CAR Standards for Magnetic Resonance Imaging

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The standards of the Canadian Association of Radiologists (CAR) are not rules, but are guidelines that attempt to define principles of practice that should generally produce radiological care. The physician and medical high-quality physicist may modify an existing standard as determined by the individual patient and available resources. Adherence to CAR standards will not assure a successful outcome in every situation. The standards should not be deemed inclusive of all proper methods of care or exclusive of other methods of care reasonably directed to obtaining the same results. The standards are not intended to establish a legal standard of care or conduct, and deviation from a standard does not, in and of itself, indicate or imply that such medical practice is below an acceptable level of care. The ultimate judgment regarding the propriety of any specific procedure or course of conduct must be made by the physician and medical physicist in light of all circumstances presented by the individual situation.

I. INTRODUCTION AND DEFINITION

Magnetic resonance imaging (MRI) is a cross sectional imaging method based on an interaction between radiofrequencv (RF) electromagnetic fields and certain nuclei in the body (usually hydrogen nuclei) after the bodv has been placed in a strong magnetic field. MRI provides excellent differentiation of normal tissues and exceptional sensitivity to disease. This sensitivity is based on the high degree of inherent contrast due to variations in the magnetic relaxation properties of different tissues, both normal and diseased, and the dependence of the MR signal on these tissue properties.

Magnetic resonance angiography (MRA) involves the use of selected MRI pulse sequences in order to visualize blood vessels. Functional magnetic resonance imaging (fMRI) uses powerful gradients in order to study diffusion (diffusion weighted MRI), perfusion (perfusion weighted MRI), and brain activation during pre-defined tasks (brain mapping).

This document is an updated version of the standards (first published in 1994) for the use of MRI, for the qualifications of personnel involved in the clinical application of MRI, and for quality assurance practices in MRI. The CAR Subcommittee on MRI Standards, of the CAR Task force on Radiology Standards was formed to recommend standards for the utilization of MRI for clinical diagnosis in fixed and mobile sites. It is recognized that by circumstance the available technology at individual MRI sites in Canada will vary and that the submitted standards act a guidelines for MRI practice, to which individual centers should attempt to aspire.

II. QUALIFICATIONS OF PERSONNEL

A. The Radiologist

That Physicians involved in the performance, supervision and interpretation of magnetic resonance imaging should be Diagnostic Radiologists and must have a Fellowship or Certification in Diagnostic Radiology with the Royal College of Physicians and Surgeons of Canada and/or the Collège des médecins du Québec. Also acceptable are foreign Specialist qualifications if the Radiologist so qualified holds an appointment in Radiology with a Canadian University.

As new imaging modalities and interventional techniques are developed additional clinical training, under supervision and with proper documentation, should be obtained before radiologists interpret or perform such examinations or procedures independently. Such additional training must meet with pertinent provincial/regional regulations. Continuing professional development must meet with the requirements of the Maintenance of Certification Program of the Royal College of Physicians and Surgeons of Canada.

B. Medical Physicists

A medical physicist (on-site or contracted part-time) shall have the responsibility for the

initial acceptance testing and for conducting and overseeing quality control testing of the MR scanner.

The medical physicist shall be certified by the Canadian College of Physicists in Medecine and shall have specific training and experience in MRI. Training and experience shall include detailed knowledge of the physics of MRI, system components and performance, safety procedures, acceptance testing, and quality control testing.

C. MR Technologists

The medical radiation technologist must have Canadian Association of Medical Radiation Technologists (CAMRT) certification in magnetic resonance (RTMR) or be certified by an equivalent licensing body recognized by the CAMRT.

Under the overall supervision of the radiologists, the technologist is responsible for patient comfort and safety, examination and preparation of patients, performing the MRI scans, technical and quality evaluation of images and relevant quality assurance.

Continued education of technologists is encouraged by the C.A.M.R.T. and should meet pertinent provincial regulations.

D. Service Engineers

The service engineer shall be responsible for system installation, calibration, and preventive maintenance at regularly scheduled intervals. The service engineer's qualification will be ensured by the corporation responsible for service and the manufacturer of the MR equipment used at the site.

III. CONTRAINDICATIONS

Contraindications include, but are not limited to, the presence of cardiac pacemakers, ferromagnetic heart valves, ferromagnetic intracranial aneurysm clips, neuro stimulators, certain otic implants and ferromagnetic foreign bodies in critical locations, e.g., the eye. Relative contraindications include claustrophobia and obesity.

The safety of MR scanning during pregnancy has not been established. The decision to scan during pregnancy should be made on an individual basis after consideration of medical necessity and alternate imaging methods. This particularly applies to scanning during the first trimester.

IV. TECHNIQUES

The committee has attempted to enumerate the currently accepted techniques for MRI based on clinical experience, as summarized in peer-reviewed literature'. Because the clinical application of MRI is still under development, it is not intended that the enumerated techniques (and indications in the reference document) be all-inclusive. It is very important that each site offering MRI have documented procedures for the indications and technical factors for each anatomic site.

These procedures will need to be reviewed frequently. The final judgment regarding appropriateness of a given examination for a particular patient is the responsibility of the radiologist.

The indications for scanning could include any part of the human body, depending on the MR software and hardware available and the efficacy and availabilitv of competing imaging methods.

To accomplish its clinical purposes, MRI must be performed with adequate attention to technical abilities of the MR scanner.

Spatial resolution, slice thickness, signal-to-noise (SNR), and acquisition time are all inter-related sequence parameters which have a major influence on the delectability of disease. In the performance of any MR examination, major decisions have to be made regarding the appropriate coil, the imaging plane(s), the field of view (FOV), the slice thickness and slice gap, the imaging matrix, the number of excitations, the requirement for ECG gating and respiratory compensation, band width selection, the pulse sequence parameters which maximize signal and contrast to noise and contrast needs.

The purpose of these guidelines is not to prescribe the details of individual techniques, but rather to address the spectrum of recognized MR applications and to outline the minimum requirements necessary to undertake these, and to which the radiologist, in conjunction with ancillary staff should aspire.

Techniques and references are presented by anatomic site*.

V. CHOICE OF AN MR SYSTEM

Many systems are available on the market with different field and gradient strengths. In addition, closed and open configuration are offered. Purchase of a system is subject to financial and site considerations. Knowledge of the referral base and clinical needs is also necessary and will help choose the appropriate system. Before purchasing a system, it is recommended that a team be set up which will include a radiologist with previous MR experience, a medical physicist with previous MR experience, technologists and administrators.

VI. PRINCIPLES OF CONTRAST AGENT USE

There are many potential indications for injection of contrast agents:

A. When breakdown of the blood-brain barrier is suspected, the intravenous administration of gadolinium chelates may increase the sensitivity of magnetic resonance imaging in the central nervous system.

B. When characterizing the vascularity of pathology outside of the central nervous system, or when improved lesion conspicuity is achievable due to differential vascularity and subsequent enhancement.

C. For visualizing vessels both in the central nervous system and outside the central nervous system.

D. For performing perfusion studies.

E. New contrast agents for use in the liver, pancreas or bowel loops or for blood pool are or will be available in the next few years.

In general, with many applications (gadolinium chelates), it is desirable to acquire Tl-weighted images (either spin echo (SE) or gradient echo (GE)) using the same technique both before and after the administration of gadolinium chelates. (When images are acquired only after administration of gadolinium chelates, it may be diffficult to distinguish other causes of high signal intensity, i.e., extracellular methemoglobin from subacute hemorrhage, flow related enhancement from inflowing blood or CSF, or fatty lesions, from gadolinium-enhancement.) In practice, a pre-injection Tl-weighted image in a single plane is generally adequate for comparison. It is often useful to obtain fat saturated T1-Weighted images to better visualize gadolinium enhancement at sites where there is a lot of fat (e.g. orbits, base of skull, pelvis, etc.).

Gadolinium chelates should not be administered to patients with known or suspected hypersensitivity to the product or with severe hepatic insufficiency.

VII. RECOGNIZED CLINICAL APPLICATIONS OF MR

A. Adult and Pediatric Brain

B. Adult and Pediatric Spine

C. Head and Neck

D. Abdomen and Pelvis (Male and Female Genitourinary System)

E. Musculoskeletal System

F. Cardiac

G. Chest

H. Vascular and Magnetic Resonance Angiography

I. Breast Imaging

A. Brain

In both the adult and pediatric brain, magnetic resonance imaging is more sensitive than x-ray computed tomography for the detection of parenchymal abnormalities in the brain (1). This is particularly true in the posterior fossa (2,3) where CT is degraded by beam-hardening, Hounsfield artifact. The advantage of MRI is based on the greater sensitivity of long TR, short TE ('proton density (PD) weighted" images) and long TR, long TE 'T2-weighted images" (T2WI) to alterations of water content compared to the differences in electron density seen by CT.

In infants, the water content of the brain is much higher than in adults. The excess water present in the newborn is gradually lost from both the grey and white matter during the first two years of life. In order to optimally visualize pathology and differentiate grey and white matter on T2W images during this time period it is often useful to prolong the TE and TR values. TR times of 3000 msec or more and TE times of 120 msec or more are useful. It is also useful to obtain axial TIW sequences. This may be helpful to more fully evaluate for possible congenital disorders of migration which demonstrate abnormalities of the sulci and gyri and to be used in conjunction with T2W images to evaluate myelin deposition.

The minimum standard MR technique for scanning the brain should endeavour to maximization SNR and spatial resolution and should include the following:

1. A dedicated head coil should be used for imaging.

2. Imaging in at least two separate planes.

3. T1-weighted images are usually obtained in the sagittal plane together with axial T2-weighted images in the axial plane. In addition, routine examinations might include axial T1-weighted, proton density-weighted or flair images. Conventional or fast spin echo pulse sequences can be used. The choice of pulse sequences should be tailored to the clinical indication of the study (e.g. multiple sclerosis, IAC's, pituitary fossa).

4.Slice thickness of no greater than 5 mm provided that current technology with user-defined bandwidth selection is available. With older technology, slice thickness of at most 6 mm can be tolerated.

5. Slice gap between 20 and 50%.

6. Matrix and slice profile selection resulting in an in plane spatial resolution in the order of I mm.

7. Maximum use of motion and flow artifact reduction techniques; i.e. first order flow compensation.

8. Gadolinium-enhanced studies are performed when lesion diagnosis and improved conspicuity are required. If flow compensation is available, it has been found to be useful in the evaluation of gadolinium-enhanced images in the posterior fossa which are otherwise degraded by flow artifacts arising from the transverse and sigmoid sinuses.

The exact combination of repetition time TR and echo delay time TE to produce the desired contrast depends on field strength since TI increases with increasing field. For example, when the field strength is increased from .35 Tesla to 1.5 Tesla. the TI of the brain increases by 62%. Thus to have comparable amounts of Tl-weighting (short TR) orT2 or proton density weighting (longTR), TR must be scaled to T1 at different field strengths.

New pulse sequences are now available for imaging in the brain. These include:

1. Fluid attenuated inversion recovery (FLAIR) which produces T2-weighted images with dark CSF. It is particularly useful for detection of multiple sclerosis lesions.

2. Diffusion weighted pulse sequences which enable study of proton motion with the use of powerful gradients. The most common clinical indication is for detection of acute ischemic stroke.

3. Perfusion studies using bolus injection of gadolinium and rapid acquisition of multiple brain volumes. Perfusion studies are usually done to determine regional cerebral blood flow and blood volume in patients presenting with acute ischemic stroke.

B. Spine

The role of MRI in the spine has been well established by comparative studies with conventional imaging methods using surgical correlation as an objective measure of accuracy. The areas of greatest proven value include degenerative diseases involving both the cervical and lumbar spine, vertebral inflammatory lesions, congenital malformations and intramedullary lesions such as syringomyelia and neoplasms. Equally useful are the applications of MRI in evaluating extradural, intradural and extramedullary neoplasms, trauma, and patients with signs and symptoms of cord compression.

The minimum standard MR technique for imaging the spine includes the following:

1. A dedicated neck coil (either posterior alone or in combination with an anterior neck coil) for the cervical spine and a dedicated spine surface coil or phased-array surface coils for the thoracic and lumbar spines.

2. A combination of sagittal Tl-weighted and T2-weighted images might be obtained. Again, protocols should be tailored to answer specific clinical questions. For exemple, when evaluating nerve roots, axial T1- or T2-weighted images should be added.

3. A maximum slice thickness of between 3-5 mm and 1.5-2 mm for cervical spine and corresponding nerve roots.

4. Slice gap between 20-30% for TI-weighted images, and 30-50% for T2-weighted images.

5. Matrix and slice profile selection resulting is an in plane spatial resolution in the order of 1-2 mm.

6. Depending on the indication, either the combination of gradient moment nulling, cardiac gating, and saturation pulses for spin echo imaging (conventional or fast spin echo), or gradient moment nulling, with or without cardiac gating and saturation pulses for gradient echo imaging, should be used. Sagittal or axial gradient echo proton density-weighted sequences may be used as substitutes for T2-weighted sequences, especially for cervical and thoracic spinal bio-mechanical clinical problems.

7. Gadolinium chelates should be used in evaluation of intramedullary and leptomeningeal diseases especially in tumor involvement. Contrast should also be routinely utilized in the differentiation of scar from disk, especially in the post-operative failed back.

C. Head and Neck

The major strengths of magnetic resonance imaging (MRI) in the head and neck region include the outstanding soft tissue contrast, the multiplanar capabilities, the noninvasiveness (except for injection of gadolinium chelates). MR techniques include combination of SE, 2D and 3D GRE sequences, fat suppression or fat saturation sequences, and magnetic resonance angiography (MRA). The drawbacks include the insensitivity to calcification, degradation of the images caused by motion artifacts or by the presence of metallic dental appliances in the mouth.

Patients in whom neurological findings are present, in addition to the head and neck symptoms, require a complete examination of the brain.

The minimum standard MR technique for scanning the head and neck should endeavour to maximization SNR and spatial resolution and should include the following:

1. A dedicated head coil should be used in suprahyoid applications, a dedicated neck coil for infrahyoid applications and dedicated surface coils for the temporomandibular joint (TMJ) and globe.

2. A combination of Tl-weighted and T2-weighted images in sagittal, axial and coronal planes are needed. Depending upon the pathology being evaluated, fat saturation and T2*GRE sequences should be used in addition.

3. Slice thickness of between 5-7 mm is suitable for most applications. For TMJ's and optic nerves a slice thickness of 3-4 mm should be used.

4. Slice gap between 20-30%, preferably 20%.

5. Matrix and slice profile selection resulting in an in-plane spatial resolution in the order of 3 mm.

6. Maximum use of motion and flow artifact reduction techniques; i.e. respiratory compensation and in flow pre-saturation.

7. Gadolinium-enhancement studies are performed when lesion diagnosis and improved conspicuity are required, i.e. tumor characterization, aggressive inflammatory process or vascular anomalies. Fat saturation or TlWl GRE sequences are desirable in order to optimize the additional contrast afforded whenever gadolinium chelates are utilized.

D. Abdomen and Pelvis

Adequate images of the abdomen may generally be obtained in high, mid, and low field strength systems. The precise technical factors employed may, however, vary depending on the instrument, its field strength, and the range of motion compensation techniques which are available. The points pertaining to field strength alluded to above will equally apply.

The minimum standard technique should include:

1. The body coil is suitable for most applications but when available, a phase array surface coil is preferable. However, when high spatial resolution is required specific configurations of phased-array surface coils and/or intraluminal surface coils can be used. FOV should be appropriate to the size of the abdominal or pelvic cavity.

2. TI-weighted and T2-weighted images through the upper abdomen generally should be acquired axially. Examinations in other planes may be useful to evaluate anatomy and pathology. Depending upon the pathology being evaluated fat saturation and T2*GRE sequences should be used in addition. Fast GRE breath hold techniques are useful for evaluation of hepatobiliary ducts and the arterial phase of some organs such as the pancreas. In the evaluation of the pelvis a combination of sagittal and axial sequences is often the most helpful for evaluation of lesions involving midline structure whereas a combination of coronal and axial sequences may be more helpful in fully assessing lesions of the bony structures, pelvis side walls and ovaries. For imaging the uterus, ideal planes are along the long and short axis of the corpus.

3. Slice thickness of between 7-10 mm is suitable for most applications in which the body coil is used. If phased-array coils or intraluminal coils are used, slice thickness in the order of 2-5 mm can be used.

4. Slice gap between 20-30%, preferably 20%.

5. Matrix and slice profile selection resulting in an in-plane spatial resolution in the order of 3-5 mm.

6. Maximum use of motion reduction techniques such as signal averaging techniques, respiratory ordered phase encoding, and gradient moment nulling techniques, selective fat saturation, and short T I inversion recovery (STIR) are examples of techniques which may be used in isolation or in combination to reduce motion related artifacts on abdominal MR imaging. Breath hold techniques should be used when available. In addition, a bowel movement reducing agent such as buscopan or glucagon should be used for all examinations except liver evaluation.

7. Gadolinium-enhanced studies are performed when lesion detection, characterization and improved conspicuity are required. Fat saturation or TlW GRE sequences are desirable in order to optimize the additional contrast afforded whenever gadolinium chelates are utilized. Gadolinium enhancement is specifically important for detection and characterization of liver, pancreatic and renal lesions. It is also useful for staging endometrial and cervical carcinoma. Imaging of bile and pancreatic ducts (MRCP) should be achieved with heavily T2-Weighted sequences either with a thick slab 3D technique or with a thin multislice sequence followed by reconstruction, without or with breath hold.

E. Musculoskeletal

The minimum standard MR technique for scanning musculoskeletal system should endeavour to maximization of SNR and spatial resolution and should include the following:

1. Dedicated volumetric coils should be used for as many joint and non-joint applications as possible to obtain ideal, uniform image contrast and spatial resolution and evaluation of the region of interest.

2. A combination of TIWI and T2WI images and multiple planes of section will be required in many instances. Depending upon the pathology being evaluated, fat saturation, 3D TI, T2*GRE and, fat suppressed proton density snd STIR sequences are useful. The evaluation of cartilage surface will require a combination of 3D GRE and Fast 3D GRE. Use of intra-articular contrast injection is being investigated for that purpose.

3. Slice thickness of between 3-10 mm is suitable for most applications. 3D GRE images afford slice thickness of 0.7-3 mm for the evaluation of intra-articular pathology.

4. Slice gap between 0-20%, preferably contiguous.

5. Matrix and slice profile selection resulting in an in-plane spatial resolution in the order of 0.53 mm.

6. In peripheral musculoskeletal applications use of motion and flow artifact reduction techniques are dependent upon the anatomic region being evaluated; i.e. respiratory compensation in shoulder imaging.

7. The use of gadolinium chelates for enhancement permits more specific detection, characterization, and staging of musculoskeletal masses, and their recurrence. Gadolinium also has a role in the evaluation of inflammatory disorders. Finally intraarticular injection is being investigated, particularly following previous surgery, in the presence of joint instability, and in the assessment of certain types of joint derangement.

8. Use of vitamin E capsules is recommended to locate subtle soft tissue masses in order to confirm that the examination has included the relevant area of clinical concern.

F. Cardiovascular
There are a variety of techniques now available for MRI of the cardiovascular system. These are used in varied combinations depending upon the indication for the scan. MR studies of the heart and great vessels have usually required either prospective or retrospective cardiac gating. Evaluation of the heart may include the following techniques:

Routine applications:

1. Multislice ECG gated technique for routine evaluation of the heart.

2. Multiphasic multislice technique for the evaluation of cardiac dimensions and function.

3. The biphasic technique is performed by acquiring images at multiple anatomical locations at end diastole and end systole.

4. Fast GRE sequences ('turbo-GRE") have made it possible to acquire images of the heart without gating, and for some special sequences (segmental turbo GRE) during a single breath-hold. The value of this technique is currently limited but it may have increasing value as a method to evaluate myocardial perfusion by monitoring the first pass distribution of MR contrast media.

5. Echoplanar (EPI) imaging provides multiple images during a single cycle without the necessity for ECG gating in an acquisition tie of 30 to 50 msec. It is expected that the fast MR techniques will undergo considerable development in the next few years.

6. Cine MR imaging can be accomplished by ECG referencing of repetitive GRE sequences. These images are laced together in a cinematic display so wall motion of the ventricles, valve motion, and blood flow patterns in the heart and great vessels can be visualized.

7. Flow-sensitive imaging techniques now permit the measurement of blood flow expressed either as velocity or volume flow per unit time. See H. Vascular/Magnetic Resonance Angiography (MRA).

The minimum standard MR technique for scanning the central cardiovascular system should endeavour to maximization SNR and fidelity of anatomic registration and should include the following:

1. In adult cardiac applications the body coil is suitable. The selected FOV should be appropriate to the size of the thoracic cavity. For pediatric applications, volumetric coils appropriate to the child size and age should be used.

2. The relative weighting in a given image is governed by the RR interval. Relatively TIWI or PD images in a combination of transverse, axial and coronal planes and oblique planes are suitable when evaluating cardiac anatomy, i.e. congenital heart disease.

3. When alternate cardiac and pericardial pathologies are under evaluation TIWI and T2WI in a combination of transverse, axial and coronal planes are acquired. Additional planes may be required in certain instances.

4. Slice thickness of between 5-10 mm is suitable for most applications.

5. Slice gap between 20-30%, preferably 20%.

6. Matrix and slice profile selection resulting in an in-plane spatial resolution in the order of 3-5 mm.

7. Optimized cardiac gating and respiratory ordered phase encoding motion reduction techniques should be employed.

8. The role of gadolinium chelates for the evaluation of ischemic heart disease has yet to be determined.

G. Chest
MRI is presently used as a problem solving modality. The principle applications are evaluation of the

chest wall, mediastinal and hilar structure. All other pertinent imaging studies should be reviewed before MRI imaging is undertaken.

The minimum standard MR technique for scanning the chest should endeavour to maximization of SNR and fidelity of anatomic registration and should include the following:

1. In adults the body coil is suitable. The selected FOV should be appropriate to the size of the thoracic cavity. For pediatric applications, volumetric coils appropriate to the child size and age should be used.

2. For the evaluation of mediastinal and hilar structure adjacent to the heart cardiac gating is always required, with the relative weighting in a given image governed by required RR interval. Relatively Tl-weighted or PD-weighted images in a combination of transverse, axial and coronal planes and oblique planes are suitable when evaluating anatomy. For evaluation of the superior mediastinum, cardiac gating is not always required, providing greater flexibility over TI and T2 weighting.

3. When alternate mediastinal, hilar and chest wall pathologies are under evaluation Tl-weighted and T2-weighted (2 RR and 3 RR) images in a combination of transverse, axial and coronal planes; additional planes may be required in certain instances. Additional sequences (e.g. STIR) maybe of value in specific instances.

4. Slice thickness of between 7-10 mm is suitable for most applications.

5. Slice gap between 20-30%, preferably 20%.

6. Matrix and slice profile selection resulting in an in-plane spatial resolution in the order of 3-5 mm. Vascular conspicuity is improved with 2 averages (2 NEX).

7. Optimized cardiac gating, respiratory ordered phase encoding motion reduction techniques and spatial pre-saturation should be employed.

8. Gadolinium chelates should be utilized in the evaluation of recurrent or post-therapy residual chest wall and mediastinal tumors.

H. Vascular / Magnetic Resonance Angiography (MRA)

One of the remarkable features of magnetic resonance imaging is the sensitivity of amplitude and phase of its signal to moving spins, a situation that applies to flowing blood. There are three major families of MRA techniques: time of flight (TOF) or inflow angiography, phase contrast (PC) angiography (related to the phase shift of the flowing proton spins) and dynamic gadolinium-enhanced (DGE) MRA. High field MR unit (1.5 Tesla) with high-speed gradient will give the best results especially for breath-hold DGE MRA.

1. TOF methods

TOF MRA imaging methods provide vascular contrast based on tagging of the longitudinal magnetization of spins flowing into a region of interest. The more common approach is the creation of vascular contrast during a single scan acquisition followed by removal of stationary tissue by image processing.

If the arterial system is to be examined, an inferior (lower limb angiography) or superior (carotid angiography) saturation band must be used to eliminate venous signal. To get an adequate signal slice, acquisition must be perpendicular to flow direction.

Inflow-enhancement-based TOF angiography can be performed using a sequential two-dimensional (2D-TOF) or a three-dimensional (3D-TOF) Fourier transform. Coverage of larger anatomic area and better signal especially for low flow are obtained with 2D-TOF techniques. Better spatial resolution are given with 3D TOF techniques but signal loss at the distal portion of the volume of interest can be observed. If 2D TOF sequence are used, an overlap of 20 to 25 % within slices must be obtained to allow quality MIP reconstruction.

2. Phase contrast

2D or 3D PC angiograms are obtained using phase difference and encoding for velocity, which will avoid flow aliasing. This technique gives a good signal especially in case of low flow (venous flow) with excellent background suppression. Flow can be analyzed in all three directions.

Limitations of this technique are:

- Use of long TE for signal sampling which will give other T2* effects that may degrade image quality,
- Image degradation from pulsatile flow,
- Signal flow aliasing if encoding is inappropriate.

3. Breath Hold DGE MRA
This technique involves the administration of a large (0.2 mmole/kg) dose of a gadolinium-chelated contrast agent during a breath-hold 3D gradient echo acquisition (20-30 secondes). This technique provides an excellent signal without motion artefact related to respiratory motion. Adequate timing of the bolus is critical to get adequate signal without venous enhancement. Better signal to noise ratio can be obtained with substraction.

4. Clinical applications
Cervical carotid artery: Neck coil, 3D TOF or 2D TOF. Effective slice thickness 1.5-2.5mm.

Intracranial carotid artery and circle of Willis: Head coil, 1.5-2.5 mm, 3D TOF or 3D PC.

Cerebral veins: Head coil, slice thickness 2-4mm, 2D or 3D PC.

Aortic arch and carotid arteries: Body coil or body phased array, DGE MRA, effective thickness 1-2mm, short acquisition time is required to avoid jugular enhancement.

Thoracic aorta: Body coil or body phased array. Slice thickness 3-5mm. Anatomic studies are best achieved with conventional cardiac gated spin-echo sequences. Angiography can be performed using gated 2D TOF techniques or DGE MRA. The latter gives better visualisation of slow flow dissection and aortic ulceration.

Abdominal aorta: Body coil or body phased array. Slice thickness 3-5mm (aneurysm) or 1-2mm (renal artery). Best results are obtained with breath hold DGE MRA, especially for renal arteries. Cine-phase contrast sequence can be used for quantification of flow in renal arteries.

Iliac arteries: Body coil or body phased array. Slice thickness (2-4mm). Best results are obtained with breath hold DGE MRA. 2D TOF gated sequences can be used, but images can be limited by ghost artefact and signal loss due to tortuosity.

Femoral arteries: Body coil or body phased array. Slice thickness 2-4 mm. 2D TOF with or without cardiac gating (required if no proximal stenosis). Better results can be obtained with DGE MRA.

Infra popliteal arteries: Head or knee coil. Separate study of each side is preferred. 2D TOF. Slice thickness 2mm. Cardiac gating not required

Entire bilateral lower limb angiogram using DGE MRA with dedicated coil are under investigation. Preliminary data are promising.

I. Breast Imaging
MRI is useful in investigating patients with breast prosthesis, for excluding implant rupture. Research is currently underway to define other indications.

VIII. EQUIPMENT SPECIFICATIONS

The MR equipment specifications and performance shall meet all provincial and federal guidelines, including HPB guidelines. The guidelines include, but are not limited to, specifications of maximum static magnetic field strength, maximum rate of change of magnetic field strength (dB/dt), maximum radiofrequency power deposition (specific absorption rate), and maximum auditory noise levels.

It is recommended that purchase and upgrade specifications be written by the medical physicist in consultation with the supervising physician and MR technologist.

IX. SPECIFICATIONS OF THE EXAMINATION

The examination shall be performed within current HPB guidelines. When necessary, contrast and sedation shall be administered in accordance with institutional policy and provincial and federal law by a physician, who has trained in cardiopulmonary resuscitation. An appropriately equipped emergency cart must be immediately available to treat serious adverse reactions.

MR compatible ventilators, and appropriate patient monitoring should be available at those sites undertaking general anesthesia and sedation studies.

X. SAFETY GUIDELINES

Safety guidelines, practices, and policies shall be written, enforced, documented, and reviewed at least annually by the supervising radiologist and the MR charge technologist. These guidelines take into consideration potential interactions of the magnetic field with ferromagnetic objects in the environment of the scanner. They also consider potential hazards engendered by objects implanted within the patient as well as within personnel in the area.

XI. QUALITY CONTROL PROGRAM

The objective of an MR quality control (QC) program is to provide a series of tests and measurements which may be performed on a regular basis to determine if the MR system is performing in a reproducible and predictable manner. Protocols for routine system performance testing are still evolving. Quality control test should be conducted under the supervision of the medical physicist (if present on site), with review at least every six months by the supervising radiologist. A preventive maintenance program is recommended as a mean to minimize unscheduled down time.

A quality control program with written procedures and logs shall be maintained at the MR site.

The ongoing quality control program assesses relative changes in system performance as determined by a technologist and medical physicist (if present on site).

A. Technologist Quality Control Tests

The following quality control tests shall be performed and documented by an MR technologist knowledgeable in quality control procedures at the frequencies indicated in parenthesis:

1. measurement of central frequency (daily)
2. measurement of system signal-to-noise ratio on a standard head or body coil (weekly)
3. processor sensitometric testing (daily) unless automatic sensitometry is not available

B. Medical Physicist Quality Control Tests

The following quality control tests shall be reviewed by the medical physicist annually, and after any major upgrade or major change in equipment:

1. review of daily quality control testing records
2. measurement of image uniformity
3. measurement of spatial linearity
4. measurement of high contrast spatial resolution
5. measurement of slice thickness, locations and separations
6. assessment of image quality and image artifacts
7. eddy current compensation
8. system shim

All quality control testing shall be carried out in accordance with specific procedures and methods*

Preventive maintenance shall be scheduled, performed and documented by a qualified service engineer on a regular basis. Service performed to correct system deficiencies shall also be documented and service records maintained by the MR site.

XII. ACCEPTANCE TESTING

Acceptance testing is intended to measure quantifiable system parameters which may then be compared to the manufacturer's specifications. A complete evaluation of the system performance shall be conducted by a medical physicist after completion of installation and prior to regular patient imaging'.

Preventive maintenance shall be scheduled, performed and documented by a qualified service engineer on a regular basis. Service performed to correct system deficiencies shall also be documented and service records maintained by the MR site.

XIII. QUALITY IMPROVEMENT PROGRAM

A documented, systematic quality improvement program shall be established under the direction of the supervising physician in order to monitor and evaluate such problems as claustrophobia, sedation, administration of contrast agents, equipment malfunctions and accidents (such as metallic objects entering the scan room) endangering patients or workers. Monitoring should include the evaluation of the accuracy of radiologic interpretations as well as the appropriateness of examinations. Incidence of complications and adverse events should be recorded and periodically reviewed in order to identify opportunities to improve patient care.

Data should be collected in a manner that complies with statutory and regulatory peer review procedures in order to protect the confidentiality of the peer review data.

Notes

For specific details on techniques and indications, as a model, see ACR Reference Document MRI Indications and Techniques - 1992 for examples of.- Brain; Head and Neck; Spine; Abdomen and pelvis, Musculoskeletal; Pediatric; Cardiovascular, Vascular/MRA; Safety and Sedation; and Quality Assurance. See also ACR Glossary of Terms, Third Edition, 1991.

A suggested protocol for acceptance testing is contained in "Acceptance Testing of magnetic Resonance Imaging Systems. Report of American Association of Physicists in Medicine (AAPM) Nuclear Magnetic Resonance Task Group No. 6, Medical Physics. 1992;19(l):217-219".