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PRS GLOBAL OPEN

ORIGINAL ARTICLE
Craniofacial/Pediatric

Characterization of Auricular Growth within the Pediatric Population Using Computed Tomography Scan Measurements

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Background: In patients with microtia, auricular reconstruction is ideally performed promptly to prevent impaired socialization during formative childhood years. The earliest viable age for reconstruction is widely accepted from 7–10 years of age, as full auricular size is achieved around age 8, with some variability dependent on sex. This retrospective study aims to provide an auricular growth curve that accounts for age and sex, enhancing the individualized approach to ear reconstruction.

Methods: A total of 319 images of unaffected patients who underwent computed tomography angiography of the head and neck were reviewed, with bilateral cartilage height and width measured according to a consensus-standardized image measurement protocol. Means and SDs of cartilage height and width were calculated for both sexes, and analysis of ear growth was performed through plotting the mean cartilage height, width, and width:height ratio over time.

Results: Cartilage height and width differed significantly between male and female groups. Maximum cartilage height was reached at age 11 for female and at age 12 for male patients, whereas maximum cartilage width was reached at ages 10 and 8, respectively. On average, the width:height ratio for female group was 0.58. For male group, the average width:height ratio was 0.59.

Conclusions: An auricular growth map was designed using computed tomography measurements demonstrating maximum auricular size at age 11 and 12 respectively for female and male patients, with both sexes having a width:height ratio maintained at approximately 0.6 throughout growth. *(Plast Reconstr Surg Glob Open 2023; 11:e5210; doi: 10.1097/GOX.0000000000005210; Published online 16 August 2023.)*

INTRODUCTION

Microtia encompasses a spectrum of congenital deformities of the auricle, ranging from mild external defects to the complete absence of an ear. The psychosocial effects of congenital deformities are difficult to quantify but have been shown to have a detrimental impact on the social development of affected children.[1] A variety of surgical and nonsurgical options have been developed for recreation of the missing auricle, including autologous reconstruction using rib cartilage, the use of pre-made alloplastic implants, and fabrication of ear prosthetics. Autologous reconstruction using costal cartilage has gained popularity due to the ability to replace cartilage with like tissue, as well as its safety in case of extrusion or infection. However, some of the limitations of autologous reconstruction include availability of adequate costal cartilage volume for production of the auricular framework, as well as determining the appropriate auricular size to ensure symmetry as the patient grows into adulthood.

Autologous auricular reconstruction most commonly occurs between ages 7 and 10.[2] Ideally, surgery would be performed as early as possible to prevent impaired socialization or isolation during formative years of childhood. The age range of 7–10 years is widely accepted by those who perform autologous reconstruction, and is dependent on the presence of adequate costal cartilage

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Received for publication April 12, 2023; accepted July 11, 2023.

DOI: 10.1097/GOX.0000000000005210

Disclosure statements are at the end of this article, following the correspondence information.

for the reconstructive framework and a nearly full-grown contralateral auricle. Currently, it is commonly accepted that adult auricular size is achieved around age 8, with some variability in final size dependent on factors such as gender and body height.[3] As such, reconstructive surgeons often sculpt auricular frameworks that reflect the projected final auricular size for each individual pediatric patient. However, there have been limited comprehensive studies illustrating an ear growth curve that corroborates this growth pattern. Characterization of average auricular cartilage size at various ages in the pediatric population would allow for more accurate estimations of age-specific auricular morphology. An auricular growth curve that accounts for age and gender would enhance the individually tailored approach to ear reconstruction, improving long-term esthetic outcomes and patient quality of life. This study aimed to develop a predictive model that characterizes auricular growth in the pediatric population using computed tomography (CT) scan measurements of patients without auricular anomalies.

Takeaways

Question: How do we characterize ear growth during adolescence when planning auricular reconstruction?

Findings: We performed a retrospective study that assessed ear cartilage height and width, using computed tomography angiography images stratified by age and sex. The average width:height ratio was consistent throughout growth, and growth continues past the currently accepted age of 8–9 years, with no significant differences in ear size by gender.

Meaning: These data demonstrate a consistent height:width ratio throughout growth and begin to characterize the trajectory of ear growth much older than previously theorized.

METHODS

This retrospective study was approved by the institutional review board at Cincinnati Children's Hospital Medical Center. All research activities were Health Insurance Portability and Accountability Act compliant. An imaging report search engine (Illuminate Insight, Softek, Kans.) was used to conduct a query of patients who underwent clinically indicated computed tomography angiography (CTA) of the head and neck at Cincinnati Children's Hospital Medical Center between May 2010 and January 2022, yielding 483 patients. Imaging reports were then excluded for the following reasons: (1) any ear abnormality described in imaging reports; (2) images where patients have been described to have genetic disorders or craniofacial anomalies in imaging reports; (3) images obtained outside of this institution; (4) images in which complete visualization of the ear was not possible (clipped images). After exclusions, 460 patient imaging reports remained eligible. A goal was set for inclusion of 10 patients for each gender and age group between ages 3 and 18 (20 patients per year of age). Only 19 patients were available for the age group of 18 years, resulting in a final study sample of 319 unique patients.

Image Measurement Protocol

CTA imaging postprocessing and measurements were performed by four independent reviewers according to a consensus-standardized image measurement protocol using institutional Picture Archiving and Communication System (PACS) (Merge PACS, Merge Healthcare, Wis.) blinded to all clinical and demographic information. To standardize the image processing and measuring protocol, reviewers were individually trained by an experienced board-certified pediatric radiologist. Axial CTA images with 2-mm slice thickness were set to soft tissue windows, and optimal visualization of the ear was obtained using PACS two-dimensional multiplanar reformation tool. Scans were scrolled through, and the slices with the most optimal visualization of the targeted ear components were used for measurement. Cartilage height was measured from superior most helix to inferior lobule, and width, by drawing a perpendicular line from anterior tragus to posterior helix. Three of the reviewers measured 80 patients, whereas one reviewer measured 79 patients.

Statistical Analysis

Statistical analysis was carried out using RStudio Version 2022.02.2, packages dplyr and ggplot2, with α set at 0.05. Means and SDs of cartilage height and width were calculated for male and female patients aged 3–18 years. Exploratory analysis of trends in ear growth was performed through plotting the mean cartilage height, width, and width:height ratio over time. Additionally, the percentage changes in cartilage height and width were calculated for each consecutive year and plotted along with a smoothed curve of conditional means to visualize trends in growth rate over time. To develop models of ear growth curves, patient age and gender were used as predictors to be included in the model. Four different models were built, including both linear and nonlinear models, and we compared r^2 values to determine which model best estimated cartilage height and width.

RESULTS

Study Sample

There were 319 individuals included in the analysis. Of these individuals, 159 (49.8%) were female and 160 (50.2%) were male. The mean age for both male and female patients was 10.5 ± 0.6 years. Means and SDs for cartilage height and width were calculated for each age (3–18 years) and further stratified by gender and side (Table 1). On average, the width:height ratio for female groups was 0.58, with an adult (age 18) width:height ratio of 0.56 (Fig. 1). For male patients, the average width:height ratio was 0.59, with a width:height ratio of 0.56 occurring at age 18.

Cartilage Height and Width

There was no significant difference between mean right and left cartilage height or width in the studied

Table 1. Mean and SD of Cartilage Measurements Stratified by Sex (Male/Female Patients), Type of Measurement (Height/Width), and Side (Right/Left)

	Height (Left)		Width (Left)		Height (Right)		Width (Right)	
Age	Female Patients	Male Patients	Female Patients	Male Patients	Female Patients	Male Patients	Female Patients	Male Patients
3	45.8 (4.2)	40.7 (4.8)	27.8 (3.1)	27.1 (2.6)	46.2 (5.0)	42.9 (5.7)	27.6 (1.4)	28.9 (5.7)
4	45.1 (3.5)	50.3 (3.4)	26.2 (1.5)	29.7 (2.2)	45.1 (3.5)	51.0 (3.1)	26.4 (1.4)	30.6 (1.4)
5	47.1 (4.5)	49.6 (4.8)	27.6 (3.3)	30.0 (2.5)	47.1 (4.5)	50.0 (5.5)	27.3 (2.8)	30.0 (2.8)
6	50.4 (1.8)	50.8 (3.2)	28.7 (2.4)	30.8 (2.3)	50.7 (1.8)	51.0 (2.8)	29.0 (2.2)	30.8 (2.3)
7	52.1 (3.4)	52.2 (4.6)	29.6 (2.5)	29.7 (3.8)	52.2 (3.2)	52.6 (4.1)	29.2 (2.8)	29.6 (3.3)
8	52.3 (3.5)	51.6 (5.4)	30.6 (2.2)	33.6 (2.2)	52.1 (2.0)	50.3 (8.3)	28.3 (3.9)	35.4 (5.0)
9	50.3 (3.6)	53.1 (5.6)	31.3 (2.3)	32.8 (4.8)	51.4 (2.8)	54.7 (6.0)	31.3 (2.2)	34.0 (2.8)
10	50.3 (9.6)	52.6 (3.7)	33.6 (7.5)	31.3 (3.9)	53.6 (2.9)	53.4 (4.6)	32.8 (3.3)	30.0 (4.2)
11	58.2 (5.0)	54.6 (4.4)	31.5 (3.5)	32.7 (3.5)	55.4 (4.3)	55.1 (4.3)	31.7 (2.0)	34.5 (5.4)
12	54.2 (3.2)	58.0 (5.5)	31.4 (1.9)	32.0 (1.7)	53.0 (3.8)	58.2 (3.7)	30.2 (1.9)	31.4 (2.7)
13	54.7 (6.3)	55.2 (6.5)	32.8 (1.7)	31.0 (2.8)	55.4 (5.2)	58.2 (4.6)	30.9 (2.4)	30.0 (4.2)
14	52.6 (5.3)	56.2 (5.2)	29.1 (2.5)	31.9 (2.8)	53.7 (5.2)	55.5 (4.8)	29.7 (0.8)	31.9 (2.1)
15	54.4 (5.2)	56.6 (4.0)	30.7 (2.7)	32.1 (2.5)	52.8 (3.0)	58.2 (4.3)	31.0 (2.1)	32.6 (2.4)
16	54.3 (3.1)	54.0 (3.4)	30.2 (1.6)	31.8 (2.2)	54.3 (4.0)	56.2 (2.5)	30.2 (2.2)	32.2 (2.2)
17	56.1 (3.2)	57.0 (4.9)	32.1 (4.5)	31.6 (2.2)	54.2 (3.5)	57.2 (4.3)	31.2 (2.8)	32.3 (3.0)
18	52.8 (4.0)	53.7 (4.5)	29.5 (2.8)	30.8 (3.1)	52.0 (2.4)	55.0 (3.7)	29.6 (2.4)	31.0 (2.7)

Cartilage measurements are in millimeters (mm).

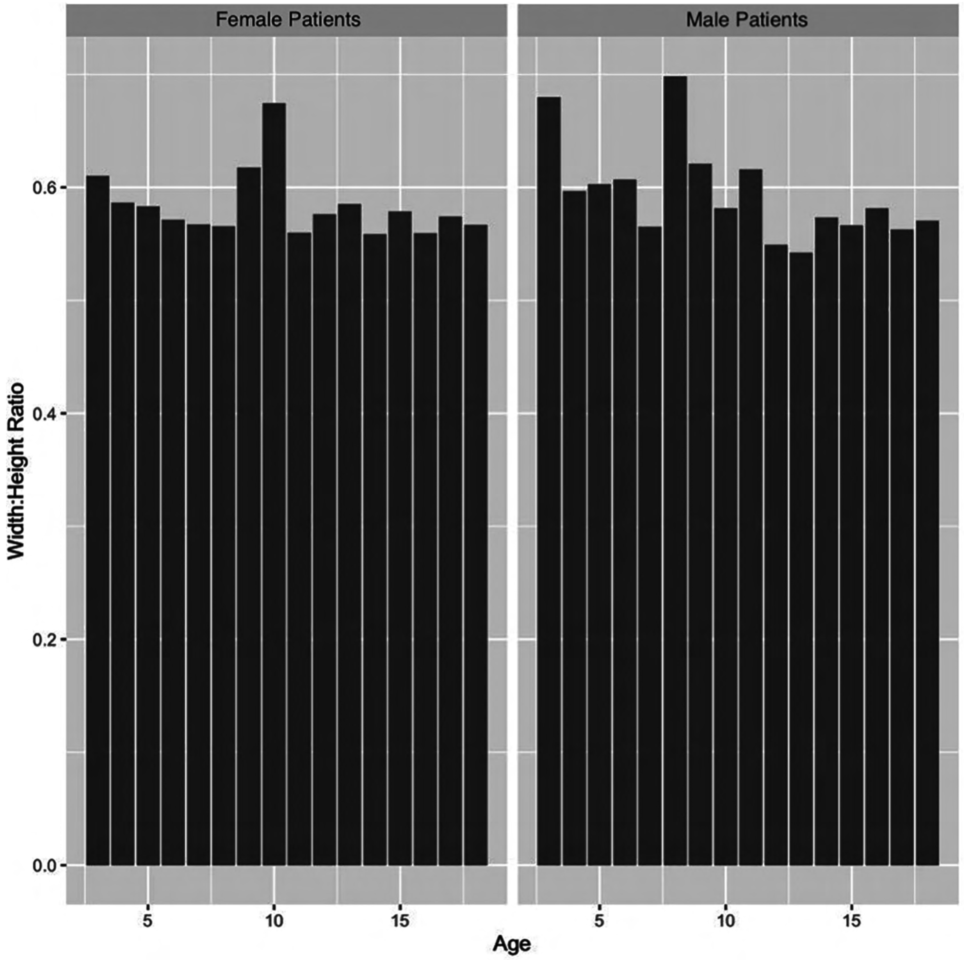

Fig. 1. Average width:height ratio at each age stratified by sex.

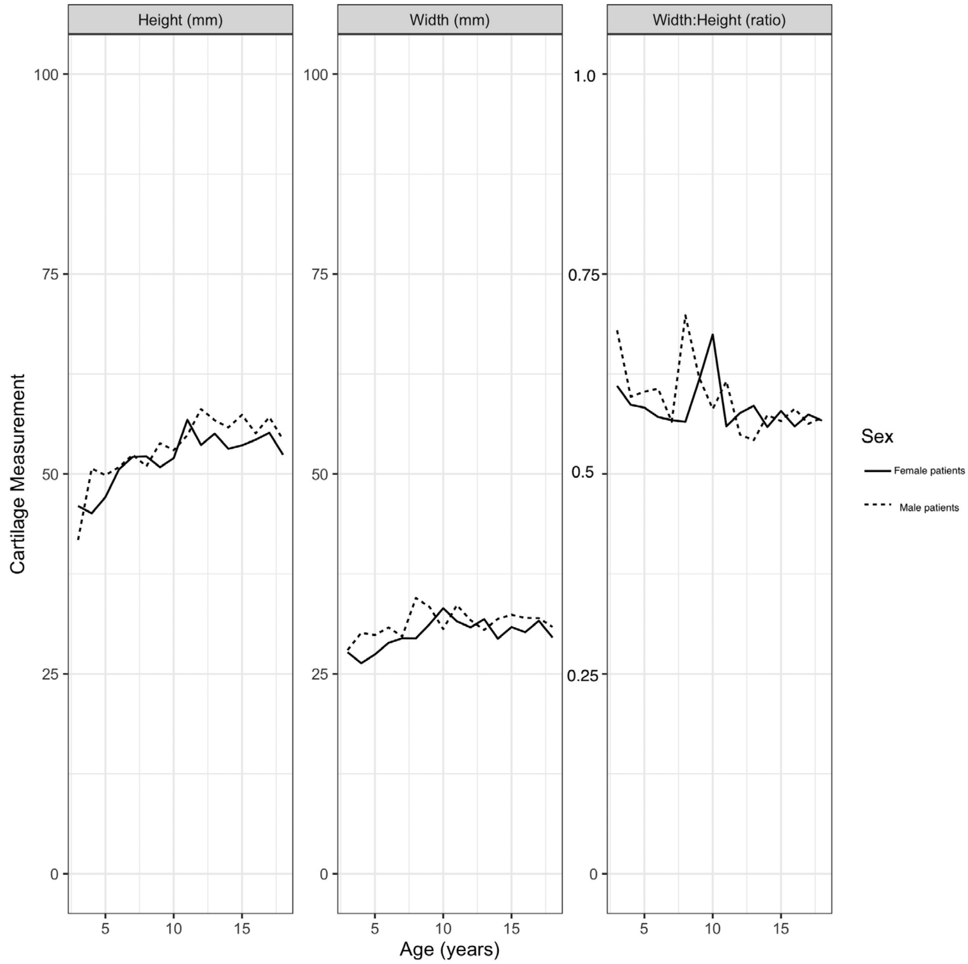

Fig. 2. Mean cartilage height, width, and width:height ratio progression over time, stratified by gender. Cartilage measurements are in millimeters.

patient sample ($P = 0.13$ and $P = 0.90$, respectively). As such, data for right and left ears were aggregated for the remainder of height and width analyses. Mean cartilage height and width were greater in the male groups compared with female groups ($P = 0.001$ and $P < 0.001$, respectively). Mean cartilage height was 51.87 mm for female and 53.30 mm for male groups; mean width was 29.98 mm for female and 31.37 for male groups (Fig. 2). The mean difference in cartilage height between ages 3 and 18 was 6.41 mm for female and 12.54 mm for male groups. The mean difference in cartilage width was 1.84 mm for female and 2.89 mm for male groups. Maximum cartilage height was reached at age 11 for female and age 12 for male groups. Cartilage height and width at age 18 were not significantly different between males and female groups ($P = 0.116$, $P = 0.139$). For the female group, maximum growth rate for height and width (as determined by percent-change from one year to the next) occurred between ages 6 and 7 (Fig. 3). For the male group, maximum growth rate for height and width occurred between age 3 and 4. A total of four models were fitted for both cartilage height and width (Fig. 4). The model with the highest r^2 (0.343 for height, 0.184 for width; Table 2) was the same for both height and width (Model 4): $y = \beta_0 + \beta_1\,(age) + \beta_2\,(male\ patients) + \beta_3\,(age^2) + \beta_4\,(age \times male\ patients) + \beta_5\,(age^2 \times male\ patients)$. This is the curve that most accurately modeled cartilage growth between ages 3 and 18.

DISCUSSION

Ear reconstruction before school age is a goal of many reconstructive surgeons to prevent the ridicule, bullying, and psychological burden a condition like microtia or traumatic ear loss poses to patients. Autologous ear reconstruction requires the harvest of a significant amount of autologous cartilage. Awaiting the development of a rib cage of at least 60 cm in circumference, the commonly accepted threshold to successfully harvest enough cartilage, can prove challenging. As performing ear reconstruction at an earlier age could help mitigate the psychological problems mentioned, a better understanding of ear growth patterns, age of highest ear growth spurt, earliest age at which final dimensions are available, and the possibility of performing surgery at an earlier time point may aid the reconstructive surgeon in the decision-making process.

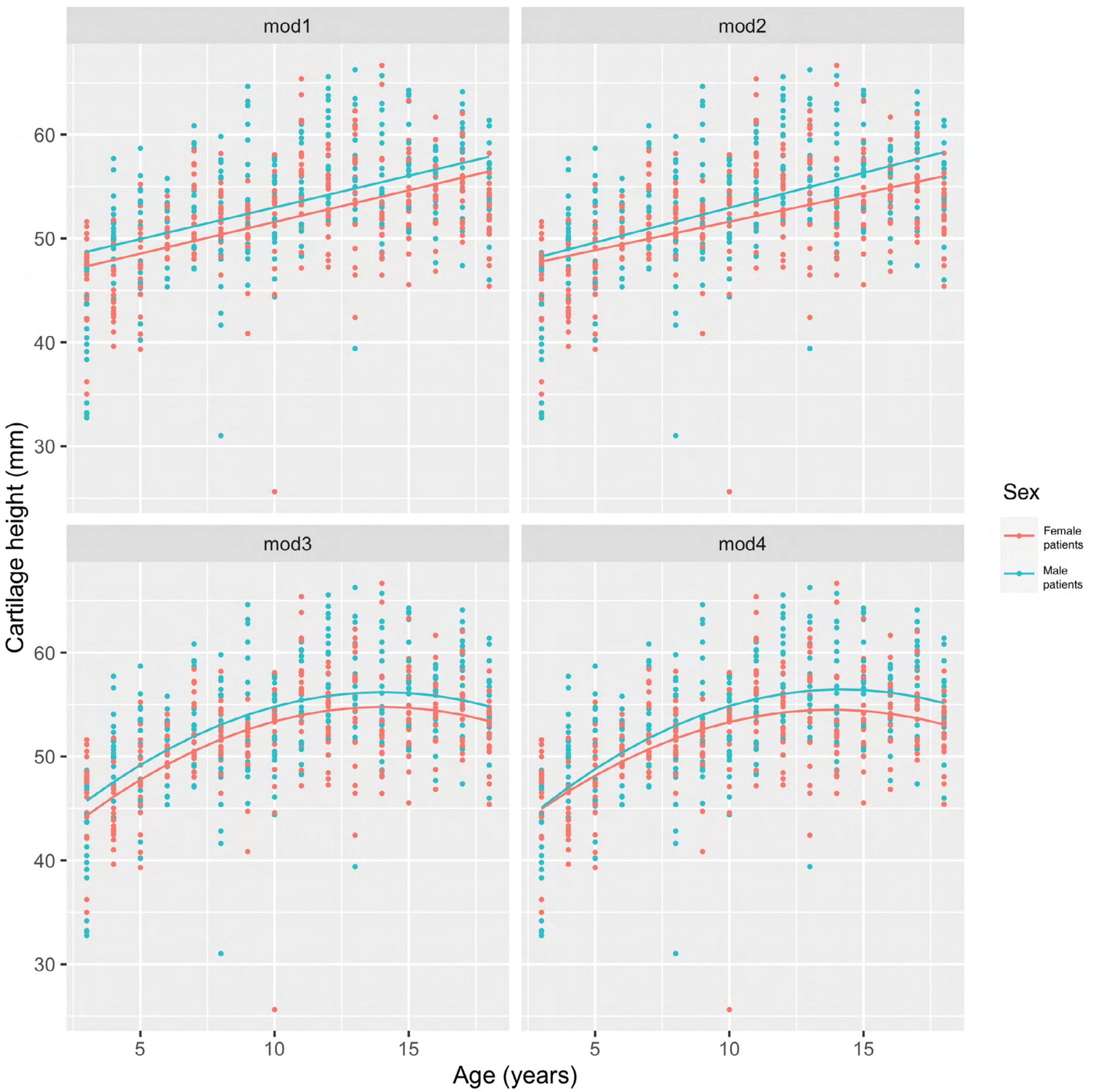

Fig. 3. Graphs of the four different models built to assess curve fit for prediction of ear cartilage height.

Although most literature suggests final auricular dimensions are significantly impacted by gender and body height, the empirical consensus by most reconstructive surgeons is that ears are fully developed by about age 8.[3] A study consisting of a Chinese pediatric population found that maximum ear length was reached at age 14, results much more consistent with our study.[9] A paucity of data on the trajectory of auricular cartilage growth indicates a need for studies to further enhance individualized surgical planning.

Differences in left-right auricular height and width throughout development were analyzed within age and gender subsets. Current literature shows that within subjects, ears are bilaterally symmetric only to a certain extent, with the highest degrees of asymmetry noted in the helix, tragus, and lobule.[4–6] The measurement algorithm for height involved the caudal end of the earlobe as an endpoint, as well as the anterior border of the tragus for width. One cross-sectional study found that facial asymmetry was larger in adolescents than in adults, suggesting that small growth imbalances throughout development were the cause.[6,7] Despite evidence of asymmetry in the literature, this study saw no significant difference between left and right auricular cartilage height and width within

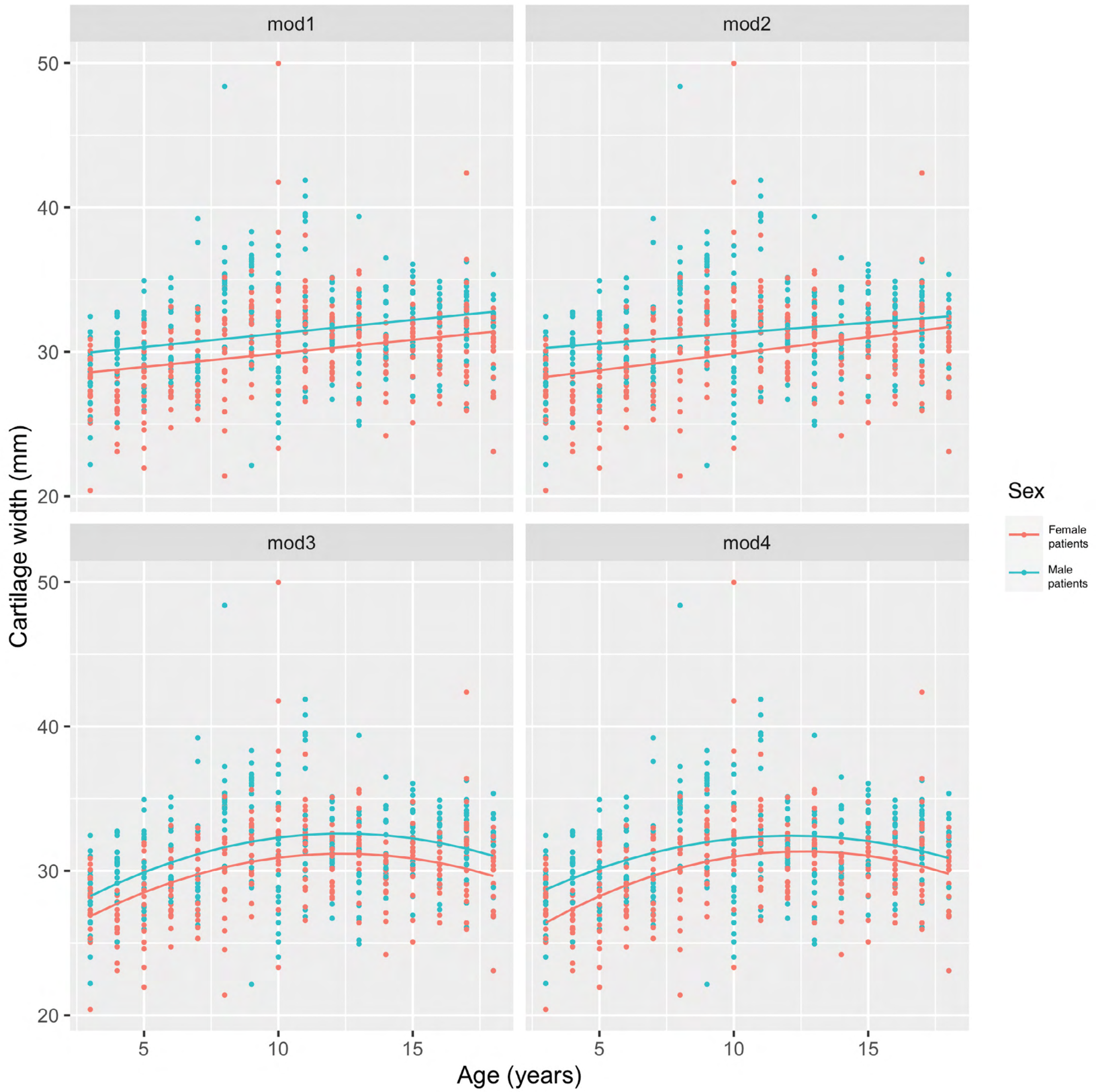

Fig. 4. Graphs of the four different models built to assess curve fit for prediction of ear cartilage width.

Table 2. r^2 Values for Curve Fitting Procedure

Model	Height	Width
1. $y = \beta_0 + \beta_1 (age) + \beta_2 (male\ patients)$	0.261	0.107
2. $y = \beta_0 + \beta_1 (age) + \beta_2 (male\ patients) + \beta_3 (age \times male\ patients)$	0.262	0.110
3. $y = \beta_0 + \beta_1 (age) + \beta_2 (male\ patients) + \beta_3 (age^2)$	0.342	0.181
4. $y = \beta_0 + \beta_1 (age) + \beta_2 (male\ patients) + \beta_3 (age^2) + \beta_4 (age \times male\ patients) + \beta_5 (age^2 \times male\ patients)$	0.343	0.184

age groups divided by gender, indicating that they may be bilaterally symmetric throughout growth.

Growth trajectories of the height and width of auricular cartilage were analyzed for both genders for each age between ages 3 and 18. Auricular dimensions reached maximum size at age 11 in female patients; however, male auricular size did not reach maximum dimensions until age 12. According to Sforza et al, auricular dimensions of female individuals at 12–14 years of age are nearly identical to adult female values, whereas male individuals did not achieve adult auricular dimensions until later in adolescence. Our study further emphasizes that maximum ear growth may not be reached until later in adolescence, around age 11–12 for both male and female groups, which is significantly older than the currently accepted age of 8. Gender differences in auricular growth pattern paralleled facial growth patterns, where female patients had reached adult dimensions by age 13–14 and male patients lagged in achieving adult facial dimensions.[6] This investigation demonstrated findings in which male subjects achieved maximal ear dimensions later in adolescence than their female peers. It is likely that these consensus results are related to differences in onset of pubertal growth between adolescent male and female individuals. These findings suggest ear reconstructions should make graft sizes consistent with projected sizes around age 11–12, either waiting until the child reaches that age or predicting the size of the ear at that age. Additional studies are needed to determine the applicability of the growth models and auricular dimensions to individual patients, especially given that this study had growth curves with low r^2 values demonstrating their lack of significance and applicability.

Neither final cartilage height nor width demonstrated significant differences at age 18 between male and female cohorts. These findings contradict current literature, which indicates that gender is a factor in the final size of auricular cartilage, with adult male individuals having larger ears than adult female individuals regarding all dimensions.[3,6] The cranial proportions of female patients will likely be comparable in size with their reconstructed ears earlier in age, and thus, they may be better surgical candidates at younger ages. However, it is also important to recognize the growth potential of autologous cartilage when used for ear reconstruction, with data showing similar growth between the normal ear and the reconstructed ear.[8] The measurements taken were of cartilage and did not include soft tissue, therefore direct use to guide reconstruction should not be taken due to the omission of the soft tissue aspect of ear size. This study also demonstrated that both male and female patients throughout growth maintain an auricular width:height ratio of 0.59 and 0.58 respectively, suggesting a ratio that can be applied when crafting ear reconstructions. A ratio of 0.6 is a number that can be utilized to ensure reconstructive models align with proportions seen in the population.

This study is the first of its kind to investigate the connection between gender and age with the growth trajectory of ear height and width in pediatric patients, especially within the wide ranges of ages 3–18. The outlined method for image processing and auricular measurements is intuitive and easily applicable by other institutions seeking to estimate ear cartilage size by age and gender. A limitation of any study with multiple reviewers is the potential for interobserver variation, though variability was minimized with the use of a consensus-standardized protocol for data collection. Additionally, any potential effects of height or weight on auricular cartilage size were not accounted for by this investigation. Measurements were performed on a limited sample size of 20 patients per age group (10 male, 10 female patients), with only 19 patients available for the age group of 18 years due to lack of available CT scan in that age group. These small sample sizes may have allowed a few outliers to skew results. Furthermore, the assigned sex at birth for each patient is unknown, given that we only have the patient reported gender, potentially including transgender individuals across groups, which may skew the data. There may be true differences in auricular cartilage dimensions between genders, which require a larger sample size and highly powered investigation to detect. This study is limited by its small sample size within each age group. Furthermore, each age group consists of a different cohort of patients, which impacts accurately analyzing growth over time. Future studies could involve training and utilizing machine learning to efficiently measure a far larger subset of auricular cartilage to drastically increase sample size and power.

The initial goal of this project was to develop a predictive model for ear width and height. Given the unavailability of longitudinal data from the same patients at multiple ages, as well as the limited number of predictor variables available for inclusion in our models, we were unable to produce robust predictive models of future ear size. The models presented here describe ear growth curves from age 3 to 18, but do not allow for predicting an individual patient's future auricular measurements based on that patient's data at an earlier time point. Although this is still useful as a general guide to ear size, developing models that would allow for individualized projections would increase the clinical utility of these models and is an important future direction for this research. Longitudinal studies of individual patients are needed to get a clearer picture of ear growth over time, which then could be used to shape surgical recommendations for ear reconstruction.

CONCLUSIONS

Determining the size of the auricle and an adequate age for auricular reconstructions remain significant challenges in autologous ear reconstruction. By measuring the height and width of the auricular cartilage of subjects aged 3–18, this study mapped the growth trajectory of the ear by gender. The final height and width at age 18 did not significantly differ between genders. This data indicates that for surgeons performing auricular reconstructions, gender may not be a significant factor in determining the final auricular framework dimensions. As the cranial proportions of female patients will likely be comparable in size with their reconstructed ears earlier in age, they may be better surgical candidates at younger ages, provided that enough cartilage is present, accounting for the fact that our study identified ear growth continuing longer than the currently accepted age of maximal size. This data demonstrated a consistent height:width ratio throughout growth and begins to characterize the trajectory of ear growth. However, further studies with longitudinal measurements and applicability to individual patients are needed to guide clinical practice.

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