Reliability of computer-generated prediction tracing

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The computer is fast becoming an indispensable tool in many areas of dental practice. The speed with which many laborious tasks can be completed has led to a proliferation of applications, including many related to diagnosis and treatment planning that can be carried out in the office of the practitioner.

To understand how we have progressed to the use of some of these applications, it is necessary to go back to very early attempts to predict craniofacial growth and development. Broadbent,[1] in his early work in 1937, suggested that in the average patient, the face grows downward and forward along a straight line. The ability to predict has been recognized as one of the hallmarks of science. For example, if we plug a particular set of numbers into a complex mathematical equation, we will always get the same result. Combining certain elements or chemical compounds under the same circumstances will always produce the same reaction. We can be certain that if an apple falls from a tree, unless there is a strong gust of wind, it will fall straight to the ground.

Why do we need to predict? Baumrind[2] summed it up simply in his chapter in Melsen's *Current Controversies in Orthodontics.* He stated that orthodontics is an art struggling to become a science, that the ability to predict makes the orthodontist feel scientific, and it is psychologically comfortable for the orthodontist to have the ability to predict.

Orthodontists have long recognized that the establishment of treatment objectives is always necessary for the development of a successful

Abstract

The reliability of a commercially available computer prediction program (Quick Ceph II) was evaluated using pretreatment and posttreatment cephalograms of 30 patients who were treated during an active period of growth. The computer prediction was compared with the actual treatment result, and the growth forecast with the computer program was compared with the growth forecast using a manual method. Using paired student's t-tests, predictions for 5 of the 10 variables measured were found to be statistically reliable. Comparing the relative accuracy of growth prediction in terms of absolute values, the computer came closer to the actual result in four of the nine variables, while the manual method came closer in three variables. Predictions for the other two variables were virtually the same using both methods. The manual method of prediction was sufficient to give a reasonably good graphic representation of growth changes to create a VTO. However, the computer offers the added advantages of quicker access to information and somewhat greater accuracy in producing the tracing, as well as its use in patient education.

Key Words

Computer • Prediction tracing • Growth forecast • Cephalometrics • Reliability.

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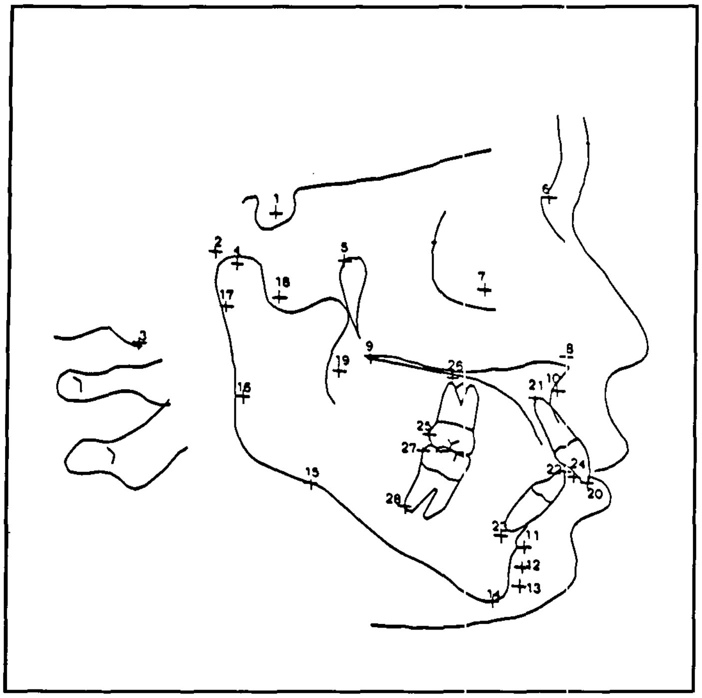

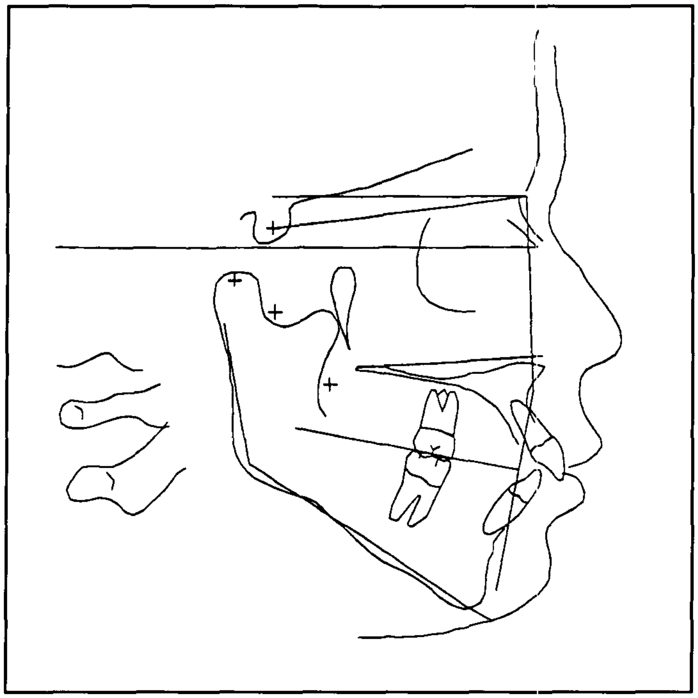

Figure 1
Landmarks used in the study: 1. sella; 2. porion; 3. basion; 4. hinge axis; 5. pterygoid; 6. nasion; 7. orbitale; 8. ANS; 9. PNS; 10. A point; 11. B point; 12. PM (point where curvature changes between B point and pogonion); 13.pogonion; 14. menton; 15. corpus left; 16. ramus down; 17. articulare; 18. R3 (most inferior point of the sigmoid notch); 19. R1 (deepest point on the anterior border of the ramus; 20. Mx1 crown; 21. Mx1 root; 22. Md1 crown; 23. Md1 root; 24. occlusal plane; 25. Mx6 crown; 26. Mx6 root; 27. Md6 crown; 28. Md6 root.

Figure 2
Horizontal plane constructed (7 degrees from the SN line at Nasion).

treatment plan. Holdaway coined the term visual treatment objective (VTO) in 1971, but it has been more often associated with Ricketts[3] and the Rocky Mountain Data System (RMDS). The purpose of the VTO is to forecast both the patient's growth and the anticipated influence of treatment to yield a "posttreatment" cephalometric picture or blueprint. The VTO introduced by Ricketts involves a complex construction sequence that generates predictions in six areas: the cranial base, the mandible, the maxilla, the occlusal plane, the location of the dentition, and the soft tissue profile. Using generalized growth averages, points and lines may be projected to produce a tracing that represents the direction and amount the patient may be expected to grow over a given period of time, usually the estimated duration of treatment. Using this new tracing, the VTO is then constructed by creating more normal or ideal dental and/or skeletal positions.

Many other techniques have been developed to create VTOs.[4,5,6,7,8] Growth prediction plays a significant role in creating a reasonably reliable VTO. In attempts to make predictions, Hixon[9] pointed out that the accepted standard error for most measurements should not be more than 5% or 6% of the total distance measured. Because craniofacial growth is a relatively slow process, a small error in constructing the tracing could cause a significant difference in the result obtained.

Some of the problems which have been cited with the use of the cephalogram are:

1. The originating rays are not parallel; they emerge from a small source, which causes enlargement and distortion.
2. Landmark identification errors are caused by overlapping anatomical structures or points that require interpretation (e.g., gonion, pogonion, A point, sella).
3. Mechanical errors sometimes occur when drawing points and lines.

In 1980 Richardson[10] found that traditional methods of landmark identification were only slightly less accurate than using a digitizer. Most of the software available currently requires the user to digitize the radiograph by inputting the landmarks with a computer mouse or digital pen. In the early 1970s, before computers became standard equipment in the average office, Rocky Mountain Data System (RMDS) was developed with the purposed of enabling the orthodontist to take advantage of computerized cephalometric analysis and development of individualized treatment objectives for each patient. In 1975 Greenberg and Johnston[11] tested the accuracy of the RMDS and found it to be just about equal in accuracy to estimates using constants from an independent growth sample. While they found it to be more accurate than forecasting no growth at all, it had limited clinical utility, and it was suggested that a forecast grid that could be superimposed over a tracing would be at least as useful. However, they did conclude that although the commercial forecast was limited in accuracy, it did provide a graphic representation of the most probable pattern of growth, and it allowed the clinician to visualize the various treatment alternatives.

With the tremendous advances in computer technology, computers are now smaller, faster, and cheaper; they have greater memory and are generally found in the orthodontic office.

Materials and methods

A sample of 30 patients, all treated at the Columbia University Orthodontic Clinic and judged by three faculty members to be well treated, was studied. The average age of the sample at the start of treatment was 11 years and 8 months. All the cases selected were treated on a nonextraction basis with complete upper and lower fixed appliances. Nonextraction cases were selected to minimize the effects of tooth movement on the final outcome. Quick Ceph Two Version 9.0 (Ortho Processing, Chula Vista, Calif) was used on a Macintosh Two SI computer with a high resolution color monitor. Twenty-eight landmarks were digitized on the pretreatment cephalograms, and the soft tissue profile was traced (Figure 1). A growth forecast was then generated according to the length of active treatment. Quick Ceph limits growth forecasts to up to 14 years for females and up to 18 years for males. Due to what the manufacturer calls a "special radial method" to calculate growth, the amount of growth in different directions varies with facial type (e.g., in hyperdivergent skeletal patterns the forecast is in a more vertical direction, while in hypodivergent cases it is in a more horizontal direction). To simulate soft tissue changes due to treatment, the user may select either the Holdaway ratio or the Ricketts ratio. The Holdaway method indicates that lip movement is in a 1:1 ratio to incisor movement after lip strain has been eliminated. The Ricketts ratio is predicated on a 2:3 ratio of lip movement in response to upper incisor movement.

With the tracing produced from the growth forecast as a base, the treatment simulation application was then used to create a VTO by moving the teeth into corrected positions. Because all of the cases were treated nonextraction, minimal and mostly bodily movement (except in cases with extreme incisor flaring) was needed to establish ideal overbite, overjet, axial relations of the incisors, and Class I molar relationships. Next, the posttreatment cephalogram was digitized in the same manner. Using 10 measurements from the Columbia Analysis,[12] which had been previously programmed, standard descriptive statistics (Statview SE + Graphics, Abacus Concepts Inc, Berkeley, Calif) were used to determine how close the prediction came to the actual posttreatment result. The measurements used in this part of the study were: SNA, SNB, ANB, SN-MP, PP-MP, Y-axis, L1-MP, U1-SN, U1-L1 and L1-APo.

This part of the study essentially tested the reliability of the treatment simulation program, the skill of the user in constructing the VTO and how close the clinician came to attaining ideal treatment objectives. In order to further test the growth forecasting application, a second and arbitrary method of "growing" the original tracing was devised. The same 30 cases were traced manually using the same points as the computer program, and angular and linear measurements were made. A Horizontal Plane was constructed as in the Burstone Analysis[13] (seven degrees from the SN line at nasion). See Figure 2. To simulate growth, all points were advanced 1 mm downward and 1 mm forward per year of treatment, and these measurements were made either parallel or perpendicular to the horizontal plane. Using the Y- axis as a guide, any case which had a Y-axis greater than two standard deviations above normal was advanced 1.5 mm downward and only 0.5 mm forward. Likewise, if the Y-axis was more than two standard deviations below normal, all points were advanced 1.5 mm forward and only 0.5 mm downward. This was the only concession made to facial type. In order to get a better idea of overall changes in size, additional measurements were made of total anterior face height (from nasion to menton) and posterior face height (from sella to gonion). The ratio of posterior to anterior face height (S-Go/N-Me) for both methods was also calculated. In this part of the study, measurements of tooth position were eliminated and focus was placed on craniofacial size and shape change.

Table 1
Predicted cephalometric results (VTO) for 30 patients

	SNA	SNB	ANB	SN-GoGN	PP-GoGN	Y-Axis	L1-GoGN	U1-SN	U1-L1	L1-APO
1	80.600	74.000	6.500	45.800	36.400	74.700	88.700	104.800	120.700	.300
2	85.400	82.400	3.000	32.800	23.900	65.700	101.000	105.100	121.000	4.400
3	82.300	80.500	1.800	32.100	25.900	66.200	102.600	104.400	120.900	4.600
4	80.700	80.200	.500	34.200	34.600	68.400	93.300	112.300	120.300	5.700
5	89.000	83.600	5.400	32.000	25.200	69.100	99.800	109.700	118.500	8.900
6	87.500	85.300	2.200	28.800	22.100	61.900	100.500	107.900	122.700	2.700
7	85.600	79.700	5.900	26.900	16.000	66.700	104.500	104.700	123.900	.300
8	86.200	78.900	7.300	38.100	28.200	69.800	92.700	108.600	120.700	2.400
9	88.500	87.000	1.500	24.600	22.900	60.000	101.400	113.600	120.400	2.200
10	80.800	73.800	7.000	41.100	33.600	74.900	94.200	101.500	123.100	4.800
11	84.100	84.100	0	28.700	23.100	63.100	96.700	112.700	121.900	7.300
12	74.600	74.600	0	31.700	19.800	67.900	91.500	109.800	127.000	-3.600
13	82.500	76.400	6 100	39.700	30.600	69.900	93.400	102.400	124.400	.700
14	70.800	76.800	2 900	33.600	22.300	67.100	101.400	104.000	121.100	3.800
15	84.700	80.800	3 900	37.300	28.900	68.400	96.100	109.900	116.700	8.600
16	83.600	80.200	3 400	26.800	19.400	65.800	99.900	101.200	132.100	0
17	80.000	77.700	2 300	34.300	29.200	64.500	97.400	105.200	123.100	-.400
18	91.400	89.500	1.900	27.100	28.200	59.900	96.900	114.600	121.400	2.400
19	85.800	81.200	4.600	31.800	25.700	64.100	99.800	107.700	120.800	2.700
20	93.100	89.000	4.000	30.400	31.400	60.900	92.600	115.000	122.000	3.800
21	82.100	79.100	3.000	37.600	33.400	72.100	96.800	105.000	120.700	3.700
22	88.700	83.500	5.300	30.600	19.200	65.700	92.400	93.300	138.700	0
23	83.100	77.100	6.000	34.500	27.600	68.900	97.700	107.900	119.900	1.500
24	88.700	85.800	2.900	29.700	28.400	62.800	95.500	114.300	120.500	2.300
25	83.900	77.100	6.800	31.600	20.900	63.500	101.300	101.300	125.800	.900
26	81.900	78.700	3.200	33.800	21.800	67.500	98.400	103.200	124.600	2.200
27	85.700	84.100	1.600	33.900	29.500	64.100	96.500	106.900	122.700	4.900
28	83.600	79.900	3.700	41.500	41.400	73.000	93.600	103.000	121.800	9.200
29	84.900	82.500	2.400	38.000	37.200	70.300	88.100	104.400	129.500	5.400
30	90.600	89.000	1.600	26.700	16.600	61.400	100.200	107.500	125.600	3.900

Results

The measurements for the predictions (VTOs) are shown in Table 1, and the actual posttreatment results are shown in Table 2. The mean, standard deviation, standard error, and range for each measurement, both predicted and actual, were recorded. A comparative summary of the actual and predicted results is presented in Table 3. Six of the ten measurements showed relatively large differences of the means, with the lower incisor to mandibular plane showing the greatest difference. The angles SN-MP and PP-MP showed the smallest differences of the means.

Paired student's t-tests were done to establish statistical significance at the $P < .05$ level. A probability greater than .05 would indicate that the difference of the means is not statistically significant, and therefore the prediction could be considered accurate. On that basis, ANB, SN-MP, PP-MP, U1-SN and U1-Li can be considered ac-

Table 2
Actual cephalometric results (VTO) for 30 patients

	SNA	SNB	ANB	SN-GoGN	PP-GoGN	Y-Axis	L1-GoGN	U1-SN	U1-L1	L1-APO
1	76.500	68.200	7.300	49.000	35.400	78.800	88.100	83.300	139.500	1.700
2	83.000	78.800	4.200	34.700	27.900	67.600	101.600	114.400	109.300	3.300
3	87.300	84.300	3.000	29.500	24.200	65.200	108.500	107.200	114.800	9.300
4	77.200	77.700	-.500	36.000	34.200	70.700	96.200	100.000	127.900	5.800
5	85.900	81.800	4.100	34.100	27.800	71.100	106.000	115.700	104.100	10.800
6	81.500	80.000	1.600	31.800	23.900	64.600	90.400	104.300	133.500	1.700
7	85.100	84.000	1.100	17.900	10.900	59.800	111.400	114.800	115.900	4.000
8	70.900	75.800	4.200	38.700	26.900	72.400	107.700	99.700	113.900	7.900
9	84.300	82.200	2.100	29.700	22.300	63.700	104.400	120.400	105.500	7.100
10	77.800	70.900	6.800	44.300	35.900	77.100	99.300	93.700	122.700	6.200
11	83.200	82.200	1.000	31.300	25.000	65.200	99.600	111.600	117.500	6.300
12	69.200	72.700	-3.500	31.700	20.400	70.000	102.800	106.900	118.600	2.600
13	81.800	78.800	3.000	32.700	27.900	66.200	100.100	105.700	121.500	4.800
14	78.300	74.500	3.800	35.700	25.200	68.600	106.200	105.700	112.300	4.600
15	76.600	77.300	-.700	43.200	32.600	73.800	99.900	110.500	106.500	13.100
16	77.000	75.800	1.200	26.700	18.700	69.000	97.800	101.700	133.800	0
17	78.300	75.100	3.200	34.100	26.500	67.600	106.200	103.600	116.100	4.600
18	88.500	87.600	.900	22.900	21.200	59.300	86.700	114.100	136.300	3.000
19	88.500	82.900	5.600	29.300	21.100	63.000	104.700	113.300	112.700	4.700
20	86.700	81.100	5.500	39.600	31.800	72.000	104.800	93.100	122.500	6.200
21	76.800	73.800	3.00	36.000	27.000	74.700	97.200	99.100	127.600	2.400
22	88.600	85.000	3.600	28.800	17.300	63.600	101.100	105.600	124.500	1.200
23	79.000	75.700	4.200	36.500	30.700	72.300	108.700	95.200	119.600	6.900
24	83.500	81.800	1.700	31.100	27.300	65.200	104.900	123.000	100.900	9.600
25	80.400	75.000	5.300	33.200	22.000	71.800	105.800	98.900	122.100	3.900
26	78.800	74.600	4.200	35.400	21.600	70.400	104.100	104.300	116.200	5.100
27	81.300	81.100	.300	35.500	36.100	65.900	90.900	107.900	125.700	7.900
28	79.200	72.900	6.200	48.900	46.400	78.400	100.600	104.900	105.600	10.600
29	89.300	82.500	6.800	34.200	34.600	69.200	100.600	101.000	124.100	4.300
30	92.600	91.200	1.300	23.600	16.200	58.400	83.300	109.800	143.300	1.600

curate predictions while SNA, SNB, Y-axis, L1-MP and Li-APo are statistically inaccurate.

A comparison of the arbitrary manual method and computerized methods of prediction in relation to the actual results is summarized in Table 4A. Table 4B shows the absolute values of the differences of the means, which indicate that the manual predictions were closer for SNA, SNB, SN-MP and PP-MP, while the computer was closer for ANB, Y-axis and S-Go. The ratio S-Go/N-Me and the distance N-Me were virtually the same for both methods. Student t-tests for significance were done. They show that for the manual predictions, SNA, SN-MP, PP-MP, and the ratio S-Go-/ N-Me could be considered reliable, while for the computer predictions, ANB, SN-MP, PP-MP, S-Go, N-Me and S-Go/N-Me could be considered reliable.

Table 3
Summary of means

Measurement	Actual X ± SD	(range)	Predicted X ± SD	(range)	Difference (predicted - actual)
SNA	81.9 ± 5.1	(69.2 - 92.6)	84.6 ± 3.9	(74.6 - 93.1)	+2.7
SNB	78.8 ± 5.2	(68.2 - 91.2)	81.1 ± 4.3	(73.8 - 89.5)	+2.3
ANB	3.0 ± 2.5	(-3.5 - 7.3)	3.5 ± 2.1	(0.0-7.3)	+0.5
SN-GoGn	33.8 ± 6.9	(17. 9 - 49)	33.2 ± 5.0	(24.6 - 45.8)	+0.67
PP-GoGn	22.6 ± 7.3	(10.9 - 46.4)	26.8 ± 6.3	(16.0 - 41.4)	+0.2
Y-Axis	68.5 ± 5.3	(58.4 - 78.8)	66.6 ± 4.1	(59.9 - 74.9)	-1.9
L1-GoGn	100.6 ± 6.9	(83.3 - 111.4)	96.8 ± 4.1	(86.1 - 104.5)	-3.8
U1-SN	105.6 ± 8.5	(83.3 - 123)	106.9 ± 4.4	(98.3-115)	+1.3
U1-L1	119.8 ± 10.7	(100.9 - 143.3)	123.1 ± 4.3	(116.7 - 138.7)	+3.3
L1-APo	5.4 ± 3.1	(0.0 - 13.1)	3.2 ± 2.9	(-3.6 - 9.2)	-2.2

Discussion

The computer program overestimated growth at points A and B, resulting in poor predictions for SNA and SNB. However, since both were overestimated, the prediction for the ANB difference was fairly close to the actual posttreatment value. Both predictions for lower incisor position appeared to be inaccurate. This could be due to difficulty in placement of the tooth while using the treatment simulation application or failures of the clinician to attain the desired visual treatment objective. The most consistently accurate prediction was for the angle palatal plane to mandibular plane, while the least accurate was for the angle lower incisor to mandibular plane. Overall, it appears that the most reliable predictions were those involving angular measurements of anatomical planes, which are not greatly affected by treatment, while the least reliable had to do with anteroposterior or angular measurements of the incisors, which can be affected by the user's positioning of these teeth and the final treatment result attained.

Because all patients selected for this study were treated without extractions in order to minimize errors of tooth placement when using the prediction program, it might be assumed that if extraction cases had been used, the differences found might have been even greater. The angular measurements involving some of the anatomical planes (e.g. SN-MP, PP-MP) that can be considered an indication of facial proportion showed insignificant differences, which reinforces the concept that growth is gnomonic in nature (changes in size but not in shape). It has been shown[14] that points A and B are more readily affected by change in incisor position and subject to changes in axial inclination and spatial position that occur during treatment. This could make those points more susceptible to error in prediction.

The data presented show that, in terms of predicting proportional change, there is not a great deal of difference between the arbitrary manual method and the computer program. The computer tended to overestimate changes in size while the manual method tended to underestimate them. On the average, the computer came slightly closer to the actual result. However, in about one-third of the cases, the manual predictions were closer. This illustrates the problem of being able to forecast overall group behavior but limited ability to forecast for the individual.

Conclusions

From this study, it can be concluded that a manual method of prediction tracing is about as effective as a computer program in producing a reasonably good graphic representation of growth changes which take place during treatment, to assist in developing a visual treatment objective. The results of manual growth predictions could be enhanced by the use of some type of forecast grid, such as the Johnston grid.[15,16] The differences between the manual and the computer predictions are probably not significant

Table 4A

Measurement	X + SD (range) Manual		Actual		Quick Ceph	
SNA	83.76	(73.5 - 91)	81.99	(69.2 - 92.6)	84.65	(74.6 - 93.1)
SNB	79.88	(72.5 - 88)	78.83	(68-2 - 91.2)	81.08	(73.8 - 89.5)
ANB	4.14	(-0.5 - 8)	3.11	(-3.5 - 7.3)	3.56	(0 - 7.3)
SN-MP	33.78	(25 - 46)	33.78	(17.9 - 49)	33.19	(24.6 - 45.8)
PP-MP	27.48	(15 - 44)	26.55	(10.9 - 46.4)	26.78	(16 - 41.4)
Y-Axis	65.22	(37 - 75)	68.50	(58.4 - 78.8)	66.61	(59.9 - 74.9)
S-Go	79.45	(66 - 01.5)	81.86	(71.3 - 92)	81.72	(70 - 91.3)
N-ME	121.1	(109 - 136.5)	124.73	106.7 - 140.8)	126.027	(112.5 - 41.7)
S-Go / N-ME	0.66	(0.58 - 0.78)	0.66	(0.55 - 0.80)	0.65	(0.58 - 0.73)

clinically because of the relatively small increments of growth which take place over the course of most orthodontic treatments. These findings are similar to those of Greenberg and Johnston[11] in their evaluation of the Rocky Mountain Data System.

The main advantages of the computer may be the speed with which a large amount of information may be accessed, somewhat more accuracy in producing the tracing itself, and its effectiveness as a communication tool in patient education.

Table 4B

Measurement	Absolute value of mean difference Manual - Actual	Quick Ceph - Actual
SNA	3.09	3.60
SNB	2.61	3.31
ANB	1.60	1.58
SN-MP	2.28	2.99
PP-MP	2.35	2.46
Y-Axis	4.15	3.19
S-Go	4.38	3.61
N-ME	6.12	6.12
S-Go / N-ME	0.03	0.03

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