Craniofacial proportionality in a horizontal and vertical plane, a study in norma lateralis*

Benjamin H. Williams, D.D.S. M.S.
Columbus, Ohio

The human skull or cranium consists of a complex collection of bones serving a number of functions. It is divisible into the cerebral cranium, or calvaria, and the visceral cranium, or face. The bones of the face and the areas to which they contribute show wide ranges of variability in their rate, time, and sequence of growth and in their final size. When these parts are combined and constitute a pattern, they may or may not be in harmony with each other. It is believed that the pattern of an individual is established well before birth and remains remarkably stable. Growth of this pattern is an even and orderly process, proceeding on diminishing gradients. (Brodie '50).

The external form of the vertebrate organism is based on the relative growth along three axes: (1) one axis is longitudinal, with cephalic and caudal ends; and (2 and 3) the other two are at right angles to each other, one dorso-ventral and the other lateral, at right angles to the longitudinal axis. (Krogman '40). Growth, then, is in three planes, and balance and symmetry are thus inherent in the basic vertebrate growth pattern. Mass is achieved by growth in all three dimensions, but, because the increases are different in the three dimensions, such growth results in something other than a mere blowing up. This process which witnesses the transformation of the infant to the adult has been called by various names such as development or maturation.

The study of the proportions of the human body has occupied attention for many years. Some of the earliest Egyptian statues were carved from a set standard. The sculptors of Greece relied extensively upon a definite formula of proportion, "the canon of Polycletus". (Wilder '26). According to this canon the face was one-tenth and the head one-eighth of the total height of the body. The face was divided into three equal parts from the chin to the lower border of the nose, thence to the upper border, and from the latter to the hair line.

Angle ('07) was of the opinion that, "the study of orthodontia is indissolubly connected with art as related to the human face". He was aware "that while all human faces are greatly alike, yet all differ". He continued that "lines and rules for their measurements have ever been sought by artists, and many have been the plans for determining some basic line or principle from which to detect variation from the normal".

It has long been an observed fact that the head is closest to its adult size at birth, that the trunk is next and the limbs last. One would therefore say that the head at birth was relatively larger in proportion to the rest of the body and relatively small in the adult. This would certainly seem to indicate a change in proportion. Certain studies however, have indicated that such ultimate changes in total proportions may result from the interaction of growth

*Presented at the Second Reunion Meeting of the Department of Graduate Orthodontia, University of Illinois, Chicago, Illinois, March 1951.

rates which are coordinated with each other. Thus Scammon and Calkins ('29) found that in general the linear growths of the various parts of the body were in uniform ratios during the fetal period. This seemed to conflict with the well-known fact that the proportions of the various regions changed during this period. However, they demonstrated clearly that these changes in proportion arose through inequalities of growth rates already established in the earlier embryonic period. The newly recognized law of uniform fetal growth ratios was shown to be in complete harmony with the previously known "law of developmental direction".

Both environmental and hereditary factors play an important role in influencing facial proportions. Draper ('35) has related facial features to disease; Wylie ('47) has described modification of head form to environment; Ivanousky ('23) has reported changes in measurements during famine; and Stockard and associates ('41) have investigated the basis of genetic and endocrinic differences in form and behavior.

Some attempts have been made to determine the relationship between the growth of facial components in cross sectional studies on skeletal and living human material. Using measurements from skull collections, Izard ('27) claimed a definite proportion between face and dental arch. The maximum breadth of the dental arch is said to bear a constant ratio to the maximum bizygomatic width. Likewise, a constant ratio is said to exist between the length of the arch and the depth of the face. Meredith and Higley ('51) failed to confirm Izard's results.

Hellman ('39) used an index or ratio in order to describe facial proportions independent of absolute size. Thus he was able to study the various parts of the face in relation to each other. In one of his papers, Hellman ('35) concluded that the infant's face is transformed into that of the adult by an increase in size, by changes in proportion, and by adjustment in position.

In longitudinal studies of human head growth, Broadbent ('41) demonstrated by a method of superposing serial tracings of head X-rays, a remarkable stability of certain parts of the facial skeleton. Brodie ('41), using a similar though quantitative method on a sample of white males from the third month to the eighth year of life found facial growth so orderly that basic angular measurements remained contant in the same individual. He concluded that the morphogenetic pattern of the face was established by at least the third month of life and thereafter did not change.

Tirk ('48) employed a planimeter on tracings of serial cephalometric roentgenograms after dividing the face into its functional areas. The findings indicated an early establishment of the facial pattern and the maintenance of the proportions of these areas to one another, at least in norma lateralis.

In a statistical analysis of measurements derived from cephalometric roentgenograms, Wylie ('44) showed that the nasal and dental heights were among the most stable of the craniofacial dimensions. He accepted as true the assertion of Brodie that proportionality of facial parts did not change during growth and developed an "Assessment of Anteroposterior Dysplasia". (Wylie '47). He had noted considerable variation between the lengths of the segments which, combined, contribute to the anteroposterior dimension of the face, and also that such variation did not necessarily lead to great overall differences. The study of individual cases revealed that where one segment was overly large its effect might be obscured by another that was smaller than average. Dysplasia resulted when deviations of like kind in the same direction were clustered in the same individual.

In spite of the seeming agreement in the findings of Brodie, Tirk, Wylie and other recent workers, certain questions have arisen regarding the constancy of proportions of facial parts during growth. As data has accumulated on the period of puberty and young adulthood, these stages have been subjected to intense scrutiny. Bjork ('47) has reported on the differences between the profiles of boys and those of men of conscript age. Lande ('51) has made a longitudinal study of males from the third to the eighteenth year showing some changes in the configuration of the bony facial profile with age.

The present study was undertaken to ascertain statistically what changes, if any, occur with age in certain craniofacial proportions in the horizontal and vertical planes. Utilizing measurements from lateral roentgenographic tracings, a statistical analysis was made and certain anatomical points were found to remain proportionally stable while others changed.

Material and Method

The material used in this investigation was derived from the files of the Department of Orthodontia, University of Illinois. Thirty cases were chosen which had not received orthodontic treatment and were in normal or ideal occlusion, according to the Angle Classification. Of these thirty cases, twenty-four were males and six were females. Films showing the teeth in occlusion were picked at random from each patient's file on the basis of the quality of the film. Because possible age changes were our main interest, two films were utilized, one before and one after the probable onset of puberty. The mean pre-puberal age was 8.13 years with a standard deviation of 0.94; post-puberal age, 15.16 years with standard deviation of 0.87.

Measurements were made on the tracings of oriented headplates. The technique for taking and tracing these cephalometric films has been described. (Brodie '41). Bilateral anatomical points and structures are at times not superposed on well oriented lateral head films. For this reason, the mid-point between the bilateral structures was used, with the exception of the upper left first molar. This reduced the distortion caused by differences in the distance from the mid-line to the various points used and thus allowed all structures to be considered as lying in the mid-line. This procedure also tended to eliminate errors caused by slightly improper orientation of the patient during exposure of the film.

The factor of size distortion, introduced by the distance of the film from the mid-saggital plane of the head, did not require consideration since all measurements were converted to proportions. The group was not divided according to sex since changes in proportion due to this factor were not considered in this investigation.

Definitions of the anatomical points of interest employed are given in the glossary of terms and a typical tracing illustrating these points is shown in Figure 1.

Glossary of Terms

S *The center of sella turcica.* Located by inspection.

N *Nasion.* The mid-point of the suture between frontal and nasal bones.

Bol *Bolton point.* The highest point of the concavity of the condyloid fossa of the occupital bone.

P *Porion (cephalometric).* The uppermost point on the soft tissue overlying the external auditory meatus.

O *Orbitale.* The lowest point on the inferior margin of the orbit.

ANS *Anterior nasal spine.*

A *Subspinale.* The most posterior mid-line point on the pre-maxilla between the anterior nasal spine and prosthion.

B *Supermentale.* The most posterior mid-line point on the mandible between infradentale and pogonion.

Po *Pogonion.* The most anterior point in the mid-line of the mandibular symphysis.

Gn *Gnathion.* A point on the chin determined by bisecting the angle formed by the facial and mandibular planes. (The facial plane passes through nasion and pogonion. The mandibular plane used is a line tangent to the lower border of the mandible posteriorly and to the cross-section of the symphysis anteriorly.

Go *Gonion.* A point on the gonial angle determined by bisecting the angle formed between the mandibular plane and the plane representing the posterior border of the ramus.

C *Point C.* Formed by the intersection of the plane representing the posterior border of the ramus and the plane drawn parallel to the anterior nasal spine-Bolton plane, through the lowest point of the sigmoid notch of the mandible.

Ptm *Pterygomaxillary junction.* The point at which the maxillary tuberosity abuts against the pterygoid process of the sphenoid bone.

6 *Maxillary first molar.* A point midway between the mesial and distal buccal cusps of the left maxillary first molar.

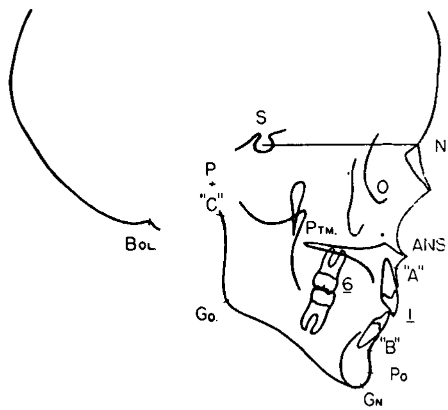

Fig. 1. Points used in this study.

1 *Upper central incisor.* A point representing the incisal edge of this tooth.

Tracings of the lateral head plates were made in the usual manner and the anatomical points were located. The tracings were then laid on millimeter graph paper as follows: the graph paper was divided into four quadrants by two coordinates, or axes of reference; one horizontal which we will call X, and one vertical, which we will call Y; these intersected in the middle of the page. Plane S-N was chosen as the plane of reference and was laid on the X axis with S superposed at the intersection of the X and Y axes. (Figure 2).

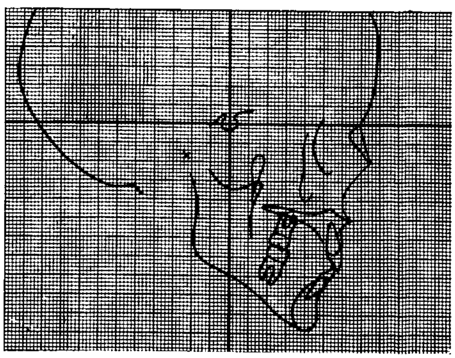

Fig. 2. Plane of reference and axes.

Positions for each anatomical point could be established in relation to the X and Y axes for both the pre- and post-puberal age groups. These were defined as distances in millimeters from the respective axes. The mean position of each point in the pre-puberal group was compared with that in the post-puberal group. (See Table 1 and Figure 3). Proportions or ratios were employed, using the distance S-N as 100% along the X axis, and the distance from the X axis to Gn as 100% along the Y axis. The mean of the proportions for each point, along these axes, and for the pre- and post-puberal age groups were determined and expressed in percentages. (Table 1). Henceforth, these mean proportions will be called the relative distance of the various points, such as the relative distance of point A.

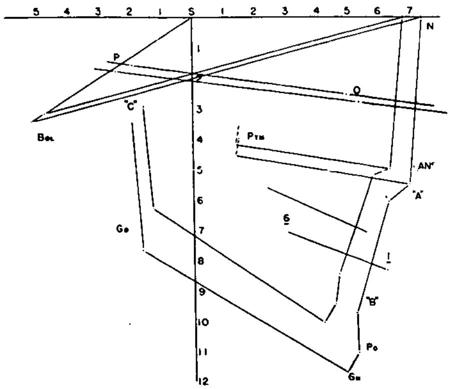

Fig. 3. Mean position of each anatomical point in pre-puberal and post-puberal groups.

The absolute distances of any point, such as A, was expressed as X′ A or Y′ A.

TABLE 1

MEAN DISTANCE IN MILLIMETERS AND THE MEAN PROPORTION IN PERCENT OF THE ANATOMICAL POINTS ALONG THE X AND Y AXES

Anatomical Points	*Dimensions*		*Proportions*	
	Pre-	*Post*	*Pre-*	*Post*
SN	67.7	73.8	100.00	100.00
X' ANS	63.7	70.1	94.18	95.13
Y' ANS	47.9	55.1	47.08	46.94
X' A	58.1	63.2	85.83	85.75
Y' A	52.0	60.8	51.46	51.75
X' *1*	56.7	62.7	83.88	85.18
Y' *1*	71.1	83.3	70.88	70.32
X' B	47.1	52.7	69.67	71.62
Y' B	84.6	97.4	84.25	82.93
X, Po	45.9	53.3	67.92	72.41
Y, Po	94.3	110.7	94.60	95.11
X' Gn	42.2	49.6	62.68	67.39
Y' Gn	100.4	117.4	100.00	100.00
Y' Go	62.6	76.3	62.98	63.90
X' Go	13.1	16.6	19.44	22.44
X' C	16.0	19.9	23.74	26.97
Y' C	29.1	33.4	28.51	28.44
X' P	19.6	24.8	29.05	33.67
Y' P	15.5	17.5	16.35	14.88
X' O	49.6	53.4	73.98	65.51
Y' O	25.2	27.9	25.25	21.30
X' *6*	23.2	29.8	34.29	40.41
Y' *6*	55.7	70.2	55.41	58.62
X' Ptm	14.7	14.7	21.81	19.89
Y' Ptm	34.5	39.5	34.36	32.85
X' Bol	48.0	52.3	70.91	71.11
Y' Bol	31.3	34.1	31.27	29.19

A few key anatomical points were selected which would define the position of the upper and lower faces in relation to the cranial base. These points were: A, B, Gn, Go, and C. Bolton point was included to relate the posterior cranial base to the anterior cranial base; similarly, orbitale was related to point A. These points were statistically analyzed to determine whether the mean proportions observed in the tables in the pre- and post-puberal groups changed with age.

Because of an interest in lower face growth, the following relations were also studied: X′ Go+X′ Gn/SN; the actual length of Go Gn/SN; X′ Go/X′ Gn; X′ C/X′ Bol; and X′ Go/X′ C.

Snedecor's "t" values, using the method of paired comparisons, (Snedecor '48) answered this question and we accepted the 5% level as the critical level of probability as the standard of statistical significance. (Table 2).

In connection with X′ Go/X′ Gn and X′ Go/X′ C, it was found profitable to apply an analysis of covariance in order to establish F values.

For each proportion limits were set around the mean of the difference between the pre- and post-puberal groups. This was established by use of the confidence or fiducial inference at the .05 level. According to this statistic, 95% of the population should fall within these limits. These calculations were made in order to facilitate comparisons with other groups in future studies.

Observations

Certain impressions could be gained by comparing the mean relative distance of each point along the X and Y axes in the pre- and post-puberal age groups. An example of relative constancy is afforded by point A. Ptm remained stable in its position from the Y axis, but showed a decrease in its relative distance along both axes. The upper first molar revealed an increase in its relative distance along both axes. Point C tended to increase its relative distance along the X axis, but it remained fairly stable in the Y axis. Bolton point was apparently stable in the X axis and showed a slightly decreased relative distance in the Y axis. The numeral value of these findings only revealed the mean pattern or trend. (Table 1).

A statistical analysis was applied to determine whether or not these observations were significant. Could the differences in the relative positions shown by these anatomical points in the pre-puberal and post-puberal age groupings be accounted for on the basis of mere chance? The "t" value was calculated by the method of paired comparisons.

The "t" values confirmed that the following relations remained stable: X′ A, Y′ A, X′ Bol, Y′ C, and X′ O/X′ A. The following relations were shown to differ significantly in the two groups: X′ B, Y′ B, X′ Gn, X′ Go, Y′ Go, X′ C, Y′ Bol, X′ O/Y′ A, Go Gn/SN, X′ Go+X′ Gn/SN, and X′ C/X′ Bol.

X′ Go/X′ Gn and X′ Go/X′ C, which had low "t" values, displayed high standard deviations. For this reason the statistical analysis was further pursued using the method of covariance. The analysis of covariance allows a comparison; for example, the pre- and post-puberal X′ Go/SN proportions, and the pre- and post-puberal X′ Gn/SN proportions. At the same time it informs us whether the X′ Gn distance was proportional to, or bore any relation to the X′ Go distance. F was found to be statistically different for the relationship X′ Go/X′ C, while F was found to be highly significant for the relationship X′ Go/X′ Gn.

Other relations showing highly significant differences were: X′ Gn, X′ Go, X′ C, Y′ Bol., Y′ O/Y′ A, Go Gn/SN, and X′ Go+X′ Gn/SN. (Table 2).

Fiducial limits of the differences of the two groups were established in order that comparisons might be made with other groups in future studies. These are compiled in Table 2. For points which are relatively stable, the fiducial limits will be found to be narrow. For example, X′ A with a mean difference of 0.1%, will show limits from -0.95 to 1.15%. On the other hand, the relations which show a significant difference in their means in the pre- and post-puberal groups had broader fiducial limits. For example, X′ Gn with a mean difference of 4.4%, had limits from 2.7 to 6.1%.

Discussion

This investigation seems to indicate that the relative distance of certain anatomical points maintains a constant relationship to the cranial base (S-N plane) and/or to the total facial height (Y′ Gn distance). Point A was found to be stable in its proportional relationship in both planes, and verified the findings of other investigators.

On the other hand it would appear that the relationship of the horizontal distance of Gn from a reference axis to the length of the anterior cranial base is altered. Does this mean that the mandible is growing more rapidly than the cranial base? Lande ('51), in a study of the facial profile, pointed out that in some individuals the lower face as typified by Gn appeared to grow

TABLE 2.

Table Showing the Standard Deviation, Standard Error, "t" Value, the Probability Value, the Mean Difference, and the Fiducial Limits of the Mean

Anatomical Points	*s*	*SE*	*"t"*	*P*	*The Mean Difference*	*Fiducial Limits*	
X' A	2.82	.51	0.19	>.8	0.1	-.95	1.15
Y' A	2.95	.54	0.56	>.5	0.3	-.80	1.40
X' B	4.20	.77	2.48	>.01	1.9	..33	3.47
Y' B	2.47	.45	3.10	<.01	-1.4	-.47	-2.32
X' Gn	4.64	.85	5.19	<.001	4.4	2.66	6.13
X' Go	3.66	.67	4.46	<.001	3.0	1.64	4.36
Y' Go	2.90	.53	2.84	<.01	1.5	.42	2.58
X' C	2.72	.50	6.45	<.001	3.2	2.19	4.21
Y' C	3.20	.58	0.85	.4	-0.5	.69	-1.69
X' Bol	3.35	.61	0.33	>.7	0.2	-1.05	1.45
Y' Bol	2.29	.42	4.07	<.001	-1.7	-.85	-2.55
X' O/X' A	3.11	.64	1.26	>.2	-0.8	.51	-2.11
Y' O/Y' A	2.78	.57	4.40	<.001	-2.5	-1.33	-3.68
Go Gn/SN	3.19	.58	13.21	<.001	7.7	6.51	8.89
X' Go+X' Gn / SN	4.11	.75	10.13	<.001	7.6	6.07	9.13
X' Go/X' Gn	8.31	1.52	1.98	.08	3.0	Used F	Value
X' C/X' Bol	8.32	1.47	3.41	<.01	5.0	2.00	8.00
X' Go/X' C	13.06	2.39	0.38	.7	0.9	Used F	Value

BY ANALYSIS OF COVARIANCE

Relations	*F*	*P*	*F Values*
X' Go/X' Gn	11.83	<.01	F1% = 7.08
X' Go/X' C	7.20	<.01	F5% = 4.00

relatively more in the horizontal plane. It seems that a part of this change occurs at the symphysis. Brodie ('50) noted that the images of the mandibular symphysis of the same individual at an early age could not be superposed with those of a later stage of growth. He also showed a change in the relationship of the alveolar process to the skeletal portion of the mandible, which he explained by stating that after a certain age the denture was not moving forward at the same rate as was the total facial skeleton.

An examination of the X′ B distance, which in part reflects mandibular alveolar process, revealed a change. It must also be noted that the change was not as great as that occurring at gnathion, nor was the mean difference between the pre- and post-puberal age groups as great. In other words, B does not appear to be moving forward as rapidly as Gn.

The constancy in the two groups of X′ O/X′ A would seem to indicate a stable relative growth rate in the horizontal direction in the upper face. The relative growth along the X axis of the upper face might be construed to be fairly constant, while the components of the lower face indicate a variable relationship. On the whole it would seem that the vertical proportions are quite variable and would indicate the need for further study.

It is attractive to consider the possible role of the hormonal changes occurring during the period under study. Could the change in relative proportions reflect hormonal influence on growth gradients of the craniofacial sites? Since this study was limited to two groups taken at a wide interval, it would be desirable to have a study taken at closer intervals to answer some of these questions.

Whenever we apply statistical procedures to the evaluation of a problem, great care must be taken to apply the correct procedures, especially if we are to extend the data to the description of an individual. This cannot be done until comparisons are made with other groups representing various classes of malocclusions.

A continuation of investigations along the lines employed in the present study are being planned by the author.

SUMMARY

A comparison of the same individuals before and after the onset of puberty was made to determine the craniofacial proportionality in a horizontal and vertical plane. The relative distance of certain anatomical points apparently remain stable. They are: X′ A, Y′ A, X′ Bol, Y′ C and X′ O/X′ A. Other relations showed statistical differences in the two groups. They are: X′ B, Y′ B, X′ Gn, X′ Go, Y′ Go, X′ C, Y′ Bol, Y′ O/Y′ A, Go Gn/SN, X′ Go+X′ Gn/SN, X′ Go/X′ Gn, X′ C/X′ Bol, and X′ Go/X′ C.

ACKNOWLEDGEMENTS

The author wishes to extend sincere thanks to his advisor, Dr. Allan G. Brodie for his stimulating advice during the investigation of this problem, to Dr. Allan G. Brodie and Dr. Milton B. Engel for their counsel during the preparation of this thesis, and to Dr. Gerhardt Von Bonin, and Mr. Henry Swain for their helpful advice with the statistical problem.

VII. Bibliography

Angle, Edward H. 1907 Malocclusion of the Teeth, 7th ed. S.S. White Dental Mfg. Co., Philadelphia.

Bjork, A. 1947 The Face in Profile. Svensk Tandl. Tidakr., supp. 40, No. 5B.

Broadbent, B. Holly 1941 Ontogenetic Development of Occlusion. Angle Orthodontist, 11: 223-241.

Brodie, Allan G. 1950 Appraisal of Present Concepts in Orthodontia. Angle Orthodontist, 20: 24-38.

——————, 1941 On the Growth Pattern of the Human Head, From the Third Month to the Eighth Year of Life. Am. J. Anat. 67: 209-262.

Draper, George 1935 The Relation of Face, Jaws, and Teeth to Human Constitution and Its Bearing on Disease. Dent. Cosmos, 77: 825-840.

Hellman, Milo 1935 The Face in its Developmental Career. Dent. Cosmos, 77: 685-699, 777-787.

——————, 1939 Some Facial Features and Their Orthodontic Implications. Am. J. Orthodontics, 25: 927-951.

Ivanousky, A. 1923 Physical Modifications of the Population of Russia Under Famine. Am. J. Phys. Anthrop. 6: 331-353.

Izard, G. 1927 Goniomandibular Angle in Dento-facial Orthopedia. Internat. J. Orthodont., 13: 578-581.

Krogman, Wilton M. 1940 Growth Theory and Orthodontic Practice. Angle Orthodontist ,10: 179-191.

Lande, M. J. 1951 Growth Behavior of the Human Bony Facial Profile as Revealed by Serial Cephalometric Roentgenology. Master's Thesis, University of Illinois.

Meredith, H. V., and L. B. Higley 1951 Relationship Between Dental Arch Widths and Widths of the Face and Head. Am. J. Orthodontics, 37: 193-204.

Scammon, R. E., and L. A. Calkins 1929 The Development and Growth of the External Dimensions of the Human Body in the Fetal Period. The University of Minnesota Press, Minneapolis.

Snedecor, George W. 1948 Statistical Methods. The Iowa State College Press, Ames, Iowa.

Stockard, C. R., O. D. Anderson and W. T. James 1941 The Genetic and Endocrinic Basis for Differences in Form and Behavior. Am. Anat. Memoirs, no. 19, Wistar Inst., Philadelphia.

Tirk, Theodore M. 1948 A Study of the Growth of the Head by Planimetric Method. Angle Orthodontist, 17: 76-94.

Wilder, H. H. 1926 The Pedigree of the Human Race. Henry Holt and Company, New York.

Wylie, Wendell L. 1944 Statistical Analysis of the Constancy of Certain Facial Dimensions. J. Dent. Res., 22: 200-201.

——————, 1947 The Assessment of Anteroposterior Dysplasia. Angle Orthodontist, 17: 97-109.

——————, 1947 Factors Modifying Head Form in Man. Am. J. Orthodontics, 33: 145-154.