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ORIGINAL ARTICLE

Comparison of fetal and adult tympanic membrane sizes: a cadaveric study

Orhan Beger[1] · Yusuf Vayisoğlu[2] · Alev Bobuş Örs[1] · Deniz Ladin Özdemir[3] · Fatma Müdüroğlu[4] · Pourya Taghipour[5] · Oykut Dağtekin[6] · Derya Ümit Talas[2]

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Abstract

Objective The work aimed to compare fetal and adult tympanic membrane (TM) sizes for understanding dimensional development from intrauterine life to adulthood.

Methods Fifty-six temporal bones (18 fetuses, 10 elderly adults, half male and half female in each group) were included in this study. Using a digital image software, the TM height, width and area were measured.

Results The mean area, height and width of the TM in adults were found as 58.84 ± 22.01 mm^2, 9.06 ± 1.33 mm, and 8.10 ± 1.43 mm, respectively. Moreover, the mean area, height and width of the TM in fetuses were measured as 47.62 ± 12.57 mm^2, 8.22 ± 1.12 mm, and 7.25 ± 1.15 mm, respectively. The TM dimensions were increasing in fetuses between 20–32 weeks of gestation. However, the TM dimension was statistically similar at the 7th month, the 8th month and adult periods. The TM height was greater than its width in fetuses and adults.

Conclusion The calculated regression equations of the TM parameters in fetuses may be used to estimate its size. The TM size did not change from the 7th gestational month, and thus the membrane reached adult diameter in fetal life. The TM height and width showed a very wide range; therefore, we thought that the 12 mm (the height) × 10 mm (the width) graft might be ideal dimension during the repair of the TM perforations.

Keywords Tympanic membrane · Eardrum · External auditory canal · Fetus · Cadaver · Ear

Introduction

The tympanic membrane (TM) located between the external auditory canal and tympanic cavity is a semi-transparent, thin and oval-shaped tissue. At the meatal end, the TM attaches to the tympanic sulcus through a fibrocartilaginous annulus that surrounds the membrane. The malleolar folds divide the membrane into two parts, the pars flaccida (minor-loose part above the folds) and pars tensa (major-taut part below the folds). The outer surface of the TM is concave, and the depression in the midpoint is called the umbo. The mallear stripe, a bright line starting from the umbo and extending forward and upwards, is formed by the handle of the malleus. Sound waves conveyed from the external auditory meatus to the TM are transferred to the ossicular chain (malleus, incus and stapes) through the membrane [28]. These standard morphological definitions related to the TM are well known; however, studies conducted on its size appear to be largely neglected [6]. In some clinical articles (e.g., the shortest diameter reported as 5 mm by Wahid and Nagra [29]), the TM dimensions were reported differently compared to classical anatomy textbooks (e.g., the shortest diameter reported as 8–9 mm by Gray’s Anatomy [28]). In this regard, considering the significance of the elasticity, shape and dimension of the TM in terms of its function [9],

✉ Orhan Beger
obeger@gmail.com

1 Department of Anatomy, Faculty of Medicine, Mersin University, Ciftlikkoy Campus, 33343 Mersin, Turkey

2 Department of Otorhinolaryngology, Faculty of Medicine, Mersin University, Mersin, Turkey

3 Faculty of Medicine, İstanbul Okan University, İstanbul, Turkey

4 Faculty of Medicine, İstanbul University-Cerrahpaşa, İstanbul, Turkey

5 Faculty of Medicine, Mersin University, Mersin, Turkey

6 Department of Histology and Embryology, Mersin City Hospital, Mersin, Turkey

further investigation is needed for anatomists and ear professionals to understand its size.

The TM perforation (which may cause hearing loss, tinnitus, or sudden pain) due to blunt trauma or barotrauma (e.g., diving, slap, martial arts, scuba diving, cotton-tipped applicators, blast injury, and traffic accident) is repaired with different materials (e.g., fat, dura, deep temporalis fascia, cartilage, paper patches, or urinary bladder matrix) using surgical procedures such as myringoplasty or tympanoplasty [7, 11–13, 18, 22–25, 29]. Therefore, knowledge related to the TM size may be useful for ear professionals to estimate its diameters during total myringoplasty procedures [8]. On the other hand, approximately two-thirds of the TM perforations occur in children under 18 years and one-third under 6 years [7]. However, the majority of studies related to the TM containing area calculations, diameter measurements, and shape examinations were focused on adult temporal bones [9, 19, 21, 26, 30]. Considering that the tympanic cavity volume is approximately 50% higher in adults than in newborns [14], anatomical data focused on the comparison of fetal and adult shapes of the TM may be useful for otologists to guess its size during preoperative graft design in pediatric patients. In this context, the current work aimed to compare fetal and adult TMs for the estimation of its growth pattern in children.

Material and methods

After the ethical approval of the institutional review board, 56 temporal bones (18 fetuses aged with 24.27 ± 3.24 weeks, 10 adults aged with 75.70 ± 14.11 years, half male and half female in each group) were included in the work. All temporal bones with no structural abnormalities were dissected by the same otologist (DÜT) in the anatomy laboratory of Mersin University. Fetal and adult heads were placed in a position suitable for otologic surgery. Retroauriculer incision was performed and then for better viewing the external auditory canal and the TM, the auricle was reflected anteriorly. The TM was evaluated under a surgical microscope (Carl Zeiss f170, Carl Zeiss Meditec AG, Germany). In the same position/distance, the TM with a millimeter scale was photographed in fetuses using a camera (Nikon d3300 digital camera, Nikon, Tokyo, Japan) adapted to the microscope and in adults using an endoscope (0°, 4-mm diameter, 18-cm length, Karl Storz Gmbh & Co., Tuttlingen, Germany). The images of the TM transferred to a digital image analysis software (Rasband WS, ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA, https://imagej.nih.gov/ij/, 1997–2018) were processed to perform measurements. The determined parameters in fetal and adult cadavers were as follows (Figs. 1 and 2):

- The height of the TM (the vertical or longest diameter, the line passing through the mallear stripe)
- The width of the TM (the horizontal or shortest diameter, the line passing through the umbo and perpendicular to the mallear stripe)
- The surface area of the TM including the pars flaccida and pars tensa.

The measurements were performed on 10% formalin-fixed temporal bones; however, the effect of fixation on the TM was disregarded due to the findings of Beger et al. [4] (who observed that this cadaver preservation method did not cause a statistically significant shrinkage in tissues). Using a digital caliper (0.01 mm precision, Mahr, 16 ER, Göttingen, Germany), the foot lengths of the fetuses were measured for the estimation of their ages (weeks or months). By two researchers, the measurements including the area, height and width of the TM were repeated three times to check intra-observer reproducibility (the repeated measures ANOVA and reasonable significant difference Tukey test) and inter-observer reproducibility (intra-class correlation coefficients: ICC). The variance homogeneity of

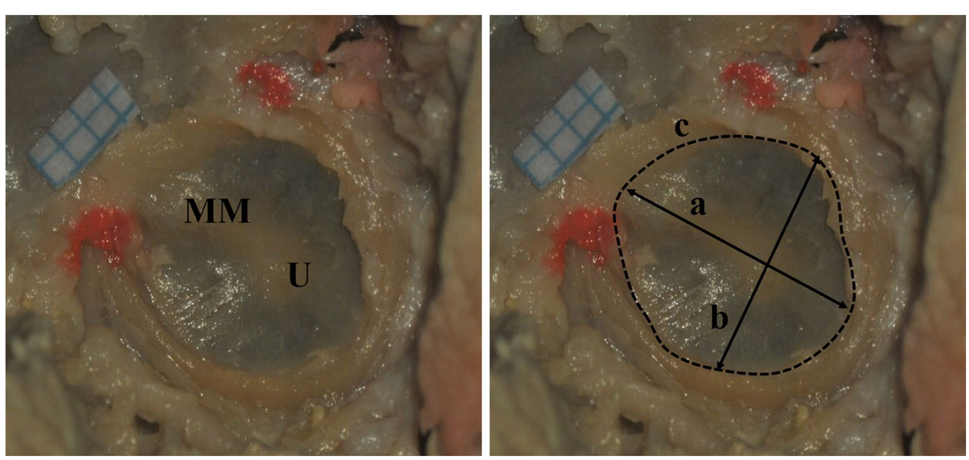

Fig. 1 The photographs show the fetal tympanic membranes and the parameters. **a** the vertical diameter, **b** the horizontal diameter, **c** the surface area. *MM* manubrium mallei, *U* umbo

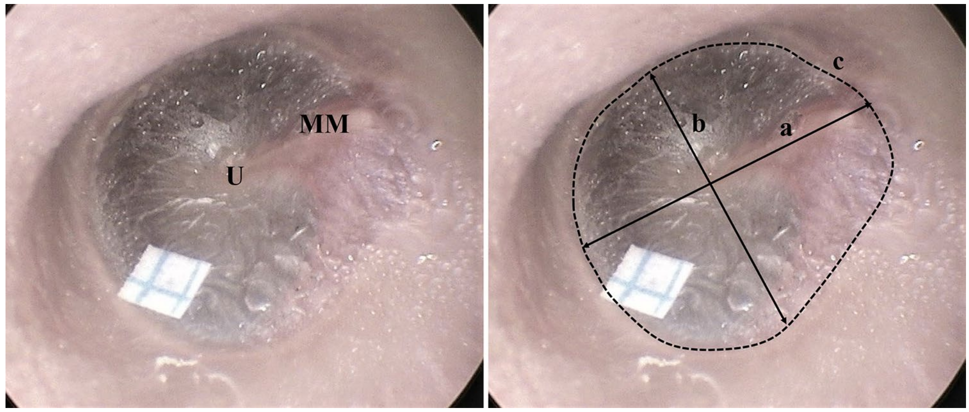

Fig. 2 The photographs show the adult tympanic membranes and the parameters. **a** the vertical diameter, **b** the horizontal diameter, **c** the surface area. *MM* manubrium mallei, *U* umbo

the parameters was performed with Levene test, while the normality control with Shapiro–Wilk test. Changes in the TM area, height and width according to gestational weeks (between 20 and 32 weeks) were determined with One-way ANOVA and post-hoc Bonferroni test. These tests were also used to determine alterations in numerical values in the transition from the 5th month of gestation to adulthood. Male–female (the independent sample *t* test), right–left side (the paired sample *t* test), vertical—horizontal diameter (the paired sample *t* test), and fetus—adult (the independent sample *t* test) comparisons were performed with the student *t* tests. Correlations between the TM area, height and width in fetuses or adults were evaluated with the Pearson correlation coefficient test. Using the simple linear regression, regression equations for the parameters were calculated. Statistical "*p*" value was 0.05.

Results

As a result of inter-observer (ICC = 0.980–0.996, $p < 0.001$) and intra-observer ($p > 0.05$) evaluations, the reliability of dataset belonging to the TM parameters was observed as excellent. The demographic information of fetal and adult cadavers including their ages, sexes, and numbers were presented in Table 1. The average data (mean ± standard deviation) was given in Tables 2, 3, 4, 5. Our findings related to the TM were as follows:

- According to ages between 20 to 32 weeks of gestation, the TM area (p = 0.001), width (p < 0.001) and height ($p = 0.025$) were increasing in fetuses (Table 2).
- In terms of sex or side, the TM parameters did not statistically differ in fetuses or adults ($p > 0.05$) (Table 3).

Table 1 The demographic data of fetal and adult cadavers.

Specimens	Ages		Foot lengths (mm)	Male numbers	Female numbers
Fetuses	5th months	20 weeks	30.54 ± 0.40	1	1
	6th months	21 weeks	32.66 ± 0.86	1	1
		22 weeks	35.37 ± 0.63	0	2
		23 weeks	37.08 ± 0.15	1	0
		24 weeks	39.97 ± 0.84	1	0
	7th months	25 weeks	41.61 ± 0.38	1	0
		26 weeks	45.61 ± 0.43	1	1
		27 weeks	48.22 ± 0.15	0	1
		28 weeks	51.64 ± 0.19	0	1
	8th months	29 weeks	53.50 ± 0.12	1	0
		30 weeks	54.15 ± 0.77	1	1
		31 weeks	57.44 ± 0.55	0	1
		32 weeks	60.38 ± 0.40	1	0
All fetuses	24.27 ± 3.24 weeks		43.69 ± 9.76	9	9
All adults	75.70 ± 14.11 years		–	5	5

Table 2 Statistical analysis of numerical values belonging to fetal tympanic membranes

Fetal ages (weeks)	Side numbers	Height (mm)	Width (mm)	Area (mm^2)
20	4	7.56 ± 0.85	6.18 ± 0.49	39.10 ± 5.52
21	4	7.89 ± 1.13	6.49 ± 0.77	43.94 ± 12.59
22	4	7.94 ± 1.25	6.40 ± 0.37	40.68 ± 7.25
23	2	9.05 ± 0.98	7.96 ± 1.16	49.78 ± 7.73
24	2	6.79 ± 0.39	5.66 ± 0.16	31.09 ± 1.68
25	2	6.34 ± 0.51	6.23 ± 0.45	30.71 ± 3.28
26	4	7.89 ± 1.25	7.47 ± 1.03	47.32 ± 13.76
27	2	9.12 ± 0.09	8.56 ± 0.66	63.27 ± 3.42
28	2	8.63 ± 1.09	6.89 ± 0.11	43.04 ± 11.06
29	2	9.15 ± 0.36	8.64 ± 0.36	67.17 ± 7.60
30	4	9.26 ± 0.42	7.97 ± 0.30	53.85 ± 5.19
31	2	8.88 ± 0.28	8.98 ± 0.03	61.55 ± 0.80
32	2	8.88 ± 0.18	8.65 ± 0.14	60.72 ± 6.68
p		0.025	< 0.001	0.001

- The area ($p=0.018$), height ($p=0.015$) and width ($p=0.019$) of the TM in adults were greater tha–n that in fetuses (Table 4).
- The TM height and area in fetuses at the 5th and 6th month were smaller than that in fetuses at 8th month and adults, while the width in fetuses at the 5th and 6th month were smaller than that in fetuses at the 7th and the 8th month, and adults (Table 5). In addition, the area, height and width of the TM were statistically similar at the 7th month, the 8th month and adult periods (Table 5).
- In fetuses, the height–area ($p<0.001$, $r=0.862$), the height–width ($p<0.001$, $r=0.752$), and the width–area ($p=0.001$, $r=0.899$) showed strong positive correlations.
- In adults, the height–area ($p<0.001$, $r=0.919$), the height–width ($p<0.001$, $r=0.802$), and the width–area ($p=0.001$, $r=0.878$) showed strong positive correlations.
- The height of the TM was greater than the width in fetuses and adults ($p<0.001$).
- In fetuses, regression equation was calculated as: $y=0.183+1.868\times$ weeks for the area, $y=4.834+0.133\times$ weeks for the height, and $y=1.870+0.212\times$ weeks for the width (Fig. 3).

Discussion

The TM abnormalities may be associated with congenital aural atresia or stenosis, Treacher Collins syndrome, Fanconi anemia, and congenital cholesteatoma [16, 17, 27, 31, 32].

Table 3 Male-female and right-left comparisons of numerical values belonging to fetal and adult tympanic membranes.

Specimens	Fetuses						Adults					
	Male ($N=18$)	Female ($N=18$)	*p*	Right ($N=18$)	Left ($N=18$)	*p*	Male ($N=10$)	Female ($N=10$)	*p*	Right ($N=10$)	Left ($N=10$)	*p*
Height (mm)	7.96 ± 1.23	8.48 ± 0.96	0.164	8.20 ± 1.19	8.23 ± 1.07	0.936	9.32 ± 1.43	8.80 ± 1.24	0.399	9.20 ± 1.51	8.92 ± 1.19	0.653
Width (mm)	7.20 ± 1.17	7.30 ± 1.16	0.797	7.17 ± 1.30	7.34 ± 1.01	0.661	8.19 ± 1.60	8.02 ± 1.32	0.800	7.85 ± 1.65	8.36 ± 1.21	0.438
Area (mm^2)	46.20 ± 13.42	49.03 ± 11.88	0.508	46.08 ± 11.96	49.16 ± 13.31	0.470	62.96 ± 21.52	54.73 ± 22.84	0.418	59.49 ± 25.87	58.20 ± 18.76	0.900

Table 4: Fetus-adult comparison of numerical values belonging to tympanic membranes

Parameters	All fetuses ($N = 36$)	All adults ($N = 20$)	p
Height (mm)	8.22 ± 1.12 (5.98–9.89)	9.06 ± 1.33 (7.11–11.47)	0.015
Width (mm)	7.25 ± 1.15 (5.44–9.03)	8.10 ± 1.43 (5.14–9.99)	0.019
Area (mm^2)	47.62 ± 12.57 (28.39–72.55)	58.84 ± 22.01 (29.66–94.77)	0.018

Table 5 Growth pattern of the tympanic membranes from fetal life (between V and VIII gestational months) to adulthood

Parameters	5th month ($N = 4$)	6th month ($N = 14$)	7th month ($N = 8$)	8th month ($N = 10$)	Adults ($N = 20$)	p
Height (mm)	7.56 ± 0.85$^{b, c}$	7.69 ± 1.21$^{b, c}$	8.38 ± 1.07	9.09 ± 0.34	9.06 ± 1.33	0.004
Width (mm)	6.18 ± 0.49$^{a, b, c}$	6.52 ± 0.86$^{a, b, c}$	7.59 ± 0.96	8.44 ± 0.47	8.10 ± 1.43	<0.001
Area (mm^2)	39.10 ± 5.52$^{b, c}$	40.12 ± 9.97$^{b, c}$	50.24 ± 12.98	59.43 ± 6.99	58.84 ± 22.01	0.004

[a]Comparison to 7th months

[b]Comparison to 8th months

[c]Comparison to adults, $p < 0.05$

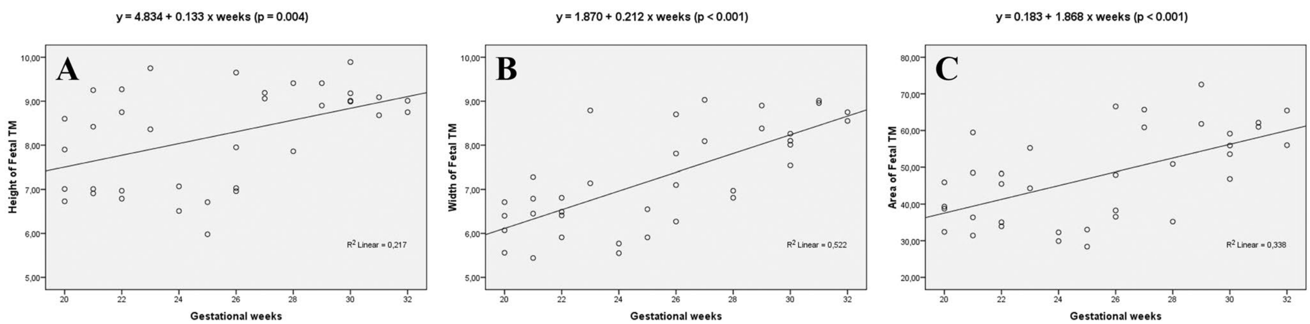

Fig. 3 The charts show the linear functions for the height (**a**), width (**b**), and area (**c**) of the tympanic membranes in fetuses

Dimensional changes of the TM are a component of such malformations; however, the membrane is defined as small or hypoplastic without numerical values [16, 17, 27, 32]. Schuknecht reported that the TM remained incomplete in patients with total congenital aural atresia [27]. Taking into account ultrasonographic imaging of the tympanic rings of 80 fetuses aged between 12–32 weeks, Leibovitz et al. [20] claimed that congenital hearing loss depending on congenital aural atresia or microtia might be diagnosed with prenatal images of the ring. The authors also suggested that the ring diameters coincide with the TM measurements [20]. Our study focusing on the TM size in the second trimester may be valuable in defining various malformations during prenatal imaging. On the other hand, blunt trauma (e.g., slap, foreign body, and combat explosions) and barotrauma (e.g., scuba diving and air travel) may cause intra-TM hemorrhage or perforation [7, 11–13, 18, 22, 25, 29]. Worsening symptoms (e.g., tinnitus, conductive hearing loss, sudden severe pain, or sensorineural hearing loss) indicate surgical intervention such as myringoplasty or tympanoplasty [24]. Autogenous grafts (e.g., deep temporalis fascia, fat, cartilage, and dura) may be used to repair the TM [8, 15, 24]. Chow et al. [8] reported that considering the measurements (the horizontal diameter as 9–10 mm, the vertical diameter as 8–9 mm) of Wajnberg [30], 9 mm × 10 mm fascia graft (or slightly larger) was required for myringoplasty. However, Wahid and Nagra [29] stated the vertical and horizontal diameters as 10 mm and 5 mm, respectively. In classical anatomy textbooks (Gray's Anatomy) [28], the vertical diameter reported as 9–10 mm, and the horizontal diameter as 8–9 mm. Due to great diversity on the TM dimensions, we think that further morphometric studies are needed by taking contradictory data about its size into consideration.

In adults, the area, vertical and horizontal diameters of the TM in this study were found as 58.84 ± 22.01 mm^2, 9.06 ± 1.33 mm, and 8.10 ± 1.43 mm, respectively. The literature values related to the measurements of the TM parameters were given in Table 6, in where the average data range in adults were presented as 7.50–9.40 mm for the vertical diameter, 7.90–8.60 mm for the horizontal diameter, and 55.40–65.35 mm^2 for the surface area [9, 19, 21, 26, 30]. Therefore, our adult TM measurements were compatible with the mean values in the literature. Salvinelli et al. [26] compared their findings (in situ measurement) with those of

Table 6 The literature data related to TM parameters

Studies	Years	Region	Numbers	Technique	Samples	Sample fixation methods	Height (mm)	Width (mm)	Area (mm^2)
Decraemer et al. [9]	1991	Belgium	–	Moire interferometer	Temporal bones	4% formaldehyde	–	–	65.35 (real area)
									59.74 (projected area)
Kirikae [19]	1960	Japan	25	–	–	-	7.50 ± 0.50	7.90 ± 0.80	55.40 ± 4.50
Lim [21]	1970	USA	20	–	Adult temporal bones	–	9-10.20	8.50-9	–
Salvinelli et al. [26]	1991	Italy	280	Calliper rule	Adult cadavers	–	9.40 ± 1.50	8.60 ± 0.90	–
Wajnberg [30]	1987	Israel	28	–	Adult temporal bones	–	8-9	9-10	–
This study	2020	Turkey	20	ImageJ	Adult cadavers	10% formalin	9.06 ± 1.33	8.10 ± 1.43	58.84 ± 22.01
			36	ImageJ	Fetal cadavers	10% formalin	8.22 ± 1.12	7.25 ± 1.15	47.62 ± 12.57

Kirikae [19] (measurement after dissection, and so that tissue disruption) (Table 6), and reported that larger diameters were due to measurement methodology, not genetic differences. Wajnberg [30] reported that in adults, the horizontal diameter (range, 9–10 mm) of the TM was greater than the vertical diameter (range 8–9 mm). However, in the other papers [6, 21, 26], similar to our study, the vertical length of the TM was reported to be greater than the horizontal length. Chow et al. [8] reported that 9 mm (the vertical) × 10 mm (the horizontal) deep temporalis fascia graft (or slightly larger) was required for myringoplasty. The adult vertical (7.11–11.47 mm) and horizontal (5.14–9.99 mm) diameters of the TM in this study showed a very wide range. In this regard, we thought that the 12 mm (the vertical) × 10 mm (the horizontal) graft might be the ideal dimension during the reparation of the TM perforations.

In fetuses, the area, vertical and horizontal diameters of the TM in this work were found as $47.62 \pm 12.57\ mm^2$, 8.22 ± 1.12 mm, and 7.25 ± 1.15 mm, respectively. The linear functions, representing the growth dynamic of the TM parameters in fetuses between 20–32 weeks, may be used to estimate its size. Studies focused on the TM size are quite limited in fetuses [6]. In the study of Bruzewicz and Suder [6] conducted on 33 fetal cadavers aged between 4 and 8th month, quantitative data were evaluated graphically; therefore, it was difficult to compare directly their findings with our measurements. Bruzewicz and Suder [6] stated that the TM seemed to reach vertically elongated shape from the 8th month, similar to that in adults. In addition, they suggested that the morphometric expansion of the TM continued until birth [6]. However, when examining the graphs in their study [6], the height was almost completely similar in fetuses at the 7th month and the 8th month, and interestingly the width in fetuses at the 7th month was more than that at the 8th month. In this study, we found that the area, height and width of the TM did not change from the 7th month of gestation, and thus the TM reached adult size in fetal life. This knowledge may be useful for otologists during the calculation of graft sizes (e.g., deep temporalis fascia, fascia lata, and dura) to repair the TM perforations in children, especially in infants and young children.

Similar to the anatomical structures such as the ear ossicles, tympanic ring, and stapedial tendon in the middle ear [1, 2, 5], we found that the TM reached adult size in intrauterine life. Anson et al. [1] stated that the diameter of the tympanic ring / annulus had a width close to adult size at 35 weeks of gestation. In our opinion, the TM shows a similar growth dynamic with the tympanic ring. The anatomical structures (e.g., the malleus, incus, stapes, tympanic ring, round window, oval window, and stapedius muscle) in the middle ear go through different development processes, but they are almost adult-sized before birth [28]. In the middle ear after birth, the most important morphometric changes are the increases of the distance between the membrane and stapes footplate, and the tympanic cavity volume [10, 14]. The inferior part of the tympanic annulus grows laterally, without changing diameter; therefore, the angular change between the tympanic annulus plane and skull base occurs [3, 10]. By age 4–5 years, this change causes the TM to orient from the horizontal position in newborn to the oblique position in adults [3, 10].

Conclusion

The calculated linear functions of the TM parameters in fetuses may be used for estimation of its size. Our findings showed that the TM shape did not change from the 7th gestational month, and thus the membrane reached adult diameter and shape in fetal life. The TM height and width showed a very wide range; therefore, we thought that the 12 mm (the height) × 10 mm (the width) graft might be the ideal dimension during the repair of the TM perforations.

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Author contributions: OB, DLÖ, FM, PT, DÜT: project development, data collection, data analysis, manuscript writing. YV, ABÖ, OD: Data analysis, Manuscript editing.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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