Can frontal sinus development be used for the prediction of skeletal maturity at puberty?

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The precision of a new procedure predicting skeletal maturity on the basis of frontal sinus development was tested in 59 boys with an Angle class-II division-1 malocclusion. Lateral head films were used for the analysis of frontal sinus development, and handwrist radiographs were used for the assessment of skeletal maturity. The results showed that skeletal maturity could be predicted with a certainty of about 85% when using a 1-year prediction interval and with a certainty of about 75% when using a 2-year prediction interval. In conclusion, the study showed that skeletal maturity can be predicted with rather high accuracy by means of the analysis of frontal sinus development as imaged on lateral headfilms. □ *Frontal sinus; growth; maturity; orthodontics; pubertal growth; somatic*

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For the appropriate planning of orthodontic therapy with regard to appliance selection, timing of treatment, and retention after treatment, information is needed about the patient's stage of somatic maturity.

Even though a great physiologic and gender variability of the frontal sinus size and its development from childhood to adolescence has been reported (1, 2), moderate associations between somatic maturity and frontal sinus development as depicted on lateral head films could be demonstrated (3). However, in routine clinical work assessment of somatic maturity is difficult. Certain skeletal developmental stages of the hand and wrist have been shown to be closely associated with the pubertal growth spurt (4–7), and therefore handwrist radiographs have been recommended for an indirect assessment of somatic maturity.

The aim of the present investigation was to test the accuracy of a new prediction procedure for skeletal maturity on the basis of frontal sinus development as imaged on lateral head films.

Materials and methods

Materials

The subject material comprised 59 boys (10–19.5 years; mean, 14.4 years) with an Angle class-II division-1 malocclusion. All children were treated orthodontically. Lateral head films and handwrist radiographs existed for all subjects. The head films and handwrist radiographs were taken at yearly intervals covering at least a 2-year period.

Methods

Analysis of the lateral head films. Two headfilms from each subject were used for predicting skeletal maturity. The radiographs were selected without any knowledge of the child's skeletal maturity stage and analyzed at a 1- or 2-year interval basis. Thus two prediction intervals of 1 (T1) and 2 years (T2) were formed. Different pairs of radiographs were used for the 1- and 2-year prediction.

On the basis of the method of Ertürk (8) the radiographs were oriented with the nasion sella line horizontally. The peripheral border of the frontal sinus was traced, and the highest (Sh) and lowest (Sl) points of sinus extension were marked. Perpendicular to the interconnecting line Sh–Sl the maximum width of the frontal sinus was assessed (Fig. 1). The average yearly growth velocity (mm/year) of the frontal sinus width was calculated. The radiographic magnification of 7% was not taken into account.

Analysis of handwrist radiographs. The handwrist radiographs were evaluated in accordance with the method described by Hägg & Taranger (7). The epiphyseal development of the middle phalanx of the third finger and of the distal part of the radius were used as indicators of skeletal maturity.

Skeletal maturity prediction. To make possible the prediction of skeletal maturity on the basis of the analysis of the frontal sinus growth velocity, the following findings from a previous investigation on the development of the frontal sinus during puberty (9), performed in 26 boys, are needed:

1) Sinus growth velocity at puberty is closely related to body height growth velocity (Fig. 2).

2) Sinus peak coincides with skeletal maturity stages MP3-G or MP3-H in 65% of the subjects.

3) In male subjects the average age at sinus peak is 15.1 years.

4) In a 1-year observation interval a peak growth velocity of at least 1.3 mm/year is attained by 84% of the subjects (Table 1).

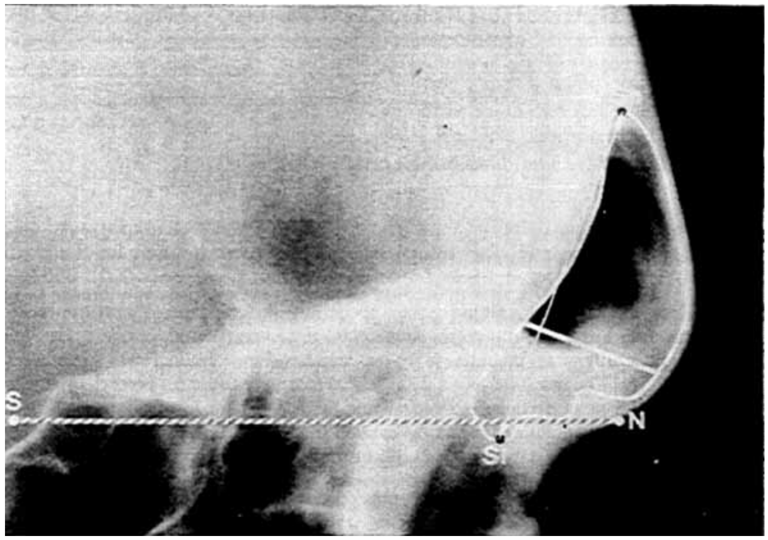

Fig. 1. Assessment of the maximal frontal sinus width perpendicular to the inter-connecting line Sh-Sl (3, 9).

Table 1. Number of subjects with a sinus growth velocity of at least 1.3 mm/year (threshold value T1) and at least 1.2 mm/year (threshold value T2) before (−), at and after (+) sinus peak (Sp). Analysis of lateral headfilms from 26 male subjects at a 1- (T1) and 2- (T2) year interval basis. From Ruf & Pancherz (9)

T1		−3	−2	−1	Sp	+1	+2	+3
	Subjects (%)	30	16	20	84	27	16	5
T2		−3 and −2	−2 and −1	−1 and Sp	Sp and +1	+1 and +2	+2 and +3	
	Subjects (%)	20	10.5	70	70	30	5	

5) In a 2-year observation interval a peak growth velocity of at least 1.2 mm/year is attained by 70% of the subjects (Table 1).

These specific sinus growth velocities (1.3 mm/year for the 1-year interval and 1.2 mm/year for the 2-year interval) were assigned as threshold values T1 and T2, respectively.

Prediction procedure. The sinus growth velocity (Sv) in each individual is compared with the threshold values T1 and T2, respectively.

In case the Sv is as high as or higher than the T value (T1 or T2), it can be expected that sinus peak has been reached during the prediction interval. It can therefore be assumed that skeletal maturity stage MP3-G or MP3-H has been attained.

In case the Sv is lower than the T value (T1 or T2), it

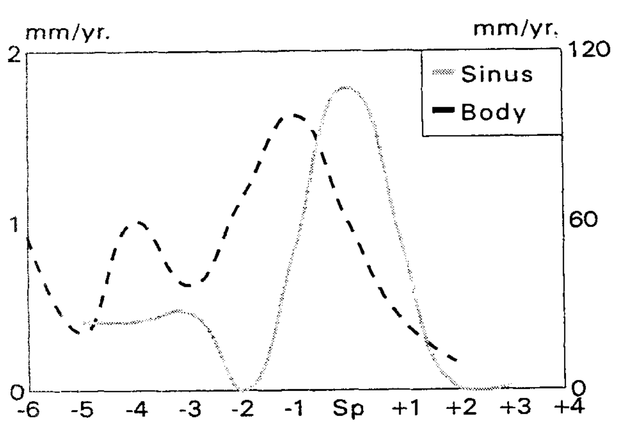

Fig. 2. Pubertal body height growth velocity and sinus growth velocity (mm/year) in a boy followed up from 10 to 18 years of age.

Table 2. Prediction procedure for skeletal maturity on the basis of the evaluation of frontal sinus growth. The results from the comparison of the frontal sinus growth velocity (Sv) with the respective threshold value (T) and the prediction of skeletal maturity are given

Sinus data	Prediction
Sv > T	Skeltal maturity MP3-G or MP3-H
Sv < T, and age < 15.1 years	Skeltal maturity before MP3-G
Sv < T, and age > 15.1 years	Skeletal maturity MP3-I or later

Table 3. Prediction of skeletal maturity at puberty in 59 boys for the 1-year prediction (T1) interval. The following are shown: the consecutive case numbers, the sinus growth velocity (Sv) during the observation interval, the age at the midpoint of the observation interval (only when required for the prediction), the predicted skeletal maturity stage, the actual skeletal maturity stage at the beginning (1) and at the end (2) of the observation interval, and the result of the skeletal maturity prediction

Case no.	Sv (mm/yr)	Age at prediction (years)	Prediction of skeletal maturity	Skeletal maturity 1	Skeletal maturity 2	Result*
1	1.5		MP3-G/H	MP3-FG	MP3-G	*
2	0	>15.1	MP3-I	MP3-I/R-I	MP3-I/R-IJ	*
3	1	>15.1	MP3-I	MP3-I/R-IJ	MP3-I/R-IJ	*
4	2.7		MP3-G/H	MP3-FG	MP3-G	*
5	0	<15.1	<MP3-G	MP3-FG	MP3-FG	*
6	0	>15.1	MP3-I	MP3-I/R-IJ	MP3-I/R-J	*
7	0.5	<15.1	<MP3-G	MP3-F	MP3-FG	*
8	1.5		MP3-G/H	MP3-G	MP3-H	*
9	2		MP3-G/H	MP3-FG	MP3-G	*
10	0	>15.1	MP3-I	MP3-I/R-IJ	MP3-I/R-IJ	*
11	0	>15.1	MP3-I	MP3-FG	MP3-G	–
12	5.5		MP3-G/H	MP3-G	MP3-G	*
13	0.5	<15.1	<MP3-G	MP3-E	MP3-F	*
14	0	<15.1	<MP3-G	MP3-F	MP3-FG	*
15	0.4	>15.1	MP3-I	MP3-I/R-I	MP3-I/R-IJ	*
16	2		MP3-G/H	MP3-FG	MP3-G	*
17	1.3		MP3-G/H	MP3-G	MP3-H	*
18	1.8		MP3-G/H	MP3-G	MP3-H	*
19	1.4		MP3-G/H	MP3-FG	MP3-G	*
20	0.5	<15.1	<MP3-G	MP3-E	MP3-E	*
21	2		MP3-G/H	MP3-G	MP3-H	*
22	1.6		MP3-G/H	MP3-FG	MP3-H	*
23	1.5		MP3-G/H	MP3-G	MP3-G	*
24	1.5		MP3-G/H	MP3-FG	MP3-H	*
25	1.1	>15.1	MP3-I	MP3-FG	MP3-G	–
26	0.7	<15.1	<MP3-G	MP3-E	MP3-F	*
27	1	<15.1	<MP3-G	MP3-FG	MP3-FG	*
28	0	<15.1	<MP3-G	MP3-FG	MP3-FG	*
29	1.4		MP3-G/H	MP3-G	MP3-H	*
30	1.4		MP3-G/H	MP3-FG	MP3-H	*
31	0	<15.1	<MP3-G	MP3-G	MP3-I/R-IJ	–
32	1	<15.1	<MP3-G	MP3-E	MP3-F	*
33	0	>15.1	MP3-I	MP3-I/R-I	MP3-I/R-IJ	*
34	2		MP3-G/H	MP3-H	MP3-H	*
35	1	<15.1	<MP3-G	MP3-E	MP3-F	*
36	0.5	<15.1	<MP3-G	MP3-E	MP3-F	*
37	8.7		MP3-G/H	MP3-FG	MP3-H	*
38	0	<15.1	<MP3-G	MP3-FG	MP3-G	–
39	1.7		MP3-G/H	MP3-F	MP3-FG	–
40	1.5		MP3-G/H	MP3-FG	MP3-G	*
41	1.4		MP3-G/H	MP3-FG	MP3-G	*
42	1.8		MP3-G/H	MP3-H	MP3-H	*
43	0	>15.1	MP3-I	MP3-H	MP3-I/R-IJ	–
44	1.5		MP3-G/H	MP3-FG	MP3-G	*
45	1	>15.1	MP3-I	MP3-H	MP3-H	–
46	1.5		MP3-G/H	MP3-G	MP3-H	*
47	1.5		MP3-G/H	MP3-G	MP3-H	*
48	3		MP3-G/H	MP3-G	MP3-H	*
49	2		MP3-G/H	MP3-H	MP3-I/R-IJ	*
50	1.1	<15.1	<MP3-G	MP3-F	MP3-FG	*
51	2		MP3-G/H	MP3-FG	MP3-G	*
52	1	<15.1	<MP3-G	MP3-FG	MP3-FG	*
53	4		MP3-G/H	MP3-FG	MP3-G	*
54	1	<15.1	<MP3-G	MP3-E	MP3-E	*
55	3		MP3-G/H	MP3-G	MP3-I	*
56	1.5		MP3-G/H	MP3-G	MP3-H	*
57	0.9	<15.1	<MP3-G	MP3-H	MP3-I	–
58	0	<15.1	<MP3-G	MP3-G	MP3-I/R-I	–
59	0.5	>15.1	MP3-I	MP3-I	MP3-I/R-IJ	*

Cases 11 and 25 were late growers, and Cases 31 and 57 were early growers
* Implies a correct prediction; – implies an incorrect prediction.

Table 4. Prediction of skeletal maturity at puberty in 59 boys for the 2-year prediction (T2) interval. The following are shown: the consecutive case numbers, the sinus growth velocity (Sv) during the observation interval, the age at the midpoint of the observation interval (only when required for the prediction), the predicted skeletal maturity stage, the actual skeletal maturity stage at the beginning (1) and at the end (2) of the observation interval, and the result of the skeletal maturity prediction

Case no.	Sv (mm/yr)	Age at prediction (years)	Predicted skeletal maturity	Skeletal maturity 1	Skeletal maturity 2	Result
1	1	<15.1	<MP3-G	MP3-G	MP3-H	–
2	0.2	<15.1	<MP3-G	MP3-E	MP3-F	*
3	0.4	<15.1	<MP3-G	MP3-E	MP-FG	*
4	2.3		MP3-G/H	MP3-F	MP3-FG	–
5	1.5		MP3-G/H	MP3-FG	MP3-H	*
6	1.3		MP3-G/H	MP3-G	MP3-I/R-IJ	*
7	0.9	<15.1	<MP3G	MP3-E	MP3-F	*
8	1.9		MP3-G/H	MP3-FG	MP3-H	*
9	1	<15.1	<MP3-G	MP3-E	MP3-FG	*
10	0.5	>15.1	MP3-I	MP3-I/R-IJ	MP3-I/R-J	*
11	0.5	<15.1	<MP3-G	MP3-E	MP3-FG	*
12	0.2	<15.1	<MP3-G	MP3-F	MP3-G	–
13	0.7	<15.1	<MP3-G	MP3-F	MP3-G	–
14	1.7		MP3-G/H	MP3-FG	MP3-H	*
15	2.3		MP3-G/H	MP3-G	MP3-I/R-I	*
16	0.7	<15.1	<MP3-G	MP3-F	MP3-FG	*
17	0.7	>15.1	MP3-I	MP3-I	MP3-I/R-J	*
18	0.9	>15.1	MP3-I	MP3-H	MP3-I/R-IJ	–
19	1.3		MP3-G/H	MP3-E	MP3-FG	–
20	1.5		MP3-G/H	MP3-E	MP3-FG	–
21	1.4		MP3-G/H	MP3-H	MP3-I/R-I	*
22	2		MP3-G/H	MP3-H	MP3-I	*
23	1.7		MP3-G/H	MP3-G	MP3-I	*
24	1.5		MP3-G/H	MP3-FG	MP3-H	*
25	0.7	>15.1	MP3-I	MP3-I/R-I	MP3-I/R-J	*
26	1	<15.1	<MP3-G	MP3-E	MP3-FG	*
27	1.2		MP3-G/H	MP3-F	MP3-G	*
28	1	<15.1	<MP3-G	MP3-F	MP3-FG	*
29	0	>15.1	MP3-I	MP3-I/R-IJ	MP3-I/R-J	*
30	3.6		MP3-G/H	MP3-F	MP3-H	*
31	1.5		MP3-G/H	MP3-G	MP3-I/R-IJ	*
32	1.4		MP3-G/H	MP3-E	MP3-FG	*
33	1	>15.1	MP3-I	MP3-I/R-IJ	MP3-I/R-J	*
34	0.9	<15.1	<MP3-G	MP3-FG	MP3-H	–
35	1	<15.1	<MP3-G	MP3-E	MP3-FG	*
36	1.4		MP3-G/H	MP3-E	MP3-G	*
37	1.5		MP3-G/H	MP3-H	MP3-I/R-IJ	*
38	1	<15.1	<MP3-G	MP3-F	MP3-G	–
39	1.2		MP3-G/H	MP3-G	MP3-I/R-IJ	*
40	1.5		MP3-G/H	MP3-E	MP3-FG	–
41	0.5	>15.1	MP3-I	MP3-G	MP3-I/R-IJ	–
42	0.7	>15.1	MP3-I	MP3-I/R-I	MP3-I/R-IJ	*
43	0.5	>15.1	MP3-I	MP3-I	MP3-I/R-IJ	*
44	1	<15.1	<MP3-G	MP3-FG	MP3-G	–
45	1.2		MP3-G/H	MP3-G	MP3-I/R-IJ	*
46	0.5	>15.1	MP3-I	MP3-G	MP3-I	–
47	0.3	>15.1	MP3-I	MP3-H	MP3-I/R-IJ	*
48	0	>15.1	MP3-I	MP3-H	MP3-I/R-IJ	–
49	1.5		MP3-G/H	MP3-G	MP3-I/R-IJ	*
50	2.4		MP3-G/H	MP3-F	MP3-G	*
51	0.7	>15.1	MP3-I	MP3-I/R-I	MP3-I/R-J	*
52	1	<15.1	<MP3-G	MP3-E	MP3-G	–
53	2.2		MP3-G/H	MP3-E	MP3-G	*
54	1.7		MP3-G/H	MP3-E	MP3-G	*
55	1.5		MP3-G/H	MP3-F	MP3-H	*
56	2.2		MP3-G/H	MP3-F	MP3-G	*
57	0.7	<15.1	<MP3-G	MP3-E	MP3-FG	*
58	1.8		MP3-G/H	MP3-G	MP3-I	*
59	1	>15.1	MP3-I	MP3-H	MP3-I	–

* Implies a correct prediction; – implies an incorrect prediction.

is not known whether the subject is pre-peak or post-peak. The age of the subject is therefore also needed to predict skeletal maturity. The sinus growth peak is reached at an average age of 15.1 years (9). Therefore a subject less than 15.1 years old at the time of prediction in combination with an Sv lower than the T value means that the sinus growth peak has not been reached. Consequently, skeletal maturity stage MP3-G should not have been reached either. On the other hand, if the subject's age is more than 15.1 years at the time of prediction and the Sv is lower than the T value, it can be assumed that sinus growth peak has been passed, and consequently the skeletal maturity stage MP3-H should have been passed as well. The prediction procedure is summarized in Table 2.

Results

In testing the accuracy of the prediction procedure the skeletal maturity was assessed correctly in 50 of 59 subjects (84.7%) for the 1-year prediction interval and in 44 of 59 subjects (74.5%) for the 2-year prediction interval (Tables 3 and 4).

Discussion

The present investigation was constricted to boys to exclude reported gender differences (2). During the preliminary selection of material two boys had to be excluded because of lack of sinuses.

Orthodontic therapy could theoretically have affected sinus enlargement, as all subjects were treated with a Herbst appliance (10), which has a marked headgear effect on the maxilla (11). Baer & Harris (12) interpreted the development of the frontal sinus as a process of structural adaptation to the forward and downward growth of the midface. The restraint of maxillary growth induced by the Herbst appliance could thus possibly inhibit frontal sinus enlargement. However, sinus growth did follow body height growth even during the active period of orthodontic treatment, so that an influence of Herbst therapy on the enlargement of the frontal sinus does not seem likely.

An assessment of skeletal maturity can be of great value for orthodontic treatment planning, as it enables an estimation of the residual jaw growth potential of the individual.

As the presented procedure for evaluating skeletal maturity on the basis of the frontal sinus development works with mean values, it is difficult to predict cases differing greatly from the mean. Therefore skeletal maturity could be judged incorrectly in cases with an extremely early or late pubertal growth maximum if sinus growth velocity is below the threshold value. Nevertheless, this limitation of the method applies for handwrist radiographs as well, since they are not capable of detecting individuals with large differences between somatic and skeletal maturity at puberty. Bergensen (5) reported in his growth study that, although the individuals with retarded or accelerated skeletal maturation accounted only for 30% of his subject material, they were responsible for 57% of the prediction errors. In the present material early and late maturers (n = 4) affected exclusively the 1-year prediction interval, accounting for 44.4% of the incorrect predictions (Table 3).

In a previous investigation (9) it was shown that different skeletal maturity stages correspond with different sinus growth velocities. During a longer observation interval a subject may attain several skeletal maturity stages, thus making the prediction of the actual skeletal maturity stage more difficult. This might explain the larger amount of incorrect predictions observed in the 2-year prediction group.

The disadvantage of the presented prediction procedure is that it requires two lateral headfilms taken at an interval of at least 1 year. Two radiographs are seldom available at the beginning of orthodontic treatment but frequently during the course of therapy. When this is the case, additional handwrist radiographs for skeletal maturity assessment could be avoided.

Further research is required to investigate the applicability of the presented procedure on female subjects not included in the present investigation.

Conclusion

The precision of the prediction procedure assessing skeletal maturity on the basis of the analysis of frontal sinus development as depicted on lateral head films was rather high. Correct predictions were possible in 85% of the subjects when using a 1-year prediction interval and in 75% of the subjects when using a 2-year prediction interval.

Even though the presented prediction procedure cannot replace handwrist radiographs in routine pre-treatment orthodontic diagnostics, it may give important information during the course of therapy with regard to the individual's stage of skeletal development when two lateral headfilms are available.

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