Received:
28 December 2017

Revised:
28 March 2018

Accepted:
06 May 2018

<https://doi.org/10.1259/bjr.20180018>

Cite this article as:

Ghosh A, Singh T, Singla V, Bagga R, Srinivasan R, Khandelwal N. Read-out segmented echo planar diffusion imaging of the female pelvis—utility in endometrial carcinoma—a preliminary experience. *Br J Radiol* 2018; **91**: 20180018.

SHORT COMMUNICATION

Read-out segmented echo planar diffusion imaging of the female pelvis—utility in endometrial carcinoma—a preliminary experience

^{1,2}ADARSH GHOSH, MD, ¹TULIKA SINGH, ¹VEENU SINGLA, MD, ³RASHMI BAGGA, MD, ⁴RADHIKA SRINIVASAN, MD and ¹NIRANJAN KHANDELWAL, MD

¹Department of Radiodiagnosis and Imaging, Postgraduate Institute of Medical Education and Research, Chandigarh, India

²Department of Radiodiagnosis, All India Institute of Medical Sciences, New Delhi, New Delhi, India

³Department of Obstetrics and Gynaecology, Postgraduate Institute of Medical Education and Research, Chandigarh, India

⁴Department of Cytology and Gynaecologic Pathology, Postgraduate Institute of Medical Education and Research, Chandigarh, India

Address correspondence to: Tulika Singh

E-mail: tulikardx@gmail.com

Objective: Susceptibility artefacts from bones and bowel, geometric distortion makes diffusion imaging of the pelvis difficult. We discuss the difficulties of single-shot-echo-planar (ss-ep) DWI and evaluate a new diffusion-weighted imaging (DWI) technique—readout segmented echo planar (rs-ep) DWI in endometrial carcinoma and discuss the imaging physics.

Methods: Institute review board approval was obtained and five consecutive patients underwent both rs-ep and ss-ep-DWI of the female pelvis and two radiologists compared the images. ROIs were drawn on the endometrium on the b400 images—signal to noise was calculated and compared using *F* test.

Results: The rs-ep-DWI had less imaging artefacts, less bowel-related susceptibility and geometric distortion

compared to ss-ep-DWI. There was statistically significant greater SNR in ss-ep-DWI compared to rs-ep-DWI. This resulted in increased graininess of the readout segmented diffusion images. Artefacts in SS-EPI-DTI may make fibre tracking fallacious and rs-ep DTI may have fewer artefacts.

Conclusion: rs-ep-DWI is a new imaging arsenal in imaging of the female pelvis in general; however further reduction in imaging time and improvement in signal to noise may be desirable.

Advances in Knowledge: rs-ep-DWI affords lesser imaging artefacts from susceptibility and geometric distortion; at a higher time dividend and may find a place in oncological imaging.

INTRODUCTION

Endometrial carcinoma is the most common gynaecological malignancy in the western world exceeding the incidence of cervical carcinoma and ovarian malignancies.¹ Usually, the disease presents early with excessive bleeding or postmenopausal bleeding per vagina.² Though the clinical diagnosis is by fractional curettage as an outdoor procedure, MRI is the workhorse of the preoperative imaging of patients with the extent of myometrial invasion determining the further management.

Diffusion-weighted imaging (DWI) is used to quantify restriction to random motion of water molecules across biological membranes. It has been postulated that increased cellularity impedes random diffusion of water. Thus diffusion weighting has been used as a functional marker of tissue cellularity and by extension malignancy. It has been used for diagnosis of several malignancies in the abdomen

and pelvis as well as in their staging. Endometrial carcinoma is treated according to the extent of myometrial invasion with radical surgery and pelvic lymph node dissection being reserved for diseases with myometrial invasion beyond 50% with a less radical approach being utilized for endometrial carcinoma restricted to the superficial 50% of the myometrium.³ Dynamic contrast-enhanced MRI remains the gold standard for diagnosing myometrial invasion however issues remain with the risk of nephrogenic systemic sclerosis as well as adverse reactions due to contrast agent administration.

DWI has been suggested as an alternative tool or an adjunct to improve the diagnostic accuracy of imaging in staging of endometrial carcinoma.^{4–7} However, the uterus specifically and the pelvis remains a difficult organ to image with single shot echo planar DWI (ss-ep-DWI) especially because of bowel loops in the adjoining pelvis as well as the

Figure 1. A 46-year-old multiparous female presented with bleeding per vagina, and was diagnosed with Type 2 endometrial carcinoma. In the SS-EPI-DWI in the sagittal plane we see that there is susceptibility due to clumped small bowel loops anterior to the enlarged uterus. The inhomogeneity of the induced magnetic field results in geometric distortion, with anterior-posterior stretching of the pixels. This makes the interpretation of the tumour myometrial interface (arrow) difficult. The post-contrast dynamic sequence shows the actual anterior border of the myometrium and the tumour-myometrial interface, thus the geometric distortions in SS-EPI-DWI makes anatomical correlation difficult (1a inset). RS-EPI-DWI (b) acquired in the same imaging plane shows almost no susceptibility artefact with excellent delineation of the anterior tumour-myometrial interface, making interpretation of the myometrial interface and invasion easier. The spatial resolution of the images is also better than the SS-EPI-DWI images.

surrounding bones interfere with imaging quality with susceptibility artefacts often obscuring and distorting the signals from surrounding uterine myometrium, eddy currents and patient motion causing shearing and surrounding distortion of the images.⁸

Imaging resolution on ss-ep-DWI and subsequent apparent diffusion coefficient (ADC) maps sometimes may not have an adequate spatial resolution to comment on the extent of myometrial invasion as well as to delineate the myometrial-endometrial junction adequately and these artefacts have been studied in imaging of the male pelvis.⁹

Read-out segmented echo planar DWI (rs-ep-DWI), (RESOLVE) is a technique marketed by Siemens Healthcare^{10,11} which obtains quality high spatial resolution DWIs in the brain and other difficult to image organs including the pelvis. It uses echo planar imaging with readout segmentation of the k space trajectory in the readout direction with reduced susceptibility based image distortion and motion induced phase errors and blurring artefacts providing high-resolution DWI images. The reduction of the TE and the encoding time allows for a better image quality.

We demonstrate the feasibility of the rs-ep diffusion imaging of the pelvis for local staging of endometrial carcinoma and compare the images obtained from ss-ep-DWI and rs-ep-DWI.

METHODS AND MATERIALS

Institutional review board approval was obtained, and informed consent was obtained from the patients. Five patients undergoing

routine MRI on a Seimens 1.5T scanner—machine type-Aera with software v. syngo MR D13 for staging of biopsy-proven endometrial cancer underwent rs-ep-DWI in addition to routine imaging which included T_2 weighted imaging in three axial planes, dynamic contrast-enhanced imaging and post-contrast fat saturated T_1 weighted images, the rs-ep-DWI images were in the sagittal orientation; 20 slices of 5 mm thickness with 30% slice gap were acquired with FoV Read: 230 mm and FoV Phase: 100%. Repetition time was 4600 ms echo time was 70 ms with a flip angle of 180 deg. Strong fat saturation was used and water suppression was used for flow compensation; b values of 0, 400, 800 s m^{-2} were used. The acquisition time varied from 6 to 9 min.

The routine single-shot echo planar DWIs were acquired with the following parameters. Orientation: sagittal, number of slices: 24, FoV read: 250 mm, FoV Phase: 82.5%, slice thickness: 5 mm, slice gap: 20%, repetition time: 4600 ms, echo time: 62 ms, fat suppression: SPAIR, strong flow compensation: water suppression: subtraction: b values 0, 400, 800 s m^{-2} . The acquisition time varied from 2 to 3 min. The diffusion images and ADC maps obtained from the two imaging sequences were anonymized. The images were viewed on a workstation by two radiologists with 10 and 3 years of experience in viewing pelvic MRI in consensus and in case of discrepancy the opinion of a third senior radiologist prevailed in consensus. The two radiologists independently drew three ROIs each on the endometrial tumour on the b 400 images and the signal to noise ratio was calculated using the formula

$$\text{SNR} = \frac{\text{Mean Signal intensity in the ROI}}{\text{S.D of signal intensity in the ROI.}}$$

The SNR of b 400 images of ss-ep-DWI and rs-ep-DWI were subsequently compared by F test.

RESULTS

There was a statistically significant difference in the SNR for the endometrial ROIs obtained by both the radiologists. The SNR [mean (SD)] was 11.01 (5.84) for the rs-ep-DWI and 20.52 (10.38) for ss-ep-DWI for radiologist 1 (f value- 3.15, p-value 0.039) and 10.06 (4.68) for rs-ep-DWI and 12.41 (7.80) for ss-ep-DWI (f value- 2.76, p-value 0.067) for radiologist 2.

Qualitatively, the rs-ep-DWI images had a lesser amount of susceptibility artefact and geometric distortions and a subjective better spatial resolution than ss-ep-DWI images. The susceptibility artefacts/and geometric distortion in the ss-ep-DWI interfered with adequate evaluation of the tumour myometrial interface.

DISCUSSION

Geometric distortion and susceptibility artefacts

Echo-planar imaging is the workhorse of diffusion imaging; however, it is not without its own disadvantages. Heterogeneity of the magnetic field results in focal image distortion and signal dropout. This is further compounded by the low bandwidth used in EPI, which fails to compensate the above-mentioned artefacts. Even with a highly shimmed homogeneous Z magnetic field, bowel loop air and the pelvic bony cage will result

Figure 2. A 51-year-old nulliparous female with postmenopausal spotting was founded to have Grade 1 endometrioid adenocarcinoma of the uterus, with preoperative staging MRI showing superficial myometrial invasion (a, ss-ep-DWI, b, rs-ep-DWI). A 46-year-old female with excessive vaginal bleeding was founded to have Grade 2 endometrioid adenocarcinoma of the uterus, with preoperative staging MRI showing deep myometrial invasion with intact serosal lining (c, ss-ep-DWI, d, rs-ep-DWI). The hardware limitations associated with SS-EPI imaging results in a greater blurring of the images and makes the interpretation of the extension of the tumour into the myometrium difficult. RS-EP DW images (b) shows better delineation of the tumor myometrium interface [white hollow arrows] compared to the SS-EP DW images (a) and also delineated the deep myometrial invasion without serosal invasion with greater clarity on rs-ep-DWI (d) as compared to ss-epi-DWI (c)] (white solid arrows) adding to imaging confidence.

in inhomogeneous magnetization of the pelvic tissues which results in distortion of the induced Larmor frequency across the voxels acquired during imaging. Though adequate bowel preparation and anti-spasmodics may reduce bowel-induced artefacts, susceptibility from the surrounding bones and residual bowel air still pose a problem especially in prostatic and uterine diffusion imaging. This geometric distortion results in difficulty in correlating the diffusion images with the anatomic images obtained (Figure 1a).^{10,11} Ss-ep-DW images showed significant susceptibility artefacts in all five of the patient's (Figure 1a). The interface of the bowel air and the soft tissue (uterus) results in inhomogeneity of the induced tissue magnetic field from point to point resulting in different Larmor frequencies. This results in stretching of the pixels in one particular direction which causes spatial misshaping as seen in the Figure 1a, whereby the uterine images are stretched anteriorly and this may interfere in the interpretation of the diffusion images especially when anatomical images need to be coregistered (compare to Figure 1a inset).

Though preliminarily T_2 weighted images are important for spatial resolution and determination of myoinvasion- TT_2 weighted images may be rendered difficult to interpret in cases with fibroids, post-menopausal atrophy, in such cases post contrast images and trace diffusion weighted images are interpreted to evaluate the myometrial invasion- and higher spatial resolution diffusion images are desirable in cases with contrast contraindicated to enable evaluation of tumour invasion.

The spatial resolution of the EPI images is degraded by the hardware limitations associated with the acquisition of such images. The long echo trains and the resultant T_2^* decay of the signal during the long signal readout results in poor image resolution and image quality. In the ss-ep-DWI the tumour myometrial interface is poorly delineated due to image blurring and poor spatial resolution and in Figure 2a,c we see that an exact tumour myometrial interface is not delineated adequately to make a satisfactory comment about the same.

Figure 3. The signal to noise of the SS-EPI DWI is greater than the RS-EPI-DWI. This is reflected in the RS-EP DWI parametric ADC maps (b) which shows greater noise as perceived in the form of signal from the surrounding air and a subjectively greater pixelated appearance of the images as compared to the SS-EP-DWI-ADC maps (a). RS-EPI-DTI, shot echo planar diffusion tensor imaging; SS-EPI DWI, segmented echo planar diffusion tensor imaging.

The workaround

Unlike ss-ep-DWI where a single line of the k space is acquired with every single radiofrequency pulse, in rs-ep-DWI a number of smaller segments “shots” are acquired with limited traversal of the k space in the frequency encoding direction, however, there is a complete traversal of the phase encoding direction. There is a pre-phasing gradient pulse which helps to identify the position of the readout segments along the frequency encoding direction. The frequency encoding direction is covered less extensively during each EPI shot and thus results in lesser susceptibility artefact and geometric distortion with higher imaging resolution. There was no significant susceptibility noted in any of the five patients imaged.^{10,11} Improved anatomical delineation with improved imaging demonstration of a tumour- myometrial interface allowed better imaging interpretation of tumour invasion on the rs-ep-DWI. The geometric distortion seen due to susceptibility from the bowel air was absent in the rs-ep-DWI (Figure 1b) and the tumour myometrial interface is better delineated allowing better interpretation of tumour invasion. The rs-ep-DW images had a better clarity and delineation of the uterine outline, endometrial-myometrial junction as well as tumour myometrial junction allowing better reporting confidence (Figure 2b,d).

The cost

A 2d navigator is obtained at the centre of the k space to account for the bulk motion of the patient during image acquisition between each shot which is acquired, and this method fails when patient motion is severe, resulting in reacquisition of the segment and this is responsible for the long acquisition time of rs-ep-DWI. The acquisition time of rs-ep-DWI was approximately 9 min compared to 3 min for the routine DWI protocol used in our patient series. This has the disadvantage of not only

affecting the table time and patient turnover, also may result in significant image distortion due to patient motion.^{10,11}

Signal to noise ratio

There was a statistically significant less SNR in the rs-ep-DWI images compared to the ss-ep-DWI images, and this finding is concordant to similar studies in the brain. However, this low SNR apparently does not affect reader preference for the rs-ep-DWI images presumably because of the fewer susceptibility artefacts, geometric distortions and a better spatial resolution.^{11,12} The rs-ep DWIs, as well as the ADC maps, were significantly noisier “with increased graininess” compared to the ss-ep-DW images that were obtained. There was significant noise in the form of a signal from the surrounding air in the rs-ep DWIs (Figure 3).

The way forward: RS-EPI-diffusion tensor imaging

Diffusion tensor imaging has been studied extensively in the male pelvis for the staging and characterization of prostatic carcinoma. Few studies have also applied the same for the evaluation of the normal female pelvis and endometrial carcinomas. The disadvantage of ss-ep-DTI remains increased susceptibility artefacts, geometric distortion, poor resolution and eddy currents. We carried out rs-ep-DTI of the pelvis in the sagittal plane of a normal volunteer and there was no significant susceptibility artefacts, geometric distortion or eddy currents (Figure 4d) when compared to the ss-ep-DTI which was obtained in a patient with endometrial carcinoma which showed significant eddy currents, susceptibility artefacts and geometric distortions. Distortion and susceptibility artefacts in the ss-ep-DTI results in an abrupt change in the pixel to pixel fractional anisotropy and directional changes in the tracts resulting in mismatching of the tracts. This is demonstrated in Figure 4a whereby the geometric distortion

Figure 4. The base images of SS-EPI-DTI of the same patient as figure 1 shows significant susceptibility artefacts and geometric distortion and eddy currents (a). These focal distortion causes significant changes in the parametric fractional anisotropy maps generated (b). When these maps are used for fibre tracking there is a fallacious paucity of the myometrial fibres anteriorly as compared to the posterior myometrial fibres (c) due to abrupt pixel to pixel change in FA and acute changes in the direction of the fibres even though there is no invasion seen in the anatomical images (inset 4b). The FA maps from RS-EPI-DTI images of a healthy control shows no significant artefacts and distortion with the comparative anatomical image in inset.

in the trace diffusion images in different diffusion sensitizing directions results in heterogeneity of the FA map in the anterior myometrium (Figure 4b). This results in the paucity of anterior myometrial fibre in fibre tracking (Figure 4c) even though the myometrium is not involved in the anatomical images. These pitfalls may be avoided with rs-ep-DTI.⁸

The main limitations of our evaluation were the very small number of cases included—we intended to evaluate the feasibility of rs-ep-DWI and DTI in the female pelvis and optimize the parameters which would help in the acquisition of better diffusion images for the workup of endometrial carcinoma. However further studies evaluating the practical feasibility

of rs-ep-DWI/DTI is needed before it can be introduced into routine oncological imaging.

In conclusion, rs-ep-DWI resulted in the better anatomical delineation of endometrial-myometrial interface as well as invasion by endometrial tumours and improved reporting confidence, however, increased scanning time added to patient discomfort and has the potential disadvantages of significant artefact in the form of patient motion. In conclusion, rs-ep diffusion appears to be a new weapon in the ever-increasing arsenal of functional imaging and may be used especially in conditions where contrast is contraindicated and would allow for better reporting confidence and tumour evaluation.

REFERENCES

1. Jemal A, Siegel R, Xu J, Ward E. Cancer statistics, 2010. *CA Cancer J Clin* 2010; **60**: 277–300. doi: <https://doi.org/10.3322/caac.20073>
2. Sala E, Rockall A, Kubik-Huch RA. Advances in magnetic resonance imaging of endometrial cancer. *Eur Radiol* 2011; **21**: 468–73. doi: <https://doi.org/10.1007/s00330-010-2010-5>
3. Benedetti Panici P, Basile S, Maneschi F, Alberto Lissoni A, Signorelli M,

- Scambia G, et al. Systematic pelvic lymphadenectomy vs. no lymphadenectomy in early-stage endometrial carcinoma: randomized clinical trial. *J Natl Cancer Inst* 2008; **100**: 1707–16. doi: <https://doi.org/10.1093/jnci/djn397>
4. Beddy P, Moyle P, Kataoka M, Yamamoto AK, Joubert I, Lomas D, et al. Evaluation of depth of myometrial invasion and overall staging in endometrial cancer: comparison of diffusion-weighted and dynamic contrast-enhanced MR imaging. *Radiology* 2012; **262**: 530–7. doi: <https://doi.org/10.1148/radiol.11110984>
 5. Rechichi G, Galimberti S, Signorelli M, Franzesi CT, Perego P, Valsecchi MG, et al. Endometrial cancer: correlation of apparent diffusion coefficient with tumor grade, depth of myometrial invasion, and presence of lymph node metastases. *AJR Am J Roentgenol* 2011; **197**: 256–62. doi: <https://doi.org/10.2214/AJR.10.5584>
 6. Lin G, Ng KK, Chang CJ, Wang JJ, Ho KC, Yen TC, et al. Myometrial invasion in endometrial cancer: diagnostic accuracy of diffusion-weighted 3.0-T MR imaging-initial experience. *Radiology* 2009; **250**: 784–92. doi: <https://doi.org/10.1148/radiol.2503080874>
 7. Rechichi G, Galimberti S, Signorelli M, Perego P, Valsecchi MG, Sironi S, et al. Myometrial invasion in endometrial cancer: diagnostic performance of diffusion-weighted MR imaging at 1.5-T. *Eur Radiol* 2010; **20**: 754–62. doi: <https://doi.org/10.1007/s00330-009-1597-x>
 8. Le Bihan D, Poupon C, Amadon A, Lethimonnier F. Artifacts and pitfalls in diffusion MRI. *J Magn Reson Imaging* 2006; **24**: 478–88. doi: <https://doi.org/10.1002/jmri.20683>
 9. Mazaheri Y, Vargas HA, Nyman G, Akin O, Hricak H. Image artifacts on prostate diffusion-weighted magnetic resonance imaging: trade-offs at 1.5 Tesla and 3.0 Tesla. *Acad Radiol* 2013; **20**: 1041–7. doi: <https://doi.org/10.1016/j.acra.2013.04.005>
 10. Porter DA, Heidemann RM. High resolution diffusion-weighted imaging using readout-segmented echo-planar imaging, parallel imaging and a two-dimensional navigator-based reacquisition. *Magn Reson Med* 2009; **62**: 468–75. doi: <https://doi.org/10.1002/mrm.22024>
 11. Morelli JN, Saettele MR, Rangaswamy RA, Vu L, Gerdes CM, Zhang W, et al. Echo planar diffusion-weighted imaging: possibilities and considerations with 12- and 32-channel head coils. *J Clin Imaging Sci* 2012; **2**: 31. doi: <https://doi.org/10.4103/2156-7514.96548>
 12. Fries P, Runge VM, Kirchin MA, Stemmer A, Naul LG, Williams KD, et al. Diffusion-weighted imaging in patients with acute brain ischemia at 3 T: current possibilities and future perspectives comparing conventional echoplanar diffusion-weighted imaging and fast spin echo diffusion-weighted imaging sequences using BLADE (PROPELLER). *Invest Radiol* 2009; **44**: 351–9. doi: <https://doi.org/10.1097/RLI.0b013e3181a00d09>