IMPROVEMENT OF BRAIN ANGIOGRAPHIC IMAGES USING 1.5T SUPER CONDUCTIVE MRI UNIT OF IMAM KHOMEINI HOSPITAL

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Abstract: ***Due to the importance of selecting imaging parameters in magnetic resonance brain angiography, this study was carried out to choose optimum theoretical and experimental parameters for improving image contrast and resolution and achieve shorter imaging time for practical reasons.***

**** A 1.5T super conductive magnet MRI with gradient power of 13 nT/m and Larmour frequency of 63 MHz with imaging coil of 30 cm was used.***

In this study, 8 healthy volunteers and 34 patients were the subjects of brain angiography. Flip angles of 15-20 degrees for peripheral brain vessels and 35-45 degrees for internal brain vessels were found to give higher contrast and better image resolution with a artifact. Using our optimum imaging parameters, (ie [TR/TE/FA/FOV], [40ms/7ms/20°/1mm 023cm]), besides obtaining high quality angiography images, routine imaging time of 9-12 minutes was reduced to 7.3 mintues.
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Key words: ***Magnetic resonance angiography (MRA), 3-dimensional time of flight mangenetic resonance angiography (3D-TOF-MRA), maximum intensity projection algorithm (MIP), fast low angle shot (FLASH).***

INTRODUCTION

Attempts have been made to image human cardiovascular systems almost immediately after x-ray discovery, using contrast media coupled with improved technology, angiography (1,3).

With the invention of magnetic resonance (MRI) imaging and because of its high contrast images of soft tissue together with its tomographic abilities (2,6), much attention has been paid to this method of imaging and development techniques have been rapidly improving. One of the MRI's advantages is its intrinsic sensitivity to any tissue movement which was discovered in 1950 (1,4,12). Changes in singnals due to the physiological movement, can be used to gain quantified data for constructing vessles anatomy (1,5). Following magnetic resonance angiography (MRA) procedures can be carried out non-invasively:

1- Obtaining MR images for parenchymal structure of vessels.

2- Measuring quantity of blood flow in arteries with high contrast and resolution.

Research in angiography using MRI, development of more new and efficient techniques to eliminate artifacts, improving image quality together with short imaging time are being carried out in most centers throughout the world (1,2,5,12-13) and Iran is no exception.

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MATERIALS AND METHODS

Optimization of parameters

Preliminary study and practical works started simultaneously. The instrument used in this research was a 1.5T superconductive magnet MRI (picker, Vista Q 800) which is installed in the Medical Imaging Center of Imam Khomeini General Hospital with gradient power of 13 nT/m. Larmour frequency for hydrogen in mid field in this unit is 63 MHz, imaging coil is of circular type with 30 cm diameter which works both as transmitter and receiver of radio-frequency (RF) waves.

Pulse repetition used in this work was spolid gradient which has commercial name of flash (2,4,8) and it may have different names by other manufactures (1-2,6).

In this work, parameters selected for improving image quality were based on theoritical calculations and data from other researchers (8,12). Data were used on volunteers and evaluation of images were carried out. To extend clinical results from different subjects, comparision of images and their evaluation were carried out by three independent radiologists.

Ernest angle formula was used to obtain optimum flip angle and repetition frequency for FLASH angiographic technique. Ernest angle indicates that the maximum signal for flip angle (α), depends on T_1 (1-3) of blood and was calculated from:

α_E=Arc cos [exp(-TR/T_1)].

Figure 1 showes variation of flip angle as a function of (TR).

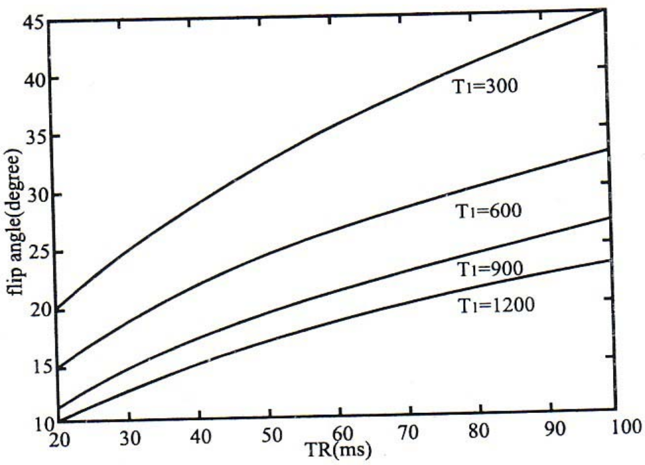


Fig. 1. Graph of optiumum flip angle as a function of time of repeat for several T_1

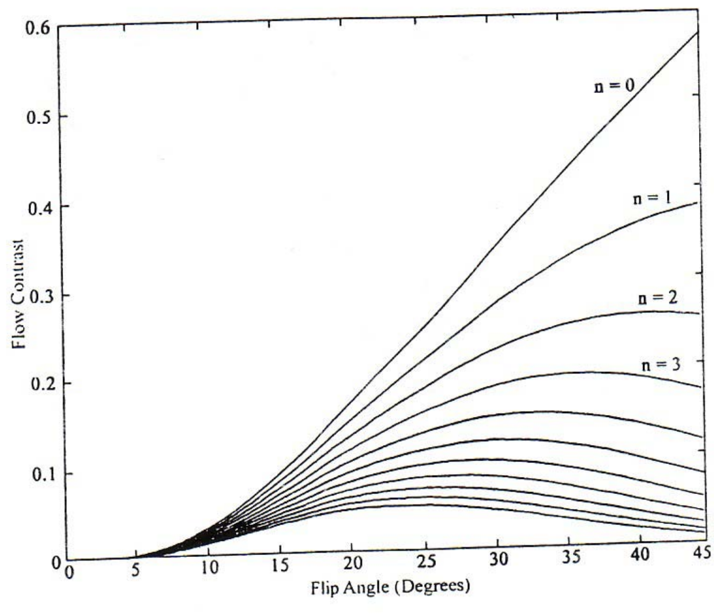


Fig. 2. Graph of low contrast versus flip angle for different n. Parameters ([TR/TE] 40ms/7ms)

To optimize contrast we used the following equations and total signal for all tomographs was calculated using different blood speed and spins.

$S = \sin\alpha\,[M_s + (1 - A^{n+1})(1 - M_s)(1 - A)(n+1)]$

M_s is saturation magnetization and n is the number of slices (1,5). Physical values of different parameters are as follow:

$E_1 = \exp(-TR/T_1)$

$A = E_1 \cos\alpha$

$M_s = (1 - E_1)\, M_o / (1 - E_1 \cos\alpha)$

$n = Z/VTR$

Here, Z, V and M_o are slice thickness, velocity and magnetization. In 3D-TOF, for imaging a volume of thickness Z, Spins with velocity V, receive n excitation pulses and become increasingly saturated. Blood contrast was calculated from the following formula (1,5,9):

$\Delta S_{blood} = S_{blood} - S_{back\ ground}$

$$\Delta S_{blood} = [M_o - M_s]\, A\, \frac{Z}{VTR}\, \exp\left[\frac{-TE}{T2}\right] \sin\alpha$$

As the formula indicates, to improve blood flow image contrast, it is necessary to reduce spin and saturation effect for flowing spins, therefore by using optimum imaging parameters obtained previously, flow contrast for different n was optimized. Flow contrast for different TE and blood velocity also were calculated.

Figure 2 indicates how flow contrast varies with flip angle.

Total data acquisition time is influenced by TR (6,11) and can be calculated from (4,8):

$T_A = T_R \times N_{acq} \times \text{Matrix (phase)} \times N(\text{slices})$

Matrix (phase) is the size of matrix in phase direction, $N_{acq.}$ is the number of data aquizition and N (slices) is the number of slices or volume.

Since the aim of this study was to obtain high quality images in the shortest possible time, attempt was made to use short TR and small matrix size together with smallest possible $N_{acq.}$.

(a) normal subject.

After the subject's head was positioned in the center of the main magent, images were taken at the sight of Willis loop and surrounding arteries for echo times of 7ms, 10ms, and 12 ms.

Other imaging parameters were:

TR/FA/NSS, 40 MS/20°/1
Band width 15.625
Field of view 23 cm
Matrix size 190×180
Number of transverse cuts: 64 and slice thickness 1mm

Maximum intensity projection algorithm (MIP) images were obtained from different angles along the z axis and contrast to noise ratio (C/N) between blood and brain tissue in each image was calculated using standard formula (1,10,13) for this ratio ie:

$C/N = (S_{blood} - S_{brain}) / \delta$

In which, S_{blood} is the signal received from the horizontal branch of the internal carotid artery (ICA) and in the Vicinty of Petrus bone, S_{brain} is signal intensity of brain tissue in the vicinity of ICA and δ is standard deviation of noise measured in air (4,10). Here the echo time that gives the highest C/N ratio is chosen as the optimum.

In the next step, images were obtained using flowing sets of arrangements and at flip angles of 40°, 20° and 10 degree, ie:

{[(TE/TR/NSA)], 70ms/40ms/1}

other parameters used were the same as in the previous measurements.

(b) Patients

70 protocols in six groups were tried on 42 patients aging from 10 to 83 years averaging 41.5 years. For each Protocol, a full view at zero angle and 12 reconstructed views (MIP) with 15 degree rotation angle were produced both on z axis. Settings were, 23 cm field of view, 64 slices and 190×180 matrix in all groups.

Group 1. 12 imaging Protocols ([Tr/FA/NSA] 40ms/ 20°/1) for echo times of 7 to 12 ms.

Group 2. 12 imaging Protocols with the same settings of group I but TR= 50ms.

Group 3. 12 imaging Protocols ([TR/TE] 40ms/ 7ms) at flip angles from 10 to 45 degrees.

Group 4. 12 Protocols ([TR/TE] 50ms/ 8ms) at flip angles from 10 to 45 degrees.

Group 5. 12 Protocols ([TR/TE] 50ms/ 11ms) at flip angles from 10 to 45 degrees.

Group 6. 10 Protocols ([TR/TE/FA] 40ms/ 7ms/ 20°) and slice thickness from 0.8 to 2 mm.

Imaging time for groups 1, 3 and 6 was determind to be 7.33 minutes and that for groups 2, 4 and 5 was 9.23 minutes. Images obtained were then evaluated for resolution and the limit of detectability of arteries of concern by three independent radiologists. Artifacts and contrast were evaluated qualitatively (10).

Detectability and artifact classifications were as follow:

A) Detectability:

Category 1. Arteries which were not visible in MIP images.

Category 2. Arteries which were visible in a short distance.

Category 3. Arteries which were visible in a longer distance.

Category 4. Arteries which were quite visible but end arteries were not satisfactorily visible.

Category 5. Arteries which were completely visible and visibility extended to their end branches.

Vessels studies were:

1) internal carotid artery
2) anterior cerebral art.
3) middle cerebral art.
4) anterior communicating art.
5) posterior communicating art.
6) posterior cerebral art.
7) superior sagittal sinus
8) rectus sinus
9) transverse sinus

B) noise and artifact

Class 1. images with no artifact.

Class 2. images with slight artifact.

Class 3. images with medium artifact.

Class 4. images with considerable amount of artifacts.

In each series of data, mean and standard deviation for resolution, contrast and artifacts were calculated.

In table 1 a and b, results of qualitative evaluation of images are shown for a healthy volunteer.

Using paired t student test and SPSS statistical software, points given to each protocol in one group were compared to another protocol in the same group ($\alpha = 0.5$).

Figure 3 shows typical MR angiography image for qualitative evaluation.

Table 1. Standard deviation from the mean for artifact, contrast and resolution obtained from images of healthy volunteer in different TE (a) and different flip angle (FA) (b).

TE_{ms}	Artifact	Contrast	Resolution
	μ	μ	μ
4	1.58	3.9	4
10	2.30	3.77	2.15
12	3	2.17	2

a

FA	Artifact	Contrast	Resolution
	μ	μ	μ
10°	2.36	2.64	1.64
20°	0.5	3.9	4
40°	2.62	4.92	3.85

b

RESULTS

In figure 1 variation of flow contrast is plotted against flip angle for different values of n. It is clear that as blood speed decreases (or TR become smaller) spins in three dimensional volume receives more RF pulses (2,5). By increasing n, saturation is reached or contrast become worse, therefore in high contrast images when n is increased, it is necessary to use angles between 15 and 30 degrees.

Greatest signal intensity is obtained at 30 degrees for fat, 15-20 degrees for white mater (WM) and blood and at 10 degrees for CSF.

In figure 4 signal intensity variation for different tissues is plotted against flip angle.

Here signal intensity measurements were made for different blood speed at constant TR, TE and Z and for n= 1,3,5,10: As is demonstrated, when blood speed increases, signal intensity of blood vessels also Increases, therefore for basal cerebral artery with blood speed of 50 cm/sec, curve n= 3 and for other arteries and veins with blood speed of 15cm/se, curve n= 10 is applicable.

In figure 5 relative signal intensity for selected values of TR and TE is calculated and drawn versus flip angle using Matlab soft ware. Signal for fat, white mater (WM), gray mater (GM), blood and cerebro spinal fluid (CSF) are separately demonstrated.

Figure 6 shows plot of contrast versus TE. It indicates that, with an increase in TE, contrast is slightly decreased which is due to phase different inside the voxel since with longer TE, more blood is found between the time of excitation and recovery of signal (or Echo) (5,11).

Therefore since blood in different sections of vessel has different phases, when added, resultant signal loss is inevitable. Our results are in full agreement with those of Alsop and Hendrix (3,5).

Fig. 3. Typical MR angiography images taken in the vicinity of Petrous bone at the sight of Willis loop (arterial phase).

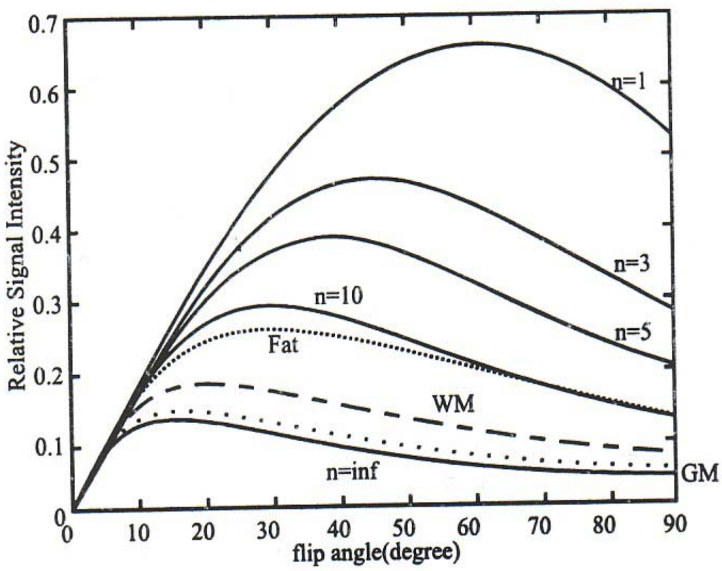


Fig. 4. Variation of signal intensity against flip angle for different tissues. At different blood speed and constant TR, TE and Z for n= 1,3,5,10.

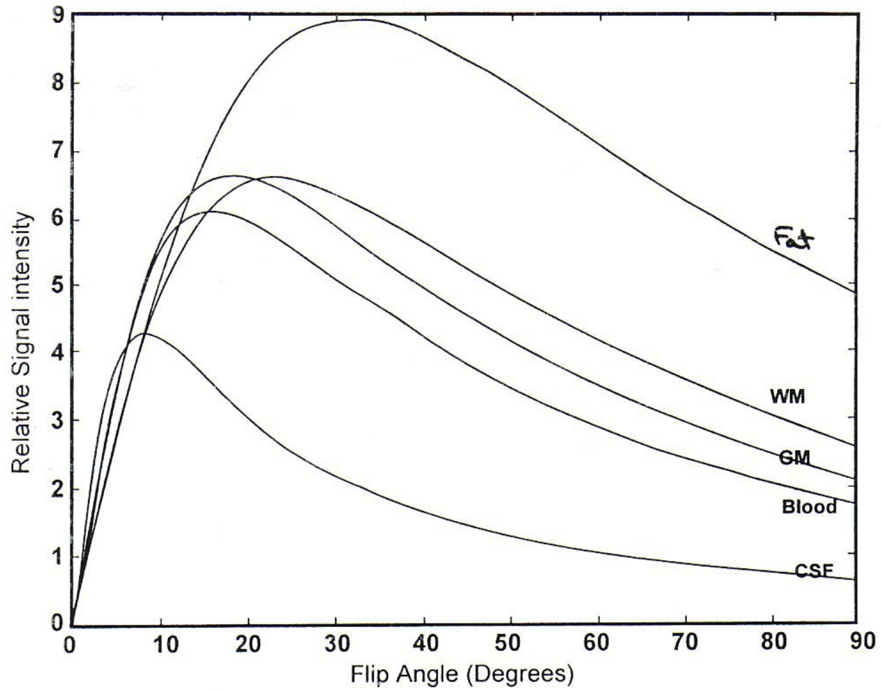
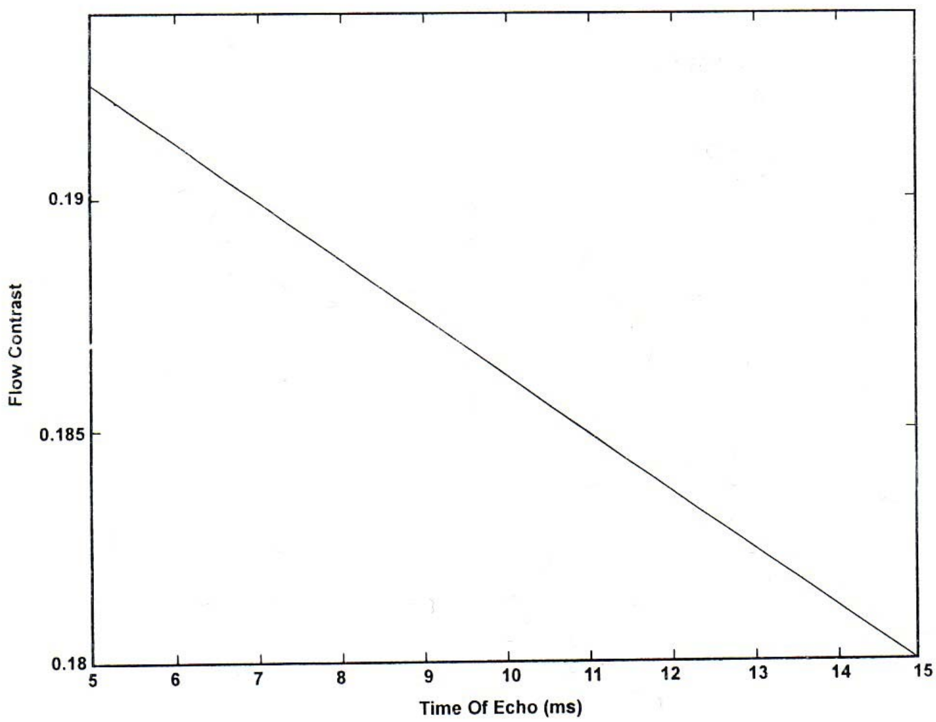


Fig. 5. Relative signal intensity values Verus flip angle, for Selected Values of TR and TE.



For echo times of 7ms, 10ms and 12ms, contrast to noise ratio of 95, 44.7 and 51.9 were obtained and for flip angles of 10, 20 and 40 degrees ratios of 5.48, 9.5 and 38.5 are measured respectively.

It is clear that at 7ms and at flip angle of 20^o. C/N ratio is the highest. Different flip angle on patients and healthy volunteers shows that high contrast and high resolution of the MIP images are obtained at flip angles of 15 and 20 degrees.

At 10 degrees angle, qualities of MIP images worsen due to the decrease in blood and increase in back ground tissue signals (10). At greater angles ($>35^o$) tissue saturation follows by partial saturation of arteries having low blood speed, possibly due to the back ground (10,13).

Although images obtained show high contrast and decreased artificat but, considerable fall in resolution power takes place therefore small peripheral arteries are quite blurred at great flip angles.

DISCUSSION

Figure 5 indicates that, by increasing flip angle, signal intensity shows marked decrease byond a certain point.

The best flip angle we obtained is 20 degrees in which besides having greatest intensity, there exists considerable difference amongst blood and other tissues' signal.

Application of our protocols with different flip angle on patients and healthy volunteers showed high contrast and high resolution of flip angles from 15 to 20 degrees, therefore our research findings indicate that the best results are achieved using 15 and 20 degrees of flip angle for peripheral arteries (high resolution) and 35 to 45 degree of flip angle for main internal brain arteries and these findings match those of Tkach and kim (13,9).

Values of flip angles play a major role in tissue and inflow signal back ground suppression. Greater flip angle provides stronger back ground suppression and here our results are comparable with the work of Munich university group who used a similar unit as the one installed at the Imam Khomeini Imaging Center.

Also our 1.5 Tesla super conductive unit at the Imam Khomeini Hospital has limitations on short TE (because of software limitation), our optimum TR FLASH sequence angiography, ie TR= 40 ms, TE= 7ms, Matrix size=190×180, filed of view 23 cm with NSA= 1 gave considerable shorter imaging time of around 7 minutes in comparison with that of Talagala and Hendrix (5,7) of 9-12 minutes. At present, 12 minutes is the routine imaging time at the Imam Khomeini Imaging Center.

In conclusion flash (3D. TOF) MR angiography provides not only images of high resolution but reconstruction in different levels, minimum artifact and visibility of tortuous vessels, provided that, optimum physical parameters be used. Echo times of 7ms and 11ms together with thin slices and small field of view can reduce signals from fatty tissues considerably.

Using following set of parameter, ie ([TR/TE/FA/FOV], [40ms/ 7ms/20^o/ 1], [50ms/ 11ms/ 20^o/ 1mm/ 23cm]) high quality MR angiography images with the minimum artifact is possible at our MRI imaging center.

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