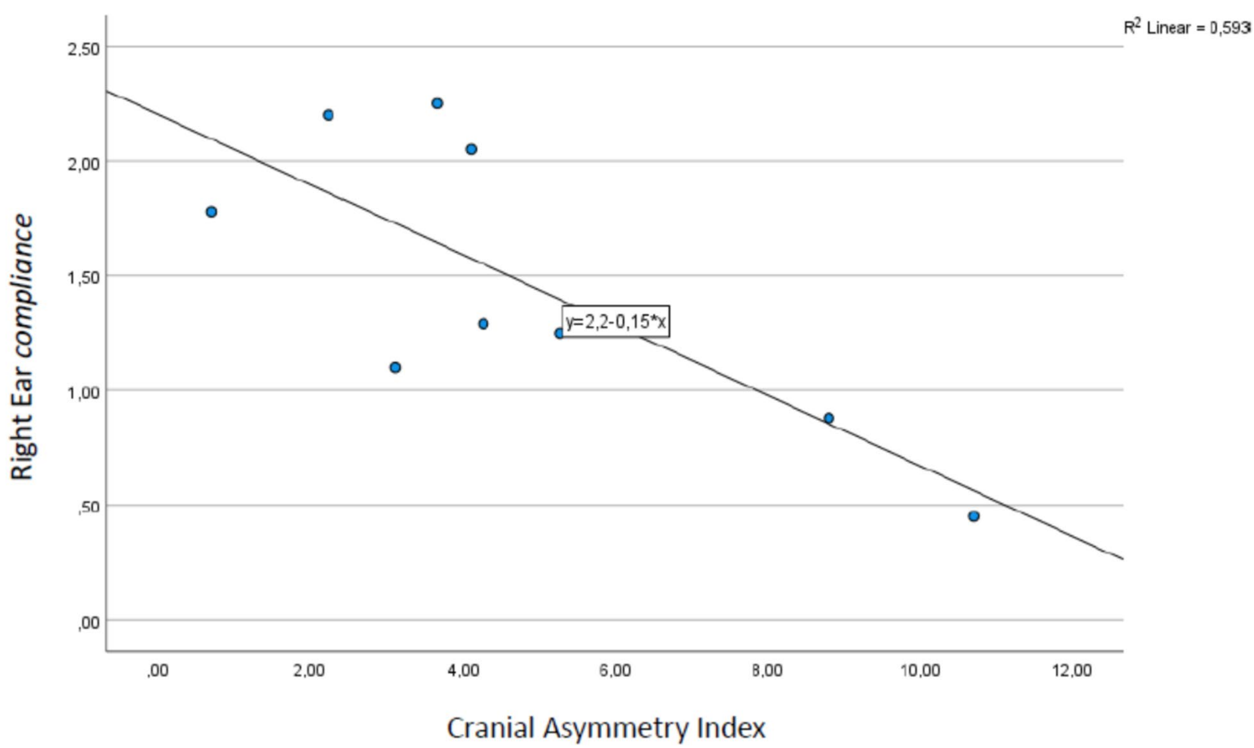

Fig. 3 Linear relationship between cranial asymmetry index and right ear compliance

the medians of the CR were compared between the "obstructed" ($\tilde{x}$=86.30) and "non obstructed" groups ($\tilde{x}$=79.25), it was observed that the "obstructed" group had a higher median.

There was a statistically significant relationship between the cephalic ratio and ear canal volume, both in the right middle ear (p=0.010; R=0.767) and in the left (p=0.008; R=0.779), with a strong positive correlation in both (Figs. 4 and 5). Thus, CR explains 41.2% (R2=0.412) of the variation in the volume of the right ear canal and 58.8% (R2=0.588) of the variation in the volume of the left canal.

There was no significant linear relationship between CR and right (p=0.887) and left (p=0.926) middle ear pressure values, nor was there a linear relationship between CR and right (p=0.618) and left (p=0.952) middle ear compliance values in the validity region of the model in the sample studied. Additionally, the detailed cranial asymmetry index, severity level of plagiocephaly, cephalic ratio, nasal obstruction, and middle ear function for each baby are summarized in Table 5.

Discussion

The aim of this study was to analyze the relationship between cranial deformations, nasal obstruction, and middle ear function. However, there seems to be no relationship between cranial deformations and nasal obstruction. In terms of middle ear function and structure, in the sample studied, there seems to be a relationship between CAI and ear canal volume, between CAI and right ear compliance, and between CR and ear canal volume.

According to Moon [2], CD can induce structural changes In the nose, such as a deviated nasal septum, leading to changes in airflow dynamics and mucociliary function, which can cause nasal obstruction. In this study, although there was no relationship between CD and nasal obstruction, it was found that most babies with plagiocephaly had obstruction, as did the majority of those with brachycephaly. Bearing in mind that none of the participants had a medical diagnosis of other possible causes of obstruction [30], these were ruled out. Thus, it suggests a tendency for babies with cranial deformities to have nasal obstruction.

It is important to note that nasal obstruction in infants can lead to sleep problems, feeding difficulties, colic and cyanotic crises, translating into a significant decrease in the quality of life of children and caregivers, along with an increase in health expenditure [31, 32].

CD can lead to craniofacial asymmetric and misalignment of the ears, the latter of which can compromise middle ear function, as evidenced by

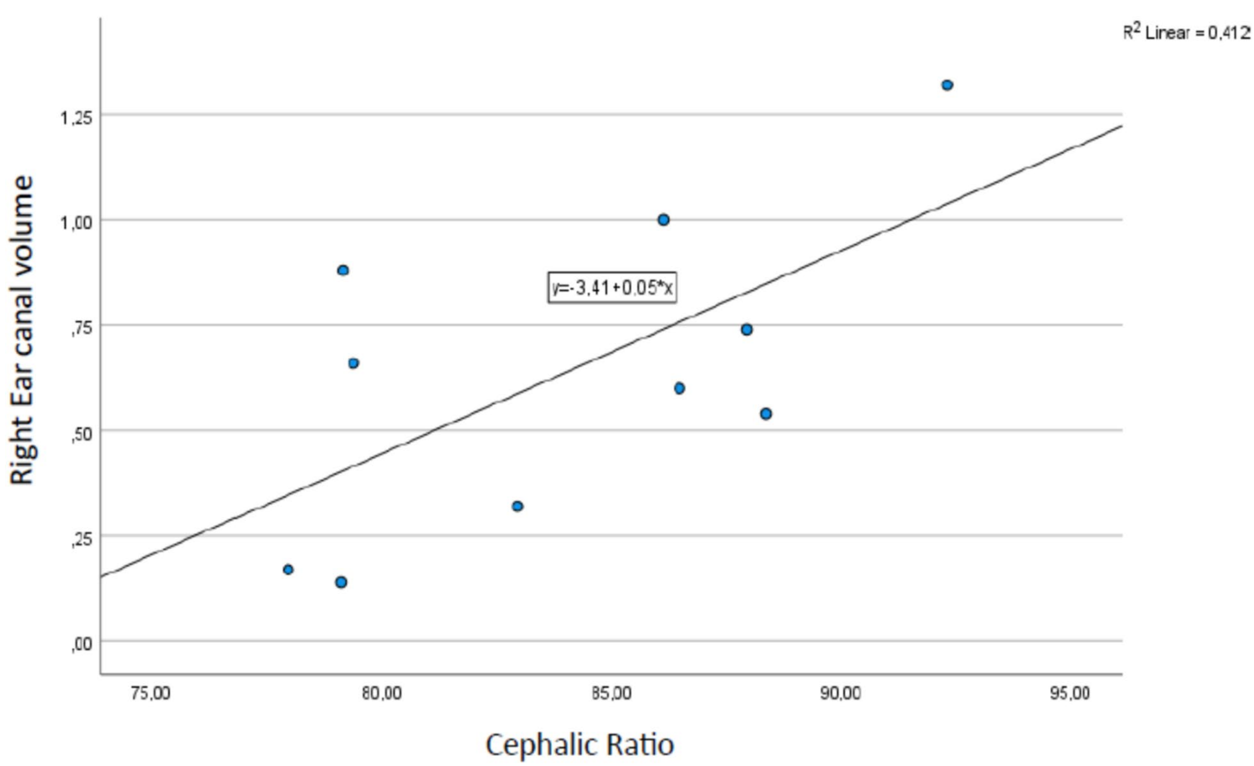

Fig. 4 Linear relationship between cephalic ratio and ear canal volume in the right ear

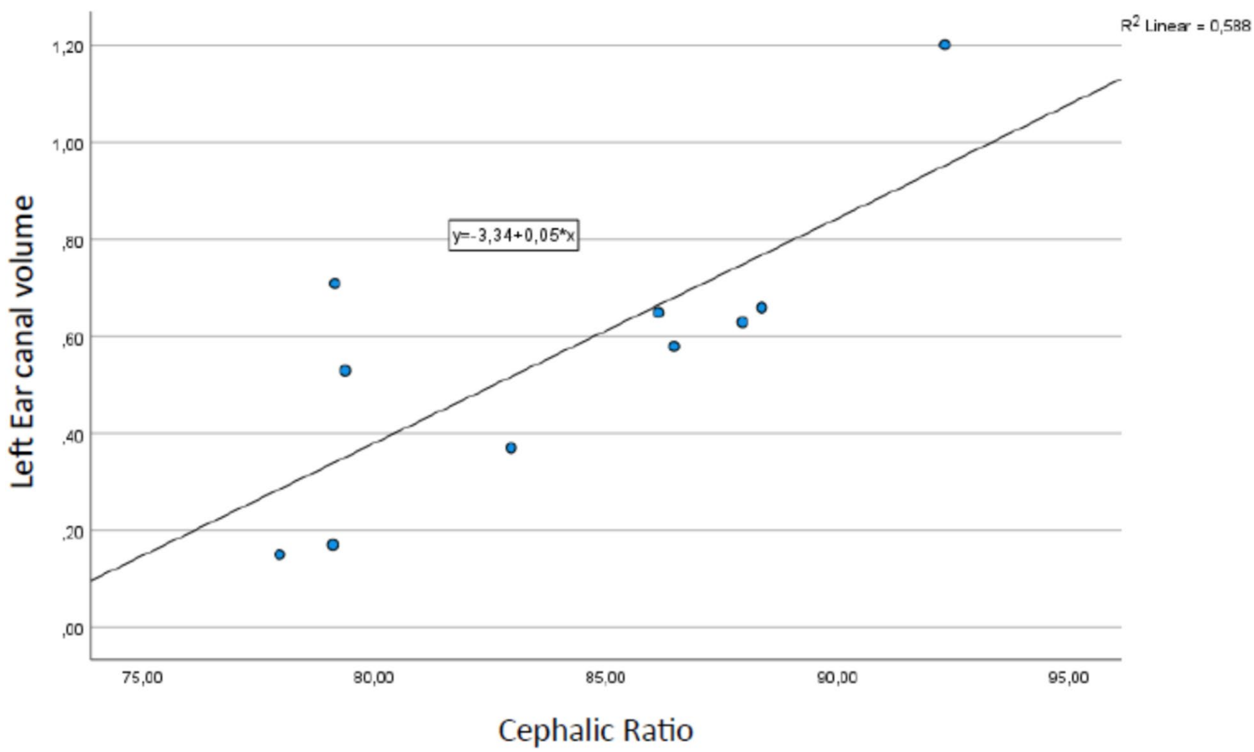

Fig. 5 Linear relationship between cephalic ratio and left ear canal volume

changes in tympanometry [3, 5]. In this study, there were no significant differences in pressure, compliance and volume between babies with and without plagiocephaly, or between those with and without brachycephaly.

On the other hand, in this sample, it seems that an increase in CAI can lead to a decrease in ear canal volume. This may be due to the fact that in cases of plagiocephaly, the deviation of the petrous part of the temporal bone in the frontal and transverse planes can lead to a change in the orientation of the ear canal [5, 33].

This study also found that an increase in ear canal volume can occur with an increase in CR. In cases of brachycephaly, there can be a change in the orientation of the TMJ bilaterally, which can cause an anterior displacement of the mandible and, consequently, a structural change in the same direction as the middle ear, due to the anatomical proximity of these structures [34, 35].

Di Francesco [36] documented that the skull base is key to the development of the face and its morphology can influence other related structures, namely the Eustachian Tube (ET). Thus, as the bony portion of the ET is located in the petrous fissure of the temporal bone, close to the occipital and sphenoid bones, the anatomical development of the ET depends on craniofacial growth and development [36]. In the present study, it seems that the greater the alteration of the CAI, the lower the compliance of the right ear. The latter translates into the mobility of the tympanic membrane [19]. Thus, according to Revai [37], decreased compliance leads to increased Eustachian tube dysfunction, which can lead to altered ventilation and drainage of middle ear contents, increasing the risk of ear infections.

Finally, in the participants analyzed, CD and middle ear pressure did not appear to be related. In the classification of CD according to CR, the median pressure values are lower in babies with brachycephaly when compared to those in babies without brachycephaly. This may be due to the fact that this condition can cause a change in the orientation of the TMJ, where a posterior displacement of the condyle or inflammation of the posterior part of the articular disc can interfere with the drainage of the middle ear, blocking the ET orifice. There are various degrees of altered ET function that can negatively impact the baby´s middle ear ventilation and increase the likelihood of the baby developing an infection [3].

Therefore, in cases where cranial deformities are detected, it is important for the physiotherapist to refer the baby to the ENT department.

Table 5 Nasal obstruction classification results and tympanometry measurements for right and left ears in babies with cranial deformities

							Right ear			Left ear		
	CAI	**Plagiocephaly Severity Level**	**Presence of Plagiocephaly**	**CR (%)**	**Classification of CD according to CR**	**Nasal Obstruction**	**Middle ear pressure (daPa)**	**Middle ear compliance (mmho)**	**Ear canal volume (mL)**	**Middle ear pressure (daPa)**	**Middle ear compliance (mmho)**	**Ear canal volume (mL)**
Baby 1	5,26	Level 2	Plagiocephaly	88,36	Brachycephaly	Obstructed	-41	1,25	0.54	-46	1,24	0,66
Baby 2	3,1	Level 1	S/A	82,95	Brachycephaly	Obstructed	-61	1,1	0.32	-81	1,73	0,37
Baby 3	4,1	Level 2	Plagiocephaly	79,37	S/A	N.O	38	2,05	0.66	25	1,91	0,53
Baby 4	4,26	Level 2	Plagiocephaly	87,94	Brachycephaly	Obstructed	47	1,29	0.74	51	1,03	0,63
Baby 5	2,24	Level 1	S/A	86,47	Brachycephaly	Obstructed	-17	2,2	0.6	24	1,57	0,58
Baby 6	6,11	Level 2	Plagiocephaly	86,13	Brachycephaly	Obstructed	15	1,29	1	-35	3,1	0,65
Baby 7	3,65	Level 2	Plagiocephaly	79,14	S/A	N.O	-37	2,25	0.88	12	2,3	0,71
Baby 8	0,7	Level 1	S/A	92,31	Brachycephaly	N.O	-51	1,78	1.32	-178	1,82	1,2
Baby 9	8,8	Level 4	Plagiocephaly	77,95	S/A	Obstructed	-122	0,88	0.17	-90	1,85	0,15
Baby 10	10,7	Level 4	Plagiocephaly	79,1	S/A	N.O	50	0,45	0.14	-189	0,65	0,17

In this study, some limitations were identified, namely the difficulty in obtaining a more representative sample size, preventing the results from being generalized to the target population. Another limitation was the fact that the final sample did not include any babies without CD, thus preventing a comparison of nasal obstructions between cases without cranial alterations. A third limitation was the lack of studies with the same purpose, which contributed to the exploratory nature of the study being restrictive in terms of reviewing the literature and comparing results with other studies.

In terms of assessment instruments, the values of tympanometry at 1000 Hz still don´t have a consensus classification and normal values for babies at the 95th percentile, as they differ according to age, equipment and authors, creating a fourth limitation [38]. In addition, the assessment method used for nasal obstruction does not define whether this obstruction is due to a structural alteration, making it impossible to be sure of the relationship with cranial asymmetry.

In future studies, it would be relevant to use a sample with larger number of participants and to include a method that provides mora data on nasal obstruction, such as the mechanism, degree and beyond.

Conclusion

In this study, there was no relationship between cranial deformities and nasal obstruction; however, it was found that most of the babies with plagiocephaly and brachycephaly had nasal obstruction.

On the other hand, it seems that an increase in CAI is related to a decrease in ear canal volume and.

Authors' contributions

Conceptualization: A.A, D.T., C.S. Data curation: A.G., A.T., M.S., G.V. Formal analysis: A.A., D.T., C.S. Methodology: C.S., A.A. Funding: not applicable. Writing – original draft: A.G., A.T., M.S., G.V. Writing – review & editing: A.M, D.T. All authors have read and approved the final version of the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Competing interests

The authors declare no competing interests.

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