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Head and Face Anthropometric Study for Chinese Children

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ABSTRACT

Anthropometric data are valuable when designing products for children. Study on anthropometric growth of children head becomes crucial for head related products such as helmets. Based on the literature, it would be helpful to explore physical growth of children at primary school age. In addition, the investigation on Chinese children's growth has not been explored in details to discover the similarity and diversity among different ethnic groups, even though differences on head shape for adults have been found between Chinese and Caucasian. This study aims at indicating the growth of head and face for Chinese children using a combination of traditional measurement and 3D scanning technology, and comparing it with Caucasian ethnicity. In this study, 102 Chinese children aged between 5 to 12 years were recruited in Hong Kong. For each participant, six dimensions on head and face were recorded including head circumference, head length, head width, forehead width, face height and morphological face height. A set of growth references were analyzed indicating physical growth on the selected dimensions for Chinese children. All the head and face dimensions were found to keep continuously increasing from 5 to 12 years old. This study statistically verifies the differences of head growth among different age groups, and proposed a measuring strategy for future sizing study to design for Chinese children.

Keywords: Chinese, Children, Growth Study, Anthropometry, Head and Face

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1. INTRODUCTION

As a fundamental part in ergonomics, anthropometry is essential in related human-centred design process (Lehto and Landry, 2012). When design for children, specific considerations should be taken into account from physical and cognitive ergonomic perspective (Hourcade, 2006). With the physical growth and development of children, seeking a proper fit for children is different from adult population. Researchers have investigated the anthropometry of children to seek proper fit for diverse products, involving footwear (Mauch *et al.*, 2008), backpack (Mououdi *et al.*, 2018), and furniture (Lee *et al.*, 2018). As for head-related product design, the anthropometry on physical growth of head and face is essential when designing for children.

Various studies were conducted on physical growth of children's head for different populations, such as British (Cole *et al.*, 1998), American (Kuczmarski *et al.*, 2000), Chinese (Li and Zhang, 2002), Turkish (Neyzi *et al.*, 2008), and Swedish (Wikland *et al.*, 2008). In these longitudinal growth studies, large sample size was selected to describe the physical growth scientifically, while only head circumference was included as head dimension, which maybe not sufficient for various head-related designs. To meet the increasing requirements of head-related products, researchers have investigated the growth of different head and face dimensions (Beek *et al.*, 1991; Farkas *et al.*, 1992; Arboleda *et al.*, 2010; Wen *et al.*, 2017). Most of previous research used traditional mea-

surements (Beek *et al.*, 1991; Farkas *et al.*, 1992; Arboleda *et al.*, 2010) or photogrammetric method (Wen *et al.*, 2017) to obtain the anthropometric measurements. However, the methods were less accurate and more time-consuming when comparing with 3D scanning measurement (Simmons and Istook, 2003). Hence, there is a need to explore children's growth of head and face with 3D scanning for related design.

Traditional measurement was the mostly used method in previous anthropometric studies, with the tools such as tape and caliper in head-related studies (Beek *et al.*, 1991; Farkas *et al.*, 1992; Arboleda *et al.*, 2010). The measuring method is easy to control certain bias factors caused by the hair, while the disadvantages were also obvious including difficulty to acquire certain dimensions on the edge and time-consuming procedure. To overcome the limitations of traditional measurement, 3D scanning technology has been widely used in recent anthropometric studies for adults (Choi and Ashdown, 2011; Luximon *et al.*, 2012), while researchers started to apply 3D scanning technology in head anthropometry for children (Ran *et al.*, 2017). Some challenges occur when scanning the head and face for children. Specifically, some inevitable body movements of energetic children may make the data collection difficult to conduct (Dou *et al.*, 2015), and the scanned point cloud may not present some particular regions covered by hair. Considering the advantages and disadvantages of both measuring techniques, measuring strategy should be explored to study children's head and face anthropometry.

For Chinese children, researchers have revealed the physical growth of the head and face dimensions in previous studies. A national standard (GB/T 26160-2010, 2010) indicated the dynamic changes of the head and face dimensions when dividing 4 to 17 years old children into five age groups. Li conducted an anthropometric investigation on head circumference for children under 7 years old (Li, 2009). However, these studies mostly contained limited dimensions and age intervals with traditional measurements. Although Ran *et al.* (2017) used 3D scanning technology to measure selected head dimensions, some of which acquired from the 3D point cloud of scanned head may not exactly presented the dimensions considering the hair obstacle. Therefore, research on more dimensions and age groups is necessary to provide a sufficient growth reference for Chinese children, and differences between various measuring methods also need to be addressed.

For ergonomic design, anthropometry for targeted population is very essential to cater specific market. To meet the increasing requirements of customers, new functionalities and appearances have to be innovative for head-related products, such as helmets, goggles, and masks. For a particular product, comparative study on anthropometry between different ethnicities can be used to discover the similarity and diversity of various markets. Between Chinese and Caucasian, Cooke and Wei (1989) compared selected head dimensions for males at age of 12 years, and Ball *et al.* (2010) revealed the differences of head shape for adults. Similarly, comparison between Chinese and Caucasian on children anthropometry is needed when designing for children.

This study employed a combination of traditional measurement and 3D scanning method to acquire anthropometric data for children in preschool and primary school aged between 5 to 12 years. The main aim of the study is to indicate the dynamic growth of head and face for Chinese children with the use of 3D scanning, compare the results with other study using different measuring strategy, and examine the differences of selected dimension between Chinese with other ethnicities.

2. METHODS

2.1 Participants

102 Chinese children (57 males and 45 females) aged from 5 to 12 years were recruited in Hong Kong. They were divided into four age groups for further analysis, including age group 1 (5-6 years), age group 2 (7-8 years), age group 3 (9-10 years) and age group 4 (11-12 years). The demographic description for the participants is shown in Table 1.

2.2 Data Collection

Before data collection, a formal approval was requested from the guardian of the juvenile participant. For each participant, both traditional and 3D scanning measurement were taken to collect the anthropometric data. Six head and face dimensions were measured in the study, including head circumference, head length, head width, forehead width, face height, and morphological face height. Additionally, age and gender was recorded as basic demographic information for further analysis.

Table 1. Demographic information of participants.

Gender	Age group	Number of participants	Height (cm)	Weight (kg)
Male	5-6 years	10	118.0±4.87	21.6±4.75
	7-8 years	10	128.6±5.64	28.3±3.10
	9-10 years	19	138.7±5.13	37.4±9.59
	11-12 years	18	150.1±6.02	41.0±8.66
Female	5-6 years	14	112.2±6.28	19.2±2.32
	7-8 years	13	123.4±6.07	23.8±3.92
	9-10 years	14	142.4±5.64	35.9±7.34
	11-12 years	4	152.9±4.91	39.8±7.10

To decrease the influence of hair, traditional measurement was taken for head circumference, head width, and head length. Specifically, a tape was used to measure the head circumference, and a caliper was used to measure the head length and head width. During measurement, the tape and caliper can be used to press the hair down so that the measurement can be taken from the surface of head as near as possible. Figure 1 presents the dimensions acquired from traditional measurements. These dimensions were measured according to measuring method from Farkas *et al.* (1992).

Following the traditional measurements, the participant was required to wear a special designed latex cap (Luximon *et al.*, 2012) and sit on a chair. Meanwhile, a plastic support was fixed in front where the participant could rest the chin to restrict head movement. The participant was asked to keep a natural countenance and sit still without movement during the scanning procedure. Artec Eva scanner was then used to obtain the 3D point cloud of the head and face. Figure 2 gives an example of the scanning results.

The 3D model was later processed to acquire the selected dimensions in RapidForm software. The head model was cleaned and aligned in Frankfurt plane (Luximon *et al.*, 2012). The plastic support was deleted in this process. Five landmarks, including glabella (gla), nasion (n), gnathion (gn), and frontotemporale (ft) left and right, were then positioned in the 3D model to further calculate forehead width (ft-ft), face height (gla-gn) and morphological face height (n-gn). The five land-

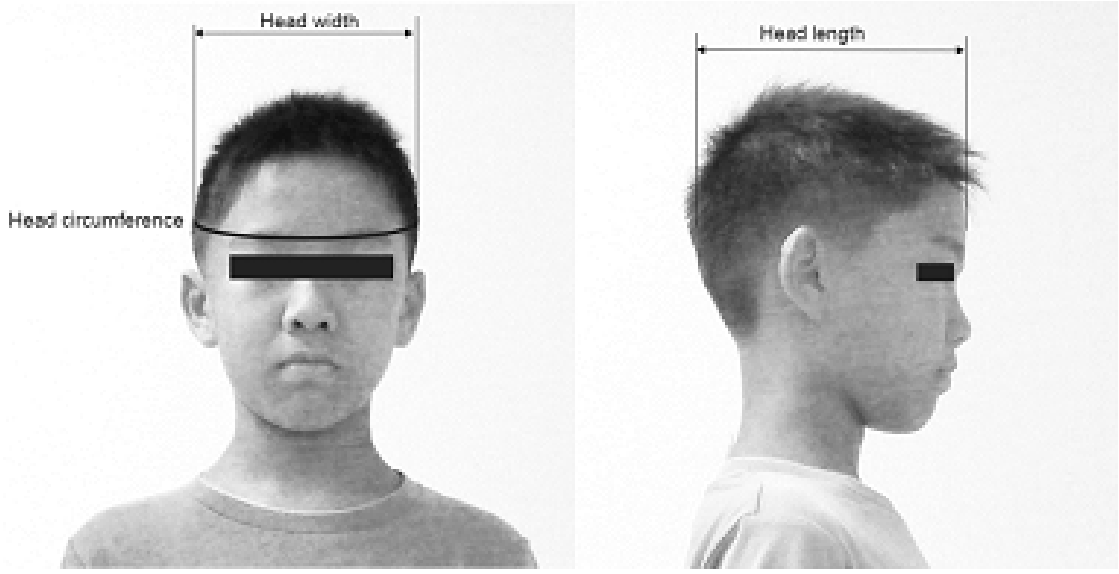


Figure 1. The dimensions acquired from traditional measuring method.

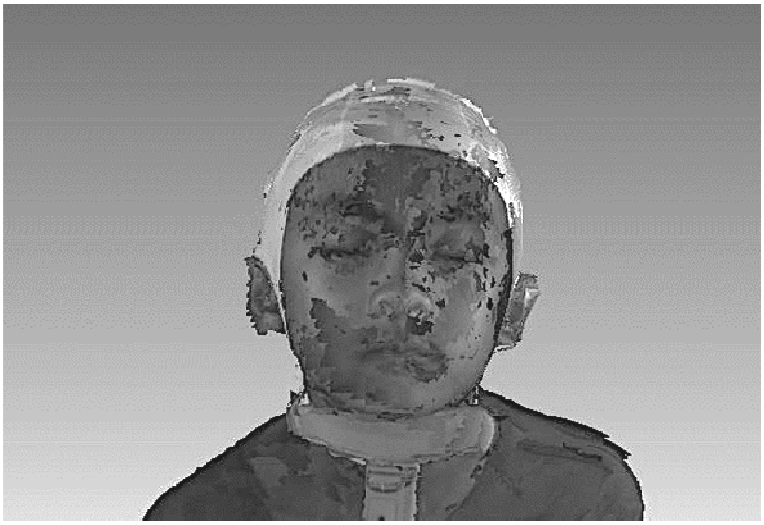


Figure 2. An example of scanning result from Artec scanner.

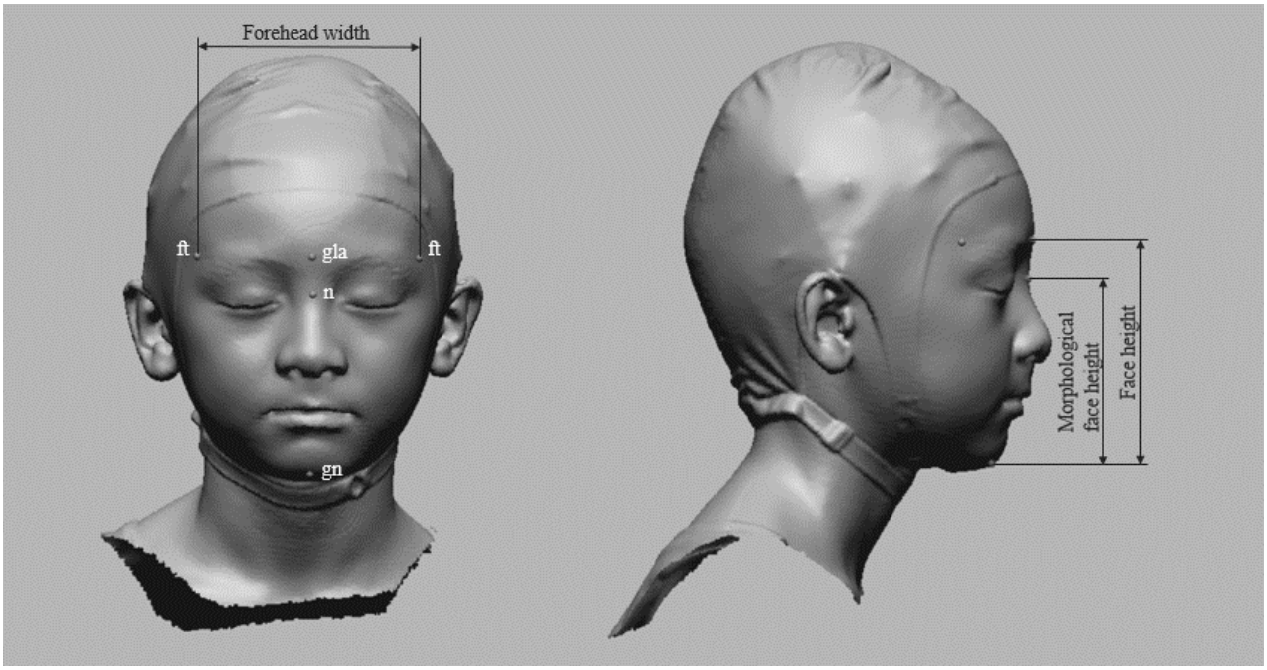


Figure 3. Landmarks and dimensions in 3D head model acquired with 3D scanning technique.

marks and three dimensions are illustrated in Figure 3.

2.3 Data Analysis

The anthropometric data were analyzed in SPSS 20.0 software. Descriptive statistics was conducted to provide the general information of the selected dimensions for each age group, which indicated the physical growth of the head and face dimensions. Analysis of Variance (ANOVA) was conducted to examine significant differences among different age groups for male and female separately.

3. RESULTS

3.1 Growth Curves Indicating the Physical Growth

Statistical description of all the dimensions for each age group are shown for both genders in Table 2 and Table 3 separately. The mean values revealed that all the selected dimensions continually grew from 5 years to 12 years for both males and females. Standard deviation, minimum value, and maximum value for each age group were also calculated. Based on the mean values, growth curves of the dimensions were plotted in Figure 4 for an intuitional view.

Table 2. General description of anthropometric growth for males (mm)

Dimension	Age group	Number of participants	Mean	Standard deviation	Minimum	Maximum
Head circumference	5-6 years	10	515.6	13.05	496.0	530.0
	7-8 years	10	528.0	10.41	512.0	540.0
	9-10 years	19	533.9	13.28	500.0	554.0
	11-12 years	18	539.1	10.13	526.0	560.0
Head length	5-6 years	10	172.6	5.38	167.0	185.0
	7-8 years	10	175.4	5.10	168.0	185.0
	9-10 years	19	178.1	6.25	166.0	189.0
	11-12 years	18	180.6	4.84	173.0	192.0
Head width	5-6 years	10	151.1	6.49	143.0	163.0
	7-8 years	10	154.6	3.50	146.0	158.0
	9-10 years	19	155.5	5.15	144.0	166.0
	11-12 years	18	156.1	4.26	149.0	165.0

Table 2. General description of anthropometric growth for males (mm) (Continued)

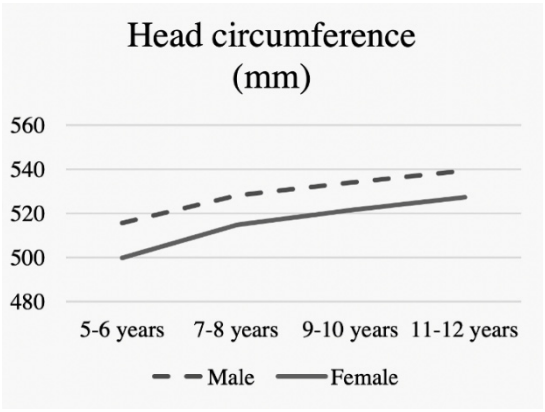
Dimension	Age group	Number of participants	Mean	Standard deviation	Minimum	Maximum
Forehead width	5-6 years	10	105.8	5.98	98.4	121.2
	7-8 years	10	112.7	5.97	107.6	124.5
	9-10 years	19	116.4	4.27	109.0	121.6
	11-12 years	18	117.5	5.42	108.4	126.4
Face height	5-6 years	10	104.4	5.11	96.5	111.0
	7-8 years	10	110.7	5.46	103.0	117.5
	9-10 years	19	115.5	3.91	106.9	120.0
	11-12 years	18	119.2	6.09	106.0	126.5
Morphological face height	5-6 years	10	88.8	5.01	81.0	96.3
	7-8 years	10	94.9	4.65	88.5	101.7
	9-10 years	19	98.4	2.90	92.0	105.0
	11-12 years	18	102.3	5.30	88.9	109.7

Table 3. General description of anthropometric growth for females (mm)

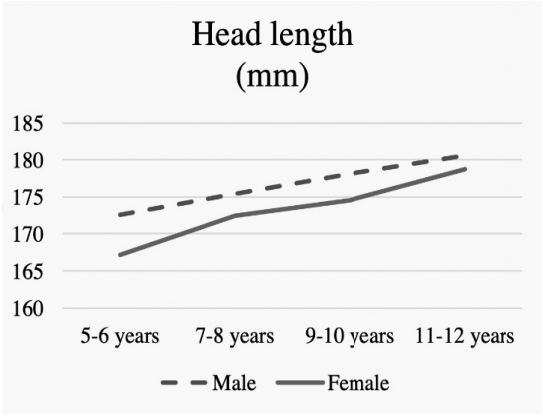
Dimension	Age group	Number of participants	Mean	Standard deviation	Minimum	Maximum
Head circumference	5-6 years	14	499.8	16.57	460.0	520.0
	7-8 years	13	514.7	14.14	500.0	552.0
	9-10 years	14	521.5	15.50	495.0	552.0
	11-12 years	4	527.3	8.22	515.0	532.0
Head length	5-6 years	14	167.2	7.51	152.0	178.0
	7-8 years	13	172.5	5.36	165.0	187.0
	9-10 years	14	174.6	6.81	165.0	187.0
	11-12 years	4	178.8	3.77	175.0	184.0
Head width	5-6 years	14	148.7	5.93	139.0	159.0
	7-8 years	13	150.7	2.32	145.0	155.0
	9-10 years	14	152.3	5.15	140.0	160.0
	11-12 years	4	153.5	5.06	147.0	158.0
Forehead width	5-6 years	14	104.9	5.08	92.9	111.6
	7-8 years	13	109.3	3.53	103.9	116.9
	9-10 years	14	113.1	3.77	108.3	119.9
	11-12 years	4	114.0	2.95	109.9	116.3
Face height	5-6 years	14	98.3	6.05	88.5	108.8
	7-8 years	13	106.5	5.39	97.5	116.4
	9-10 years	14	113.8	3.39	106.1	116.9
	11-12 years	4	117.4	6.38	110.6	125.3
Morphological face height	5-6 years	14	83.0	5.24	73.7	91.4
	7-8 years	13	90.0	4.93	81.9	97.3
	9-10 years	14	95.9	2.53	90.9	99.1
	11-12 years	4	99.8	4.67	94.7	105.1

3.2 Differences among Age Groups

ANOVA was conducted on the dimensions under the variable of age group. The results for males and females are listed in Table 4 and Table 5 respectively. It was discovered that five dimensions, including head circumference, head length, forehead width, face height and morphological face height, had significant changes among different age groups, while no statistically significant difference was found on the means of head width. Specifically, forehead width gradually increased with significant differences from age group 1 to age group 3 for both



(a)



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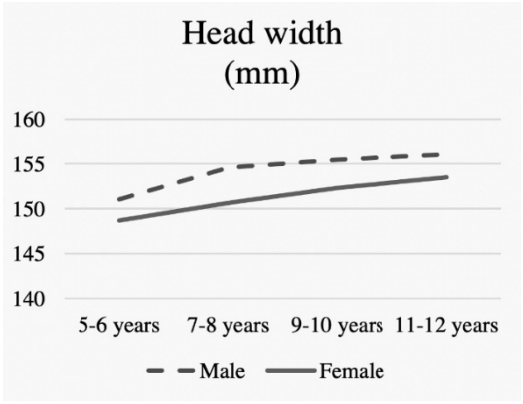

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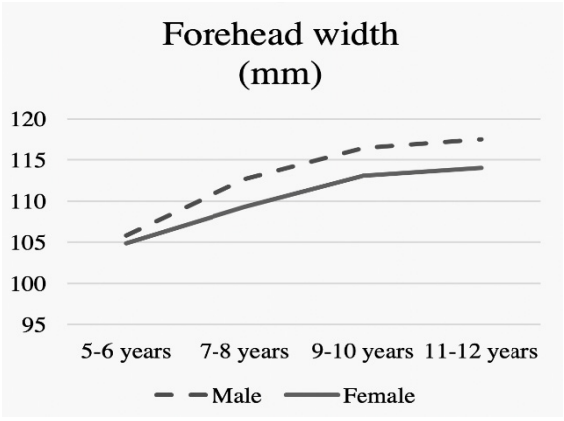

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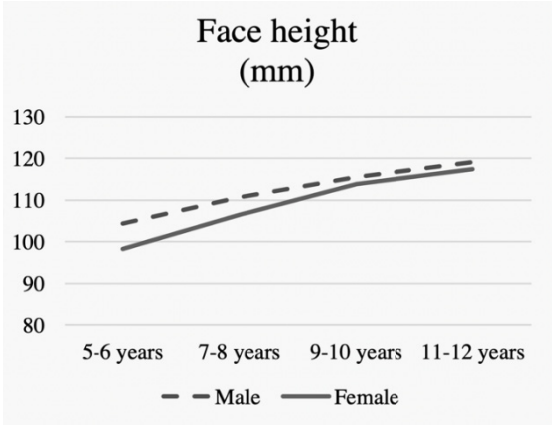

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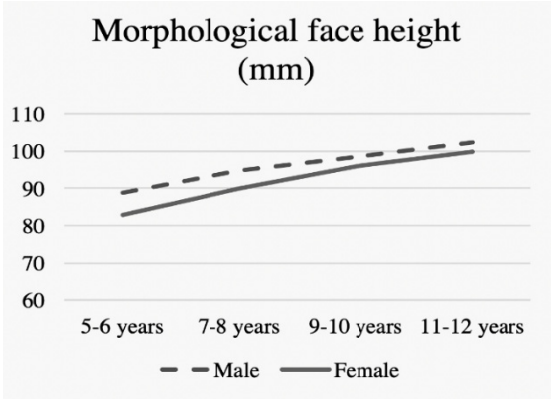

(f)

Figure 4. Growth curves of (a) head circumference, (b) head length, (c) head width, (d) forehead width, (e) face height, and (f) morphological face height.

males and females, while related results on other dimensions varied by gender. As to head circumference and head length, there were significant increase from age group 1 to age group 3 for males, and from age group 1 to group 2 for females. Face height and morphological face height had statistically significant growth from age group 1 to age group 4 for males, and from age group 1 to age group 3 for females.

Table 4. ANOVA results of dimensions for males (mm)

Dimension	F	df	p	Comparisons between different age groups			
				Age group	Mean difference	Standard error	p
Head circumference	9.04	(3, 53)	0.00*	group 1 – group 2	-12.40	5.30	0.02*
				group 1 – group 3	-18.29	4.62	0.00*
				group 1 – group 4	-23.51	4.67	0.00*
				group 2 – group 3	-5.89	4.62	0.21
				group 2 – group 4	-11.11	4.67	0.02*
				group 3 – group 4	-5.22	3.89	0.19
Head length	5.14	(3, 53)	0.00*	group 1 – group 2	-2.80	2.45	0.26
				group 1 – group 3	-5.45	2.14	0.01*
				group 1 – group 4	-8.01	2.16	0.00*
				group 2 – group 3	-2.65	2.14	0.22
				group 2 – group 4	-5.21	2.16	0.02*
				group 3 – group 4	-2.56	1.81	0.16
Head width	2.43	(3, 53)	0.08	group 1 – group 2	-3.50	2.19	0.11
				group 1 – group 3	-4.43	1.92	0.03*
				group 1 – group 4	-4.96	1.93	0.01*
				group 2 – group 3	-0.93	1.92	0.63
				group 2 – group 4	-1.46	1.93	0.46
				group 3 – group 4	-0.53	1.61	0.74
Forehead width	12.10	(3, 53)	0.00*	group 1 – group 2	-6.85	2.36	0.01*
				group 1 – group 3	-10.53	2.05	0.00*
				group 1 – group 4	-11.66	2.08	0.00*
				group 2 – group 3	-3.68	2.06	0.08
				group 2 – group 4	-4.82	2.08	0.02*
				group 3 – group 4	-1.13	1.73	0.52
Face height	19.60	(3, 53)	0.00*	group 1 – group 2	-6.28	2.31	0.01*
				group 1 – group 3	-11.11	2.02	0.00*
				group 1 – group 4	-14.82	2.03	0.00*
				group 2 – group 3	-4.83	2.02	0.02*
				group 2 – group 4	-8.54	2.03	0.00*
				group 3 – group 4	-3.71	1.70	0.03*
Morphological face height	18.06	(3, 53)	0.00*	group 1 – group 2	-6.03	2.13	0.01*
				group 1 – group 3	-9.62	1.74	0.00*
				group 1 – group 4	-13.48	1.88	0.00*
				group 2 – group 3	-3.58	1.74	0.04*
				group 2 – group 4	-7.44	1.88	0.00*
				group 3 – group 4	-3.86	1.46	0.01*

Note: * $p<0.05$.

Table 5. ANOVA results of dimensions for females (mm)

Dimension	F	df	p	Comparisons between different age groups			
				Age group	Mean difference	Standard error	p
Head circumference	6.33	(3, 41)	0.00*	group 1 – group 2	-14.91	5.80	0.01*
				group 1 – group 3	-21.71	5.69	0.00*
				group 1 – group 4	-27.46	8.54	0.00*
				group 2 – group 3	-6.81	5.80	0.25
				group 2 – group 4	-12.56	8.61	0.15
				group 3 – group 4	-5.75	8.54	0.50
Head length	4.74	(3, 41)	0.01*	group 1 – group 2	-5.25	2.50	0.04*
				group 1 – group 3	-7.36	2.45	0.01*
				group 1 – group 4	-11.54	3.68	0.00*
				group 2 – group 3	-2.11	2.50	0.40
				group 2 – group 4	-6.29	3.71	0.10
				group 3 – group 4	-4.18	3.68	0.26
Head width	1.75	(3, 41)	0.17	group 1 – group 2	-1.98	1.85	0.29
				group 1 – group 3	-3.57	1.81	0.06
				group 1 – group 4	-4.79	2.72	0.09
				group 2 – group 3	-1.59	1.84	0.39
				group 2 – group 4	-2.81	2.74	0.31
				group 3 – group 4	-1.21	2.72	0.66
Forehead width	10.94	(3, 41)	0.00*	group 1 – group 2	-4.33	1.59	0.01*
				group 1 – group 3	-8.17	1.56	0.00*
				group 1 – group 4	-9.12	2.34	0.00*
				group 2 – group 3	-3.84	1.59	0.02*
				group 2 – group 4	-4.78	2.36	0.04*
				group 3 – group 4	-0.94	2.34	0.69
Face height	26.64	(3, 41)	0.00*	group 1 – group 2	-8.19	1.99	0.00*
				group 1 – group 3	-15.47	1.95	0.00*
				group 1 – group 4	-19.11	2.93	0.00*
				group 2 – group 3	-7.28	1.99	0.00*
				group 2 – group 4	-10.92	2.96	0.00*
				group 3 – group 4	-3.64	2.93	0.22
Morphological face height	26.54	(3, 41)	0.00*	group 1 – group 2	-6.99	1.70	0.00*
				group 1 – group 3	-12.89	1.67	0.00*
				group 1 – group 4	-16.75	2.50	0.00*
				group 2 – group 3	-5.90	-1.70	0.00*
				group 2 – group 4	-9.75	2.52	0.00*
				group 3 – group 4	-3.86	2.50	0.13

Note: * $p<0.05$.

4. DISCUSSION

Growth study is important to provide references for multiple applications, such as ergonomic design and medical use. With a combination of traditional measuring and 3D scanning methods, the head dimensions were found increasing with age from 5 years to 12 years for Chinese

children in Hong Kong. It was also found that the physical growth for children's head differed by gender and specific dimensions.

For both males and females, the average values of selected dimensions for different age groups indicated the physical growth of head and face. These dimensions grew gradually from age group 1 (5-6 years) to age group 4 (11-12 years), which is consistent with previous literature (Ran *et al.*, 2017). Compared with American Caucasian (Farkas *et al.*, 1992), Chinese children have smaller head circumference, smaller head length, larger head width and lager forehead width, which is consistent with the comparison findings for adults (Goto *et al.*, 2013).

The growth differences between age groups varied on the specific head dimensions. Head circumference and head length for females had significant growth between 5 years and 8 years, while the dimensions for males increased significant between 5 years and 12 years. For both genders, head width grew slowly without significant difference between adjacent age groups within the age range of 5 to 12 years. In addition, forehead width significantly increased from 5 years for both genders and then stabilized from 9 years for males and from 11 years for females. For face height and morphological face height, it was found that females significantly grew from 5 years to 10 years, but males remained significant increase until 12 years. These results were consistent to the literature for other ethnic groups (Farkas *et al.*, 1992; Arboleda *et al.*, 2010). Farkas *et al.* (1992) concluded that females reached maturation at a younger age than males for head circumference, head length, head width and forehead width. Arboleda *et al.* (2010) also found that overall change in head width was less than head length, and growth velocity decreased for females ahead of males with the age increase.

Measuring strategy in the study was proposed considering the advantages and disadvantages of both 3D scanning and direct measuring methods. A combination of 3D scanning and traditional was suggested for head anthropometry on children. As an efficient technique in anthropometry, 3D scanning was used to present the surface shape of head and face model. Different dimensions, such as forehead width, face height, and morphological face height, can be obtained from the 3D shape. Many researchers used 3D scanning to measure the head and face dimensions for children (Goto *et al.*, 2013; Ran *et al.*, 2017). However, due to the principle of 3D scanning technique, one of the challenges for head anthropometry using 3D scanning is hair obstacles. Even though researchers used a special designed cap (Luximon *et al.*, 2012) to cover and press the hair, the thickness above the hair region still cannot be ignored. In the study, direct measurement using tape or caliper was selected for the dimensions influenced by surrounded hair, such as head circumference, head length, and head width. In order to compare to the results in previous study (Ran *et al.*, 2017), 7 to 8 years and 9 to10 years age groups were combined together and calculated. The results found that the mean values of head circumference head length and head width were smaller than 3D scanning measurement for Chinese children (Ran *et al.*, 2017).

Additionally, limitations need to be addressed for a better understanding of the findings in the study. Due to the difficulty of scanning children, the sample size may not be sufficient to present the physical growth of the large Chinese population. In the meanwhile, variation of the head and face morphology among diverse areas in China may also influence the generalization of the findings. More locations and larger sample size should be considered in the future study.

5. CONCLUSION

This study provides anthropometric information on head and face growth for Chinese children in Hong Kong. A set of references on various dimensions were presented including the head circumference, head length, head width, forehead width, face height, and morphological face height. Similar with Caucasian, the head dimensions of Chinese children were found to keep growing from 5 to 12 years old. However, morphological characteristics of head and face growth for Chinese children were found to be different from Caucasians. Chinese children were found to have smaller head circumference, smaller head length, larger head width and larger forehead width. Moreover, this study statistically verifies the differences of head growth among different age groups for males and females respectively. The physical growth under the variables of age and gender varied on specific head and face dimensions. These anthropometric references could be used to indicate the dynamic growth of head and face for Chinese children, which can be valuable for multiple purposes such as product design and medical application. Besides, the study proposed measuring strategy of head anthropometry with a combination of traditional measuring and 3D scanning methods, which could be more accurate for children.

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