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Compatibility of Cervical Spine Braces with MR Imaging: A Study of Nine Nonferrous Devices

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Several cervical spine braces and orthoses were evaluated for their compatibility with imaging in the MR scanner. Nine such devices were investigated: EXO cervical collar, Philadelphia collar, S.O.M.I. cervical orthosis, Guilford cervical orthosis, modified Guilford cervical orthosis, PMT halo cervical orthosis, modified PMT halo cervical orthosis, Bremer halo system, and Bremer MR-compatible halo system. Devices containing ferrous materials detected by a small bar magnet were not scanned. The remaining devices applied to a volunteer or a patient were scanned to evaluate image quality in the generation of images of the cervical spine and, in some cases, the brain. Orthoses that contained electrically conductive loops produced unsatisfactory scans. Replacement of ferrous materials with nonferrous metals and alloys and elimination of electrical loops proved to be necessary to make cervical braces and orthoses MR-compatible.

Cervical orthoses with aluminum or graphite-carbon composite components that are interconnected with plastic joints such as the plastic ball-and-socket joints are, to date, the most successfully designed devices for MR compatibility. To make these orthoses CT compatible, low electron density materials are presently being evaluated to replace the titanium skull pins.

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The management of acute spinal trauma requires recognition, stabilization, and further evaluation of the extent of the injury. In the stabilization of cervical spine injury, a variety of braces and orthoses are available to the clinician. As MR imaging emerges as an essential technique for the further work-up of spinal injury, the incompatibilities of standard life-support equipment and of some spine-stabilizing devices in the MR suite have become apparent. We evaluate nine such cervical braces and orthoses for their MR compatibility. A device is MR-compatible if it can be safely placed within the scanner and introduces few, if any, artifacts on the images.

Material and Methods

Several cervical collars and braces were evaluated for their MR compatibility. All devices were first screened for ferrous materials by means of a small hand-held bar magnet. Devices with any detectable amounts of ferrous-containing components were thought to be unacceptable for placement in the MR scanner and were excluded from further testing. The remaining devices were applied to a healthy volunteer. A few braces tested were already fitted to patients. Scanning of the cervical spine and, in some instances, the brain, was performed on a 1.0-T cryogenic system (Picker, Highland Heights, OH) with a body coil as the resonator and an HQ lumbar spine coil (Picker, Highland Heights, OH) as the receiver. Scanning parameters for sagittal spine images were 550–600/20/4 (TR/TE/excitations) and 2000–3000/80/1 with motion compensation, slice thickness 4 mm, field of view 25–30 cm, and acquisition matrix 256 × 256. Gradient-echo axial images were acquired with parameters of 300/16/4, slice thickness 3.5 mm with 100% gap, field of view 30 cm, and acquisition matrix 256 × 256. Parameters for axial brain images were 650/20/2, slice thickness 8–10

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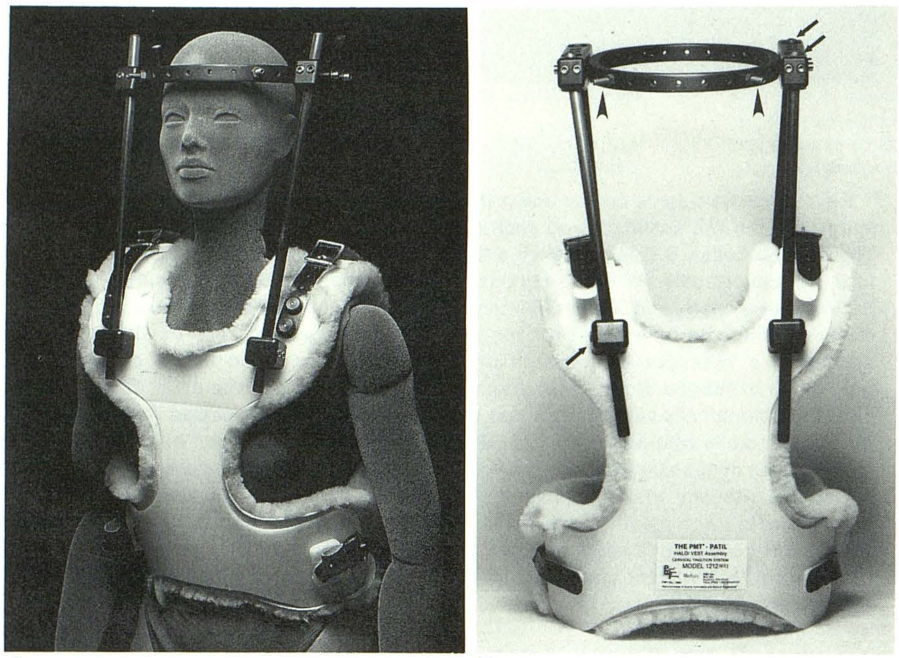
mm, field of view 25 cm, and acquisition matrix 256 × 256. Some brain images were acquired with the body coil as the transmitter and receiver. Scanning parameters were the same as above.

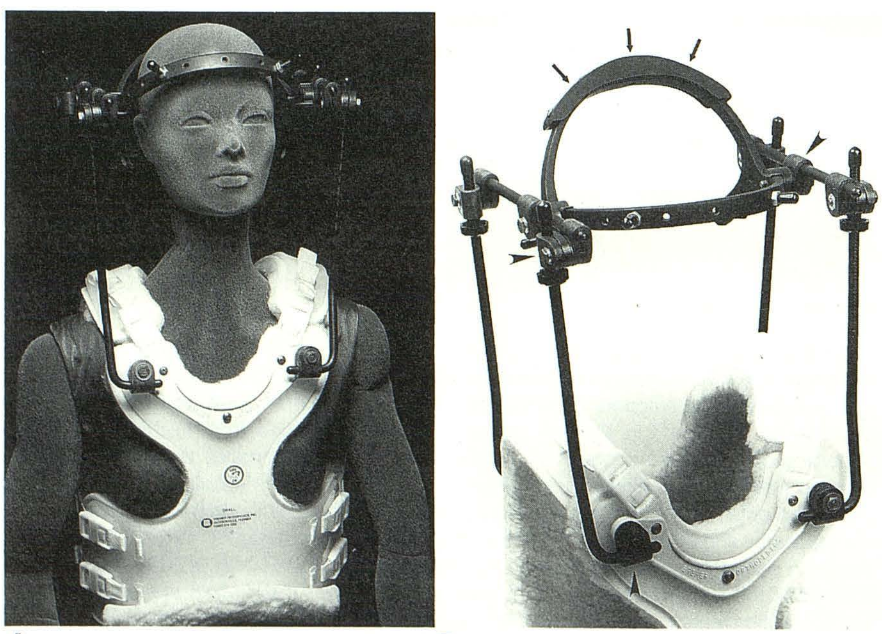
Devices evaluated were the EXO adjustable cervical collar (Florida Manufacturing Co., Daytona, FL), the Philadelphia collar (Philadelphia Collar Co., Westville, NJ), the S.O.M.I. cervical orthosis (U.S. Manufacturing Co., Pasadena, CA), a PMT halo cervical orthosis (PMT Corp., Chanhassen, MN), a Guilford cervical orthosis (Guilford & Son, Ltd., Cleveland, OH), a PMT halo cervical orthosis with graphite-carbon composite rods and halo ring (Fig. 1), a modified Guilford cervical orthosis, a standard Bremer halo crown and vest (Bremer halo system), and a preproduction MR-compatible Bremer halo system (Bremer Medical Co., Jacksonville, FL), (Fig. 2). The Philadelphia collar was a later version that had plastic fasteners. The modified Guilford cervical orthosis had all ferrous materials replaced with nonferrous components, that is, brass and monel rivets and plastic fasteners. The preproduction Bremer halo system had the crown split in its center and reconnected with a plastic bridge. Stainless steel fasteners were replaced with titanium fasteners. The halo crown and vest were joined by aluminum rods that were separated from metal



A B

Fig. 1.—*A*, A PMT halo cervical orthosis with rods and halo ring made of a graphite-carbon composite.

***B*, Components are interconnected with plastic ball-and-socket joints (*arrows*). Titanium pins in the halo ring replace stainless steel pins (*arrowheads*).**



A B

Fig. 2.—*A* and *B*, Preproduction Bremer halo crown and vest system has the crown split in the center and reconnected by a plastic bridge (*arrows* in *B*). Aluminum rods join the halo crown and vest but remain electrically separated by the use of plastic joints (*arrowheads* in *B*).

fittings by plastic joints. The modified PMT orthosis used graphite-carbon composite rods and halo, which were interconnected with plastic ball-and-socket joints. In all modified devices, titanium skull pins replaced stainless steel pins in the halo. All modifications were made by a local orthotic company (Bremer Brace of Florida, Inc., Jacksonville, FL). Modifications of fasteners, rivets, and other materials were made with substitute materials of equal or greater strength. The strengths of orthotic devices remained unchanged or increased.

Results

Results are summarized in Table 1.

Examinations of the EXO adjustable collar, the S.O.M.I. cervical orthosis, and the standard Guilford cervical orthosis with a small bar magnet revealed significant amounts of ferrous materials. These devices were excluded from study in the MR scanner.

A T1-weighted cervical spine MR examination on a volunteer fitted with the pink Philadelphia collar with plastic fasteners demonstrated no metal blowout artifacts in the images. Similar results were obtained with the volunteer wearing the modified Guilford cervical orthosis. Although some distortion of the superficial soft tissues in the lower occipital area was present, presumably due to the loop formed by the occipital and mandibular shells, there was no distortion in the region of interest (Fig. 3). Scanning of the cervical spine and the brain in a volunteer fitted with the standard or the prepro-

TABLE 1: Cervical Spine Devices: Physical Characteristics and Image Quality

Device	Alterations	Ferrous Components	Image Quality			
			Spine			Brain
			T1	T2	GE	T1
EXO adjustable collar	None	Yes	NI			NI
Philadelphia collar	Plastic fasteners	No	ACC			NI
S.O.M.I. cervical orthosis	None	Yes	NI			NI
Guilford cervical orthosis	None	Yes	UNAC			NI
Modified Guilford orthosis	Monel rivets; plastic fasteners	No	ACC			NI
PMT halo cervical orthosis	None	No	ACC			NI
Bremer halo cervical orthosis	None	No	ACC			UNAC
MR-compatible Bremer orthosis	Split crown; plastic spacers; titanium fasteners	No	ACC	ACC	ACC	ACC[a]
Modified PMT halo orthosis	Graphite carbon composite rods and halo; plastic ball-and-socket joints	No	ACC	ACC	ACC	LQ[b]

[a] Body-coil image.
[b] Surface-coil image.
Note.—NI = not imaged, ACC = acceptable, UNAC = unacceptable, LQ = limited quality.

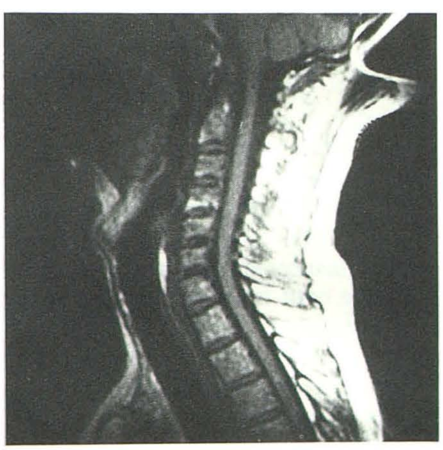
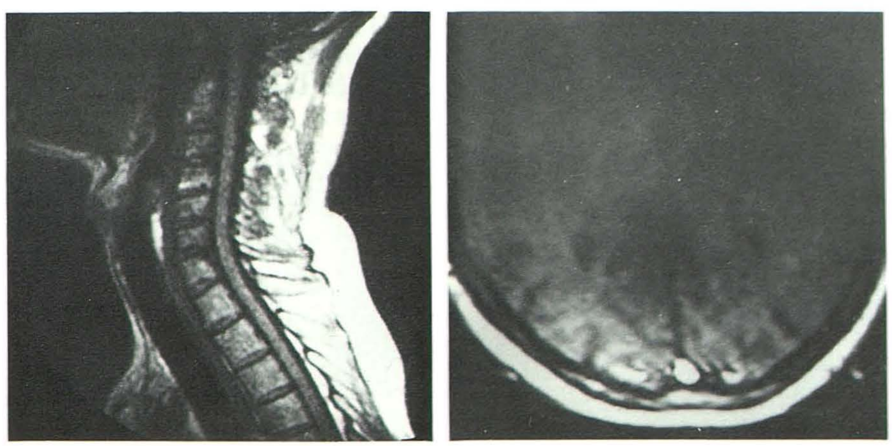


Fig. 3.—T1-weighted cervical spine MR image obtained with the patient wearing a modified Guilford cervical orthosis. Minimal distortion of the posterior cervical soft tissues below the occiput is presumably due to an electrical loop formed by the mandibular and occipital shells.



A B

Fig. 4.—*A* and *B*, T1-weighted cervical spine (*A*) and brain (*B*) MR images obtained with a standard Bremer halo cervical orthosis in place. Cut-off in the anterior aspect of the brain image is due to eddy currents induced within the halo crown by the magnetic field gradients, which alter frequency and phase-encoded spatial information.

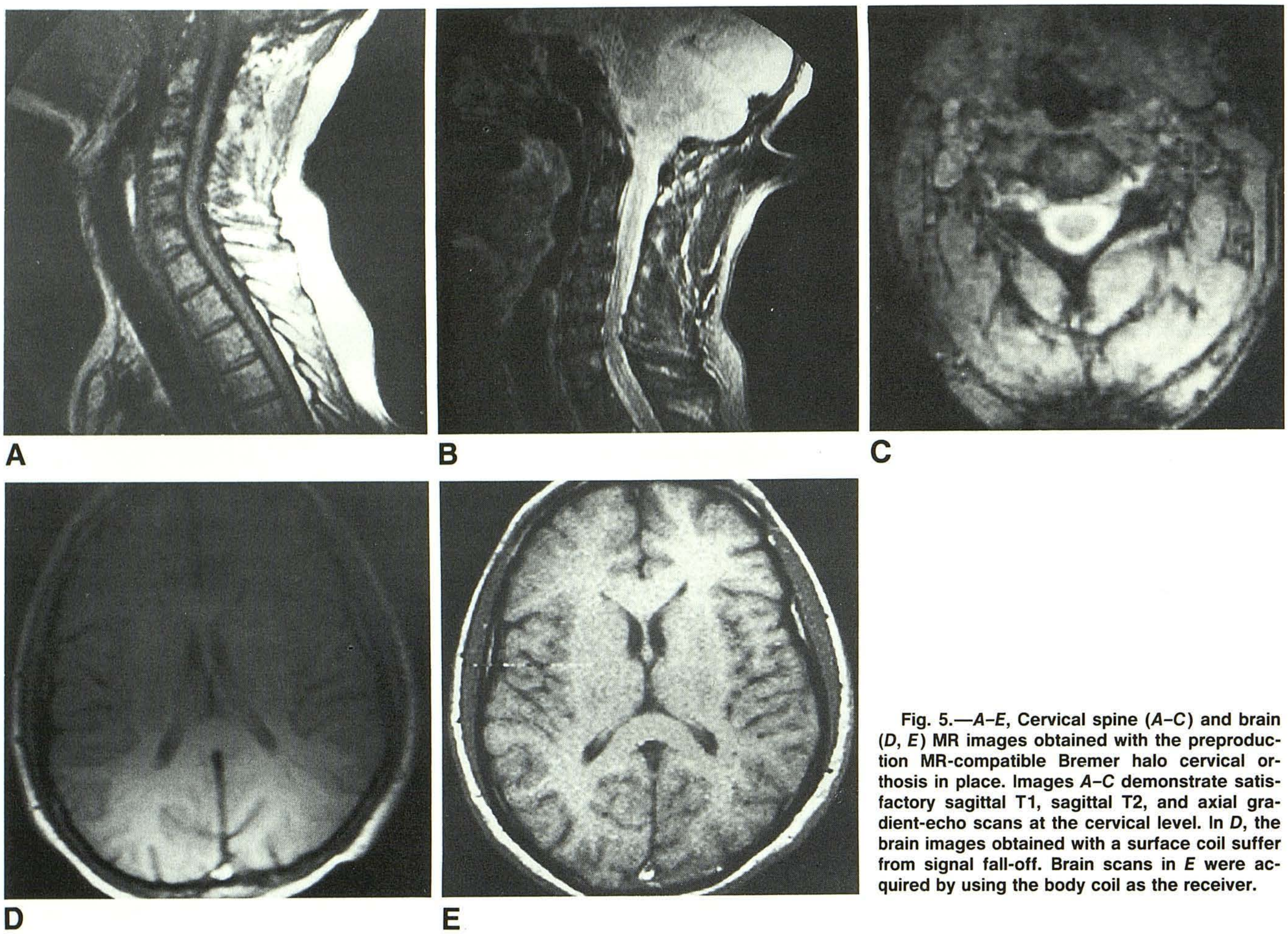


Fig. 5.—*A–E*, Cervical spine (*A–C*) and brain (*D, E*) MR images obtained with the preproduction MR-compatible Bremer halo cervical orthosis in place. Images *A–C* demonstrate satisfactory sagittal T1, sagittal T2, and axial gradient-echo scans at the cervical level. In *D*, the brain images obtained with a surface coil suffer from signal fall-off. Brain scans in *E* were acquired by using the body coil as the receiver.

duction MR-compatible Bremer halo crown and vest or the standard or the modified PMT cervical orthosis was performed by placing the flat lumbar spine coil between the posterior aluminum rods of the orthosis. The standard Bremer device gave a satisfactory T1-weighted cervical spine examination (Fig. 4A), but the brain examination produced unacceptable images distorted by image cut-off ("loop effect") (Fig. 4B). T1, T2, and gradient-echo images of the volunteer wearing the preproduction MR-compatible Bremer halo system were satisfactory for the cervical spine examination (Figs. 5A–5C). Signal fall-off rendered the T1 brain images suboptimal. However, all areas of the brain could be seen by adjusting level and window settings (Fig. 5D). Brain images obtained with the body coil as the receiver were of diagnostic quality despite some loss in the signal-to-noise ratio and the spatial resolution (Fig. 5E). The standard PMT cervical orthosis introduced no artifacts in the cervical spine images (Fig. 6). T1, T2, and gradient-echo cervical spine and T1-weighted brain scans obtained with the PMT device containing graphite-carbon composite components were acceptable (Figs. 7A–7C), though brain images obtained with the surface coil were again limited by signal fall-off (Fig. 7D).

A patient fitted with a standard Guilford cervical orthosis was inadvertently scanned at a later date, and the images produced were significantly distorted by blowout artifacts (Fig. 8A). Repeat scanning with the device removed confirmed the orthosis as the cause of the artifacts (Fig. 8B).

Discussion

The utility of MR imaging in spinal trauma has become apparent in view of the numerous publications appearing in the literature over the past few years. The MR appearance of the spine and spinal cord in acute trauma is well-described in animal models [1, 2], case reports [3, 4], and clinical series [5–9]. In the acutely and subacutely injured patient, edema and hemorrhage in the spinal cord and hemorrhage in the extradural space may be identified and possibly differentiated. Such diagnostic information aids management of the patient. Acquiring such information may be difficult, as many MR facilities are remote from the primary care site. Cervical spine stabilization with MR-compatible devices will be required for safe transport and successful imaging.

As the role of MR imaging increases in the management of acutely injured patients, limitations to performing the examinations must be overcome. Such limitations include the inability to bring life-support equipment into the scan room, the introduction of blowout artifacts in the images due to ferrous materials in or on the patient, and artifacts caused by electrically conductive "loops" in hardware on the patient. Addressing the latter two limitations, we evaluated several cervical spine-stabilizing braces and orthoses. Devices that contain even small amounts of ferrous materials cast significant blowout artifacts into the image and distort anatomic structures adjacent to the blowout artifact. Spatial location in MR is determined by magnetic gradient-induced frequency and phase-encoding, which is directly related to magnetic field strength. Local inhomogeneities in the magnetic field cause alterations in the frequencies and phases of precessing protons. Ferromagnetic materials distort the uniformity of the main magnetic field, resulting in variations of local magnetic field strengths. Subsequent errors in frequency and phase-encoding of spatial information distort the reconstructed images [10]. Detection of ferrous materials with a small bar magnet should allow exclusion of devices containing such materials from being introduced into the MR scanner.

The presence of electrical loops in or on the patient is a more difficult problem. Ferromagnetic and nonferromagnetic conductors, in response to gradient-coil–induced magnetic field fluctuations, develop eddy currents that in turn produce their own magnetic fields. These secondarily induced magnetic fields sufficiently distort the main magnetic field to degrade the MR images [11]. One device tested, the standard Bremer halo crown and vest, clearly possessed this problem with brain imaging. Interrupting the electrical loop in the halo

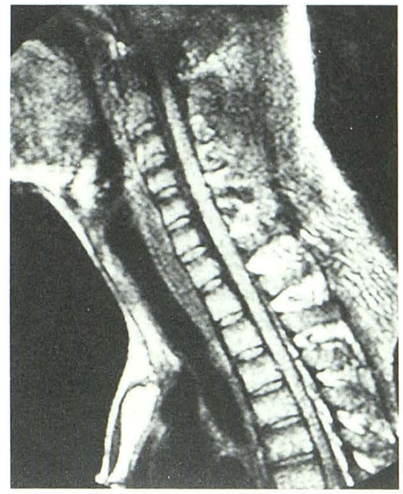
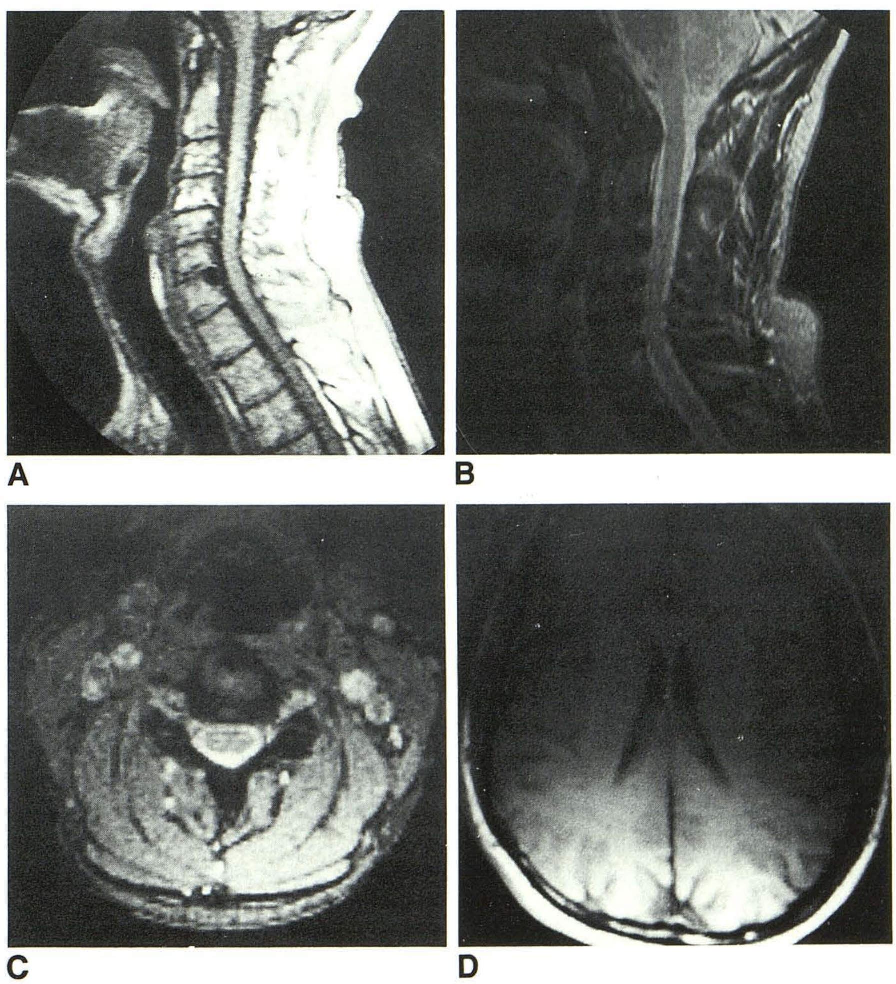


Fig. 6.—Cervical spine MR image obtained with a standard PMT cervical orthosis. Image was acquired by using the body coil as both transmitter and receiver.



A B C D

Fig. 7.—*A–D*, Cervical spine (*A–C*) and brain (*D*) MR images obtained with a modified PMT halo orthosis containing graphite-carbon composite components. Satisfactory sagittal T1 and T2 and axial gradient-echo images were produced. Brain images obtained with a surface coil suffer from signal fall-off.

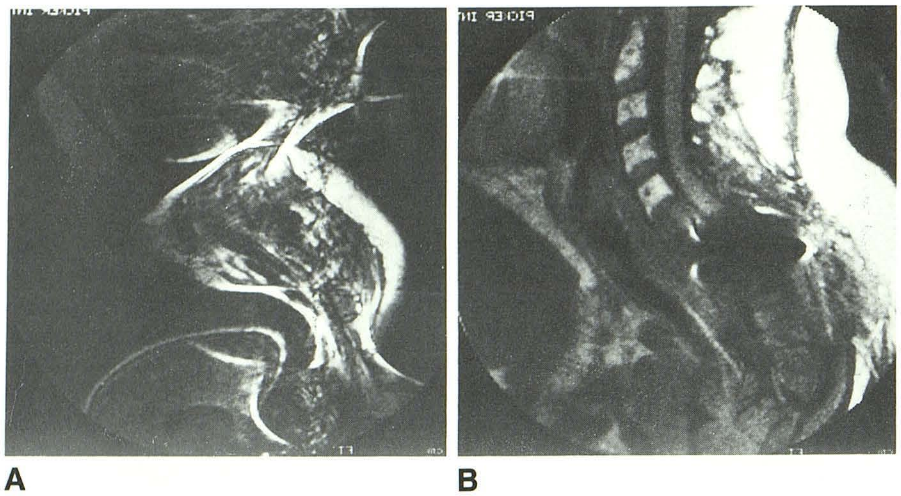


Fig. 8.—*A*, Cervical spine image with a standard Guilford cervical orthosis. Ferrous-containing rivets and fasteners cause severe blowout artifacts.

B, Same patient as in *A* with the orthosis removed. Fixation wires induce blowout artifact in the area of interest.

crown by separating nonferrous electrically conducting components with plastic spacers and by splitting the middle of the crown and inserting a plastic spacer, as in the preproduction MR-compatible Bremer halo crown and vest, alleviated the problem of induced eddy currents and unwanted associated local magnetic field alterations. A similar arrangement was present in the PMT orthosis with graphite-carbon composite components that are separated by plastic ball-and-socket type joints. Graphite has the advantage of great strength and compatibility with CT scanning. CT scanning of the head with the modified Bremer or PMT orthoses fitted to a patient remains unsatisfactory because of the titanium skull pins in the halo. Titanium is extremely electron dense and causes severe streak artifacts in CT scanning. MR surface-coil imaging of the head while the devices are in place is limited because of signal fall-off from areas of interest remote from the coil. The images are marginally acceptable, since appropriate adjustment of the level and window settings allows visualization of all areas of the brain. Brain images acquired with the body resonator in the transceive mode are quite acceptable though they suffer from some loss of resolution and signal-to-noise ratio.

Balancing material strength and stability with imaging compatibility remains the challenge in orthotic design. In evaluating several braces and orthoses, it was evident that the devices that have no ferrous components and no electrical loops are satisfactory for MR scanning. Combining these characteristics with materials of low electron density allows CT compatibility as well.

Cervical orthoses with aluminum or graphite-carbon composite components that are interconnected with plastic joints such as the plastic ball-and-socket joints are, to date, the most successfully designed devices for MR compatibility. To make these orthoses CT-compatible, low electron density materials are presently being evaluated to replace the titanium skull pins.

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