Original Article

Prenatal and postnatal growth: An ultrasound and clinical investigation

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Abstract

Background: Understanding facial development requires sound knowledge of growth at different stages. Although studies in the past have established the relationship between prenatal and postnatal growth, little research has been done using noninvasive ultrasound. The purpose of this study is to evaluate correlation between prenatal and postnatal growths using ultrasound as a fetal growth assessment tool. **Study Settings:** It is a hospital-based study where prenatal growth is measured at different intervals of gestational period and compared with the growth at birth. **Materials and Methods:** Ten subjects with normal pregnancy were studied using ultrasound. Cephalocaudal growth gradient, body proportions of the fetus were assessed and compared at different stages. Growth was also evaluated at birth and compared with the predicted growth. **Results:** The growth rate of estimated fetal weight is at maximum between the 28th and 32nd week of the fetal life ($P \leq 0.001$). The growth rate of head circumference, occipitofrontal diameter, and femur length is maximum between the 20th and 28th week of the fetal life ($P < 0.001$). Cephalocaudal growth gradient decreases with increased age of the fetus. **Conclusions:** Prenatal growth is correlated with postnatal growth. Ultrasound can be used as a tool for the measurement and prediction of prenatal and postnatal growths.

Key words: Body proportions, cephalocaudal growth, postnatal growth, prenatal growth, ultrasound

INTRODUCTION

Human growth is an outcome of complex interactions between genes and the environment. A human being undergoes a synchronized balance of growth and development of body proportions throughout the prenatal and postnatal phases. Growth commences immediately after conception and can be divided into prenatal and postnatal growths.[1] In studies of growth and development, the concept of pattern is important and refers to the changes in proportional relationships over time.[2] A normal growth pattern follows a cephalocaudal growth gradient which means that there is an axis of increased growth extending from the head toward the feet.[2] The "law of cephalocaudal differential growth" states that development begins at the cephalic end and progresses toward the tail.[3] A cephalocaudal pattern of growth is also documented in orthodontic literature, which changes in proportion with time.[1,2,4] After birth, the proportion of the head to the body is greater in an infant and gradually reduces toward adulthood which is also applied to prenatal growth. The

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growth gradient proportion has been reported in textbooks without any evidence-based study.

The earliest written records of human growth are from the Mesopotamian civilization.[5] Leonardo da Vinci also studied human growth and development from conception onward. He undertook human dissection of the placenta, fetus, and stillborn. He used his scientific study of human growth to produce drawings that correctly rendered child and adult body proportions. In 1651, William Harvey showed that during the prenatal development, there is a series of embryological stages that are distinct in appearance.[5] Growth research began with the invention of the anthropometer by Johann in 1654. The discovery of X-rays and its subsequent use in medical sciences helped in the study of skeletal development. Introduced in 1960, ultrasound is the most widely used diagnostic modality today.[6] It is the most commonly used tool to visualize different fetal anatomical landmarks and to follow growth during pregnancy.[6] Recent technological advances in ultrasound imaging which include improved spatial and contrast resolution have rekindled interest in sonographic imaging in other fields as well. Ultrasound in orthodontics has been used as diagnostic tool for the dynamic functional analysis of the tongue[7-10] and temporomandibular joint dysfunction[11] and for the measurement of muscle thickness.[12-16] Reference ranges for fetal ultrasound biometry have been reported by a number of investigators.[17-26] Many formulae and parameters have been correlated with fetal weight.[27-29] Several studies have investigated the validity of ultrasound in estimation of fetal weight by comparing with birth weight and concluded that it is a reliable tool for growth evaluation.[30-32]

Orthodontics includes the study of the growth of the face which cannot be studied without understanding body growth. In the past, various methods such as a bimetric test, vital staining, radioisotopes, implants, natural markers, and anthropometric measurements have been used to measure growth.[2] Although ultrasound is used in orthodontics, it has not been used to evaluate growth. The aim of this study is to evaluate overall body proportion and cephalocaudal growth gradient at different stages using ultrasound.

MATERIALS AND METHODS

This study included subjects reporting to the department of obstetrics and gynecology of our university hospital for routine antenatal checkups. This study was approved by our university's ethics committee. The purpose of the study and protocol was explained to the patients and informed consent was obtained before the study. Normal singleton pregnancy with no maternal medical diseases at the time of gestation was included as the subjects. A fetus with congenital anomalies, twin pregnancy, oligohydramnios, and intrauterine growth restriction was excluded from the study. Ten subjects were followed up for the study. All the subjects were examined by a single examiner. Transabdominal ultrasound was performed using a GE logic P3 ultrasound machine with 4 MHz convex probe. The imaging system provided conventional two-dimensional ultrasonographic images, generated within seconds. Images were captured and stored. Both established and new parameters were used for the study. Established parameters included in the study were (1) head circumference (HC), (2) biparietal diameter (BPD), (3) occipitofrontal diameter (OFD), (4) femur length (FL), (5) abdomen circumference (AC), and (6) estimated fetal weight (EFW). New parameters used to assess cephalocaudal growth and overall body proportions were defined and standardized. New parameters added in the study were (1) head to chin (H-C), (2) neck to hip (N-H), (3) hip to knee (H-K), (4) knee to foot (K-F), (5) shoulder to elbow, and (6) elbow to wrist. Anthropometric measurements of neonates were evaluated within 24 h of birth obtained by an infantometer, calibrated electronic weighing scale, nonstretchable tape, and with a flexible scale.

Biparietal diameter

This is the distance between the parietal eminences [Figure 1a] which was measured from the outer edge of the nearerparietal bone to the inner edge of the more distant parietal bone.[6,23,26] It can be measured through any plane of a section through a 360° arc that traverses the third ventricle and thalamus. With OFD, it is used to calculate the cephalic index (CI). BPD was compared with maximum skull width (MSW) at birth [Figure 1b].

Occipitofrontal diameter

OFD was measured in a plane perpendicular to BPD between the anterior edge of the frontal bone and the outer border of the occiput[6,23,26] [Figure 2a]. OFD was correlated with maximum skull length (MSL) at birth [Figure 2b].

Cephalic index

The CI of a fetus was calculated using OFD and BPD. CI = BPD/OFD × 100. The CI of neonates was calculated using the formula = MSW (eu-eu) × 100/MSL (g-op).[6,23,26]

Head circumference

To measure HC [Figure 3a], the correct plane of a section is the third ventricle and thalamus in the central portion of the brain.[6,23,26] Here, the cursor is placed between the outer edge of one calvarial wall and the inner edge of the other calvarial wall. HC was estimated from the measurement of the OFD and BPD using a formula for an ellipse. The HC of the fetus was compared with the HC of the neonate [Figure 3b].

Femur length

This is the linear distance between the ossifi ed portions of the femur [Figure 4].[6,24,26] To measure this parameter, a transducer is properly aligned to the long axis of diaphysis of the bone. Then, the cursor is placed properly at the correct endpoints of the bone. A normal body ratio can be correlated using FL.

Abdomen circumference

AC can be measured ultrasonographically at the position where the transverse diameter of the liver is largest and both the right and left portal veins are continuous with one another.[6,24,26] After this plane of a section is frozen in the skin, the ellipse is fit into the skin edge. If the ultrasound machine is not equipped with a computer-generated ellipse measurement capability, AC can be calculated with transverse and anteroposterior diameters of the abdomen and the formula is (D1 + D2)/× 1.57 [Figure 5].[6]

Estimated fetal weight

Many formulae and nomograms have been developed for the estimation of fetal weight.[6,27-30] Among them, the Shepard formula, which includes BPD and AC, and the Hadlock formula using BPD, FL, and AC are widely accepted and commonly used for the estimation of fetal weight.[30] Most ultrasound equipment comes with computer packages that will automatically calculate the EFW. The predicted growth at birth was compared with the actual birth weight [Figure 6] after EFW was adjusted adding average

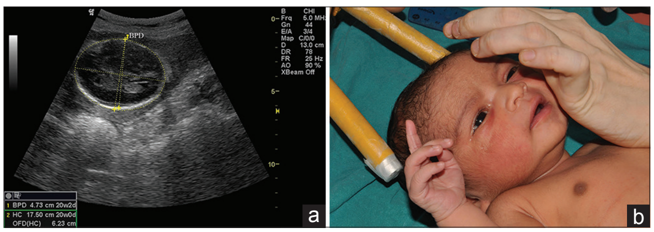

Figure 1: (a) Biparietal diameter of the fetus. (b) Maximum skull width at birth

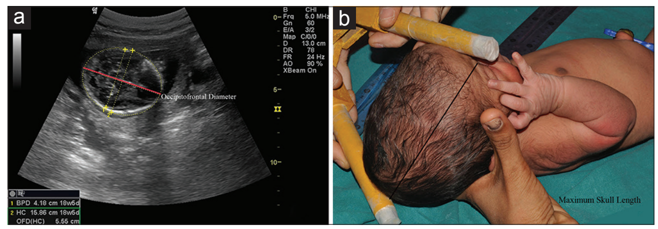

Figure 2: (a) Occipitofrontal diameter of fetus. (b) Maximum skull length at birth

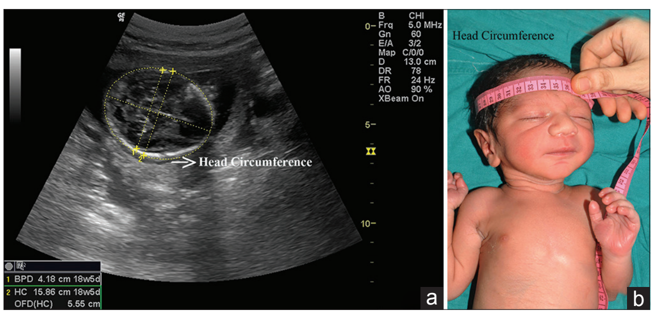

Figure 3: (a) Head circumference of fetus. (b) Head circumference at birth

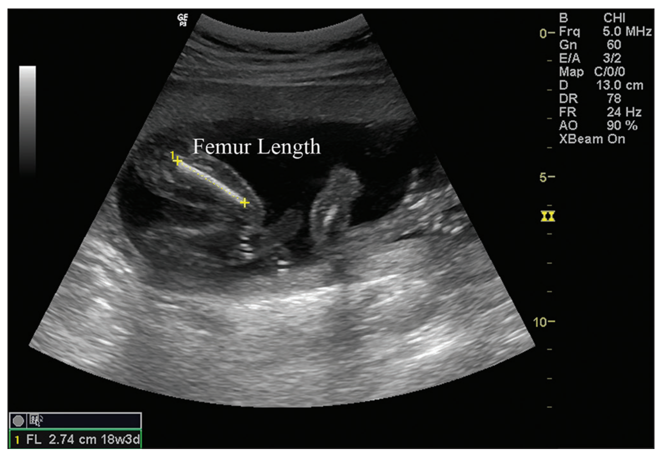

Figure 4: Femur length

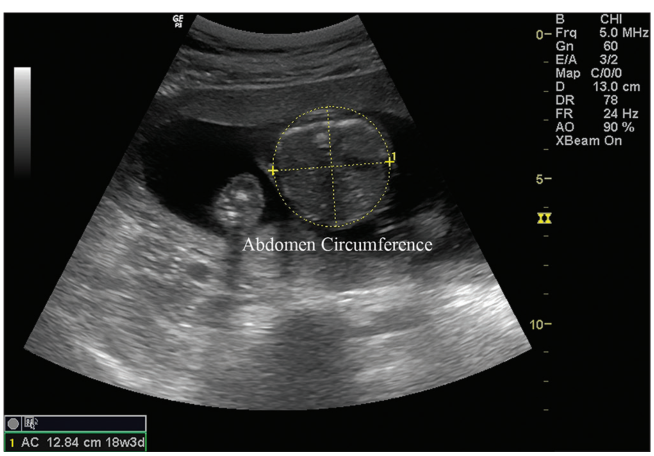

Figure 5: Abdomen circumference

Figure 6: Birth weight

growth for each day between the last scan and delivery. The deviation between predicted birth weight and actual birth weight was considered as the estimating error, which was calculated on the basis of the following formula:[30-32]

Absolute percentage error = (Predicted birth weight − Birth weight)/Birth weight × 100

Head to chin

H-C is the linear distance between the head and the chin [Figure 7a and b]. To measure this, one end of the cursor was placed at the vertex (the highest point on the head) and the other end on the inferior portion of the chin. A midcoronal plane was taken for the measurement.

Neck to hip

N-H is the linear distance measured between the first cervical vertebra and the last vertebra [Figure 8a and b]. Since the vertebral column is not straight, curvilinear measurements were taken in segments [Figure 8a]. As the gestational age increases, an N-H measurement recorded at two planes. The measurements were then added together.

Hip to knee

H-K was measured by placing one end of the cursor on the highest point of the hip bone and other end of the cursor on the lowest point of the femur/joint line [Figure 9a and b].

Knee to foot

K-F was measured from the lowest portion of the knee/joint line to the inferior portion of the heel [Figure 10a and b].

Shoulder to elbow

S-E was measured by placing one end of the cursor on acromion process of the scapula and the other end was placed on the lowest portion of the humerus/joint line [Figure 11a and b].

Elbow to wrist

E-W is the linear distance from elbow/joint line to the distal portion of the radial ulnar joint [Figure 12a and b].

Cephalocaudal growth gradient was calculated from the ratio of H-C and neck to foot which is added sum of N-H, H-K, and K-F.

All the above-mentioned parameters were measured at the 20th, 28th, 32nd, 36th weeks of pregnancy and also at birth. New parameters were derived for measuring cephalocaudal growth.[1-4] The per day growth rate of the fetus was calculated using the formula: Difference in the growth between the two intervals of scan/number of days between

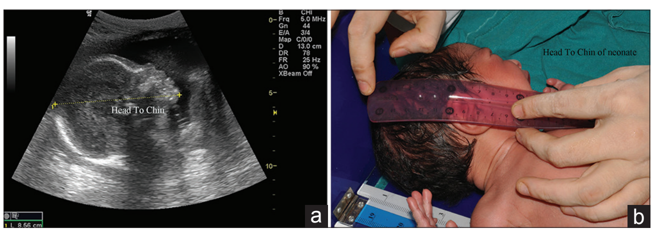

Figure 7: (a) Head to chin measurement of fetus. (b) Head to chin at birth

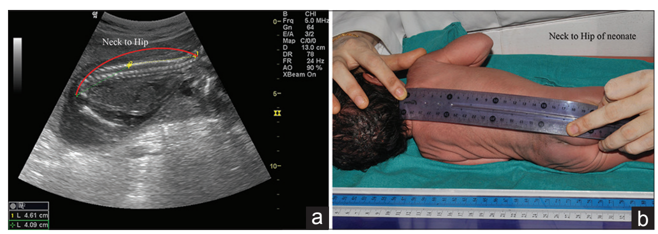

Figure 8: (a) Neck to hip measurement of fetus. (b) Neck to hip at birth

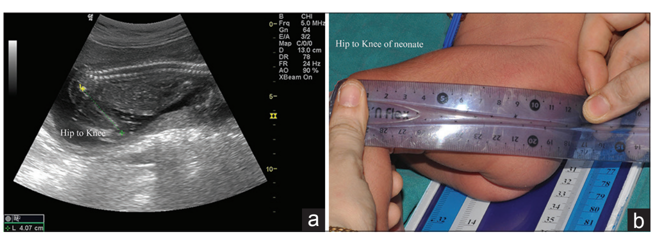

Figure 9: (a) Hip to knee measurement of fetus. (b) Hip to knee at birth

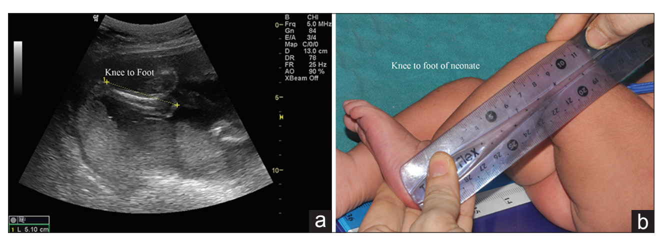

Figure 10: (a) Knee to foot measurement of fetus. (b) Knee to foot at birth

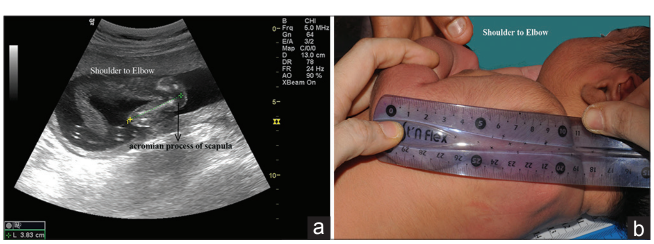

Figure 11: (a) Shoulder to elbow measurement of fetus. (b) Shoulder to elbow at birth

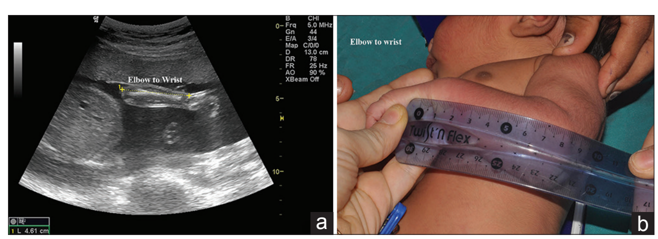

Figure 12: (a) Elbow to wrist of the fetus. (b) Elbow to wrist at birth

the intervals. Body proportions were measured and compared. A cephalocaudal growth gradient was calculated and compared at different intervals. Growth predicted and postnatal measurements were compared using the formula = (predicted– observed)/observed × 100.

Statistical analysis

Data were recorded at different intervals of the fetal period and at birth. Microsoft Excel was used to compile the data. Mean and standard deviations of each parameter were calculated. SPSS version 16 (SPSS, Chicago, Illinois, USA) was used for statistical analysis. Data were analyzed using repeated measure ANOVA. Based on the sphericity, Greenhouse-Geisser comparison test was used within the subjects.

RESULTS

Measurements were taken at different intervals of pregnancy and also at birth are listed in Table 1. The per day growth of the fetus is calculated and presented in Table 2. The growth rate of EFW was at maximum between the 28th and 32nd week of the fetal life (28.9700 ± 0.885816) and remained almost the same (28.58600 ± 4.018579) [Table 2] ($P < 0.001$). The growth rate of OFD, HC, and FL was at maximum between the 20th and 28th week of the fetal life ($P < 0.001$) and also the peak growth of other parameters was found maximum between the 20th and 28th week of the fetal life. ($P > 0.01$) [Table 2].

Cephalocaudal growth gradient decreased from 20th week (0.3434) to 28th week (0.3393) and at birth (0.3206) [Table 3]. The CI varied from 77% to 81% [Table 4].

The growth of all the parameters at birth was predicted and compared with the actual growth. The percentage error between two is calculated and listed in Table 5. BPD was comparable with MSW at birth with an error of 1.554%. OFD was comparable with the MSL at birth with an error of 0.675%. HC of the fetus can be correlated

Table 1: The parameters measured at different weeks of gestation

	20th week	28th week	32nd week	36th week	At birth
EFW (g)	455.5	1296	2497	3240	3138
BPD (mm)	52.5	72.5	85.33	93.4	93.66
OFD (mm)	67.5	94	107.833	114.5	114
Head circumference (mm)	192.6	267	313.5	336.2	347.50
Abdomen circumference (mm)	164.5	241.16	301.66	334	340
Femur length (mm)	37.16	54.83	66.83	74.5	
Head to chin (mm)	76.83	99.5	117.33	125.75	129.83
Neck to hip (mm)	110.83	138.8	165.66	167.66	210
Hip to knee (mm)	55.66	81.6	96.5	102	113.33
Knee to foot (mm)	53.16	75.5	85.16	92	107
Shoulder to elbow (mm)	54.5	70.16	80	87	92.9
Elbow to wrist (mm)	47.166	62.33	66.83	75.2	79.16

ESW – Estimated fetal weight; BPD – Biparietal diameter; OFD – Occipitofrontal diameter

Table 2: The per day growth rate of each parameter at different interval

	Mean±SD			*n*	*P*
	T_1	T_2	T_3		
EFW*	17.88160±4.194788	28.9700±0.885816	28.58600±4.018579	10	0.001
BPD	0.41232±0.076823	0.32960±0.065363	0.27400±0.063608	10	0.075
OFD*	0.53920±0.056575	0.36584±0.081613	0.15920±0.032453	10	<0.001
Head circumference*	1.55380±0.167028	1.11260±0.148485	0.72404±0.159326	10	<0.001
Abdomen circumference	1.70460±0.409269	1.42830±0.145840	1.18000±0.201866	10	0.087
Femur length*	0.36648±0.051861	0.29074±0.024727	0.26590±0.26590	10	0.027
Head to chin	0.48329±0.183050	0.44600±0.142574	0.29925±0.249088	10	0.425
Neck to hip	0.60325±0.214564	0.99700±0.783584	0.28738±0.134336	10	0.223
Hip to knee	0.55533±0.299308	0.34733±0.172862	0.25400±0.139528	10	0.326
Knee to foot	0.44275±0.091014	0.21525±0.098642	0.22850±0.181779	10	0.139
Shoulder to elbow	0.33200±0.130652	0.31320±0.143648	0.20140±0.157089	10	0.434
Elbow to wrist	0.26800±0.196022	0.22940±0.231710	0.27700±0.115789	10	0.923

*: Statistically significant. T_1 – Interval between the first and second scans (20th-28th week); T_2 – Interval between the second and third scans (28th-32nd week); T_3 – Interval between the third and fourth scans (32nd-36th); T_4 – Interval between the fourth scan and birth (36th week to birth). ESW – Estimated fetal weight; BPD – Biparietal diameter; OFD – Occipitofrontal diameter; SD – Standard deviation

Table 3: Cephalocaudal growth gradient at different intervals

	Mean±SD	*n*	*P*
20 weeks	0.343400±0.0206833	10	0.753
28 weeks	0.339300±0.0240094	10	
Birth	0.320660±0.0574562	10	

SD – Standard deviation

Table 4: Cephalic index at different interval

Cephalic index (weeks)	Mean±SD	*n*
20	77.2990±3.41867	10
28	77.6300±2.32064	10
32	78.7060±2.47602	10
36	80.8950±1.25245	10
At birth	81.7420±2.06480	10

SD – Standard deviation

Table 5: The predicted and actual growth

	Predicted measurement at birth	Actual measurement at birth	Percentage of error
Birth weight	3425.77	3138	9.145
Maximum skull width	95.116	93.66	1.554
Maximum skull length	114.77	114	0.675
Head circumference	339.84	347.50	−2.204
Abdomen circumference	343.07	340	0.905
Head to chin	129.97	129.83	0.11
Neck to hip	171.88	210	−18.152
Hip to knee	103.6	113.33	−8.58
Knee to foot	93.07	107	−12.63
Shoulder to elbow	88.746	92.9	−4.47
Elbow to wrist	73.360	79.16	−3.53

with the postnatal HC with an error of −2.204%. H-C, a new parameter used in this study, can be compared with H-C measurement at birth with the percentage error of 0.11%.

DISCUSSION

The assessment of growth is important for treatment planning and timing of orthodontic therapy. Although many studies have been conducted in the past to understand the relationship between prenatal and postnatal growth, no study has been conducted to date using ultrasound in orthodontics. Six established parameters and six new parameters were used to evaluate prenatal growth. These parameters were used as indicators and predictors to evaluate growth [Table 2 and 3].

Established parameters

The per day growth of the fetus was evaluated using all the parameters. The growth rate of EFW, OFD, HC, and FL was statistically significant ($P < 0.001$). The growth rate of EFW was maximum between the 28th and 32nd week and then remained almost the same [Table 2], and when compared to the birth weight the mean percentage error was 9.145% [Table 5], which was in the same range as reported by Pinette.[30] HC and OFD are important predictors of craniofacial growth, and growth rate was found to be maximum between the 20th and 28th week of the fetal life. Predicted and postnatal measurements of HC and OFD were found to be accurate [Table 5]. FL is the ossified portion of a femur and one of the indicators of growth. The growth of FL was maximum between the 20th and 28th week of the fetal life. A similar comparison with FL was not possible because the FL is a hard-tissue parameter, could not be measured after birth. When compared to birth measurement, BPD and AC were found to be accurate and reliable [Table 5].

New parameters

All the new parameters also showed peak growth between the 20th and 28th week of the fetal life [Table 2]. H-C, a new parameter introduced in this study, was found to be reliable and accurate. The percentage error between the predicted and actual growth of H-C was found to be 0.11% [Table 5]. The cephalocaudal growth gradient was decreased from the 20th weeks to birth [Table 3]. Cephalocaudal growth gradient at the 32nd and 36th week was not calculated because of limitations in measuring the N-H parameter. The CI ranges from 77% to 82% indicating mesocephalic head types [Table 4].

In general, peak growth of fetus was between the 20th and 28th week of the fetal life which indicates that maximum growth and development of the fetus takes place during this period. Since very few longitudinal studies have been conducted in the past, serial values with repeated ultrasounds will help in studying prenatal growth and development. As multiple parameters are required to assess prenatal growth, the newly introduced parameters can also be used to measure growth. The study of craniofacial complex, which includes maxilla and mandible, is important to orthodontists and can be studied using scheduled ultrasound examinations. Individual linear and angular measurement of facial bones can be studied and followed up using ultrasound. Further studies are required to validate newly introduced parameters.

CONCLUSION

Cephalocaudal growth decreases with age. H-C, a new parameter introduced in this study, is found to be more predictable and reliable to measure craniofacial growth. Prenatal growth influences postnatal growth. Ultrasonography as a diagnostic tool holds a remarkable future in orthodontics as a noninvasive and cost-effective technique.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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