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Magnetic resonance imaging patterns of the development of the sphenoid sinus: a review of 800 patients*

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SUMMARY

Accurate knowledge of age-related development and pneumatisation of the paranasal sinuses has become an important issue in diagnosing paranasal sinus diseases in infants and young adults. Magnetic resonance imaging (MRI) has the potential to assess bone marrow conversion and pneumatisation of the paranasal sinuses.

We retrospectively reviewed 800 children aged 0-14 years undergoing brain MRI for various indications. T1-weighted sagittal and T2-weighted axial scans were evaluated for bone marrow conversion and development of pneumatisation of the sphenoid sinus. The sphenoid sinus had a uniformly low signal intensity on T1-weighted images in all children less than four months old. Signal intensity began to change to hyperintense marrow at the age of four months. Onset of pneumatisation was observed in 19% at the age of 12-15 months. Pneumatisation was complete in all patients older than 10 years.

In conclusion, these data can be used as baseline standards of normal age-related development of the sphenoid sinus and can be of great value for the diagnostic and therapeutic management of pathologic conditions of the child's sphenoid sinus and its surrounds.

Key words: magnetic resonance imaging (MRI), sphenoid sinus, developmental patterns

INTRODUCTION

Developmentally, the paranasal sinuses represent nasal "diverticula" (Scuderi et al., 1993). Because the sinuses do not reach full size until the teenage age, radiological interpretative errors result when understanding of the developmental sequence and rate of the paranasal sinuses is lacking (Maresch et al., 1940; Fujoka et al., 1978; Weiglein et al, 1992). The paranasal sinuses normally are opaque in infants younger than one year of age. Non-aerated sphenoid sinuses usually are present at birth. Aeration of the sphenoid sinuses generally is apparent by three years of age. Growth proceeds from anterior to posterior underneath the sella turcica and continues into early adulthood (Aoki et al., 1989; Duerinckx et al., 1991; Szolar et al., 1994). As the sphenoid bone proposes to pneumatise, red marrow converts to yellow or fatty marrow (Aoki et al., 1989; Szolar et al., 1994).

Reports on radiological findings of bone marrow conversion and pneumatisation of the sphenoid sinuses are limited (Fujoka et al.,1989; Aoki et al.,1989; Szolar et al.,1994). However, there is no previously published study assessing the age-related development with MRI of the sphenoid sinus in more than 400 children. MRI appears to be very sensitive to changes in bone marrow. As the marrow changes from red to fatty, the signal intensity on T1- weighted images changes from hypo- to hyperintense.

The purpose of this study was to evaluate normal age-related developmental patterns (bone marrow conversion and pneumatisation) of the sphenoid sinus with MRI in children up to the age of 14 years and to confirm previously published results by Szolar et al. (1994).

MATERIALS AND METHODS

During a 24-months period, we retrospectively reviewed 800 children (340 girls, 460 boys), who were less than 15 years of age and underwent MRI of the skull for a variety of indications: suspicion of congenital brain anomalies, vascular disorders, developmental delay, hydrocephalus, encephalitis or brain tumours. Patients who had inflammatory paranasal sinus diseases, bone marrow diseases, or had undergone previous treatment – such as surgery, radiation therapy or chemotherapy – were excluded from the study.

All patients were examined on a 1,5 Tesla MR System (Gyroscan S15 and ACS, Philips, The Netherlands). Section thickness was 3-5 mm with a 2-3 mm intersection gap. Patients were stu-

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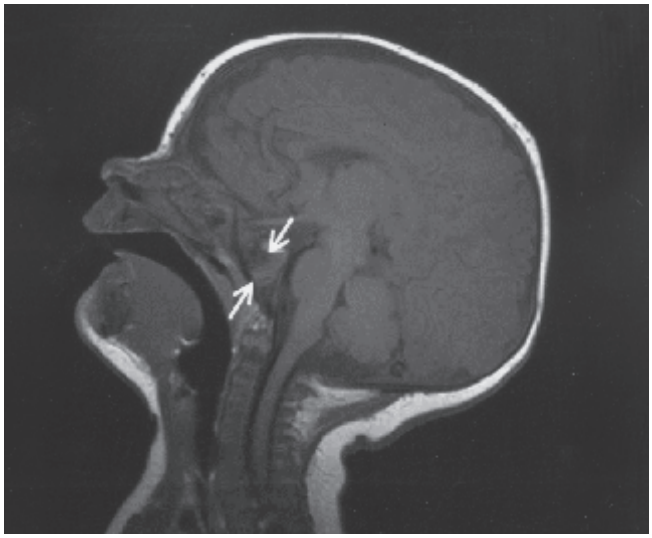

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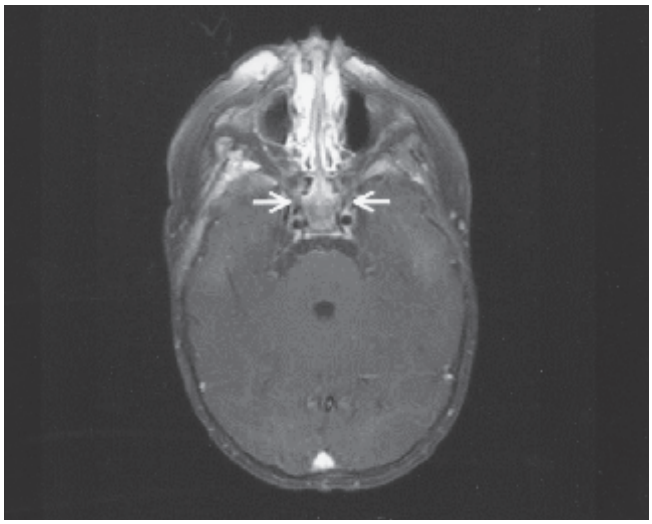

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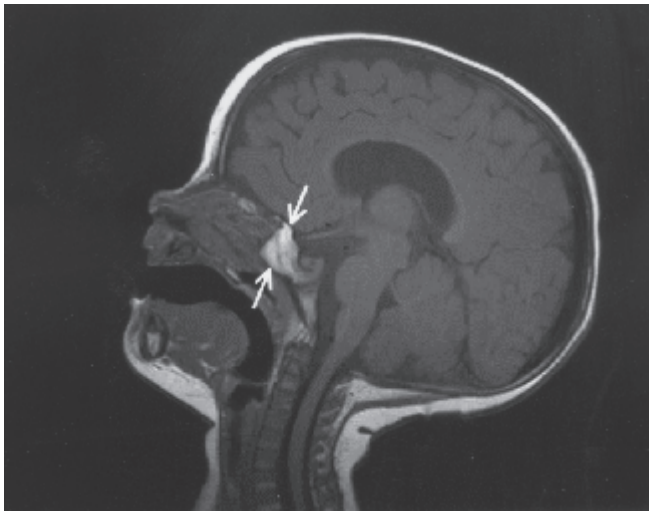

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Figure 1 (a,b,c). Midsagittal (a,c) and axial (b) T1-weighted MR-images (650/30) showing bone marrow conversion of the sphenoid bone from red to fatty. Signal reveals (a) uniformly low signal intensity in a 3-months old female infant. Signal gradually changes from (b) mixed (8-months old boy) to (c) uniformly high signal intensity (11-months old girl) (arrows).

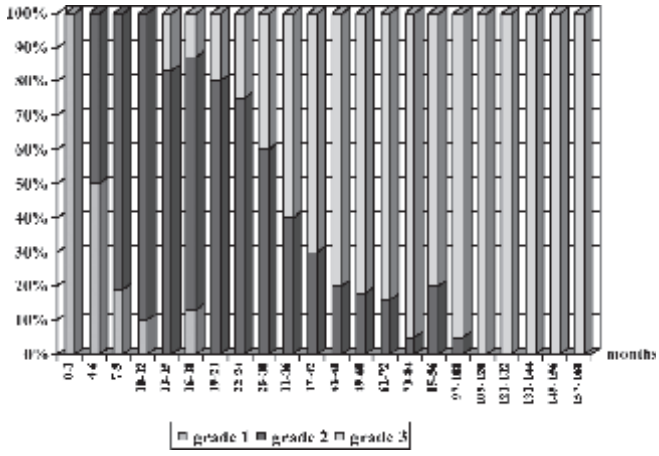
died in sagittal, axial, and coronal planes, with T1- and T2-weighted imaging sequences. Spin-echo (SE) sequences of 200-800/20-50 (repetition time msec/echo time msec) (T1-weighted images) in the sagittal plane, if available, in the coronal plane and 600-3500/29-70 (repetition time msec/echo time msec) (T2-weighted images) in the axial plane were evaluated. The acquisition matrix was 204x256 and the field of view (FOV) was 170-230 mm.

MRI images were simultaneously reviewed by three observers (P.R., O.D., D.S.) and the interpretation was dependent upon the agreement of at least two interpreters.

We investigated the MRI appearance of normal developmental changes of the sphenoid sinus. The patient age groups were subdivided into intervals of 3 months between 0 and 2 years of age, intervals of 6 months from 2 to 4 years of age and into intervals of 12 months from 4 to 14 years of age. Assessment of the sphenoid sinus included (1) analysis of signal intensity (SI) of bone marrow on T1-weighted images and (2) measurements of the pneumatised sphenoid sinus in maximum diameter in the sagittal and axial planes. The pattern of bone marrow conversion was graded from 1 to 3 based on following criteria: Grade 1 = uniformly low signal intensity (approximately isointense with muscle); Grade 2 = mixed low and high or uniformly high signal intensity; Grade 3 = pneumatisation detected to grade 2 findings.

In each patient the largest diameter of the pneumatised sinus was evaluated on mid-sagittal T1-weighted images. Length was defined as maximal extension in ventrodorsal direction on T1-weighted midsagittal images, height as maximal extension in craniocaudal direction on T1-weighted midsagittal images and width as maximal extension in transverse direction on T2-weighted axial images. T2-weighted images were reviewed to confirm fatty changes of bone marrow and to exclude pathologic conditions.

Table 1. Graphs demonstrate age-related changes of the sphenoid bone seen on MRI. The proportion with each grade (1, 2, 3) is delineated for each group.



RESULTS

The graded signal intensities of bone marrow conversion for each age group are delineated in Table 1. Mean values of the spatial extent of the pneumatised sinus are summarised in Table 2.

Table 2. Mean values of length, height and width of the pneumatised sphenoid sinus.

Age (years)	Length (mm)	Height (mm)	Width (mm)
1-2	8,4	15,2	6,2
2-3	10	16,6	14,5
3-4	12,3	14,2	[illegible]
4-5	14,7	14,6	18,7
5-6	15,3	18,2	24,2
6-7	17,9	20,6	24,7
7-8	21,2	22,6	24,9
8-9	21,9	23,1	25,1
9-10	22,5	24,6	25,8
10-11	25,2	24,9	27,5
11-12	25,7	25,1	28,7
12-13	26,3	25,9	28,9
13-14	28,6	26,4	29,7
14-15	29,1	26,8	29,6

The marrow signal intensity of the presphenoid was as low as that of muscle (red bone marrow, Grade 1) on T1-weighted images in all children less than four months old (100%). Signal intensity began to change from hypointense to hyperintense (bone marrow conversion) at the age of four months. The proportion of patients with Grade 1 intensity decreased rapidly (Figure 1a); it was not observed in children older than two years. Grade 2 finding was visualised for the first time in patients of four to six months of age (51%). Most patients (95%), however demonstrated a Grade 2 pattern (fatty bone marrow) of the sinus at 10-12 months (Figure 1b, 1c). Onset of pneumatisation (Grade 3) was observed in 19% of the patients at the age of 12-15 months (Figure 2). Pneumatisation developed gradually with age and in a ventral-to-dorsal direction. The posterior border of the sphenoid sinus did not exceed the line of the sphenooccipital synchondrosis. By age of 43-48 months, 89% of the patients showed pneumatisation of the anterior part of the sphenoid bone. Pneumatisation was complete in all children older than 10 years (Figure 3).

DISCUSSION

The development of the sphenoid sinus begins in the 3rd or 4th month of the prenatal life as bilateral invagination of nasal mucosa into the cartilaginous cupolar recesses of the nasal cavity (Maresch et al., 1940). Then the primitive sinus develops pouchlike cavities within the sphenoid concha, which are present on both sides of the presphenoid bone (Maresch et al., 1940; Weiglein et al., 1992). At birth the sphenoid bone contains red marrow and is devoid of air (Scuderi et al., 1993). Conversion from red to yellow (fatty) bone marrow is thought to occur first in the presphenoid plate from the ages of seven months to two years (Aoki et al., 1989; Szolar et al., 1994). The pneumatisation process proceeds to the anterior and basal sphenoid regions and then to the occipitosphenoidal part of the sinus. Onset of pneumatisation begins at 12 months of life and is first seen near the choana. From the 2nd to the 6th year of age the pneumatisation of the sphenoid sinus progresses rapidly. At age 12, the sphenoid sinus assumes an adult configuration (Okada et al.,1989; Vogler et al., 1998).

The MR signal intensity of bone marrow is related to the ratio of fat to cells (Vogler et al., 1988). Bone marrow in the neonate is entirely red marrow, which on T1-weighted images exhibits uniformly low signal intensity, approximately isointense with that of muscle (Okada et al., 1988). A progressive conversion to fatty marrow occurs generally from the peripheral to the central skeleton (Okada et al., 1989). Previous studies reported that in the sphenoid sinus development high signal intensity due to bone marrow conversion (fatty marrow) on T1- weighted images does not occur before 9 to 12 months of age (Aoki et al.,

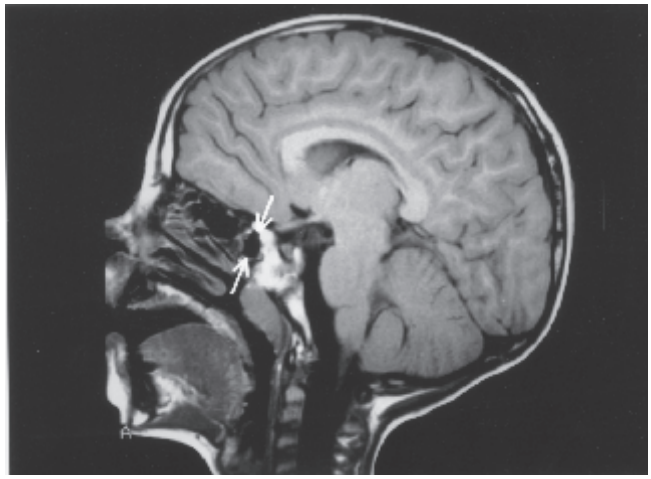


Figure 2. Midsagittal T1-weighted MR-image (650/30) in a 16-months old girl demonstrates onset of pneumatisation of the anterior part of the sphenoid bone (arrows).

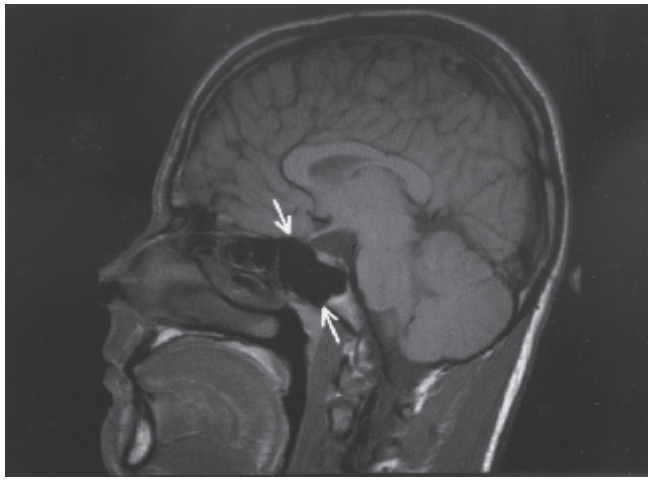


Figure 3. Midsagittal T1-weighted MR-image (650/30) shows complete pneumatisation of the sphenoid sinus in a 14- year old boy (arrows).

1989; Okada et al., 1989; Duerinckx et al., 1991). Szolar et al. (1994) as well as our study group have observed high signal intensity areas on T1-weighted images in most patients about 7 months of age (81%). The recognition of this phenomenon is useful in image interpretation, because high signal intensity differences on T1-weighted scans might be mistaken for proteinaceous fluid or haemorrhage (Aoki et al., 1989; Szolar et al., 1994). High signal intensities in children younger than 7 months may be due to fatty masses or haemorrhage. Uniformly low signal intensities after 2 years of age may suggest bone marrow disorders, such as anaemia or lymphoma (Aoki et al., 1989; Szolar et al., 1994).

Inflammatory sinus disease is a common health problem, especially in children. Infectious sinusitis is usually caused by the extension of an inflammatory process from the nasal cavity after an upper respiratory infection or from the oral cavity (Yousem, 1993). Although the sphenoid sinus is involved in inflammatory or neoplastic disorders less often than the other paranasal sinuses, the dynamics and degree of pneumatisation of the sphenoid sinus are important because of its close relationship to adjacent vital anatomic structures (Szolar et al., 1994). The most common complications of sphenoid sinusitis due to involvement of contiguous structures (optic nerve, trigeminus nerve, cavernous sinus, internal carotid artery) are meningitis, meningoencephalitis, intracranial abscess, apex orbitae syndrome and thrombosis of the cavernous sinus (Szolar et al., 1994). An understanding of embryology, regional anatomy, developmental patterns and the mucociliary clearance pathways of the paranasal sinuses is necessary for interpretation and treatment of sinus diseases.

Since many years both in children and adults endoscopic approaches are widely used for the evaluation and treatment of inflammatory and neoplastic sinonasal diseases (Stammberger and Decker, 1991). For interpretation of images accurate knowledge of development of patterns of the sphenoid sinuses is necessary. The range of bone marrow conversion and normal pneumatisation patterns of the sphenoid sinus should be taken into account before abnormalities in this region are diagnosed. Whenever surgery is planned in children, CT is still be used as a primary diagnostic imaging modality in screening for paranasal sinus diseases. However, we believe that MRI permits precise preoperative staging for endonasal surgical approaches to the sphenoid sinus and the posterior base of the skull, and helps to detect potential pitfalls, such as anatomic variants.

MRI has proved most helpful in the evaluation of regional and intracranial complications of paranasal sinus diseases (Lloyd et al., 1987; Szolar et al., 1994). Particularly in children, MRI should be used to avoid radiation exposure. Although MRI provides better visualisation of soft tissue than does CT, the main limitations of MRI in the evaluation of the paranasal sinuses are a limited ability to delineate bony details and higher costs relative to CT.

In conclusion MRI is helpful for the investigation of bone marrow changes with correlation to anatomic structures. Accurate imaging of the sphenoid and perisphenoid structures is important to identify and treat diseases of the sphenoid bone in children. The results of this study can be considered as a reference of normal age-related development of the sphenoid sinus, and can be used as a guidance in children undergoing surgery of the paranasal sinuses.

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