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Transverse Sinus Stenosis in Adult Patients With Chiari Malformation Type I

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Abstract

OBJECTIVE—Transverse sinus stenosis is an imaging finding very highly associated with elevated intracranial pressure (ICP). Patients with the Chiari I malformation may potentially have elevated ICP due to impairment of CSF flow at the foramen magnum. This study evaluated whether patients with Chiari I malformation have transverse sinus stenosis and other imaging findings indicative of elevated ICP.

MATERIALS AND METHODS—Thirty patients with Chiari I malformation treated surgically and 76 control subjects were identified retrospectively. All control subjects and all patients with Chiari I malformation (preoperatively) underwent standardized contrast-enhanced brain MRI including a contrast-enhanced 3D T1-weighted sequence from which curved reformats of the transverse sinuses were generated. Two different readers blinded to the diagnosis then independently evaluated these curved reformats for severity of transverse sinus stenosis. Orbital and skull-base findings previously described in association with elevated ICP were also evaluated. Frequency of MRI findings between the two groups was compared.

RESULTS—Patients with Chiari I malformation had significantly greater frequency of unilateral or bilateral transverse sinus stenosis than did control subjects ($p < 0.001$). There was complete interreader agreement on presence or absence of transverse sinus stenosis by patient ($\kappa = 1.0$ [95% CI, 0.89–1.0]). Logistic regression analysis controlling for age, sex, and body mass index found that transverse sinus stenosis significantly predicted Chiari I malformation versus control status (odds ratio, 11.2 [95% CI, 2.1–59.0]; $p = 0.004$) but that no other features were significantly associated with the Chiari I malformation. Patients with Chiari I malformation who had transverse sinus stenosis had significantly greater pituitary flattening than did those without transverse sinus stenosis ($p = 0.02$).

CONCLUSION—Patients with Chiari I malformation have higher likelihood of transverse sinus stenosis, which may reflect associated elevated ICP.

Keywords

Chiari malformation; MRI; transverse sinus stenosis

In the healthy adult, the cerebellar tonsils have a rounded morphology, caudally extend on average to 3 mm above the foramen magnum, and rarely extend more than 3 mm below it [1]. The Chiari I malformation is a congenital malformation defined on imaging by downward extension of peg-shaped cerebellar tonsils at least 5 mm below the opisthion-basion line, the inferior boundary of the foramen magnum, without mass lesion or other cause of acquired tonsillar herniation [1, 2]. Symptoms in Chiari I malformation are nonspecific and are attributed to anatomic crowding of the posterior fossa and upper spinal cord, and associated abnormal CSF flow dynamics may result in syringomyelia [3–5]. Treatment of symptomatic Chiari I malformation consists primarily of surgical decompression to alleviate crowding and restore normal CSF flow at the foramen magnum [6]. It is unclear whether cerebellar tonsillar impaction or impaired CSF flow dynamics at the foramen magnum may result in elevated intracranial pressure (ICP); however, at least a subset of patients with Chiari I malformation have signs and symptoms of elevated ICP that can complicate the clinical presentation and postsurgical course [7–9]. Although Chiari I malformation is not an absolute contraindication to lumbar puncture (LP), routine measurement of opening pressure (OP) is not routinely performed in Chiari I malformation owing to potential for tonsillar herniation and brainstem compression, although specific evidence for this practice in the literature is anecdotal and extremely limited [10].

Idiopathic intracranial hypertension is a syndrome of unknown cause that results in elevated ICP without intracranial mass lesion, hydrocephalus, or abnormality of CSF composition [11, 12]. Patients with idiopathic intracranial hypertension frequently have orbital MRI findings of posterior scleral flattening, distention of the perioptic nerve subarachnoid CSF space, vertical tortuosity of the optic nerve sheath complex, and protrusion or enhancement (or both) of the prelaminar optic nerve [13]. Skull-base findings of an “empty” CSF-filled sella turcica [14, 15] and cephaloceles [16] have also been described as imaging correlates of chronically elevated ICP. Additionally, smooth tapered narrowing of the bilateral transverse venous sinuses is nearly universally found in patients with idiopathic intracranial hypertension [17–20]. The finding of transverse sinus stenosis is highly correlated with increased ICP and rarely found in healthy control subjects, although it remains debatable whether it is a cause or an effect of elevated ICP in idiopathic intracranial hypertension [21–23]. Each of these imaging findings are not specific to idiopathic intracranial hypertension and have been found in other conditions that cause elevated ICP [24]. The purpose of this study was therefore to evaluate whether transverse sinus stenosis and other imaging findings associated with increased ICP are present in patients with the Chiari I malformation.

Materials and Methods

Patient Selection and Demographics

Approval for this study was obtained from the institutional review board. Patients and control subjects were identified retrospectively by searching the institution's archived electronic medical records for MRI reports from May 2010 through April 2012 of individuals who had undergone brain MRI with IV contrast administration. Inclusion criteria for the Chiari I malformation group were as follows: a presurgical MRI with 3D contrast-enhanced T1-weighted image(s) meeting the imaging criteria for Chiari I malformation (downward extension of peg-shaped ["peglike"] cerebellar tonsils 5 mm below the opisthion-basion line without mass lesion or other cause of acquired tonsillar herniation); and subsequent surgical decompression for Chiari I malformation. Exclusion criteria were presence of any intracranial imaging abnormalities (apart from the Chiari I malformation), including postoperative changes. A search for the term "Chiari" without specific age limits yielded 228 patients. After exclusion of patients whose reports mentioned "no evidence of Chiari" ($n = 157$), studies that did not have a 3D contrast-enhanced T1-weighted sequence as part of their MRI protocol during image review ($n = 13$), patients who had Chiari II malformations ($n = 6$), patients who were already postoperative from surgical decompression ($n = 8$), and patients without subsequent postsurgical decompression of Chiari I malformation ($n = 14$), there were 30 patients in the Chiari I malformation group. There were two men (7%) in the Chiari I malformation group, with a median age of 34.7 years (interquartile range [IQR], 28.9–41.9 years). Median body mass index (BMI; weight in kilograms divided by the square of height in meters) for the Chiari I malformation group was 28.1 (IQR, 24.2–35.9).

Control Group Selection and Demographics

Control subjects were selected by searching the archived data from our institution's electronic medical records over the same date range and without age limits. Inclusion was based on availability of an MRI of the brain with 3D contrast-enhanced T1-weighted image(s) showing no abnormality on review. Exclusion was based on medical records review indicating headaches, visual disturbance, or chronic seizure disorder. A search of reports for MRI of the brain with IV contrast administration using the term "normal MRI of the brain" yielded 1270 studies. The vast majority of these ($n = 1053$) consisted of a report noting "otherwise normal MRI of the brain," leading to exclusion without image review. After exclusion of patients with headaches, visual disturbance, or chronic seizure disorder found on medical records review, an additional 123 individuals were excluded. On image review, an additional 18 individuals did not have a 3D contrast-enhanced T1-weighted sequence as part of their MRI protocol. This ultimately yielded 76 control subjects for comparison with the Chiari I malformation group. Indications for having brain MRI in the control group were sensory disturbances, peripheral neuropathies, initial seizure workup, and metastatic screening. There were 14 men (18%) in the control group, with a median age of 33.4 years (IQR, 29.5–39.6 years). Median BMI for the control group was 25.6 (IQR, 21.8–30.4).

MRI Technique

MRI was performed at either 3.0 T (Trio, Siemens) or 1.5 T (Avanto, Siemens; or Signa, GE Healthcare) using a standard head coil. All patients underwent a standardized brain MRI protocol including acquisition of unenhanced axial diffusion-weighted, T1-weighted, T2*-weighted, T2-weighted, and sagittal T1-weighted images (0.7×0.7 -mm in-plane resolution at a slice thickness of 5 mm). All patients received standard dose (0.1 mmol/kg) IV gadolinium-based contrast agent (Multihance, Bracco Diagnostics), followed by contrast-enhanced axial T1-weighted and sagittal volumetric magnetization prepared gradient-recalled echo T1-weighted images (TR/TE, 1900/2–3; flip angle, 9–12°; with 1-mm isotropic voxels).

Image Analysis

Full MRI studies for all control subjects were initially reviewed by an experienced neuroradiologist to confirm that the studies were normal and, for all patients with Chiari I malformation, to ensure they met criteria for the Chiari I malformation and that there had been no surgical intervention or intracranial abnormality apart from the Chiari I malformation. Images were then reviewed by the same neuroradiologist in a randomized fashion without knowledge of case or control status for cerebellar tonsillar position relative to the foramen magnum, cerebellar tonsillar morphology (normal vs peglike), and the presence or absence of an upper cervical spinal cord syrinx. Orbital imaging findings of protrusion of the optic nerve head, enhancement of the optic nerve head, flattening of the posterior sclera, increased perioptic nerve CSF, and vertical tortuosity of the intraorbital optic nerve [13] were recorded for all patients. Pituitary tissue height on the sagittal T1-weighted image was classified into five categories based on the system of Yuh et al. [14]: 1, normal; 2, mild superior concavity ($< 1/3$ of the height of the sella); 3, moderate concavity ($1/3$ – $2/3$ of the height of the sella); 4, severe concavity ($> 2/3$ of the height of sella); and 5, no visible pituitary tissue. The frequency of cephaloceles, as defined by CSF-containing or brain and CSF-containing structures outside the expected confines of the cranial vault, was recorded in each patient [16].

Maximum intensity projections (MIPs) and curved reformats sequentially extending through the center of the right internal jugular vein, right sigmoid sinus, right transverse sinus, torcular herophili, left transverse sinus, left sigmoid sinus, and left internal jugular vein were generated by a different coinvestigator using the contrast-enhanced 3D T1-weighted sequence as previously described [17, 25]. These MIP and curved reformats were then reviewed independently by two experienced neuroradiologists in isolation from the other images to prevent any bias from knowledge of tonsillar position or other imaging findings that would suggest that the images were from a patient with Chiari I malformation or control subject. These images were assessed for presence or absence of transverse sinus stenosis on the right and left using the following grading system, adapted from that of Farb et al. [18]: 0, no stenosis; 1, up to 50% stenosis (mild); 2, 51–75% stenosis (moderate); 3, 76–100% stenosis (severe).

Statistical Analysis

Statistical analysis was performed with R (version 2.15.1, R Foundation for Statistical Computing) [26]. Medians were reported for continuous data; percentages were reported for categorical data. Continuous variables were compared using the Student *t* test, and proportions were compared using chi-square or Fisher exact tests, as appropriate. Multivariable logistic regression was used to evaluate the association of the presence of transverse sinus stenosis, increased optic nerve sheath CSF, and scleral flattening on Chiari I malformation case status, controlling for age, sex, and BMI. Quadratic-weighted (Fleiss-Cohen) kappa statistics were used to estimate interobserver agreement with regard to transverse sinus stenosis. Significance was set at the 0.05 level (two-tailed *p* value).

Results

Differences Between Chiari I Malformation and Control Groups

Differences in demographics and MRI findings between the Chiari I malformation and control groups are summarized in Table 1. For the 30 patients with Chiari I malformation and the 76 control subjects, there were no significant differences in sex ($p = 0.226$) or age ($p = 0.816$). The BMI of the Chiari I malformation group (28.2 [IQR, 24.2–35.9]) was significantly higher than that of the control group (25.6 [IQR, 21.8–30.4]) ($p = 0.014$). Control subjects had a median cerebellar tonsillar position of 2 mm above the foramen magnum (IQR, 3 mm above to 0 mm), and no control subjects had peglike cerebellar tonsils or presence of a cervical spinal cord syrinx. Patients in the Chiari I malformation group all had peglike cerebellar tonsil morphology, all greater than 5 mm below the foramen magnum, with a median tonsillar position of 9.5 mm below the foramen magnum (IQR, 7.0 mm below to 14.0 mm below). Of the 30 patients with Chiari I malformation, 10 had a cervical spinal cord syrinx. Patients with Chiari I malformation, as expected, had significantly lower cerebellar tonsillar position and higher frequency of peglike tonsils and spinal cord syrinx (all $p < 0.001$). The presence of scleral flattening was significantly more frequent ($p = 0.021$) in the patients with Chiari I malformation patients (10%) than in the control subjects (0%). No significant differences in frequency of other orbital imaging findings, pituitary grade, or frequency of cephaloceles were present between the two groups.

Transverse sinus stenosis was found in 10 of 30 (33%) patients with Chiari I malformation and only two of 76 (2.6%) control subjects. One of these two control subjects was scored independently as having mild (< 50%) unilateral transverse sinus stenosis, whereas the other was scored as having mild transverse sinus stenosis on the left (both readers) and moderate (one reader) to severe (one reader) transverse sinus stenosis on the right. Nine of 10 patients with Chiari I malformation were independently scored as having bilateral transverse sinus stenosis. The one remaining Chiari I malformation patient with transverse sinus stenosis had moderate (one reader) to severe (one reader) left-sided transverse sinus stenosis. Patients with Chiari I malformation were significantly more likely ($p < 0.001$) to have transverse sinus stenosis than were control subjects. Examples of patients with normal appearance of the transverse sinuses and patients with transverse sinus stenosis are shown in Figure 1. Simultaneous control of age, sex, and BMI by logistic regression in our final model supported that only the presence of transverse sinus stenosis (odds ratio, 11.2 [95% CI, 2.1–

59.0]; $p = 0.004$) was an independent predictor of Chiari I malformation status. Sensitivity analyses were performed to evaluate for the possibility of inadequate control for BMI on the basis of the much higher frequency of severe obesity in patients with Chiari I malformation (Fig. 2). However, transverse sinus stenosis remained an independent predictor of Chiari I malformation status when analyses were limited to case and control subjects with BMI < 36 and BMI < 30 (Fig. 2).

Interreader Concordance for Transverse Sinus Stenosis

There was 100% agreement on whether transverse sinus stenosis was present by patient ($\kappa = 1.0$ [95% CI, 0.89–1.0]). For the grading of stenosis (grade 0, 1, 2, or 3) at the patient level, there was also excellent agreement between the two independent readers ($\kappa = 0.96$ [95% CI, 0.89–1.0]). For the grading of the degree of stenosis when stenosis was present (i.e., only grades 1, 2, or 3), the interreader concordance was moderate ($\kappa = 0.71$ [95% CI, 0.20–1.00]).

Differences Between Chiari I Malformation Patients Without and With Transverse Sinus Stenosis

Results are summarized in Table 2. There were no differences in age, sex, or BMI between Chiari I malformation patients without transverse sinus stenosis and those with transverse sinus stenosis. Chiari I malformation patients with transverse sinus stenosis had a significantly higher pituitary grade ($p = 0.024$) than did those without transverse sinus stenosis. Otherwise, no significant differences in imaging findings were present between Chiari I malformation patients with transverse sinus stenosis and those without transverse sinus stenosis.

Discussion

In this study, we found that patients with Chiari I malformation have a higher likelihood of transverse sinus stenosis than control subjects after controlling for age, sex, and BMI. Multiple studies using contrast-enhanced MR venography techniques have shown that transverse sinus stenosis is nearly universally present in idiopathic intracranial hypertension and only rarely present in control subjects [17–20]. Whether transverse sinus stenosis is a cause or a result of elevated ICP remains unclear in idiopathic intracranial hypertension, with some studies showing a resolution of transverse sinus stenosis after removal of CSF and normalization of CSF OP and others showing that stenting of the transverse sinus stenosis can result in decreased symptoms of increased ICP and a reduction in CSF OP [21–23]. Regardless, a strong association between transverse sinus stenosis and idiopathic intracranial hypertension is present. Rohr et al. [24] showed that increased ICP from a variety of causes other than idiopathic intracranial hypertension, so-called “secondary intracranial hypertension,” can also result in transverse sinus stenosis.

This study also evaluated the frequency of orbital and skull-base findings on MRI that are traditionally associated with chronically elevated ICP in the setting of idiopathic intracranial hypertension [13, 27]. Only scleral flattening was found with significantly greater frequency in patients with Chiari I malformation than in control subjects. Maralani et al. [28] showed that posterior scleral flattening was the imaging finding with highest likelihood of

association with idiopathic intracranial hypertension, occurring in 53.5% of patients with idiopathic intracranial hypertension. In contrast, only 10% of our Chiari I malformation group were found to have posterior scleral flattening, and on multivariate logistic regression, it was not found to be a significant predictor of Chiari I malformation status. In this study, we also found that the median pituitary grade for Chiari I malformation patients was only grade 2 (mild superior concavity, $< 1/3$ of the height of the sella) and not significantly different from control subjects. In contrast, a study of patients with idiopathic intracranial hypertension using similar technique, median age, and sex composition, as well as the Yuh et al. [14] grading scale for pituitary grade, found a median pituitary grade of 4 (severe concavity, $> 2/3$ of the height of the sella) for patient with idiopathic intracranial hypertension [15]. Comparison between Chiari I malformation patients with and without transverse sinus stenosis showed a significantly higher pituitary grade in Chiari I malformation patients with than in those without transverse sinus stenosis. This finding supports that there is chronically elevated ICP in the setting of Chiari I malformation with transverse sinus stenosis but not in the absence of transverse sinus stenosis.

Our finding that transverse sinus stenosis is present in some patients with Chiari I malformation is potentially important for the following reasons. When transverse sinus stenosis is identified in the setting of Chiari I malformation, it indicates that further evaluation for clinical and MRI findings to support increased ICP, as well as to exclude other causes of elevated ICP, is warranted. The identification of elevated ICP in Chiari I malformation is extremely important because increased ICP can complicate the postsurgical course after posterior fossa decompression [8, 29]. Fagan et al. [8] found that 15 of 36 patients with failed decompressive surgery for Chiari I malformation were found to have elevated OP that was subsequently treated with CSF shunt placement. In that study, none of the six adult patients experienced relief of symptoms [8]. In a study by Bejjani et al. [30], however, six patients with failed surgery for Chiari I malformation were found to have elevated OP that was subsequently treated with CSF shunt placement leading to relief of symptoms.

To complicate matters, the imaging appearance of idiopathic intracranial hypertension itself can sometimes simulate a Chiari I malformation. Patients with idiopathic intracranial hypertension frequently exhibit downward displacement of the cerebellar tonsils (presumably related to the high ICP); however, only approximately 10–12% have cerebellar tonsillar position and peglike morphology meeting criteria for a Chiari I malformation [9, 31]. The imaging of these patients is potentially confusing and results in discussion of whether the idiopathic intracranial hypertension is primary to the tonsillar appearance, whether the patient has a Chiari I malformation with associated elevated ICP, or whether there is coexistence of both conditions [9, 32]. The distinction has major implications on the subsequent management of the patient, including the decision of whether to initially treat as Chiari I malformation or as idiopathic intracranial hypertension. Ultimately, it may be difficult in practice to prospectively differentiate this from a patient with a Chiari I malformation who has associated elevated ICP and papilledema, and this distinction may be made only through specific treatment of one condition and follow-up documenting either resolution or persistence of the primary underlying problem.

A potential criticism of this study is that there may have been inadequate control of age, sex, and BMI; this was primarily addressed by multivariate logistic regression analysis to control for these variables. However, because there were notable differences in the BMI distributions (Fig. 2) between case and control subjects, we performed additional sensitivity analyses by limiting analysis to case and control subjects with BMI < 36 and BMI < 30, and transverse sinus stenosis remained a significant predictor of Chiari I malformation status. Even though obesity is common, as well as associated with idiopathic intracranial hypertension, the overall incidence of idiopathic intracranial hypertension even among obese women is rare [33], and it is unlikely that the patients with Chiari I malformation in our study population would also have idiopathic intracranial hypertension simply due to obesity. Indeed, some patients in the Chiari I malformation group had BMIs as high as 52 but did not exhibit transverse sinus stenosis, which is nearly universally seen in idiopathic intracranial hypertension [17–20]. A major limitation of this study is that Chiari I malformation patients did not undergo an ophthalmic examination to assess for papilledema or undergo LP to measure the OP. That LP in patients with relative obstruction of the foramen magnum and upper cervical spinal canal carries some degree of risk makes it unlikely that correlation of imaging findings including transverse sinus stenosis with OP would be undertaken in most Chiari I malformation patients. Future studies that prospectively evaluate for papilledema and for differences in outcome between Chiari I malformation patients with and without transverse sinus stenosis would be beneficial.

Additional limitations to this retrospective study relate to selection of control subjects and patients with Chiari I malformation. Patients with headache and visual disturbances were intentionally excluded from the control group to minimize the likelihood of inclusion of patients with idiopathic intracranial hypertension or Chiari I malformation. Alternatively, it could be argued that the control subjects were not completely healthy because they did have indications for imaging, such as initial seizure and sensory disturbance; however, if control subjects were included who had increased ICP or other conditions causing the radiologic findings of interest, this would have resulted in a bias toward the null hypothesis. Another potential criticism is that dedicated contrast-enhanced MR venography was not used for evaluation of transverse sinus stenosis; however, a prior study has shown excellent concordance of the contrast-enhanced 3D T1-weighted sequence used here with contrast-enhanced MR venography for the evaluation of transverse sinus stenosis [25].

In conclusion, patients with Chiari I malformation have significantly higher likelihood of transverse sinus stenosis, a finding that is highly associated with increased ICP. This underscores the need for the radiologist, when presented with cerebellar tonsils meeting criteria for Chiari I malformation, to carefully evaluate for additional imaging findings including assessment for the presence or absence of transverse sinus stenosis to suggest associated elevated ICP.

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Fig. 1.

Fig. 1A —Examples of transverse sinus stenosis and normal appearance of transverse sinuses.

A, 39-year-old woman with Chiari I malformation. Midsagittal contrast-enhanced 3D T1-weighted image (**A**) shows peglike cerebellar tonsils (*arrow*, **A**) extending 13 mm below foramen magnum. Curved reformat (**B**) along course of right sigmoid sinus through left sigmoid sinus shows bilateral transverse sinus stenosis (*arrows*, **B**), graded concordantly by two readers as severe (grade 3, > 75% stenosis). Though proximal right transverse sinus is hypoplastic, there is stenosis more distally after area of luminal enlargement.

Fig. 1B —Examples of transverse sinus stenosis and normal appearance of transverse sinuses.

B, 39-year-old woman with Chiari I malformation. Midsagittal contrast-enhanced 3D T1-weighted image (**A**) shows peglike cerebellar tonsils (*arrow*, **A**) extending 13 mm below foramen magnum. Curved reformat (**B**) along course of right sigmoid sinus through left sigmoid sinus shows bilateral transverse sinus stenosis (*arrows*, **B**), graded concordantly by two readers as severe (grade 3, > 75% stenosis). Though proximal right transverse sinus is hypoplastic, there is stenosis more distally after area of luminal enlargement.

Fig. 1C —Examples of transverse sinus stenosis and normal appearance of transverse sinuses.

C, 39-year-old man with normal findings on MRI performed because of transient arm weakness. Midsagittal contrast-enhanced 3D T1-weighted image (**C**) shows normal morphology of cerebellar tonsils (*arrow*, **C**) at level of foramen magnum. Curved reformat (**D**) shows normal-caliber transverse sinuses, graded concordantly by two readers as normal (grade 0).

Fig. 1D —Examples of transverse sinus stenosis and normal appearance of transverse sinuses.

D, 39-year-old man with normal findings on MRI performed because of transient arm weakness. Midsagittal contrast-enhanced 3D T1-weighted image (**C**) shows normal morphology of cerebellar tonsils (*arrow*, **C**) at level of foramen magnum. Curved reformat (**D**) shows normal-caliber transverse sinuses, graded concordantly by two readers as normal (grade 0).

Fig. 1E —Examples of transverse sinus stenosis and normal appearance of transverse sinuses.

E, 40-year-old woman with melanoma and normal findings on MRI performed as part of metastatic workup, representing one of only two control subjects considered as having transverse sinus stenosis. Sagittal contrast-enhanced 3D T1-weighted image (**E**) shows normal morphology of cerebellar tonsils (*arrow*, **E**) 3 mm below foramen magnum. Curved reformat (**F**) shows left-sided transverse sinus stenosis (*arrow*, **F**) in nondominant left transverse sinus. Small bilateral arachnoid granulations are present (*arrowheads*, **F**); however, overall luminal diameter at these locations is not narrowed and is not considered as transverse sinus stenosis. This study was graded as mild (grade 1, < 50% stenosis) unilateral left-sided stenosis.

Fig. 1F —Examples of transverse sinus stenosis and normal appearance of transverse sinuses.

F, 40-year-old woman with melanoma and normal findings on MRI performed as part of metastatic workup, representing one of only two control subjects considered as having

transverse sinus stenosis. Sagittal contrast-enhanced 3D T1-weighted image (**E**) shows normal morphology of cerebellar tonsils (*arrow*, **E**) 3 mm below foramen magnum. Curved reformat (**F**) shows left-sided transverse sinus stenosis (*arrow*, **F**) in nondominant left transverse sinus. Small bilateral arachnoid granulations are present (*arrowheads*, **F**); however, overall luminal diameter at these locations is not narrowed and is not considered as transverse sinus stenosis. This study was graded as mild (grade 1, < 50% stenosis) unilateral left-sided stenosis.

Fig. 2. Plots show distribution of body mass index (weight in kg divided by square of height in m) across control subjects (*top*) and patients with Chiari I malformation (*bottom*).

TABLE 1

Differences in Demographics and MRI Findings Between Chiari I Malformation and Control Groups

Parameter	Chiari I Malformation Group (<i>n</i> = 30)	Control Group (<i>n</i> = 76)	<i>p</i>
Male sex	7 (2)	18 (14)	0.226
Age (y), median (IQR)	34.7 (28.9–41.9)	33.4 (29.5–39.6)	0.816
Body mass index, ^a median (IQR)	28.1 (24.2–35.9)	25.6 (21.8–30.4)	0.014
Cerebellar tonsils and syrinx			
Tonsil position (mm), median (IQR) ^b	9.5 (7.0–14.0)	−2.0 (−3.0 to 0)	< 0.001
Peglike tonsillar morphology	100 (30)	0 (0)	< 0.001
Cervical spinal cord syrinx	33 (10)	0 (0)	< 0.001
Transverse sinus stenosis (by patient)			
Unilaterally or bilaterally present	33 (10)	3 (2)	< 0.001
Minimum consensus grade			< 0.001
0	70 (21)	97 (74)	
1 (mild)	7 (2)	3 (2)	
2 (moderate)	13 (4)	0 (0)	
3 (severe)	10 (3)	0 (0)	
Orbital findings			
Optic nerve head protrusion	0 (0)	0 (0)	1.000
Optic nerve head enhancement	0 (0)	0 (0)	1.000
Scleral flattening	10 (3)	0 (0)	0.021
Increased perioptic nerve CSF	27 (8)	11 (8)	0.067
Vertical optic nerve tortuosity	7 (2)	1 (1)	0.192
Skull-base findings			
Pituitary grade			0.633
1	0 (0)	1 (1)	
2	47 (14)	41 (31)	
3	30 (9)	42 (32)	
4	10 (3)	9 (7)	
5	13 (4)	7 (5)	
Skull-base cephalocele	0 (0)	0 (0)	1.000

Note—Except where otherwise indicated, data are given in the form of percentage (no.) of cases. IQR = interquartile range.

^aWeight in kilograms divided by the square of height in meters.

^bPositive number indicates tonsillar position below the foramen magnum, and negative number indicates tonsillar position above the foramen magnum.

TABLE 2

Differences Between Chiari I Malformation Patients Without and With Transverse Sinus Stenosis

Parameter	Chiari I Malformation Without Transverse Sinus Stenosis (<i>n</i> = 20)	Chiari I Malformation With Transverse Sinus Stenosis (<i>n</i> = 10)	<i>p</i>
Male:sex	10 (2)	0 (0)	0.540
Age (y), median (IQR)	36.1 (27.7–43.8)	33.7 (30.8–45.3)	0.576
Body mass index ^a , median (IQR)	26.7 (23.1–31.7)	30.8 (27.7–45.3)	0.115
Cerebellar tonsils and syrinx			
Tonsil position (mm), median (IQR)	9.5 (7.0–14.3)	9.5 (7.3–13.8)	0.880
Peglike tonsillar morphology	100 (20)	100 (10)	1.000
Cervical spinal cord syrinx	25 (5)	50 (5)	0.231
Minimum grade of transverse sinus stenosis (by patient)			< 0.001
0	100 (20)	10 (1)	
1 (mild)	0 (0)	20 (2)	
2 (moderate)	0 (0)	40 (4)	
3 (severe)	0 (0)	30 (3)	
Orbital findings			
Optic nerve head protrusion	0 (0)	0 (0)	1.000
Optic nerve head enhancement	0 (0)	0 (0)	1.000
Scleral flattening	10 (2)	1 (10)	1.000
Increased perioptic nerve CSF	15 (3)	50 (5)	0.078
Vertical optic nerve tortuosity	10 (2)	0 (0)	0.540
Skull-base findings			
Pituitary grade			0.024
1	0 (0)	0 (0)	
2	55 (11)	30 (3)	
3	35 (7)	20 (2)	
4	10 (2)	10 (1)	
5	15 (3)	40 (4)	
Skull-base cephalocele	0 (0)	0 (0)	1.000

Note—Except where otherwise indicated, data are given in the form of percentage (no.) of cases. IQR = interquartile range.

^aWeight in kilograms divided by the square of height in meters.