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Development of the frontal sinus following bilateral fronto-orbital osteotomies

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SUMMARY **The presence of frontal sinuses following bilateral fronto-orbital advancement is discussed controversially in the literature.**

In a retrospective study, 33 patients (18 male and 15 female) were operated on between 1982 and 1993, with at least one year postoperative follow-up and with a minimum age of 6 years at the end of the follow-up period following bilateral fronto-orbital remodelling, were included. The average age at which the procedure was performed was 29 months with a minimum of 3 months and a maximum of 7.8 years.

The study presented shows a pneumatization of the frontal sinus in 72.7% of 33 patients following bilateral fronto-orbital advancement. The first radiographic signs of sinus development were detected between the ages of 4 and 11, average 8.3 years. There were no statistically proven correlations between frontal sinus pneumatization and age at operation or the amount of advancement or sex of the patients.

Surgical enlargement of the cranium by frontal advancement with adequate stabilization results in an enlargement of the neurocranium, thereby decreasing pressure on the inner frontal cortex and allowing frontal sinus pneumatization to proceed normally. Hence, the development of a frontal sinus may be a reflection of the effectiveness of the surgical therapy.

INTRODUCTION

According to Moss and Young (1960) the outer table of the frontal bone is functionally independent of the cerebral capsule. When the growth of the inner table ceases at the age of 6–7 years because the frontal lobes have undergone their major development, the development of the frontal sinus is due to the continuous growth of the outer table in response to the stimulus of the growing nasomaxillary facial complex (*Shapiro* and *Schorr*, 1980). The frontal sinus is radiographically detectable at 18 months and can reach the upper orbital edge from 2 years of age (*Pobornikova*, 1974). Even in some adults, the frontal sinus continues to increase in depth and height with age (*Stern*, 1939; *Finby* and *Kraft*, 1972; *Brown et al.*, 1984).

The frequency of pneumatization of the frontal sinus in large studies with a minimum sample of 500 test individuals differs widely from 82.5% in adults (*Stern*, 1939), 96.1% in youngsters older than 12 years (*Gulisano* et al., 1978) to 100% in adult male air pilots (*Süsse* et al., 1968). In another study pneumatization was seen in 504 children aged between 4 and 13 years 94.6% (*Pobornikova*, 1974).

The pneumatization of the left side seems to be more extensive (*Stern*, 1939; *Süsse* et al., 1968; *Pobornikova*, 1974; *Gulisano* et al., 1978) There is one publication analysing the phenomenon of the frontal sinus development in syndromic craniosynostoses without a history of frontal bone surgery but with craniectomies in 17 of 22 patients. In this series of 22 patients aged 10–15 years at the time of radiological examination, *McCarthy* et al. (1990) observed the presence of frontal sinuses in 18 patients (81.8%). However, the presence of frontal sinuses following bilateral fronto-orbital advancement is discussed controversially in the literature. *McCarthy* et al. (1990) observed only one case with development of the frontal sinuses in a series of eight patients following bilateral fronto-orbital advancement, whereas this phenomenon was observed by *Arnaud* et al. (1994) in 55 out of 90 patients (61%) of the cases with similar procedures.

MATERIAL AND METHODS

Only patients operated on between 1982 and 1993, with at least one year of postoperative follow-up and with a minimum age of 6 years at the end of the follow-up period following bilateral fronto-orbital remodelling were included in this study. All the patients were operated on by H. F. Sailer.

Following these criteria, 33 patients (18 male and 15 female) were involved in this study. The average age at which the procedure was performed was 29 months with a minimum of 3 months and a maximum of 7.8 years. The average age at the end of the follow-up period (most recent radiological examination) was 9.9 years with a minimum of 6 years and a maximum of 18 years.

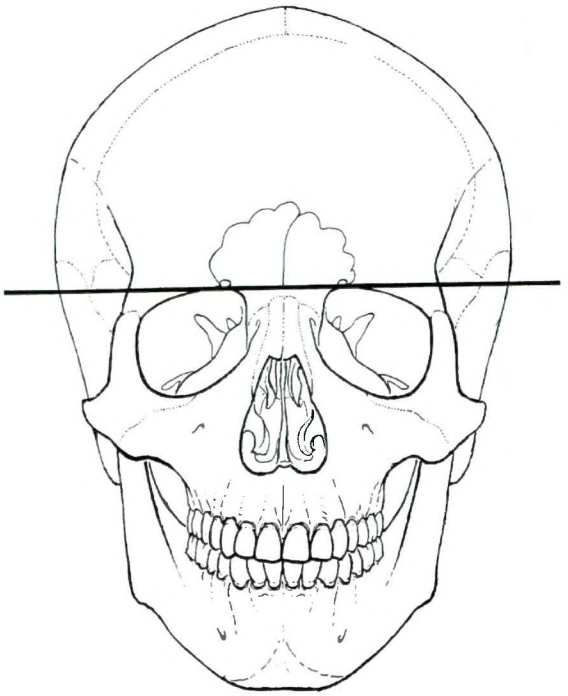


Fig. 1 – The radiological reference for frontal sinus development consisted of pneumatization at or above the level of the supraorbital rims, as projected in postero-anterior cephalograms.

Fifteen patients (9 male and 6 female) showed syndromal synostosis: Crouzon's disease 13; Saethre Chotzen 1; and otopalatodigital syndrome 1. Eighteen patients (9 male and 9 female) suffered from a non-syndromal synostosis: plagiocephaly 9; scaphocephaly 4; trigonocephaly 4; and multiple synostoses 1.

To compare our data with the literature, the radiological reference for frontal sinus development consisted of pneumatization at or above the level of the supraorbital rims (Fig. 1), as projected in postero-anterior cephalograms. The age of first radiological evidence was noted. The area of the frontal sinus was traced and measured on the latest available postero-anterior cephalogram. The resulting areas were compared with the tables of *Szilvassy* (1981) who published tables of the frontal sinus size of 215 children, with values for the average size and the standard deviation. The left and right aspects of the frontal sinuses were analysed separately. Measurements within the standard deviation of the normal dimension corresponding to a specific age category were classified as normal, whereas smaller projections of the frontal sinuses were considered as being underdeveloped. The χ^2 analysis of contingency tables was used as a statistical correlation test with Statview 4.0® software on an Apple Macintosh® Computer.

Surgical method

The principle operative techniques were established by *Tessier* (1967) and *Marchac* (1978). In the syndromic cases the surgical correction consisted of the removal of the supraorbital bar including the anterior part of the orbital roof and the lateral orbital walls. The interorbital osteotomy was led through the nasofrontal suture. The supraorbital bar was bent in a symmetrical way, replaced into a more anterior position and tilted according to the desired angulation of the forehead profile. The supraorbital bar was fixed to the nasal bone using wires in the older cases and microplates in the more recent ones. Wires were used if the bone was thinner than 2 mm and microplates and microscrews of 2–3 mm length in thicker bone.

In the non-syndromal cases, the same procedure was performed in eight cases of plagiocephaly, two cases of scaphocephaly and one case of trigonocephaly. In all other cases, a vertical median bar was left in place and only the lateral parts of the supraorbital rim with their temporal extensions were advanced. However, the medial osteotomy cuts were situated at the junction of the medial orbital wall, extending behind the anterior aspect of the supraorbital rim, and thus within the limits of the nasofrontal complex.

RESULTS

Frontal sinus development at or above the level of the supraorbital rim was seen in 24 of 33 patients (72.7%). The sinus had normal dimensions on both sides in 46% (11/24) of the patients with frontal sinus development (Table 1). Normal dimensions of the left frontal sinus were detected in two patients (2/24) with an underdeveloped right sinus in one patient and an undeveloped right sinus in the other one. Normal dimensions of the right frontal sinus with an underdeveloped left sinus were seen in four patients (4/24) and with an undeveloped left sinus in one patient (1/24). Underdeveloped frontal sinuses were seen bilaterally in 4/24 patients, and unilaterally on the left side in 2/24 patients without development on the other side. There was a clear side difference (1^2 cm or more) in 14 of these 24 patients, showing a larger pneumatization on the left side in seven and on the right side in seven cases. The other 10 patients showed more symmetrically sized frontal sinuses.

Table 1 – Frontal sinus pneumatization at or above the level of the supraorbital rim

Pneumatization	Frontal sinus	
	Right side	Left side
At or above the level of the supraorbital rim with normal size	16	13
At or above the level of the supraorbital rim with underdeveloped size	5	10
Developed below the supraorbital rim	4	5
Undeveloped sinus	8	5

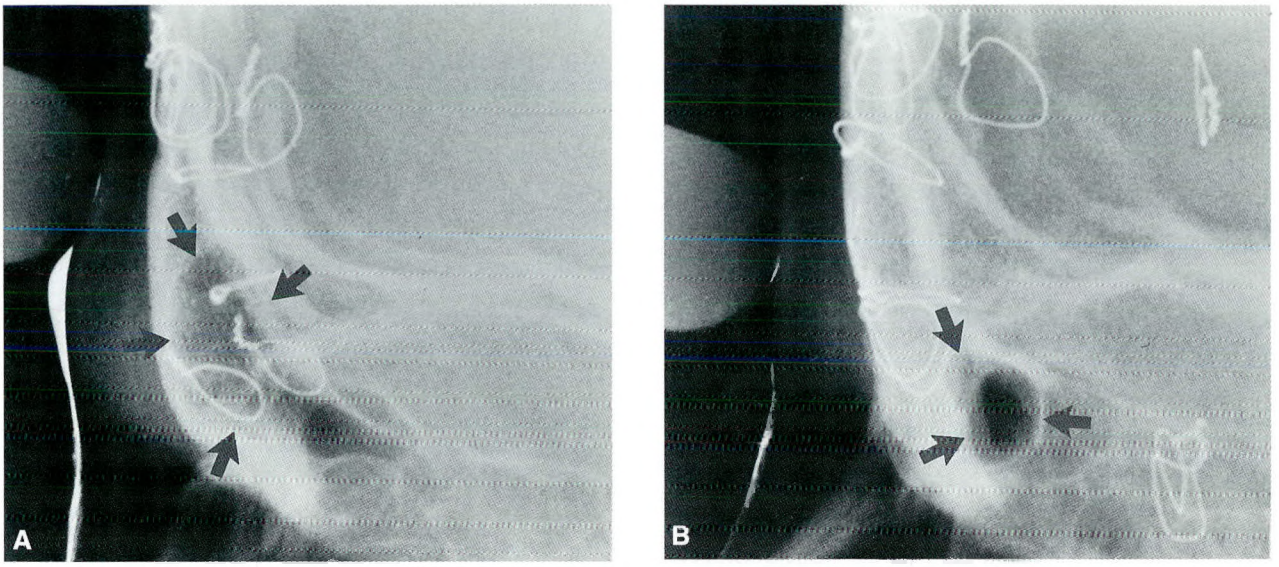


Fig. 2 – Two children (of triplets) were operated on at the age of 14 months for scaphocephaly, within two days of each other. At the latest radiographic control at age 7.3 years the female patient (A) demonstrated the development of a frontal sinus (arrows), whereas in the male patient (B) the frontal sinus development was evident (arrows) but did not progress above the level of the supraorbital rims and was therefore classified in the group with development below the supraorbital rims.

In nine patients, the frontal sinus did not reach the level of the supraorbital rims bilaterally. In five of these nine patients, frontal sinus development was detectable (Fig. 2), in the other four patients (Crouzon 3, multiple synostoses 1) there were no signs of frontal sinus development.

Age at radiologically detectable frontal sinus pneumatization

The youngest child in whom frontal sinus pneumatization at or above the supraorbital rim was found was a 4-year-old girl. In 75% of the patients, however, the pneumatization was not noticed before the age of 6 years (median overall 7.6 years). Table 2 shows the distribution of the patients according to the age when a frontal sinus could be detected radiologically.

Male/female distribution of presence of the frontal sinus

The incidence of pneumatization was higher in males (78%) than in females (67%). The age at the end of the follow-up period was almost identical in both sexes (*Table 3*). The χ^2 test showed no correlation between sex-distribution and pneumatization ($P = 0.05$).

Two of our patients were triplets. These two were operated on at the same age and the latest radiographic control at age of 7.3 years revealed frontal sinus development in the female patient (Fig. 2 A), whereas the frontal sinus development in the male patient (Fig. 2 B) was evident but did not progress above the level of the supraorbital rims.

Table – 2 Age at radiologically detectable frontal sinus pneumatization

Age at pneumatization	No of patients
4–5 years	2
5.1–6.9 years	9
7.0–9 years	8
More than 9 years	5

Table 3 – Male/female distribution of presence of the frontal sinus

Sex	Age at operation (months)	Age at end of follow-up (years)	Pneumatization
Male ($n = 18$)	26.4	10	14 = 77.8%
Female ($n = 15$)	31.5	9.8	10 = 66.7%
Total ($n = 33$)	28.7	9.9	24 = 72.7%

Table 4 – Pneumatization of the frontal sinus. Influence of age at surgery

Age at surgery	No of patients	Median age at end of follow-up period	Pneumatization
2 years or under	16	8.5	9 = 56%
Over 2 years	13	11.3	9 = 69%
Total	29	9.7	17 = 62%

Influence of age at surgery and age at latest radiography

Surgery was performed under the age of 4 in 85% of all patients (28/33). The difference in incidence of pneumatization between those operated on before and after 2 years of age (Table 4) was 11% (68%–79%) with an incidence for both groups together of 73%. The χ^2 did not show a correlation ($P = 0.05$).

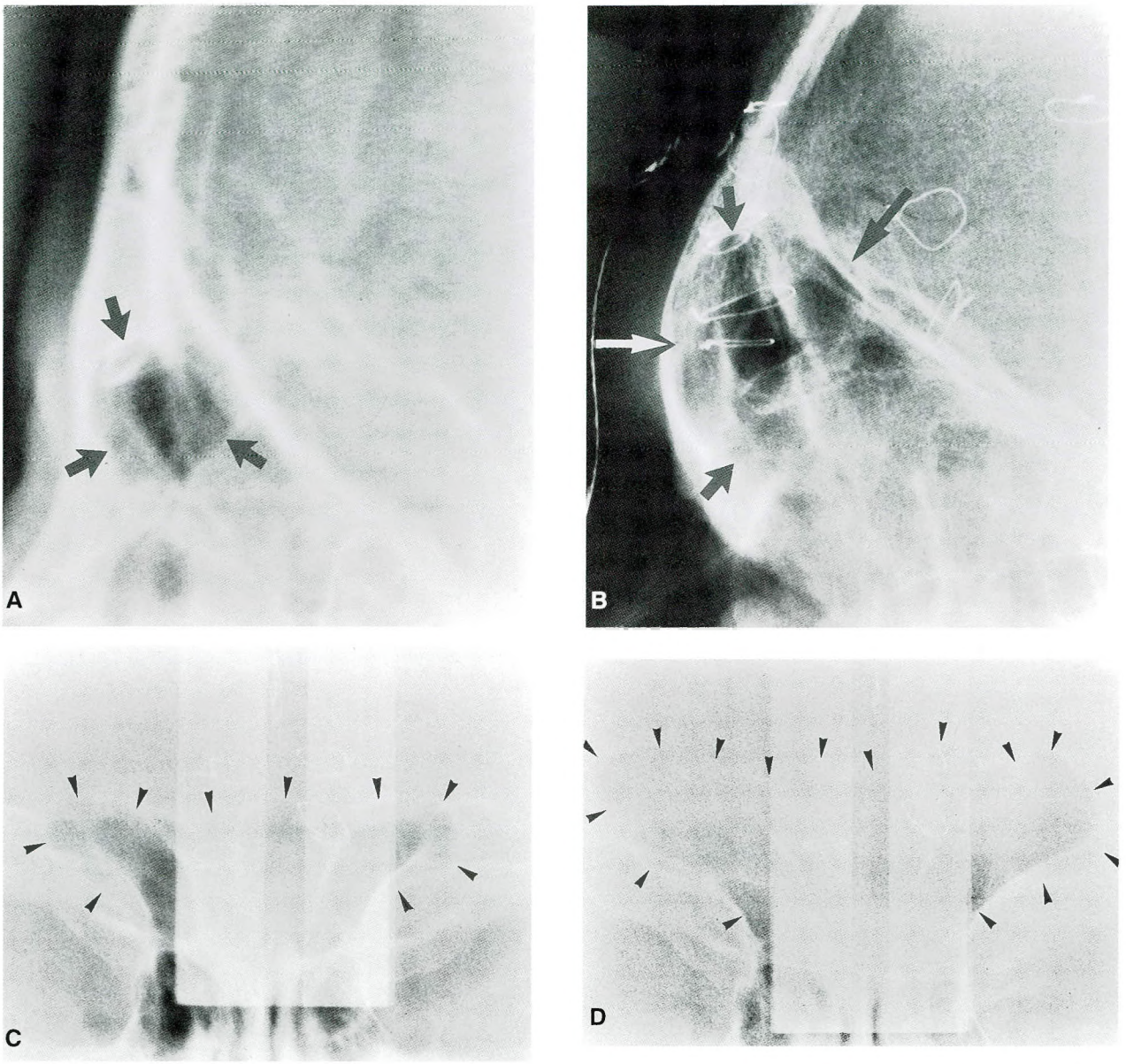


Fig. 3 – This patient with a Saethre Chotzen syndrome was operated on for his trigonocephal at age 7.8 years. A bilateral fronto-orbital osteotomy was performed using resorbable plates and wire osteosynthesis for fixation. The development of the frontal sinus was evident prior to operation (A lateral view). Further development of the frontal sinus was observed postoperatively, showing the frontal sinus (arrows) six years after operation (B lateral view). The postero-anterior cephalograms 3 years (C) and 6 years (D) postoperatively demonstrate the enlargement of the frontal sinuses (arrows).

However, the age difference between both groups at the end of the follow-up period was more than 3 years. Therefore, the 19 patients, in whom the operation was performed under 2 years of age, were separated into two groups in accordance with their ages at the end of the follow-up period. Comparing these two groups revealed that the 10 patients with the longest radiographic follow-up (median 10.1 years) showed a higher percentage pneumatization (80% vs 55%) as the nine patients with the shortest radiographic follow-up (median 6.6 years). The difference in pneumatization, therefore, seems to be due to the longer radiographic follow-up of the group with age at surgery of over 2 years. Even in cases with a partially developed frontal sinus the operation does not prevent further frontal sinus development. The frontal sinus development can progress postoperatively (Fig. 3).

There was frontal sinus pneumatization in 13/15 patients (87%) in the group of patients older than 10 years at the end of the follow-up period and in 11/18 patients (61%) of the younger age group (Table 5). There was no statistically proven correlation ($P = 0.05$) between the incidence of pneumatization and the age at the end of the follow-up period.

Table 5 – Pneumatization of the frontal sinus. Influence of age at latest radiography

Age at latest radiography	No of patients	Pneumatization
Under 10 years	18	11 = 61%
10–12 years	6	4 = 67%
Over 12 years	9	9 = 100%
Total	33	24 = 73%

Table 6 – Pathology and frontal sinus pneumatization

Pathology	No of patients	Latest radiography (median in years)	Pneumatization
M. Crouzon	13	11.8	8 = 62%
Other syndromic craniosynostoses	2	11.9	2 = 100%
Plagiocephaly	9	9.0	9 = 100%
Scaphocephaly	4	8.7	2 = 50%
Trigonocephaly	4	6.5	3 = 75%
Multiple synostoses	1	6.8	0

Table 7 Amount of frontal advancement and pneumatization

Frontal advancement	Syndromic cases	Pneumatization	Non syndromic cases	Pneumatization
0–6 mm	5	4 = 80%	15	12 = 80%
7–10 mm	5	4 = 80%	3	2 = 66.7%
11–20 mm	5	2 = 40%	0	0

Pathology and frontal sinus pneumatization

With a 78% incidence of pneumatization, the group with non-syndromic synostoses (n = 18) showed pneumatization more often than the syndromic craniosynostoses group (n = 15) with 67% (Table 6). This is demonstrated in Figure 4. Nevertheless, the radiographic follow-up period of the non-syndromic synostoses was 3 years shorter (median 8.6 years) compared with the syndromic craniosynostoses group (median 11.8 years).

Depending on the underlying pathology, the amount of frontal advancement measured in the midline ranged between 0 and 20 mm (Table 7). The average advancement of the glabella region was 8.9 mm in the syndrome group (n = 15) and 2.7 mm in the non-syndrome group (n = 18). There was no correlation between the amount of advancement and the incidence of pneumatization (P = 0.05).

DISCUSSION

In the present series, frontal sinus pneumatization following bilateral fronto-orbital advancement was seen in 24 of 33 patients (72.7%). A slightly lower percentage (61%) was reported by *Arnaud* et al. (1994). These results contrast with the study by *McCarthy* et al. (1990) of eight bilateral and three unilateral fronto-orbital advancements in a similar group of patients, who had been operated on at an average age of 21 months and followed until the age of 10.5 years. Pneumatization was noticed in only one of the bilateral cases (12.5%). In the unilateral cases, one case of bilateral pneumatization was noted, whereas in the remaining two, only the unoperated side developed. The cases published by *McCarthy* et al. (1990) show no osteosynthesis material while the cases of *Arnaud* et al. (1994) show wires only. In our Department mini- or microplates are used if the thickness of the bone allows this. *Shapiro* and *Schorr* (1980) had noted that in patients with cerebral hypoplasia, frontal sinuses reach a larger size, while the opposite is true in hypoplasia of the midface. Surgical enlargement of the cranium by frontal advancement with adequate stabilization results in an enlargement of the neurocranium, thereby decreasing pressure on the inner frontal cortex and allowing frontal sinus pneumatization to proceed normally. Hence, the development of a frontal sinus may be a reflection of the effectiveness of the surgical therapy.

The first radiographic signs of sinus development were detected between the ages of 4 and 11, with an average of 8.3 years. In the literature, development of the frontal sinus was observed as early as age 1 to 3, and by the age of 2 to 4, the sinuses can extend to the superior orbital rim (*Stern*, 1939; *Pobornikova*, 1974). No large series are available on frontal sinus area in two-dimensional projection in children. Although in certain age groups, the tables by *Szilvassy* (1981) are based on fewer probands than necessary for proper rating, they nevertheless appeared superior to an arbitrary rating system.

Frontal sinus pneumatization is similar in boys and girls until the age of 7 years (*Pobornikova*, 1974; *Szilvassy*, 1981). In our series, the youngest patient showing frontal sinus pneumatization to the supraorbital rim was a 4-year-old girl. In direct comparison of two triplets, frontal sinus development was more advanced in the female. To our knowledge, no such findings in multiple births have been reported thus far. Five of the six patients with the earliest signs of pneumatization by age 6 were females. Interestingly, the incidence of frontal sinus pneumatization found in males was higher (78% vs 67%).

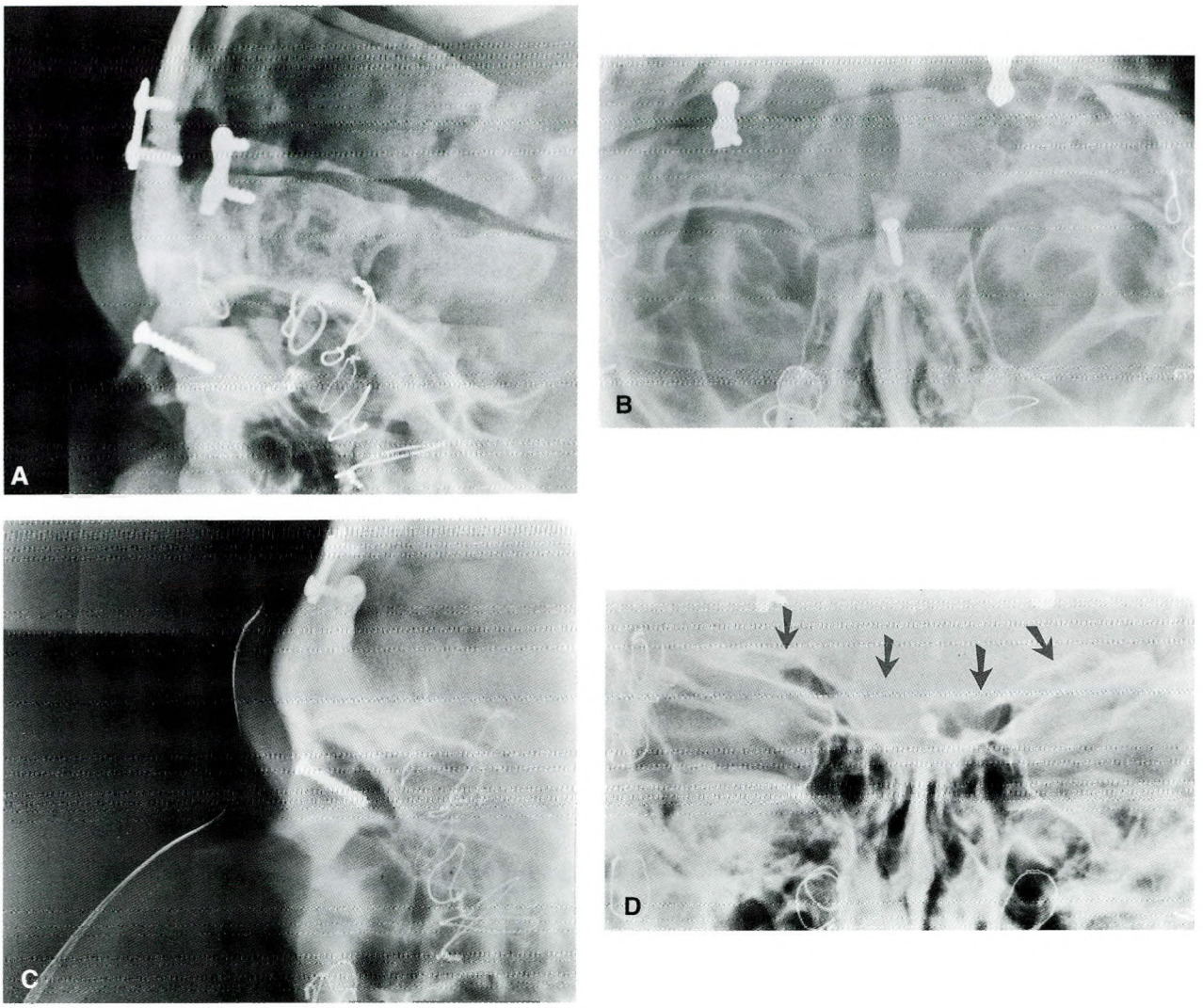


Fig. 4 a-d – This patient with Crouzon's disease had a fronto-orbital advancement of 10 mm at age 6. The X-rays 3 weeks postoperatively show the fixation using miniplates, wires and a screw at the fronto-nasal junction. Lateral view (A), frontal view (B). At age 18 the X-rays (C lateral view, D frontal view) show the development of the frontal sinuses with progression above the level of the supraorbital rims. The sinuses are underdeveloped (medially placed arrows) in size and show development into the orbital roof (laterally placed arrows).

There was no statistically significant relationship between the amount of advancement and frontal sinus pneumatization, although in our sample, the incidence of pneumatization decreases with the amount of frontal advancement. This may reflect the fact that the more severe the deformity, the less growth potential of the midfacial structures exists. *Arnaud* et al. (1994) stated that the frontal sinus seems to pneumatize according to the type of surgery. In their sample, the frontal sinus failed to develop more frequently after extensive advancement of the supraorbital bar, with no contact remaining between its inferior border and the root of the nose, than in cases of remodelling without advancement (<50% vs >80%).

Frontal sinus pneumatization was present in 62% of patients with Crouzon syndrome. In severe cases, however, no signs of frontal sinus pneumatization were seen, and of altogether four patients with no signs of pneumatization, three had Crouzon syndrome. All three Crouzon patients were female and had previously required shunt placement. *Delaire* (1976) states that the frontal sinus is usually absent in such patients. However, this contention dating back to 1976 is not based on a study covering a sufficient number of patients affected by this syndrome.

A drawback of the present study is the relatively short follow-up period. Only eight patients had reached the age of 12 at the most recent radiographic follow-up, all of whom demonstrated frontal sinus development. It can be concluded that following bilateral fronto-orbital advancement a nearly regular frontal sinus development is possible, with the exception perhaps of severe cases of Crouzon syndrome. Further long-term follow-up studies are necessary to confirm this hypothesis.

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