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Poster Abstracts: Clinical MRI—Vascular Disease

326. Magnetic Resonance Coronary Angiography Using a Rapid Clearance Blood Pool Contrast Agent: Improved Imaging Concept

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Introduction: Magnetic resonance coronary angiography (MRCA) may be improved with the aid of blood pool contrast agents. Conventional extravascular agents enhance the signal intensity of the blood pool, but due to extravasation effects they also enhance the surrounding tissues causing a decay of image contrast. Alternatively, blood pool agents (BPA) selectively enhance signal intensity of the vessel which results in increased image contrast. However once injected, a BPA may remain in the circulation for days. Therefore contrast media have been developed that behave as BPA but are rapidly excreted after administration. These so called rapid clearance BPAs improve coronary artery visualization without extravasation to the surrounding myocardium and are excreted with a rather short half-life. Potentially, a rapid clearance BPA allows screening for coronary artery disease combined with myocardial perfusion imaging using repeated injections.

Purpose: The purpose of the present study was to optimize free-breathing and breath-hold MRCA in conjunction with a novel rapid clearance BPA (P792). An improved imaging concept was evaluated. This concept consisted of starting the MRCA acquisition during the first-pass of P792 combined with an optimized scan technique.

Methods: P792 is a gadolinium macromolecule designed for human MRCA application and has high r1 relaxation (r1 = 27.1 ± 1.0 at 1.5 Tesla).

Free-breathing navigator as well as breath-hold MRCA were performed with and without P792 in a pig model. The P792 enhanced acquisitions were compared to state-of-the-art MRCA without contrast agent (T2-preparation). Additionally, the first-pass effects of P792 were studied.

In four pigs, P792 enhanced MRCA was performed one minute after injection. In seven pigs, the acquisition was started during the agent's first-pass. The contrast enhanced acquisitions were applied with a saturation prepulse and a central k-space

Table 1

Study Results

	Parameter	No Contrast Agent	P792	
Navigator	CNR	5.0 ± 1.0	8.6 ± 1.7*	(+76%)
	SNR	15.7 ± 5.5†	11.9 ± 1.6	(−14%)
	Vessel length (mm)	79.7 ± 12.1†	99.2 ± 10.9*†	(+27%)
Breath-hold	CNR	6.2 ± 0.8†	8.2 ± 0.9*	(+34%)
	SNR	9.0 ± 1.4	10.4 ± 2.1	(+21%)
	Vessel length (mm)	48.2 ± 11.6	86.5 ± 13.8*	(+90%)

*$P < 0.05$: P792 vs without contrast agent.
†$P < 0.05$: naviagtor vs breath-hold.

Table 2

MRCA Using P792 With or Without the First-Pass Effects

	P792 Steady State only	P792 First-Pass and Steady State
CNR	4.5 ± 1.8	8.6 ± 1.7*
SNR	7.4 ± 2.0	11.9 ± 1.6*
Vessel length (mm)	60.5 ± 21.8	99.2 ± 10.9*

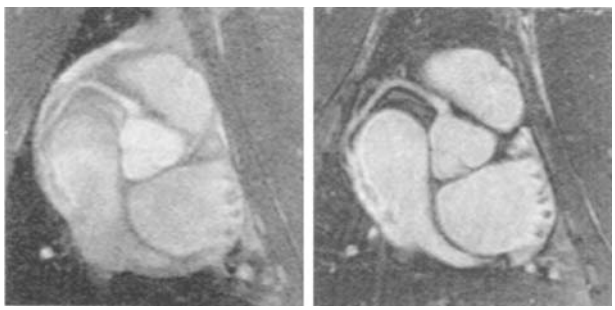
*$P < 0.05$ as compared to steady-state only.

filling order. A 1.5T Philips Gyroscan ACS/NT (Powertrack 6000) was used. The image analysis was based on contrast-to-noise ratio (CNR), signal-to-noise ratio (SNR) and vessel length visualization.

Results: P792 enhanced MRCA (starting during the first-pass) showed significant improved CNR and vessel length visualization as compared to MRCA without contrast agent (see table 1 and figure 1). When comparing the navigator and the breath-hold approach, the navigator approach revealed more distal coronary segments.

It prove beneficial to start the MRCA acquisition during the agent's first-pass as shown by the increased of CNR, SNR and vessel length visualization as compared to steady-state only ($P < 0.05$; see table 2).

Conclusion: Magnetic resonance coronary angiography with the use of a rapid clearance blood pool agent and inclusion of the first-pass effects substantially improves coronary artery visualization. The free-breathing navigator approach revealed more distal coronary artery segments as compared to the breath-hold approach. Since P792 is readily available for human use, the currently proposed imaging concept may contribute to the clinical application of coronary magnetic resonance angiography.



MRCA without contrast agent **MRCA with P792**

Figure 1. Left panel: no contrast agent. Right panel: P792 and application of a saturation prepulse for suppression for background signal. Note the bright coronary artery as compared to the dark background in the right panel. (original stack-images without formatting)

327. Altered T2 Relaxativity and Gd-DTPA Bolus Kinetics in Ischemic Skeletal Muscle

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Introduction: Ischemic skeletal muscle exercise increases relative oxygen extraction and anaerobic metabolism in regions with decreased circulation (1). Lactate production during ischemic exercise is greater than in normally perfused muscles at the same work load. Monoexponential T2 during non-ischemic exercise is considered to reflect mainly intracellular water (2, 3). The effect on T2 by osmosis could be paralleled with changes in capillary volume. The relaxativity rate (1/T2) increased in ischemic resting calf muscles (4). The response was similar in soleus and in gastrocnemius, but more pronounced in soleus and was suggested owing to different capillarity. Gd-DTPA has been used to semi-quantitatively assess tissue perfusion. However disability to separate moderate from high blood flow levels is reported (5). Differentiation between ischemic from normally perfused skeletal muscles may be possible despite this high flow limitation. Osmotic forces during ischemic exercise was presumed to prolong T2 more than a non-ischemic exercise would give at the same work load as a result of accumulation of intracellular osmoles.

Purpose: To evaluate if T2 and Gd-DTPA bolus tracing could detect exercise induced regional muscle ischemia.

Methods: Seven patients participated (mean 65 years, range 51–70), all with exercise limited intermittent claudication. A treadmill exercise test showed a highly reduced walking ability limited by pain. The ankle-index decreased in 13 legs (ischemic) to 0.32 ± 0.2 (range <0.1–0.69, $p < 0.0005$). One leg was asymptomatic with unchanged normal ankle-index 1.00 (non-ischemic). Thereafter a bilateral plantar flexion exercise was performed in the magnet, as previously described (5). Fatigue or severe pain in the lower legs ended the exercise. Imaging with a 1.5 T magnet (GE) using a Birdcase quadrature head coil was performed at rest and after exercise with simultaneous imaging of both calves. T2 was obtained by multiple echo SE (FOV 40 × 20, 256 × 128, slice thickness 10 mm, TR 1500 ms, TE (15, 30, 45, 60 ms). 44-min acquisition, 2-min interval of sampling. The T1-weighted study used fast spoiled GE (TR 9.7 ms, TE 4.6 ms, 3 NEX, flip angle 50°, FOV 30 × 15, 256 × 128, slice thickness 10 mm). At the closure of exercise a hand injected bolus of Gd-DTPA (OmniscanTM, 0.1mmol * kg − 1) was given. 7-min acquisition, 2-s interval of sampling.

Results: All legs with exercise-induced pain as well as pathologic ankle-index showed in at least one region an T2 response to exercise that was defined as abnormal (Fig. 1, Table 1). Criteria of abnormality: A) Prolonged relative intra-individual Gd-DTPA bolus arrival time of > 0.5 s (dTCA); B) Exaggerated prolonged T2 with, and C) Without a clear post-exercise recovery; D) Shortened T2; E) Delayed upslope, < 105. Non-ischemic responce (N), missing data (md).

There was a significant different responce in the calf muscles with shorter T2 in m. soleus than in m. gastrocnemius, $p < 0.0005$, evaluated with 2-w ANOVA (Fig. 2).

A less steep upslope and a clearly delayed relative arterial Gd-DTPA appearance time (dTCA) were present in most but

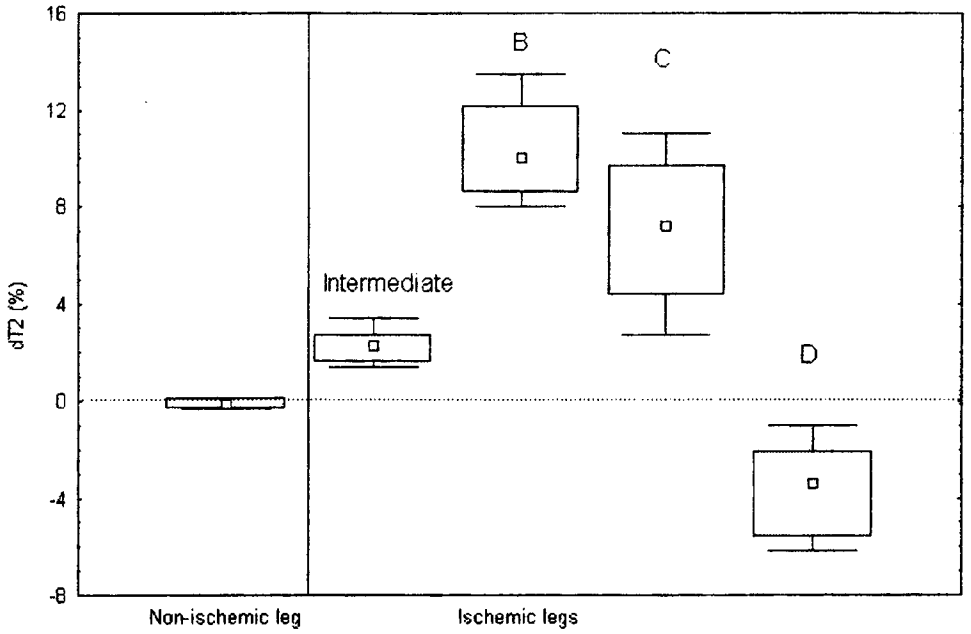

Figure 1. Outcome of the immediate post-exercise T2 presented in a box plot with median, upper and lower quartile and min-max values. Group B–D as described above.

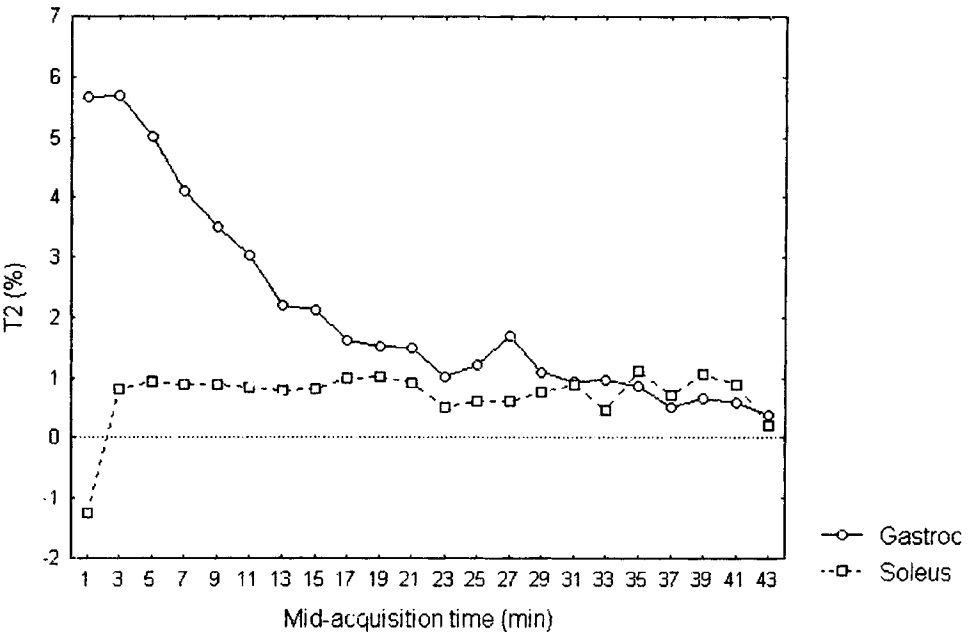

Figure 2. T2 during recovery (%-change from rest) in m. gastrocnemius (circle), and m. soleus (square).

not in all ischemic legs. The finding that all regions with a shortened T2 had a dTCA > 0.5 s suggests that there could be a more severe ischemia in regions with shortened T2. The asymptomatic leg with normal pressure response at the treadmill test showed a non-ischemic response during MRI in all parameters

Conclusion: Severe muscle ischemia induced by exercise seems to shorten T2, indicative of reduced tissue water content.

Table 1

Outcome According to Used Criteria

Pat	1		2		3		4		5		6		7	
Leg	R	L	R	L	R	L	R	L	R	L	R	L	R	L
dTCA														
Gastroc	A		A				A	N	A	A	A			A
Soleus	A	A	A	A			A	N	A		A	A	A	A
dT2														
Gastroc			B			C	C	N	md	md		B	B	D
Soleus	D	D	D	D	C	C	B	N	md	md	D	D	D	D
Upslope														
Gastroc			E	E	E	E	E	N	E	E	E			
Soleus	E	E	E	E			E	N	E	E	E			

T2 prolongs in presumed less ischemic muscles probably due to increased intracellular osmoles with accumulation of water. A diverging response is found in m. soleus compared to m. gastrocnemius, probably partly depending on their fibre type composition. Semiquantitative Gd-DTPA bolus detection cannot fully, evaluate ischemia; probably due to the effect ischemia has on tissue water content and the distribution volume of the tracer. The findings suggest that a highly ischemic muscle could be severely disturbed metabolically, but to what degree osmosis and/or water associated with the microvascular compartment affects T2 needs to be further elucidated.

328. MRI Measurement of Circulation Times in Heart Disease

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Introduction: MRI provides a convenient and potentially accurate tool for non-invasive measurement of circulation times. With the widespread use of contrast-enhanced MR angiography (CEMRA), it has become commonplace to use test doses of Gadolinium to measure transit times from an arm vein to the aorta. Contrast-injection protocols for test doses and 3D MRA sequences are precisely controlled with electronic power injectors, and this facilitates standardization of measurements. It is feasible to document cumulative transit times at multiple stations from the arm, through the right heart, pulmonary and systemic circulations. In previous reports of small series, no significant correlation has been found between circulation times and cardiovascular status. This seems surprising, in view of the intuitive relationship between cardiac functional status and vascular dynamics, and we decided to examine this relationship in a large patient cohort.

Purpose: Our hypothesis is that patients with impaired cardiac function, hypertension, left ventricular hypertrophy or coronary heart disease will have measurable differences in transit times compared to subjects without these conditions.

Methods: Ninety-eight bolus timing examinations in patients undergoing CEMRA over a two-month period at our institution were retropectively analyzed. Images were acquired at one second intervals for 40–60 seconds following injection of a 2–6 ml bolus of gadolinium contrast and a 20 ml flush of normal saline via an electronic power injector (Medrad Spectris).

For each timing examination regions of interest were drawn at the level of the pulmonary artery, ascending aorta, carotid bifurcation, and internal jugular vein. Using the bolus injection time as the zero reference, times to first appearance and to peak intensity in each region of interest were recorded. Age, height, weight and risk factors for cardiovascular disease were recorded in each subject. It was noted if the patient had documented coronary artery disease, heart failure, peripheral vascular disease, cerebrovascular disease, diabetes, hypertension, or tobacco smoking. A subset (n = 61) of patients also had echocardiographic data available from which the estimated ejection fraction and presence of left ventricular hypertrophy were recorded.

The study population included 53 women and 45 men, average age 60.8 years (range 20–91 y), average weight 78 kg (range 47–122 kg), average height 168 cm (range 150–191 cm). Fifty-four patients had radiographic evidence of cerebrovascular disease, 52 had hypertension (HTN), 32 had coronary artery disease (CAD), 27 had a history of tobacco smoking. Among the patients that had echocardiographic data available, 26 had left-ventricular hypertrophy (LVH), 17 had a history of diabetes mellitus, and 12 had an estimated ejection fraction (EF) less than 50%.

Correlation between transit times and patient age, height, weight, body-mass index (BMI), body surface area (BSA), and estimated EF was evaluated using Pearson correlation coefficients. Comparison of transit times in patients with a history of cardiovascular disease were compared with those patients without a history of cardiovascular disease using a paired Student *t*-test. For patients with echocardiographic findings of LVH and an EF less than 50%, the control group was the subset of patients who had echocardiograms but did not have any evidence of LVH or decreased EF.

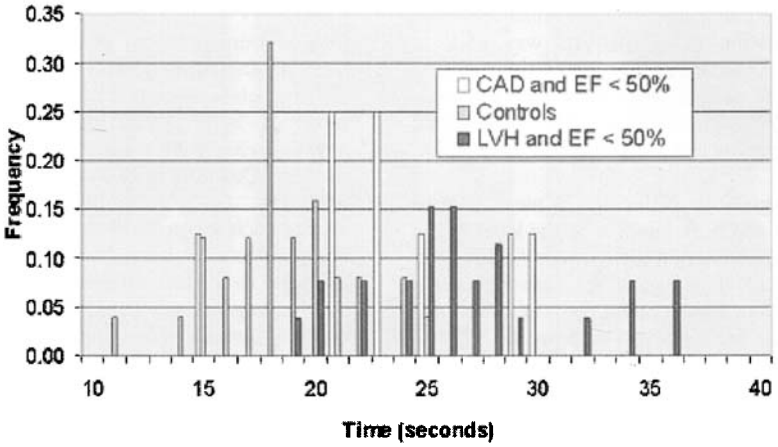

Figure 1. Time to peak intensity at the level of the carotid artery bifurcation in patients with an EF < 50% and CAD or LVH compared with controls.

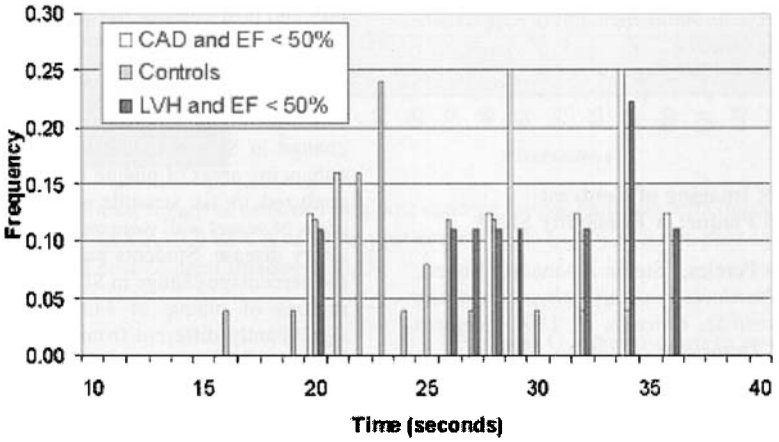

Figure 2. Time to first appearance of venous enhancement at the level of the internal jugular vein in patients with an EF < 50% and CAD or LVH compared with controls

Table 1

Mean Values and Standard Deviation of Time to First Venous Enhancement at the Level of the Internal Jugular Vein

Clinical History	Patients	Controls	Student *t*-test
Coronary Artery Disease (CAD)	26.4 ± 4.7	23.3 ± 3.7	$p < 0.01$
Ejection Fraction (EF) < 50%	28.3 ± 5.1	24.3 ± 3.9	$p < 0.05$
Hypertension (HTN)	25.3 ± 4.5	23.2 ± 3.8	$p < 0.05$
Left Ventricular Hypertrophy (LVH)	26.7 ± 4.7	23.9 ± 3.8	$p < 0.05$
CAD & EF < 50%	30.3 ± 5.0	23.9 ± 3.9	$p < 0.01$
HTN & EF < 50%	28.8 ± 5.3	23.7 ± 3.3	$p < 0.05$
LVH & EF < 50%	29.6 ± 5.0	23.9 ± 3.9	$p < 0.01$

Results: The mean time of first appearance of enhancement at the carotid artery bifurcation in all patients was 15.2 ± 2.92 seconds (range, 10–27 seconds). The mean time of first venous enhancement in all patients was 24.3 ± 4.29 seconds (range, 16–36 seconds). No significant correlation was found between transit times and patient age, weight, height, BMI, BSA, or EF.

There was a highly significant difference in mean time to first arterial enhancement and peak intensity at the level of the carotid artery bifurcation and internal jugular vein (Table 1) in patients with CAD, HTN, LVH, and an EF less than 50% when compared to patients without these conditions. The difference in mean transit times was greater when patients with CAD, HTN, LVH also had a decreased EF. The distribution of transit times in patients and controls was also examined. Significant overlap was seen between most patient groups and their respective control groups. However, separation was observed between controls and patients with an EF < 50% and CAD, LVH, or HTN (Figures 1–2).

Conclusion: Initial results indicate that circulation times as derived from MRI bolus timing are measurably increased in patients with CAD, HTN, LVH and cardiac functional impairment when compared with controls. It may be that such measurements can serve as an independent or supplemental index of cardiovascular function.

329. Time-Efficient MR Imaging of Contrast Enhancement in Carotid Plaque: A Feasibility Study

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Introduction: The composition of carotid artery plaque may be an important predictor of its propensity to rupture and cause embolic stroke. In particular, ruptured plaque has been found to contain increased neovasculature and inflammatory infiltrates when compared to stable, unruptured plaque [1,2]. Recent work has suggested that contrast enhanced MRI can be used to identify areas of neovasculature in human carotid artery plaque [3]. However, the MR techniques used have required dedicated receiver coils and single-slice imaging methods, making them impractical for screening patients in a clinical setting.

Purpose: The purpose of this study was to develop a fast, multislice method of visualizing contrast enhanced atherosclerotic plaque within the walls of the carotid arteries, which can be incorporated into a routine, contrast enhanced MR angiography (MRA) study of the carotid circulation.

Methods: The technique employed for evaluation of plaque enhancement is a fat-suppressed, T1-weighted, multi-slice, gradient-echo sequence. Time efficiency is maximized by segmenting the fat-suppression pulses with respect to slices, such that 13 slices are acquired in 90 seconds. Parameters for the sequence were TR = 230 ms, TE = 4.2 ms, slice thickness = 3 mm, FOV = 240 × 165 mm, and matrix = 512 × 256. Baseline images were acquired prior to the infusion of gadolinium for MR angiography, and at 1 and 3 minutes post contrast. Six subjects with carotid artery disease (5 male, 1 female, age range 41–84 years) and one control subject without carotid artery disease were studied. All studies were carried out on a Siemens Quantum or Sonata system, using the standard head–neck coil.

For each subject with carotid artery disease, matched pre- and post-contrast images of the common carotid arteries were analyzed to identify an area containing atherosclerotic plaque that heterogeneously enhanced following contrast infusion. To confirm that all enhancing areas were contained within the plaque (rather than within the vessel lumen), bright-blood, multi-planar reconstructions were created from the MRA study for each subject, and contours were drawn around the lumens at locations identical to those of the segmented fatsat images. These contours were then fitted to the segmented fatsat images to define the vessel lumens.

Within each heterogeneously enhancing plaque, two regions of interest (ROIs) were drawn— one in an area of the plaque which hyper-enhanced with contrast and one in a remote area of the plaque. These ROIs were drawn in identical locations on the pre- and post-contrast images. The signal intensity (SI) of each ROI was measured, and the percentage change in SI from the pre- to the post-contrast images was calculated. For the control subject, ROIs were drawn in eight separate locations in the walls of the common carotid arteries, and the percentage change in SI was calculated as above. A total of six hyper-enhancing areas of plaque and six remote areas of plaque were analyzed in six separate subjects. In addition, eight control areas of vessel wall were analyzed in the subject without carotid artery disease. Students paired t-test was used to determine if the percentage change in SI for the hyper-enhancing and remote regions of plaque at 1 min and 3 min post contrast were significantly different from those of the controls. In addition, linear signal intensity profiles were created for selected sets of carotid artery images.

Results: The carotid artery images obtained in this study demonstrated atherosclerotic plaque that heterogeneously enhanced following contrast infusion (Figure 1). For the control group (n = 8), the mean SI increase from pre to post contrast was 57.7 ± 18.8% at 1 min post contrast and 43.7 ± 16.4% at 3 min post contrast. For the hyper-enhancing group (n = 6), the mean SI increase from pre to post contrast was 134.9 ± 45.3% at 1 min post contrast and 111.9 ± 21.1 at 3 min post contrast. The mean SI increase in the hyper-enhancing group was significantly different from that of the control group at both 1 and 3 min post contrast ($p < 0.05$). For the remote areas of plaque (n = 6), the mean SI increase from pre to post contrast was 33.1 ± 17.2% at 1 min post contrast and 28.5 ± 27.3 at 3 min post contrast. The mean SI increase in the remote group was significantly different from that of the control group at 1 min, but there was no significant difference at 3 min.

Conclusion: These preliminary results suggest that evaluation of heterogeneous carotid plaque enhancement can be integrated into routine carotid MR angiography, using standard imaging coils. If hyper-enhancement is found to correlate closely with inflammation and neovascularization, this may have important clinical implications.

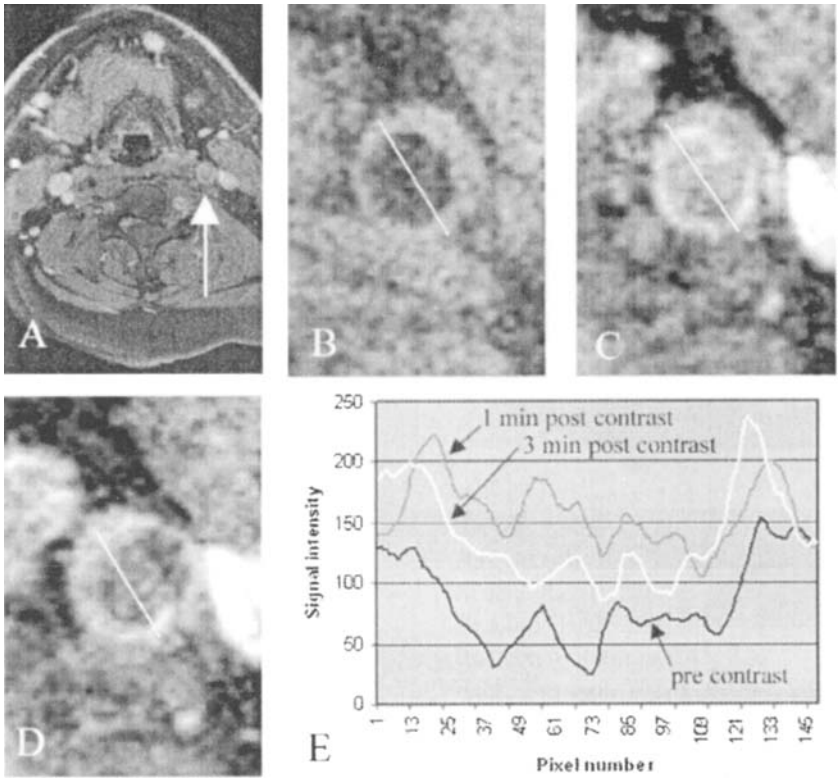

Figure 1. (A) Axial, segmented fatsat image of neck at 1 min post contrast (arrow indicates left common carotid artery (LCCA)). (B) Magnified pre contrast view of LCCA. (C) LCCA at 1 min post contrast. (D) LCCA at 3 min post contrast. (E) Signal intensity profiles for lines drawn in pre- and post-contrast images (B,C,D).

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330. Triple-Inversion Recovery Spin-Echo Sequences for The Detection Of Acute Myocardial Infarction — Sensitivity And Relation To Contrast-Enhanced MRI

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Introduction: Heavily T2-weighted magnetic resonance imaging (MRI) sequences are suitable for the detection of the infarct-related edema. This approach could be more cost-efficient (reduced protocol duration, no contrast agent) for the exclusion or confirmation of suspected myocardial infarction. However, T2-weighted sequences traditionally have provided insufficient image quality. This is different for breath-held triple-inversion-recovery spin echo techniques, which show a reproducibly high image quality with an excellent contrast-to-noise in detecting tissue edema. Especially the sensitivity of this technique in a clinical setting, however, is not known.

Purpose: Our purpose was to assess the sensitivity of triple-inversion recovery breathhold sequences to detect acute myocardial infarctions.

Methods: We have studied 23 patients (age 58 ± 7 y.) 3 ± 1 days after acute myocardial infarction, as defined by the clinical appearance, typical ECG patterns, elevated troponine T, and invasively confirmed related coronary occlusion or stenosis. In a 1.5 T MRI scanner using a body coil and a short-TI-inversion-recovery sequence (STIR, TE 64ms, TR 2 RR intervals, TI 140ms, acquisition time 16 to 20 sec) in 3 short axis views (slice thickness 20mm) and two long axis views. Results were compared to contrast-enhanced inversion-prepared gradient-echo images ("delayed enhancement", TE TI 220 to 250 msec) in the same slice position.

Results: Image quality was adequate to excellent for the diagnosis in all cases. In all patients, the infarct-related region revealed a bright signal intensity (sensitivity 100%). The edematous area tended to slightly extend that of the area of "delayed enhancement".

Conclusion: In contrast to formerly used T2-weighted sequences, heavily T2-weighted triple-inversion recovery MRI allows the confirmation of suspected acute myocardial infarction with an excellent sensitivity. Thus, in a clinical setting, contrast-enhanced MRI may only be necessary for more chronic infarctions. However, an overestimation of the infarct size has to be regarded.