Clinical Imaging 53 (2019) 12–16

Contents lists available at ScienceDirect

Clinical Imaging

journal homepage: www.elsevier.com/locate/clinimag

Pediatric Radiology

Assessment of quiet T2 weighted PROPELLER sequence in pediatric abdominal imaging

Ethan Zaccagnino[a,*], Craig Devincent[b], Nattinee Leelakanok[c], Andrew S. Phelps[b], Matthew Zapala[b], Pauline Wong Worters[d], Jesse Courtier[b]

[a] University of California San Francisco, San Francisco, CA, United States
[b] Radiology, UCSF Benioff Children's Hospital, San Francisco, CA, United States
[c] Chulalongkorn University and King Chulalongkorn Memorial Hospital, Thai Red Cross Society, Bangkok, Thailand
[d] MR Applications, GE Healthcare, Menlo Park, CA, United States

ARTICLE INFO

Keywords:
Pediatric
Abdominal
MRI
T2
Quiet
Acoustic

ABSTRACT

Introduction: Elevated acoustic noise during Magnetic Resonance Imaging (MRI) has been associated with patient anxiety and altered cochlear function. Acoustic Reduction Technique (ART) T2 weighted (T2w) periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER) has been studied in brain MR but not abdominopelvic imaging. The purpose of our study was to evaluate the image quality and acoustic noise level of ART T2w PROPELLER sequence in comparison with the conventional T2w PROPELLER sequence in pediatric abdomino-pelvic imaging.

Methods: Eleven consecutive pediatric patients undergoing abdomino-pelvic MRI were scanned on a 3 Tesla magnet using standard and ART T2w PROPELLER sequences. After scanning completion, objective sound level measurements were performed with a sound level meter and microphone. Mann-Whitney *U* test was used for a non-parametric two-tailed statistical analysis of acoustics, image rating and scan time with significance level set to 0.05. Overall inter-rater agreement was calculated using Cohen's kappa coefficient.

Results: Eleven pediatric patients (4 females and 7 males) between 26 days and 18 years of age (mean = 10.0, SD = 5.8) were included. ART T2w produced lower levels of acoustic noise than standard technique in a comparison of mean decibel readings from eleven trials of standard and ART T2w (p value = 0.00008). Streak artifacts were rated greater in ART T2w by both raters (p-value = 0.00278 and 0.00252). There was no significant difference in bile duct blurring, respiratory ghosting, pulsation, fat suppression or hepatic parenchymal depiction.

Conclusion: Presence of additional streaking artifacts should be considered along with the benefit of reduced acoustic noise from ART T2w.

1. Introduction

Magnetic Resonance Imaging (MRI) has been associated with acoustic noise levels up to 120 dB [1]. Acoustic noise can lead to difficulties in verbal communication, patient anxiety, and potential hearing impairment [1–3]. In selected populations, such as pediatric patients, acoustic noise can heighten levels of patient anxiety and lead to difficulty tolerating MRI examinations [2,4]. Current methods to reduce acoustic noise include earplugs or headphones, active noise cancellation, or specially designed gradient coils [2]. Acoustic noise can alter cochlear function despite the use of ear protection [5]. A newly available acoustic reduction technology has been developed which utilizes modifications in pulse sequence acquisition to reduce acoustic noise [6]. Prior comparison between conventional T2 weighted (T2w) Periodically Rotated Overlapping ParallEL Lines with Enhanced Reconstruction (PROPELLER, GE Healthcare, Waukesha, WI USA) and T2w PROPELLER with Acoustic Reduction Technique (ART) demonstrated equivalent image quality between the two pulse sequences, but with significant reduction in acoustic noise levels using ART T2w [1,7]. T2w PROPELLER imaging is also a valuable sequence in pediatric abdomino-pelvic imaging which has been previously validated for use in abdominal imaging [8,9]. This radial pulse sequence provides additional intrinsic motion-resistance in comparison to breath hold or respiratory gated Cartesian alternatives. Standard turbo spin-echo sequences fill the k-space in a rectilinear pattern during a repetition time (TR) period. The PROPELLER sequence is a radial k-space sampling

* Corresponding author.
E-mail address: Ethan.zaccagnino@ucsf.edu (E. Zaccagnino).

https://doi.org/10.1016/j.clinimag.2018.09.014
Received 28 March 2018; Received in revised form 19 September 2018; Accepted 20 September 2018

concept with parallel data lines rotating around the center of the k-space, which oversamples at the center of k-space. Data indicating through-plane motion based on correlation measurement are rejected. Motion artifacts are further reduced through averaging in low spatial frequencies. Redundant data sampling of PROPELLER MRI increases the signal-to-noise ratio [10]. In comparison to brain MRI, abdomino-pelvic imaging presents several additional challenges including physiologic motions which can reduce image quality [11]. ART T2w sequences have been tested for abdominal imaging using Half Fourier Acquisition Single shot Turbo spin Echo (HASTE) and Turbo Spin Echo (TSE), but have not yet been tested with PROPELLER [12]. Our study aims to evaluate the image quality and acoustic noise level of ART T2w PROPELLER sequence in comparison with the conventional T2w PROPELLER sequence in pediatric abdomino-pelvic imaging.

2. Methods

The study was performed under the approval of the institutional review board. Eleven consecutive pediatric patients (18 years of age or younger) undergoing routine clinical MRI of the abdomen were scanned over a period of 8 weeks with ART PROPELLER T2w fat saturated images in addition to standard T2w PROPELLER fat sat to obtain imaging and scan acquisition times. All exams were performed on a GE HD750-W 3 Tesla MRI magnet (GE Healthcare, Waukesha, WI) running DV25.0 software platform. Parameters are listed in Table 1. Inclusion criteria included: Use of ART T2w PROPELLER sequence, conventional T2w PROPELLER sequence, coverage of matching anatomic areas, inclusion of hepatic hilum and central bile ducts. Exclusion criteria included: Disabled fat saturation and incomplete abdominal imaging. Of note, per our Institutional Review Board policy, we were required to keep any additional research sequences to no greater than 10 min total (this is in place specifically in consideration of patients under general anesthesia). As such we required adjustment of our ART PROPELLER T2w fat saturation images to account for the time limitation requirement.

After scanning completion and the patient leaving the MRI suite, objective sound level measurements were performed with a sound level meter (Type 2250 (accuracy, ± 1 dBA), Bruel and Kjaer, Nærum, Denmark) and a microphone (Type 4189 Bruel and Kjaer, Nærum, Denmark), to avoid having the patient present while the microphone was in the scanner. The microphone was placed in the gantry at the usual position of the patient's right ear with an MRI phantom in place (Fig. 1), as done in a previous study by Alibek et al. in brain MR [6]. Measurements were performed in ambient mode (i.e., background noise in the scanner room with the fan of gantry on or off, without any scanning), during the conventional T2w PROPELLER fat sat, and ART T2w PROPELLER fat sat. Results from three measurements, each lasting 30 s, were averaged for each operation mode.

Table 1
Comparison of various scan parameters between standard and quite T2w PROPELLER fat saturated sequences. TR = repetition time and TE = echo time.

Pulse sequence	Standard T2w PROPELLER fat saturated	ART T2w PROPELLER fat saturated
Field of view (cm)	24–36	24–36
Slice thickness (mm)	4	4
Interslice gap (mm)	0	0
Number of excitations (NEX)	2	3
Bandwidth	83.33	125
Matrix	Frequency 192	Frequency 256
Over-sampling factor	1.146	1.148
Effective blade width	55	55
Acquisition time (minutes)	3:18	3:30
Number of slices	48	48
TR	6,178	14,000
TE	111	91
Echo train length	40	28

Following the completion of the scans, two readers, (attending fellowship trained pediatric radiologists with body imaging experience), evaluated both sets of images to rate the level of bile duct blurring, respiratory ghosting, streak artifacts, pulsation, fat suppression and hepatic parenchymal depiction. The image readers were blinded to the two sets of images. Criteria used to determine image rating are listed in Table 2. One pair of ART T2w and standard T2w readings were excluded from the fat saturation rating due to disabled fat saturation. Sample images are shown in Fig. 2a and b. Mann-Whitney *U* test was used for a non-parametric two-tailed statistical analysis of acoustics, image rating and scan time with significance level set to 0.05 [13]. Overall inter-rater agreement was calculated using Cohen's kappa coefficient [14].

3. Results

Eleven pediatric patients (4 females and 7 males) between 26 days and 18 years of age (mean = 10.0 y, SD = 5.8) were included. Patient height ranged between 0.510 and 1.77 m (mean = 1.41 m, SD = 0.389) and weight ranged between 3.84 and 69.2 kg (mean = 43.9 kg, SD = 24.2). Mean ambient noise level was obtained by averaging the baseline noise levels with the MRI fan on “high” level from seven trials and shown for reference (mean = 72.3 dB, SD = 0.73). ART T2w was found to produce statistically significant lower volume of acoustic noise (mean = 73.4 dB, SD = 1.8) than standard technique (mean = 92.4 dB, SD = 7.0) in a comparison of mean decibel readings from eleven trials of standard and ART T2w (p-value = 0.00008, Figs. 3 and 4). Streak artifacts were rated significantly greater in ART T2w by both raters (p-value = 0.00278 and 0.00252, Figs. 5 and 6). There was no significant difference between the remaining five categories (bile duct blurring, respiratory ghosting, pulsation, fat suppression and hepatic parenchymal depiction). Although there was no significant difference between ART T2w and standard T2w for the hepatic parenchymal depiction category, the rater 1 mean score for ART T2w was 2.1, with a score of 2 indicating indistinct parenchymal detail and limited confidence in detection of small masses. The rater 2 mean score for hepatic parenchymal depiction was 1.8. Kappa was calculated to be 0.535 with a standard error of 0.072 and a 95% confidence interval of 0.394 to 0.677, indicating ‘moderate’ inter-rater agreement. No significant difference in scan acquisition time was found (p-value = 0.93624, Fig. 7).

4. Discussion

Image quality of ART T2w was comparable to standard PROPELLER in five of six qualitative image rater categories, while producing less acoustic noise than conventional T2w. Our findings suggest efficacy of ART T2w in pediatric abdomino-pelvic MRI for acoustic reduction with minimal loss of image quality. Acoustic noise from ART T2w PROPELLER was significantly reduced compared to conventional T2w PROPELLER in our study of abdomino-pelvic imaging, similar to other studies which tested ART T2w PROPELLER in brain imaging, as well as in ART T2w HASTE and TSE in abdominal imaging [6,7,12]. ART T2w PROPELLER acoustic noise level approached ambient acoustic noise level, so further reduction of acoustic noise via active acoustic screening may not be justified, due to the associated reduction in gradient efficiency [15]. Similarly, the use of parallel imaging to further reduce acoustic noise levels may not be justified due to the decrease in signal to noise ratio associated with the technique [16].

A notable difference between our study and others who tested ART T2w PROPELLER for brain imaging was that our ART T2w scan acquisition times were comparable to conventional T2w, while ART T2w scan times in brain MR were longer (1 min 15 s for standard T2 versus 2 min 10 s for ART T2) [1]. Our qualitative assessments in the abdomen indicated statistically significantly more streaking in ART T2w, but no

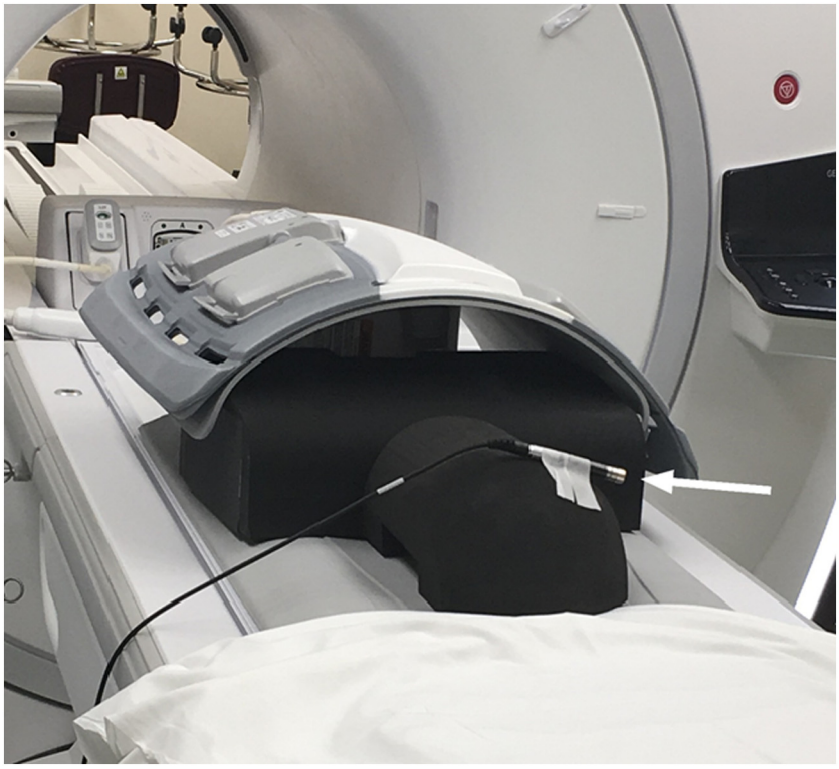

Fig. 1. Photograph demonstrating set up of microphone positioned at the expected location of the patient's right ear on an MRI phantom.

Table 2
Features used to define numerical scores during image rating.

Image rating category	Numerical scoring criteria
Bile duct blurring	1. Clear demarcation of bile ducts, no blurring 2. Mild/moderate blurring, still able to distinguish degree of dilation (mild, moderate, severe) 3. Severe blurring, unable to confidently distinguish
Respiratory ghost	1. No artifact 2. Mild/moderate ghosting artifact 3. Severe ghosting artifact
Streak artifact	1. No artifact 2. Mild/moderate ghosting artifact 3. Severe ghosting artifact
Pulsation	1. No artifact 2. Mild/moderate ghosting artifact 3. Severe ghosting artifact
Fat suppression	1. Homogeneous 2. Mild/moderate inhomogeneity 3. Poor/absent fat saturation
Hepatic parenchymal depiction	1. Clear parenchymal detail, could detect a mass 2. Indistinct parenchymal detail, limited confidence in detection of small masses 3. Poor parenchymal detail, poor confidence in detection of masses

difference was found in overall image quality for brain MR [1,7]. Streak artifacts in PROPELLER arise in the process of gridding acquired data to the parallel k-space from the oblique trajectory, and the under-sampling of k-space has been shown to increase the artifacts [17]. Additionally, artifacts due to uncorrected motion are expressed in the form of peripheral streaking in image space [18]. The increased streaking in abdomino-pelvic ART T2w may be attributable to the presence of increased physiologic movement in abdomino-pelvic imaging, such as respiratory and peristaltic movements. Partial differential equation filtering has been shown to be more effective at denoising diffusion tensor imaging data as compared to methods utilizing low-pass k-space filtering, so this may be another possible method to reduce the streak

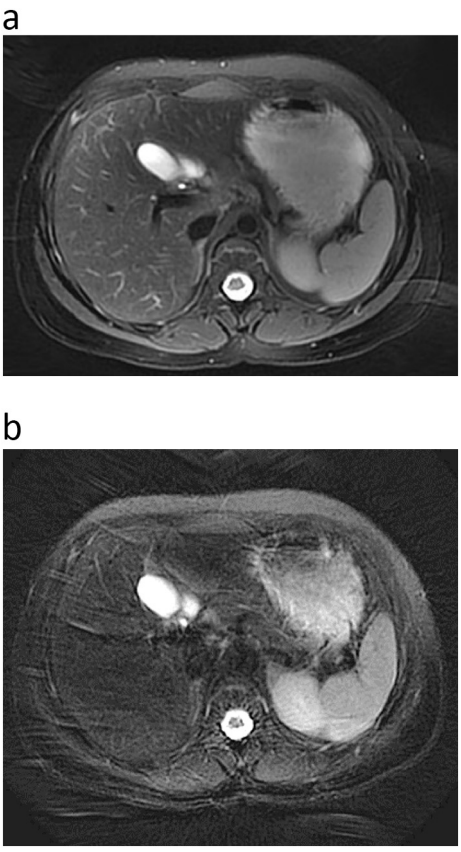

Fig. 2. a: Axial standard T2w PROPELLER fat saturated image in a 16-year-old female.
b: Axial Acoustic Reduction Technique T2w PROPELLER fat saturated image in the same patient as Panel 2a.

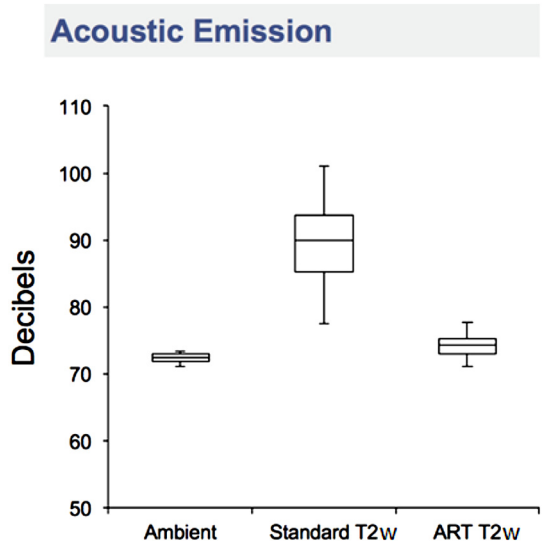

Fig. 3. Acoustic readings during standard and ART T2w PROPELLER in addition to the ambient background noise.

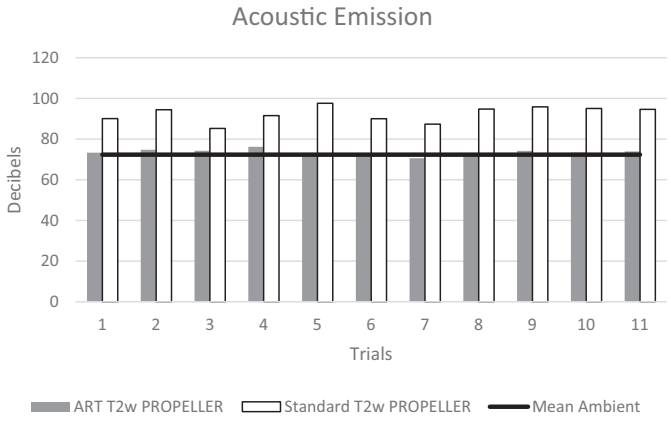

Fig. 4. Acoustic readings during each standard and ART T2w PROPELLER trial in addition to the mean ambient background noise.

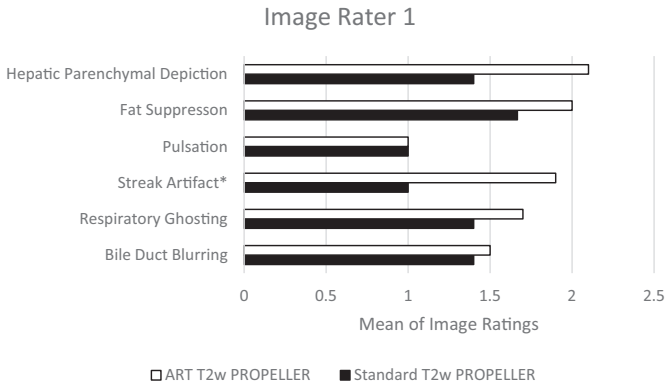

Fig. 5. Rater 1 Image Scoring Means. Lower score is better.
*Denotes category found statistically significant by Mann-Whitney *U* test.

artifacts we found associated with ART T2w PROPELLER [19].

The increased presence of excess patient movement in conventional T2w readings compared to ART T2w readings may be a useful area to study further. A study focused on comparing excess patient movement could elucidate whether ART T2w is associated with less patient movement or whether our observation was by chance.

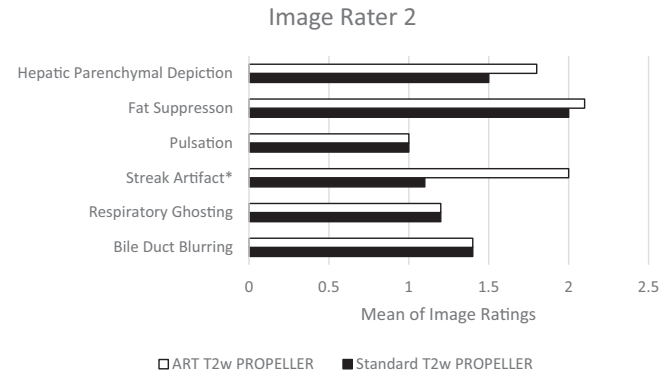

Fig. 6. Rater 2 Image Scoring. Lower score is better.
*Denotes category found statistically significant by Mann-Whitney U test.

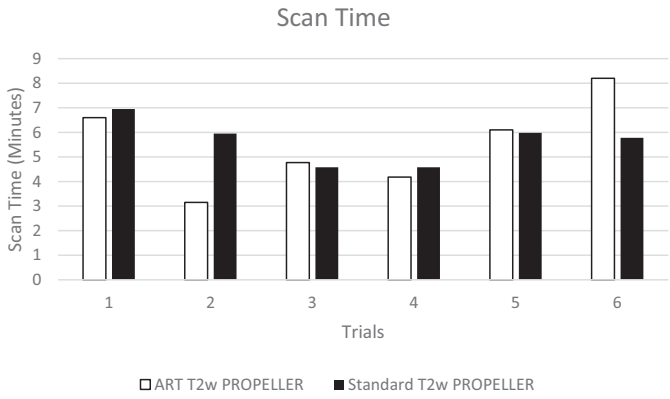

Fig. 7. Scan time comparisons of standard and ART T2w PROPELLER.

The greatest limitation to our study was the sample size. One standard T2w reading was found to have incomplete abdominal imaging, therefore both the conventional T2w and ART T2w from that patient were excluded from image rating. Within the set of included readings, two conventional and one ART T2w were reported by the image reviewers as having excess patient movement. An additional limitation was that we were required to use a slightly different technique (number of signal averages = 1) the ART T2w PROPELLER technique in comparison to our standard protocol (number of signal averages = 2) to account for our time requirements. Respiratory gating was not an option on this ART T2w pulse sequence version. This certainly could be a contributing factor in the differences in streak artifact.

5. Conclusion

Our study demonstrated ART T2w PROPELLER was associated with significantly less acoustic noise, while having comparable bile duct blurring, respiratory ghosting, pulsation, fat suppression and hepatic parenchymal depiction, but increased streak artifacts. The necessity of non-respiratory gated techniques in the ART T2w PROPELLER fat saturated sequence for the purposes of our study could be a contributing factor to increased streaking. Presence of additional streaking artifacts should be considered along with the benefit of reduced acoustic noise from ART T2w. Larger scale studies and the incorporation of a respiratory gating option for ART T2w PROPELLER may improve the ability to incorporate this into routine clinical use with the eventual goal of a silent MR abdomino-pelvic protocol.

Funding

This work was supported by GE Healthcare Waukesha, Wisconsin

United States who provided funds for the rental of the MRI microphones.

Declaration of interest

None.

References

[1] Corcuera-Solano I, Doshi A, Pawha PS, et al. ART PROPELLER MRI techniques match the quality of conventional PROPELLER brain imaging techniques. AJNR Am J Neuroradiol 2015;36:1124–7.
[2] McJury M, Shellock FG. Auditory noise associated with MR procedures: a review. J Magn Reson Imaging 2000;12:37–45.
[3] Brummett RE, Talbot JM, Charuhas P. Potential hearing loss resulting from MR imaging. Radiology 1988;169:539–40.
[4] Marcar VL, Girard F, Rinkel Y, et al. Inaudible functional MRI using a truly mute gradient echo sequence. Neuroradiology 2002;44:893–9.
[5] Radomskij P, Schmidt MA, Heron CW, Prasher D. Effect of MRI noise on cochlear function. Lancet 2002;359:1485.
[6] Alibek S, Sedat A, Mika V, et al. Acoustic noise reduction in MRI using Silent Scan: an initial experience. Diagn Interv Radiol 2014;20:360–3.
[7] Kim HG, et al. Image quality assessment of silent T2 PROPELLER sequence for brain imaging in infants. Br J Radiol 2018;91:20170680.
[8] Edwards AD, Arthurs OJ. Paediatric MRI under sedation: is it necessary? What is the evidence for the alternatives? Pediatr Radiol 2011;41:1353–64.
[9] Bayramoglu S, et al. T2-weighted MRI of the upper abdomen: comparison of four fat-suppressed T2-weighted sequences including PROPELLER (BLADE) technique. 2010;17:368–74.
[10] Dietrich M, Ulbrich E, Zanetti M, et al. PROPELLER technique to improve image quality of MRI of the shoulder. AJR Am J Roentgenol 2011;197:1093–100.
[11] Hirokawa Y, Isoda H, Maetani YS, et al. MRI artifact reduction and quality improvement in the upper abdomen with PROPELLER and prospective acquisition correction (PACE) technique. AJR Am J Roentgenol 2008;191:1154–8.
[12] Fischer S, et al. Quiet MR sequences in clinical routine: initial experience in abdominal imaging. Radiol Med 2017;122:194–203.
[13] "Mann-Whitney *U* Test Calculator." Social Science Statistics, www.socscistatistics.com/tests/mannwhitney/Default2.aspx. Accessed Oct. 22 2017.
[14] "QuickCalcs: Quantify interrater agreement with kappa." GraphPad Software, www.graphpad.com/quickcalcs/kappa1.cfm. Accesses Oct. 22 2017.
[15] Mansfield P, et al. Active acoustic screening: design principles for quiet gradient coils in MRI. Magn Reson Med 1994;33:276–81.
[16] Pierre EY, et al. Parallel imaging-based reduction of acoustic noise for clinical magnetic resonance imaging. Invest Radiol 2014;49:620-606.
[17] Hirokawa Y, et al. Evaluation of motion correction effect and image quality with the periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER) (BLADE) and parallel imaging acquisition technique in the upper abdomen. J Magn Reson Imaging 2008;28:957–62.
[18] Pandit P, Qi Y, Story J, et al. Multishot PROPELLER for high-field preclinical MRI. Magn Reson Med 2010;64:47–53.
[19] Chen B, Hsu EW. Noise removal in magnetic resonance diffusion tensor imaging. Magn Reson Med 2005;54:393–401.