MR Imaging of the Normal and Abnormal Clivus

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We retrospectively reviewed 330 T1-weighted sagittal images, 80 T2-weighted sagittal images, and 83 gadopentetate-dimeglumine–enhanced scans of normal adults to determine the MR appearance of the normal adult clivus. MR images of 21 patients with an abnormal clivus (19 with tumor invasion and two with marrow reconversion) were also evaluated retrospectively and compared with those of the control group to assess MR features distinguishing the two groups. Our study revealed that a normal adult clivus consisted of low- and high-intensity portions mixed in various proportions on T1-weighted images. The low-intensity portion was isointense or hyperintense relative to the pons and always contained foci of bright signal intensity. The low-intensity tumor of a pathologic clivus tended to be hypointense relative to the pons (17/19), and was completely devoid of foci of bright signal intensity. The normal adult clivus was approximately isointense relative to the pons on T2-weighted images. Clival tumors were grossly hyperintense relative to the pons on T2-weighted images in 11 of 17 patients. In the remaining six patients, either a portion of or the entire lesion was isointense relative to the pons and, therefore, was not detectable on T2-weighted images. A normal adult clivus can enhance to some degree (19/83). Clival tumors were found to enhance intensely. A clivus of very low signal intensity (signal void) on T1- or T2-weighted images was always abnormal. The clivus with marrow reconversion was uniformly hypointense relative to the pons on T1-weighted images and isointense relative to normal marrow on T2-weighted images.

The intensity patterns of the normal clivus on T1- and T2-weighted MR images change predictably with advancing age. Intensity patterns of abnormal clivi differ from those of normal clivi. When contrast material is used, normal and abnormal clivi generally show different patterns of enhancement.

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The superior sensitivity of MR in detecting bone-marrow diseases including tumor, inflammatory processes, and trauma has been well documented [1–10]. This results from the sensitivity of MR in detecting altered tissue constituents before any morphologic changes are detected. Alteration of the normal signal intensity of bone marrow is often the earliest and occasionally the only sign of diseased bone on MR.

The clivus, owing to its central location, is always well seen on T1-weighted sagittal scout MR images of the head. Thus, clinically suspected or unsuspected disease of the clivus may be detected on the routine cranial MR image. This prompted us to review the MR signal intensity of the clivus in both normal adults and those with disease. MR features that differentiate the two groups are discussed.

Materials and Methods

We retrospectively reviewed head MR images in a group of 330 adult patients (197 women and 133 men 20–88 years old) to establish the normal MR appearance of the clivus on T1-

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TABLE 1: Graded Signal Intensity of Normal Adult Clivus: Correlation with Age

Grade	No. (%) of Patients in Each Age Group						
	20–29	30–39	40–49	50–59	60–69	70–79	80–89
1	16 (33)	13 (18)	5 (8)	0	1 (3)	0	0
2	16 (33)	31 (42)	28 (44)	19 (40)	9 (25)	9 (20)	0
3	17 (34)	29 (40)	31 (48)	28 (60)	26 (72)	36 (80)	16 (100)
Total	49	73	64	47	36	45	16

Note.—Grade 1 = predominantly low signal intensity, occupying more than 50% of clivus; grade 2 = low-signal-intensity portion occupying less than 50% but greater than 20% of clivus; grade 3 = predominantly high signal intensity, with low signal intensity occupying less than 20% of clivus.

weighted sagittal images. The age distribution of this group is shown in Table 1. Because of limited availability of cranial T2-weighted sagittal images, we retrospectively reviewed sagittal cervical spine MR images in a control group of 80 adult patients (46 men and 34 women 22–78 years old) in order to establish the normal MR appearance of the clivus on T2-weighted sagittal images. Patients with known or suspected abnormalities involving the skull base or bone marrow were excluded. Patients who had systemic disease or who had previous radiation or chemotherapy also were excluded.

We also retrospectively reviewed cranial MR images in 21 patients with an abnormal clivus. This group is summarized in Table 2. Although all of these patients had proved systemic or periclival tumor, in only three of 21 patients was histologic confirmation obtained directly from the clival lesion. The diagnosis in unproved cases (18/21) was based on other imaging techniques, such as radionuclide bone scanning, CT, or polytomography, as well as MR findings. The diagnosis was also supported by clinical information and follow-up MR scans, which showed regression following treatment or progressive change of the lesion.

The examinations were performed with a 1.5-T imager operating at 0.5 T or a 1.5-T imager operating at 1.5 T. Midline sagittal T1-weighted spin-echo (SE) images, SE 250–750/20–30/1–2 (TR/TE/excitations), with 5- to 10-mm slice thicknesses were used for evaluation of the signal intensity of the clivus. Midline sagittal T2-weighted images of the cervical spine, SE 1900–2000/80–100/2–4, with 4- to 7-mm slice thicknesses were compared with corresponding T1-weighted sagittal images. Only images that included the entire clivus were selected. In the pathologic group, cranial T2-weighted images, SE 2000–2200/70–100/2, were obtained with 5- to 10-mm slice thicknesses. Sagittal T2-weighted images were available in only seven of 21 patients. In the remaining 14 patients, the clival lesion was evaluated with axial or coronal T2-weighted images. All images were reviewed by at least three radiologists.

The signal intensity of the clivus on T1-weighted sagittal images consisted of relatively low- and high-signal-intensity portions. The low-signal-intensity portion was considered red marrow, while the high-signal-intensity portion was considered fatty marrow. The signal intensities of clival bone marrow were arbitrarily graded from 1 to 3: 1 = predominantly low signal intensity, occupying more than 50% of the clivus (Fig. 1); 2 = low-signal-intensity portion occupying less than 50% but greater than 20% of the clivus (Fig. 2); 3 = predominantly high signal intensity, with low signal intensity occupying less than 20% of the clivus (Fig. 3). The percentages used for grading may not precisely reflect the true composition of the low- and high-intensity portions of the clival marrow since they were evaluated on single midline sagittal images only. However, the observation of a general trend of age-related changes in the composition of the clival marrow may still be possible given our use of a large sample (330 subjects).

In 83 patients from the control group and 12 patients from the pathologic group, MR images were obtained before and after administration of gadopentetate dimeglumine. Images were obtained in the sagittal plane at 5-mm thicknesses in all 83 patients in the control group and at 5- to 10-mm thicknesses in 11 patients of the pathologic group. IV gadopentetate dimeglumine was administered in a dose of 0.1 mmol/kg; postinfusion T1-weighted images were obtained 3–4 min after injection. Pre- and postinfusion MR scans were compared side by side. The window levels and widths of the images were constant for the pre- and postinfusion scans.

TABLE 2: Diagnoses in Patients with an Abnormal Clivus

Diagnosis	No. of Patients
Metastases	
Breast carcinoma	5
Prostate carcinoma	2
Lung carcinoma	1
Subtotal	8
Lymphoma	2
Chordoma	3
Meningioma	3
Pituitary adenoma	2
Nasopharyngeal carcinoma	1
Reconversion from yellow to red marrow	2
Total	21

Results

Normal Adult Clivus on T1-Weighted Sagittal Images

The graded signal intensity of the clivus marrow in each age group is summarized in Table 1. A grade 1 clivus was observed in one third of patients in the third decade. The proportion of patients with grade 1 clivus gradually decreased, becoming zero by the sixth decade. A grade 2 clivus was observed in one third of patients in the third decade. The prevalence of grade 2 clivus peaked at 44% in the fifth decade and gradually decreased thereafter. A grade 3 clivus was observed in only one third of patients in the third decade. The proportion of grade 3 clivus gradually increased in older age groups and finally reached 100% in the ninth decade. The low-intensity portion of the normal adult clivus was isointense or slightly hyperintense relative to the pons on SE 250-750/20–30 images. The high-signal-intensity portion was isointense relative to subcutaneous fat.

Normal Adult Clivus on T2-Weighted Sagittal Images

The signal intensity of normal adult clivus was equal (45/80) (Fig. 4) or slightly hyperintense (25/80) or hypointense

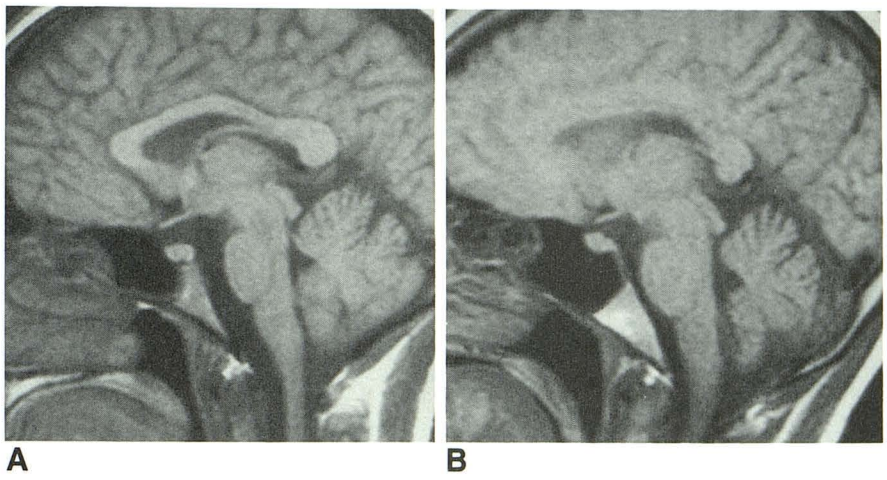


Fig. 1.—Grade 1 normal clivus on T1-weighted midline sagittal images, SE 350/30 (0.5 T), in a 25-year-old woman.

***A*, Clivus is of predominantly low signal intensity, approximately isointense relative to pons. A few foci of bright signal are seen in clival marrow.**

***B*, 35-year-old woman. Clivus is of mixed signal intensity. Low-intensity portion, occupying greater than 50% of total marrow space, is hyperintense relative to pons.**

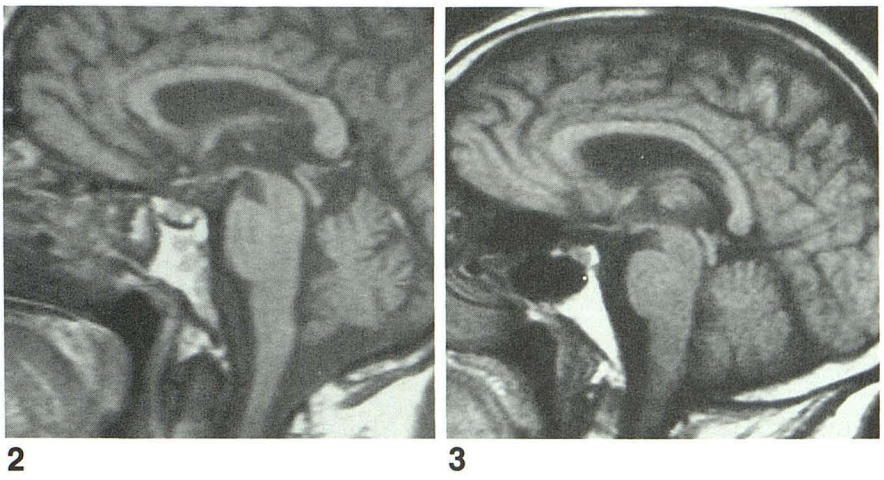


Fig. 2.—Grade 2 normal clivus with mixed signal intensity in a 77-year-old man. T1-weighted midline sagittal scan, SE 600/20 (1.5 T), shows a normal clivus with mixed low and high signal intensity. Area of low signal intensity is less than 50% but greater than 20% of entire marrow space. Low-signal-intensity area is hyperintense relative to pons. There are a few foci of bright signal intensity in low-signal-intensity portion.

Fig. 3.—Grade 3 normal clivus in a 61-year-old woman. T1-weighted midline sagittal image, SE 350/30 (0.5 T), shows a normal clivus with uniformly bright signal intensity.

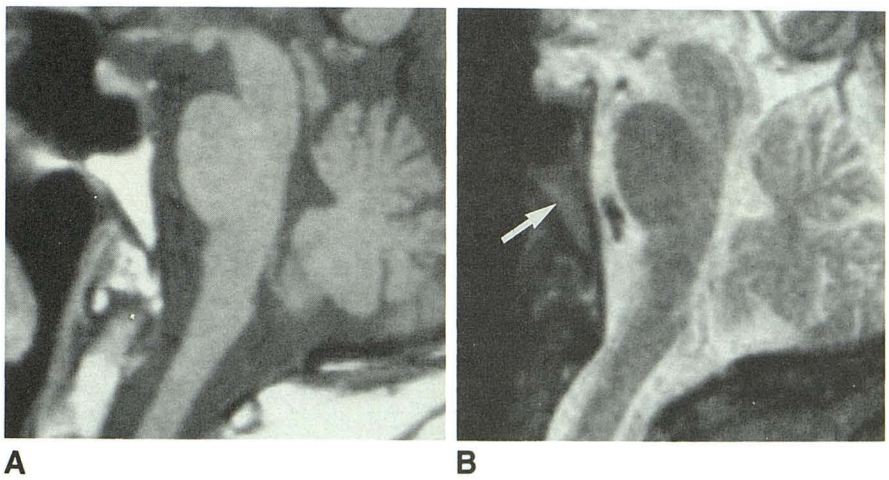


Fig. 4.—Normal clivus on T1- and T2-weighted midline sagittal images in a 63-year-old woman.

***A*, T1-weighted scan, SE 450/20 (1.5 T), shows a normal clivus with uniformly bright signal intensity (grade 3).**

***B*, T2-weighted scan, SE 1900/80 (1.5 T), shows that signal intensity of clivus (*arrow*) becomes approximately isointense relative to the pons.**

(10/80) relative to that of the pons on SE 1900–2000/80–100 images. Red and yellow discrimination diminished markedly. The fatty marrow was still slightly higher in signal intensity than red marrow on SE 1900-2000/80–100 images. The signal intensity from the clivus with a greater proportion of fatty marrow (high-grade clivus) tended to be isointense or slightly hyperintense relative to the pons. The clivus with a greater proportion of red marrow (lower-grade clivus) displayed the signal intensity equal to or slightly hypointense relative to the pons.

Gadopentetate Dimeglumine Enhancement of the Clivus in Normal Adult Patients

The prevalence of enhancement in the normal clivus in relation to the grade of preinfusion signal intensity is summarized in Table 3. Clival enhancement was observed in 19 (23%) of 83 normal patients, with greater prevalence when the preinfusion images revealed a lower grade of signal intensity. Enhancement was demonstrated in six (67%) of nine patients with grade 1 clivus intensity and in nine (26%) of 34 patients with grade 2. Enhancement was demonstrated in only four (10%) of 40 patients with grade 3 clival intensity. Contrast enhancement of the normal clivus was of mild intensity in 18 (95%) of 19 patients (Fig. 5). Enhancement was moderately intense in the remaining patient (5%) (Fig. 6).

TABLE 3: Gadopentetate Dimeglumine Enhancement of the Clivus in Normal Adults by Grade of Preinfusion Signal Intensity

Grade	Total	No. (%)	
		With Enhancement	Without Enhancement
1	9	6 (67)	3 (33)
2	34	9 (26)	25 (74)
3	40	4 (10)	36 (90)
Total	83	19 (23)	64 (77)

Note.—Grade 1 = predominantly low signal intensity, occupying more than 50% of the clivus; grade 2 = low-signal-intensity portion occupying less than 50% but greater than 20% of the clivus; grade 3 = predominantly high signal intensity, with low signal intensity occupying less than 20% of the clivus.

Abnormal Clivus

The signal intensity of the clivus was very low (signal void) in two patients with periclival meningioma on both T1-weighted (Fig. 7) and T2-weighted images. In the remaining 17 patients with tumor invasion of the clivus, the signal intensity on T1-weighted images was focally or diffusely low, hypointense relative to the pons in 15 patients (Figs. 8–10), and isointense relative to the pons in two patients. No foci of bright-signal-intensity fatty marrow were seen within the low-signal-intensity lesion in any of the patients with tumor invasion of the clivus. The signal intensity was uniformly low, hypointense relative to the pons, in two patients with yellow-to-red marrow reconversion (Fig. 11). The marrow reconversion resulted from prior repeated chemotherapy. The calvaria

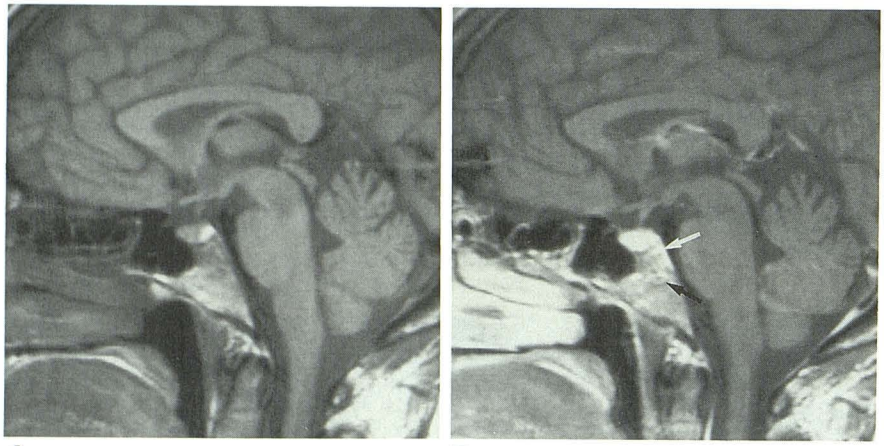


Fig. 5.—Enhancement of normal clivus in a 44-year-old woman.
***A*, Preinfusion scan, SE 600/20 (0.5 T), shows a normal clivus with mixed-signal-intensity portions (grade 2).**
***B*, Postinfusion scan shows mild enhancement of clivus near dorsum sellae. There is a curvilinear area of enhancement (*black arrow*), the morphology of which is suggestive of enhanced vascular structure. Enhancement is seen in basilar venous plexus (*white arrow*) behind upper clivus.**

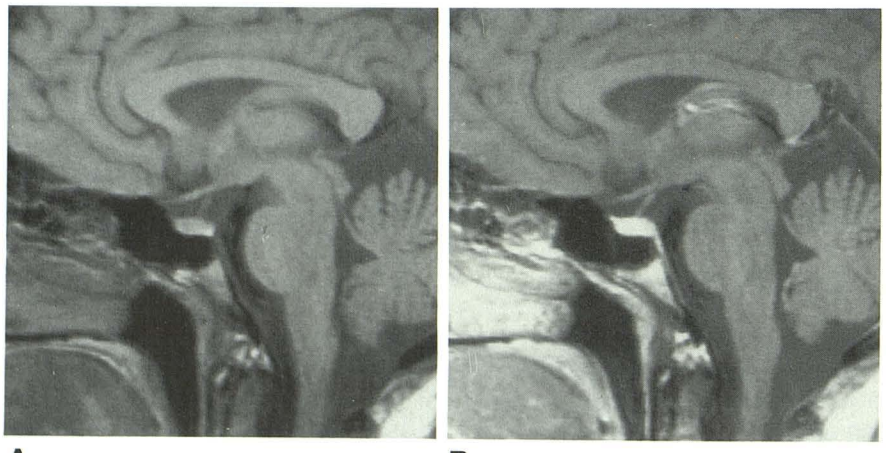


Fig. 6.—Enhancement of normal clivus marrow in a 26-year-old woman.
***A*, Preinfusion scan, SE 595/20 (1.5 T), shows a grade 1 clivus.**
***B*, Postinfusion scan shows moderately intense enhancement of clivus.**

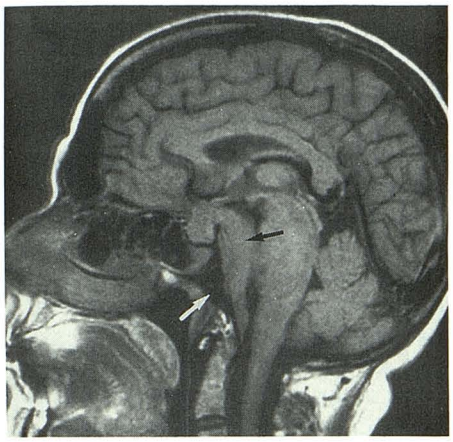
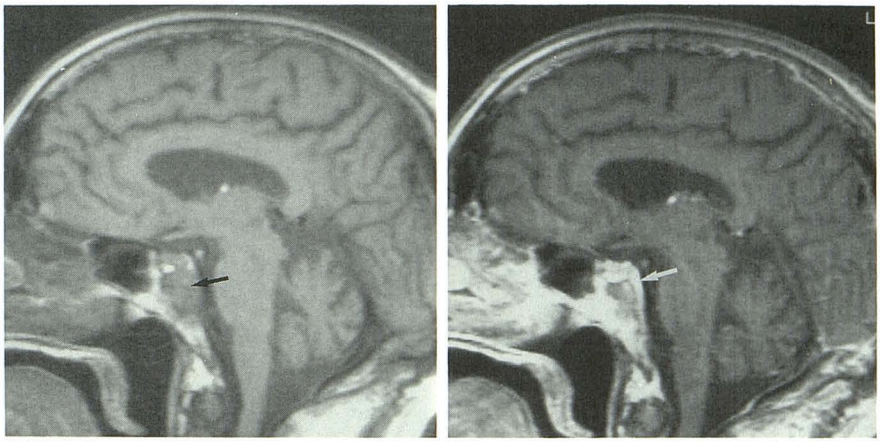


Fig. 7.—58-year-old woman with a periclival meningioma. T1-weighted midline sagittal scan, SE 750/30 (0.5 T). Very low signal intensity of clivus (*white arrow*) is caused by sclerotic change invoked by periclival meningioma (*black arrow*).



A B

Fig. 8.—74-year-old man with metastasis from prostate carcinoma, presenting with isolated sixth-nerve palsy.

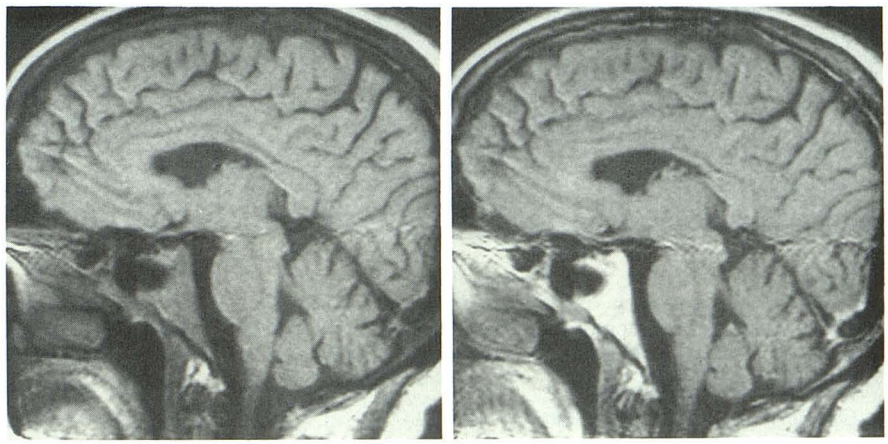
A, Preinfusion scan, SE 600/20 (1.5 T), shows focal area of low signal intensity (*arrow*) in clivus, representing metastatic tumor. Low-intensity lesion is hypointense relative to pons. No bright signal foci are seen within lesion.

B, Postinfusion scan shows intense enhancement in periphery of lesion. Central portion of lesion is poorly enhanced on scans obtained immediately after contrast infusion. Enhanced structure (*arrow*) behind clivus is basilar venous plexus.

Fig. 9.—Lymphomatous infiltration of clivus in a 43-year-old woman with isolated right sixth-nerve palsy, which improved after radiation therapy.

A, Preinfusion scan, SE 600/30 (0.5 T), shows uniformly low signal intensity of clivus, which is slightly hypointense relative to pons. There are no bright signal foci within involved clivus. Contour of clivus is normal.

B, Postinfusion scan shows diffuse, intense enhancement of clivus, which is not discernible from a normal clivus with uniformly bright signal (grade 3).

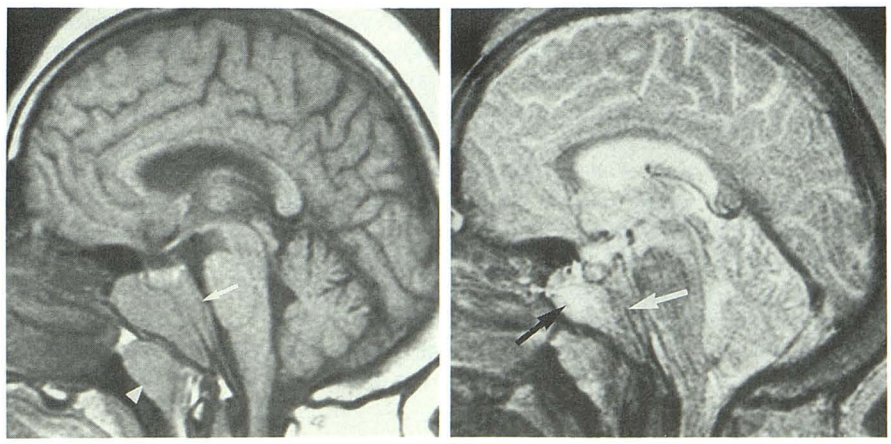


A B

Fig. 10.—77-year-old woman with bilateral sixth-nerve palsy. Biopsy of clival lesion showed lymphoma.

A, T1-weighted midline sagittal scan, SE 750/30 (0.5 T), shows uniformly low signal intensity of clivus, which is hypointense relative to pons. There are no foci of bright marrow signal intensity within involved clivus. Lesion extends into sphenoid sinus anteriorly and into prepontine cistern posteriorly (*arrow*). There is also a soft-tissue mass (*arrowhead*) in retropharyngeal region.

B, T2-weighted sagittal scan, SE 2000/100 (0.5 T), shows that anterior two thirds (*black arrow*) of lesion becomes grossly hyperintense relative to pons. Remaining posterior one third (*white arrow*) is approximately isointense relative to pons and, therefore, is not detectable on T2-weighted images, resulting in underestimating true extent of lesion.



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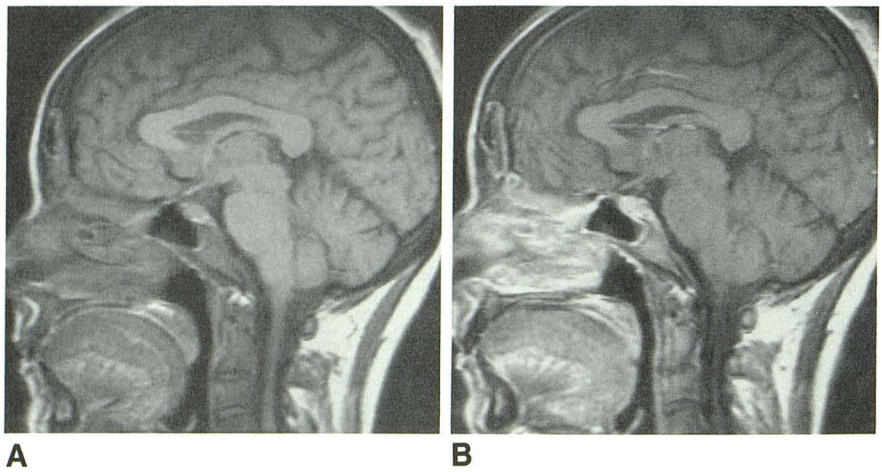

Fig. 11.—Yellow-to-red marrow reconversion in a 55-year-old woman who had prior chemotherapy for lymphoma.

A, Preinfusion midline sagittal scan, SE 425/25 (1.5 T), shows uniformly low signal intensity of clivus. Calvaria and upper cervical spine also show diffuse low-signal-intensity marrow.

B, Postinfusion scan shows moderate enhancement of clivus.

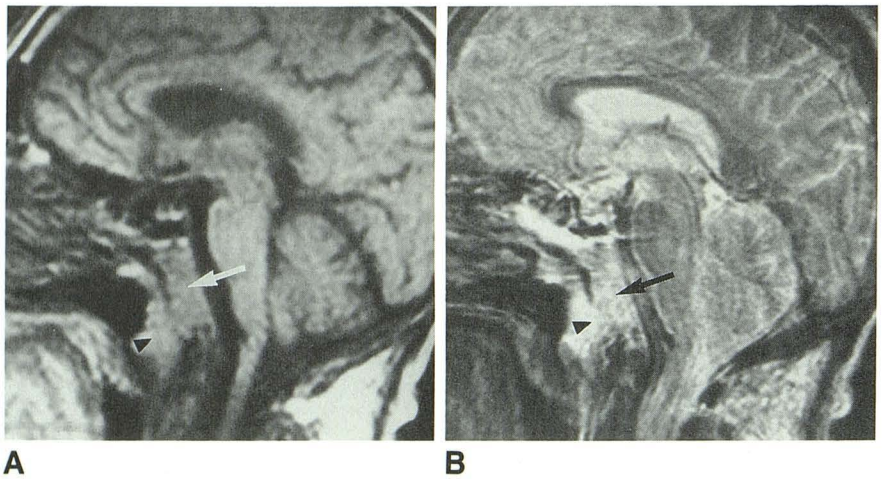

Fig. 12.—Nasopharyngeal carcinoma invading clivus in a 69-year-old man.

A, T1-weighted sagittal scan, SE 350/30 (0.5 T), shows a nasopharyngeal tumor (*arrowhead*) invading clivus (*arrow*). Involved clivus is slightly hypointense relative to pons.

B, T2-weighted sagittal scan, SE 2000/100 (0.5 T), shows that involved clivus (*arrow*) becomes grossly hyperintense relative to pons. Signal intensity of nasopharyngeal tumor (*arrowhead*) is bright also.

and the upper cervical spine, visualized on the cranial midline T1-weighted sagittal images, also showed diffuse loss of yellow marrow in these patients.

On T2-weighted images, lesions appeared as an area of homogeneously high intensity in three patients with chordoma, two with pituitary adenoma and one with nasopharyngeal carcinoma (Fig. 12). In five of eight patients with metastasis to the clivus, lesions were hyperintense relative to the normal clivus. The signal intensity was mixed with areas of iso- and hyperintensity in two patients with lymphomatous infiltration of the clivus (Fig. 10). The signal intensity was isointense relative to the normal clivus in three patients with metastasis, one with periclival meningioma and two with marrow reconversion. The diminished signal-to-noise ratio encountered on longer TR/TE images resulted in poorer anatomic definition of lesions.

Twelve of 21 patients with an abnormal clivus had gadopentetate-dimeglumine–enhanced scans. The low-intensity tumor, focal or diffuse, was intensely enhanced in all patients (Figs. 8 and 9). The reconverted clivus was mildly enhanced in one patient and moderately enhanced in the other (Fig. 11).

Discussion

Okada et al. [11], in their study of a group of normal children and young adults, demonstrated that signal from clival marrow was age-related and successively changed from uniformly low to uniformly high signal intensity on T1-weighted images. By the age of 24 years, 95% of their patients had a clivus of uniformly high signal intensity. The rate of conversion was somewhat slower in our patients. The clivus was uniformly bright in only one third of our normal patients in the third decade. The proportion of uniformly bright clivus gradually increases with advancing age. The rate increased to 80% by the eighth decade and reached 100% in the ninth decade. Our results show that interindividual variations are large in the composition of clival marrow in an adult population and that the conversion of red to yellow marrow occurs in a predictable and orderly pattern.

The hallmark of MR signal intensity caused by diseased marrow is T1 prolongation. The major factors determining the T1 changes are increased cellularity associated with tumor replacement of normal marrow and increased water content owing to bone marrow edema [10].

A clivus with uniformly low signal intensity that is hypointense relative to the pons should be considered abnormal in an adult patient. Conversely, a clivus of uniformly bright signal intensity is highly unlikely to be abnormal. The uniformly low signal intensity is attributable to diffuse tumor invasion of the clivus or marrow reconversion. In the normal adult, hematopoietic needs are met by the amount of red marrow existing

in the axial skeleton and the proximal long bones. With increasing demand for red cells, a reconversion of yellow marrow to red marrow takes place. The causes of this process include chronic anemia, heart disease with chronic heart failure, and marrow replacement disorders [10, 12]. In our two patients, reconversion occurred after chemotherapy. In these patients, diffuse low signal intensity was demonstrated in other osseous structures such as the calvaria and the upper cervical spine, a feature differentiating this process from tumor invasion of the clivus (Fig. 11).

A clivus with a pattern of mixed signal intensity presented a greater challenge in differentiating normal from abnormal. The low-signal-intensity portion of the normal clivus was isointense or hyperintense relative to the pons on SE 250–750/20–30 images (Figs. 1 and 2), whereas the signal intensity of a clival lesion was hypointense relative to the pons (Fig. 8) in 15 of 17 patients with tumor invasion. In the remaining two patients, the low-signal-intensity lesion was isointense relative to the pons. The lesion could not be detected on the basis of signal intensity alone in these two patients. However, the low-signal-intensity lesion of a pathologic clivus is completely devoid of bright marrow signal foci (Fig. 8). Foci of bright marrow signal are always present within the area of relatively low signal intensity in a normal adult clivus (Figs. 1 and 2).

The normal adult clivus became approximately isointense relative to the pons on T2-weighted images on SE 1900–2000/80–100 images (Fig. 4). Red and yellow marrow discrimination was poorer, reflecting the diminished difference in T2 relaxation times between the two types of marrow. Our study in the evaluation of the clival lesion with T2-weighted images was less than optimal because of the limited availability of sagittal T2-weighted images. T2-weighted images were valuable in detecting tumor invasion of the clivus when the lesion was sufficiently hyperintense relative to normal marrow. This occurred in 11 of 17 patients with tumor invasion of the clivus. In two other patients, only a portion of the lesion became hyperintense, resulting in an underestimation of the true extent of tumor invasion (Fig. 10). The clival lesion was not detectable on T2-weighted images in the remaining four patients with tumor invasion. The anatomic definition of the lesions, if detected, was significantly poorer on T2-weighted images. It appears that T2-weighted images are useful in detecting tumor invasion of the clivus but are inferior to T1-weighted images because of their poor spatial resolution, higher false-negative rate, and longer examination time.

A clivus of very low signal intensity (signal void) was not observed on T1- or T2-weighted images of our normal adult population. The signal void in the clivus with periclival meningioma is related to a sclerotic change of the marrow produced by tumor invasion (Fig. 7). The signal intensity of the sclerotic bone is similar to that of compact bone, which has a very low spin density because of its low content of mobile protons.

Our results show that in 23% of adults, the normal clival marrow enhanced with gadopentetate-dimeglumine. The mechanism of enhancement of normal marrow is yet to be investigated. We have observed small punctuate or curvilinear areas of low signal intensity within the marrow that enhance with contrast administration (Fig. 5). The morphology of these enhanced structures suggests that they are enhanced vessels, probably slowly flowing venous channels. A more homogeneous pattern of contrast enhancement within the marrow presumably is related to contrast material pooling within the marrow sinusoids (Fig. 6). Enhancement is observed with greater frequency within the lower-grade clivus. The clivus with a lower grade of signal intensity contains a greater amount of red marrow, which is accompanied by greater vascularity [12]; hence, enhancement is observed more frequently in the lower-grade clivus. Furthermore, enhancement may be observed more readily in the red marrow, whereas the bright signal intensity of yellow marrow obscures contrast enhancement.

Enhancement of the normal clivus usually is mild. Contrast enhancement of low-intensity tumor tends to be intense (Figs. 8 and 9). A focally or diffusely enhanced lesion therefore, may not be detected on postinfusion scans alone (Fig. 9). Enhancement of reconverted clival marrow was mild in one patient and moderate in the other (Fig. 11). The number of cases in our study was too small to define the characteristic enhancement pattern of reconverted clivus.

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