

The Apparent Diffusion Coefficient (ADC) as a Potential Marker of Inflammation Associated with Body Abscesses

Shuichi KAWADA^{*1,6}, Taro TAKAHARA^{*2}, Tamaki ICHIKAWA^{*1}, Hiroshi YAMAMURO^{*1},
Yoshimi NAGATA^{*1}, Tsuyoshi NAGATA^{*3}, Takashi AIZAWA^{*4},
Thomas C. KWEE^{*5}, Kouichi MORI^{*6} and Yutaka IMAI^{*1}

^{*1}Dept. of Radiology, Tokai University School of Medicine

^{*2}Dept. of Biomedical Engineering, Tokai University School of Engineering

^{*3}Ziosoft, Inc.

^{*4}Philips Healthcare

^{*5}Dept. of Radiology, University Medical Center Utrecht

^{*6}Dept. of Radiology, Tsuchiura Kyodo General Hospital

(Received August 2, 2016; Accepted February 14, 2017)

Objective: To assess the feasibility of apparent diffusion coefficient analysis in evaluating the inflammatory severity of extracranial abscesses.

Methods: This retrospective study included 23 patients with solitary body abscesses (except those in the brain) who underwent 1.5-T diffusion-weighted magnetic resonance imaging (DWI) at b-values of 0 and 1000 s/mm². Three types of the Apparent Diffusion Coefficient (ADC) measurements of abscesses were performed: the mean ADC value in region of interest (ROI), volume of interest (VOI), and histogram analysis of the ADC distribution in the VOI. Furthermore, two different areas were used: high-intensity area on b = 0 and b = 1000 s/mm² images. Subsequently, correlations between ADC data and C-reactive protein (CRP) levels were assessed using Pearson's correlation coefficient (R) analyses.

Results: The strongest correlation was observed between the mean ADC value in VOI and CRP level (R = 0.78, P < 0.01), followed by ROI (R = 0.77, P < 0.01) by using the high-intensity area on the b = 0 s/mm² images.

Conclusion: The mean ADC value in the ROI encompassing the abscess at a b-value of 0 s/mm² may be useful to assess the inflammatory activity of an abscess in daily practice.

Key words: Abscess, Apparent diffusion coefficient, C-reactive protein, Diffusion-weighted magnetic resonance imaging, Histogram analysis

INTRODUCTION

Body abscesses (excluding the brain) are encountered frequently in daily clinical practice. If managed inadequately, they may cause life-threatening septic shock. The timely detection of an abscess and determination of the degree of associated inflammation are important in selecting appropriate treatments such as antimicrobials or abscess drainage [1, 2]. Increased C-reactive protein (CRP) level, white blood cell counts, and erythrocyte sedimentation rate are the accurate clinical predictors of an abscess [3, 4]. However, almost all patients with suspected inflammation or an abscess are treated with mild antimicrobial therapy before admission to a large hospital, and radiological examinations provide additional help for evaluating the inflammatory activity and abscesses in serious cases.

Ultrasonography (US) and computed tomography (CT) play important roles in the diagnoses of abscesses in the body. They can also evaluate the size and shape of the abscess cavity, and are useful in determining the possibility of a puncture procedure. The therapeutic response can also be assessed by US and CT, although

it may be difficult to assess the inflammatory severity of abscesses using these modalities.

Magnetic resonance imaging (MRI) is also useful in the detection and evaluation of abscesses. The utility of MRI in this setting may be further enhanced by the addition of diffusion-weighted imaging (DWI) [5-7]. Whole-body DWI is useful for the detection and characterization of pathological processes [8]. DWI is a fast echo-planar imaging (EPI) technique, and is increasingly being used in clinical practice [5]. The diffusivity of water molecules is affected in the organized abscess environment containing microorganisms, macromolecules, and inflammatory cells [6, 9]. Oto A *et al.* [5] reported that as abscesses demonstrate high signal intensity on DWI in the abdominopelvic region, it may be possible to differentiate between an abscess and non-infected ascites by evaluating the apparent diffusion coefficient (ADC) value. In addition, Yoshizako [7] reported that ADC in the positive inflammation activity group with high CRP levels was significantly lower than that in the negative inflammation activity group in perianal fistula patients. Based on these preliminary data [5, 7, 10], we hypothesize that DWI with ADC

measurements may potentially provide information on the associated inflammatory activity of an abscess.

An abscess cavity often shows areas of high intensity on $b = 0$ s/mm² images and low intensity on high b -value images. High intensity on $b = 0$ s/mm² image shows rich water such as exudative fluid or low-viscosity pus in an abscess [11]. Therefore, not only the abscess area on $b = 1000$ s/mm² images, but also that on $b = 0$ s/mm² images may need to be considered for DWI with ADC measurements. Furthermore, it is still unknown whether the region of interest (ROI) or the volume of interest (VOI) should be used for ADC measurements in this setting.

The purpose of this study was to assess the feasibility of ADC data in evaluating the inflammatory severity of body abscesses.

MATERIALS AND METHODS

Patients

The institutional ethics committee approved this retrospective study and granted a waiver for the requirement of informed consent.

A total of 28 patients who were diagnosed with a solitary abscess by either US, CT, or MRI at the Tokai University Hospital (2003/ Oct.-2014/ Mar.) were eligible for inclusion. Three patients with two or more foci of inflammation and two patients who had undergone drainage therapy were excluded before MRI analysis. Thus, a total of 23 patients were included in the present study. All patients were clinically diagnosed with bacterial abscesses and given a clinical course of antimicrobial therapy. The patients consisted of 15 men and eight women, and ranged in age from 43 to 79 years (mean age, 61.5 ± 10.6 years). The locations of the abscesses were as follows: eight in the liver; eight in the pelvis; one in the peritoneal cavity; two in the neck; one in the prostate; and three in muscle layers of the body (i.e., the psoas major, gluteus maximus, and erector spinae muscles). Prior to the MRI examination, 18 patients had been administered antimicrobials for durations ranging from 2-53 days (mean duration, 11 ± 14 days). Eleven patients were administered antiphlogistics either orally or intravenously because of highly febrile states. Five patients did not receive antimicrobials or antiphlogistics.

MRI

All patients were examined with a 1.5-T system (Gyrosan Intera; Philips Healthcare, Best, The Netherlands) using a phased-array body coil or head and neck coil. DWI was performed in the axial plane using a short TI inversion recovery-EPI (STIR-EPI) sequence with the following parameters: repetition time/echo time/inversion time of 5000-10000/70/180 ms, slice thickness/gap of 5/1 mm, field of view was attached to the area of targets ($450 \times 450 - 350 \times 350$ mm²), acquisition matrix of 128×81 , motion probing gradients in three orthogonal axes, b -values of 0 and 1000 s/mm², number of signal averages of 7, and image acquisition under free breathing condition. Axial trace ADC maps were created from signals obtained from images with two b -values (0 and 1000 s/mm²).

Image analysis

An abscess may have two components: pus and exudative fluid. We hypothesized that whole pus exhibits high signal intensity at $b = 1000$ s/mm² (Fig. 2) and low-viscosity pus or exudative fluid shows high signal intensity at $b = 0$ s/mm² (Fig. 3). Therefore, we analyzed both areas. Two radiologists with more than 15 years of experience, who were blinded to the CRP levels and other clinical information, used a workstation (Ziostation, Ziosoft, Tokyo, Japan) to conduct volumetric segmentation on DWI at $b = 1000$ s/mm² and $b = 0$ s/mm² of abscess. We also examined the inter-observer correlation between both readers, using a Spearman's rank correlation coefficient. The level of agreement by Rho (ρ) values was categorized as follows: 0-0.20, little or no correlation; 0.21-0.40, moderate correlation; 0.41-0.70, good correlation; and 0.71-1.0, very good or excellent correlation. Edematous and fluid-rich tissues around an abscess were distinguished from the true abscess cavity using T2 weighted image (T2WI) or gadolinium-enhanced T1 weighted image (T1WI) for delineation of the abscess (Fig. 1a, b). The axial image that showed the largest area was selected for the ROI measurement at $b = 1000$ s/mm² and $b = 0$ s/mm² (Fig. 2a, Fig. 3a), respectively. Furthermore, images that showed the entire high-intensity area at $b = 1000$ s/mm² and $b = 0$ s/mm² was selected for the VOI measurement (Fig. 2b, Fig. 3b).

Then, the mean ADC value of VOIs at $b = 1000$ and $b = 0$ s/mm² were calculated. Subsequently, the mean ADC value of the ROI at the $b = 1000$ and $b = 0$ s/mm² delineations were calculated as well (Fig. 2c, Fig. 3c). An ADC histogram analysis was then conducted by means of hand-made software. Representative examples of this procedure are shown in Fig. 2d and 3d.

The definitions of kurtosis and skewness are as follows:

$$\text{Kurtosis} = \frac{\sum (X_i - \mu)^4}{N\sigma^4}$$

$$\text{Skewness} = \frac{\sum (X_i - \mu)^3}{N\sigma^3}$$

where X_i is the element value, μ is the average, σ is the standard deviation, and N is the number.

Then, the percentage of the total amount of voxels was measured for each ADC.

CRP level

Plasma CRP concentration was measured in a latex particle-enhanced turbidimetric immunoassay with an autochemistry analyzer (type 7600 or 7700, Hitachi, Japan) using the Eiken LZ test (Tokyo, Japan). The lower limit of detection for plasma CRP was 0.09 mg/dL, and the reference range was less than 0.30 mg/dL.

Statistical analysis

Statistical analyses were executed using MedCalc Software (MedCalc, Mariakerke, Belgium).

- 1) The associations between the mean ADC value in the selected ROI (at $b = 0$ and $b = 1000$ s/mm²) and CRP level were assessed using Pearson's correlation coefficient (R).
- 2) Associations between the mean ADC values of the

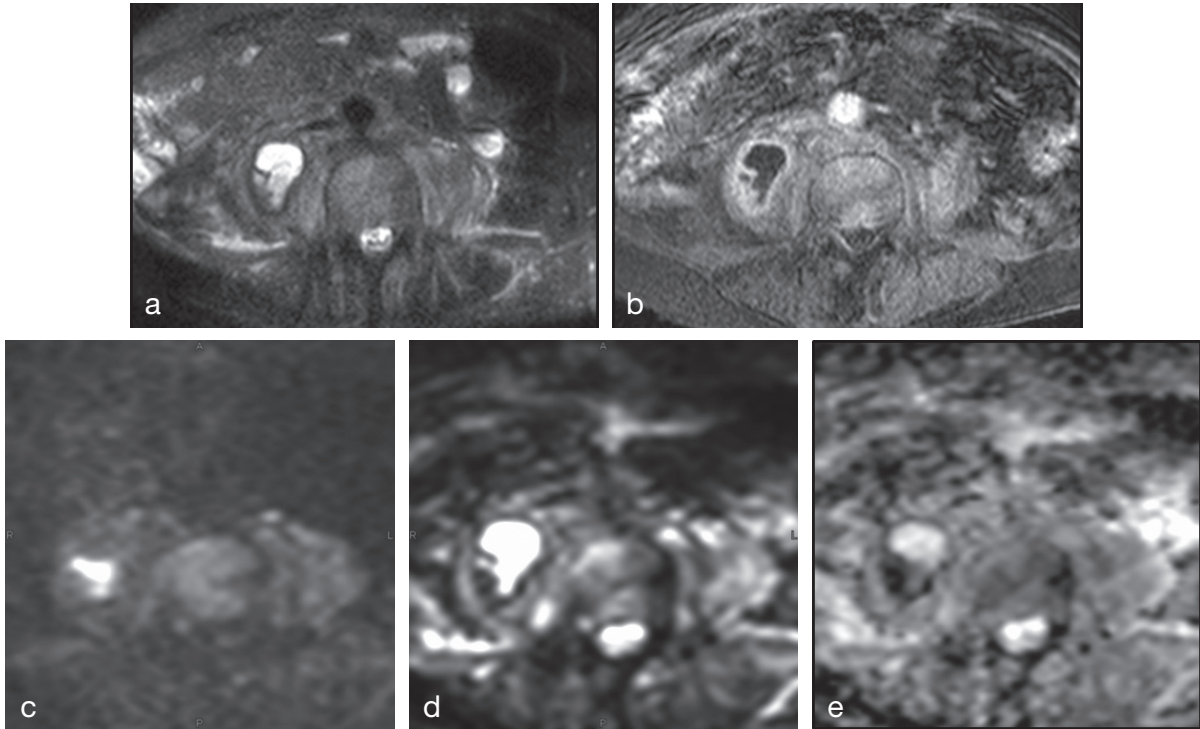


Fig. 1 A 78-year-old man with an abscess in the right psoas major with an active inflammatory process (CRP level of 13.8 mg/dL)
 a) T2-wighted fat-saturated image shows a high intensity area in the right psoas major with a capsule and bulkhead structure.
 b) T1-wighted fat-saturated image with gadolinium enhancement shows enhancement of the capsule and bulkhead structure.
 c) DWI ($b = 1000 \text{ s/mm}^2$ image) shows high intensity in the posterior portion of the inside of the abscess. Moreover, the largest high intensity area was measured to calculate the ROI.
 d) DWI ($b = 0 \text{ s/mm}^2$ image) shows high intensity inside the whole abscess.
 e) ADC map shows low intensity in the in the posterior portion of the inside of the abscess and in the capsule and bulkhead structure.

selected VOI (at $b = 0$ and $b = 1000 \text{ s/mm}^2$) and CRP level were assessed using Pearson's correlation coefficient (R).

- 3) ADC histogram analysis It was hypothesized that active abscesses (i.e., those associated with higher CRP levels) would contain more exudative fluid than less active abscesses (i.e., those with lower corresponding CRP levels); as a result, the former would contain more voxels in the higher ADC regime. Since no *a priori* threshold exists for defining which voxels belong to the "low" ADC regime and which voxels belong to the "high" ADC regime, multiple ADC thresholds ranging from 0.5 to $2.0 \times 10^{-3} \text{ mm}^2/\text{s}$ at steps of $0.1 \times 10^{-3} \text{ mm}^2/\text{s}$ were explored to separate the two groups. The percentage of voxels in the "high" ADC regime (%ADC) was measured for each of these thresholds separately at $b = 0$ and $b = 1000 \text{ s/mm}^2$. The correlation between the percentage of voxels in the "high" ADC regime (for the different thresholds described earlier) and CRP level was assessed using Pearson's correlation coefficient (R). The correlation between kurtosis/skewness and CRP level were also assessed using Pearson's correlation coefficient (R).

P -values < 0.05 were considered statistically significant. Pearson's R values ranging from 0–0.19, 0.2–0.39, 0.40–0.59, 0.6–0.79, and 0.8–1 were considered to indicate very weak, weak, moderate, strong, and very strong correlations, respectively.

RESULTS

The inter-observer correlation for the ADC values was very good ($\rho = 0.83$; $P < 0.001$). CRP levels were measured within ± 1 day of the MRI examination and ranged between 0.28 and 25.40 mg/dL (mean CRP, $8.46 \pm 7.35 \text{ mg/dL}$). Antimicrobial therapy or abscess drainage improved all abscesses based on a radiological diagnosis. Eight abscesses were drained after the MRI examination, and the culture results were after drainage were, 1; *Enterobacter cloacae*, 2; *Enterococcus faecalis*, 3; *Klebsiella pneumoniae*, 1; *Escherichia coli*, 1; *Alpha haemolytic streptococcus*, 2; *Staphylococcus aureus*, 2; *Staphylococcus epidermidis*, 1; *Peptostreptococcus*, 1 (some have overlap). One patient had a positive blood culture (*Klebsiella pneumoniae*), 13 had negative blood cultures and no cultivation test was carried out for 6 patients. None of the cases involved surgery. The overall results including the measurement types with any R are shown in Tables 1 and 2, including the R measurements. For the two types of b -values, stronger correlations were observed at b -values of 0 s/mm^2 than with b -values of 1000 s/mm^2 . Among the three types of datasets (i.e., ROI, VOI, and ADC histogram) at b -value of 0 s/mm^2 , the strongest correlation was observed for the mean ADC value in VOI analysis (Pearson's $R = 0.78$, $P < 0.01$), followed by the mean ADC value in ROI analysis (Pearson's $R = 0.77$, $P < 0.01$), and %ADC for ADC threshold of $1.8 \times 10^{-3} \text{ mm}^2/\text{s}$ (Pearson's R

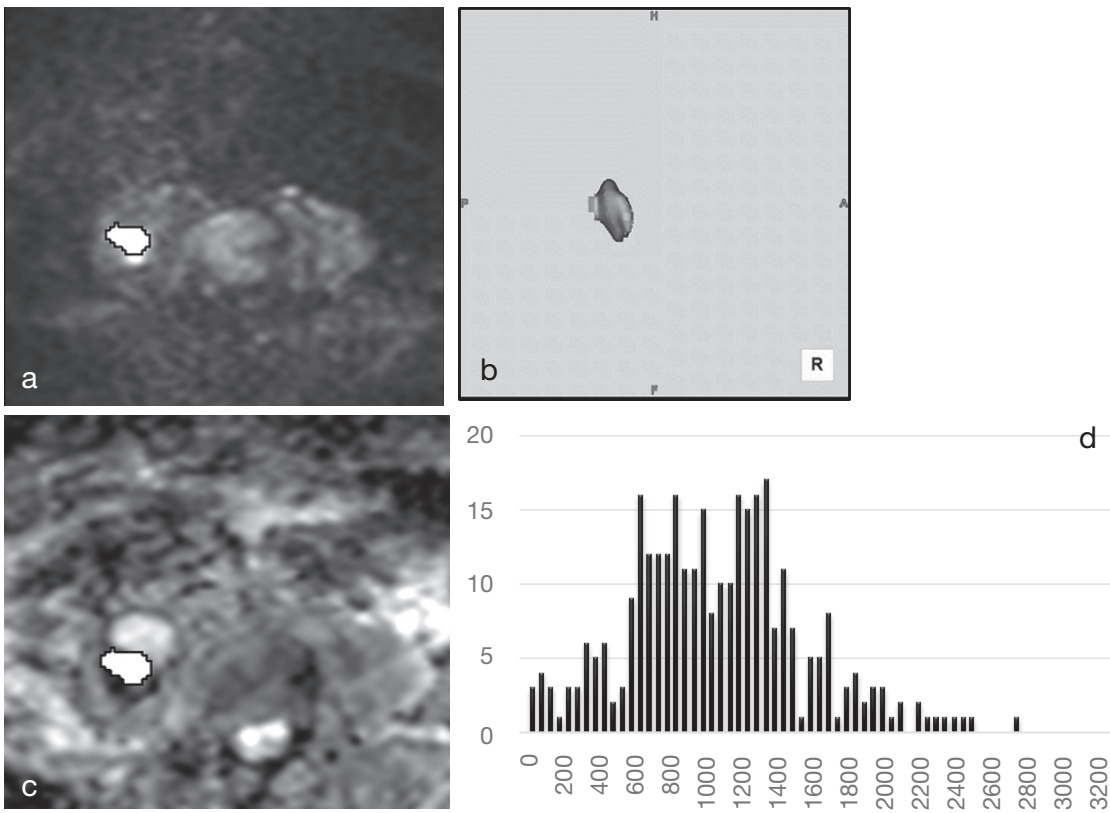


Fig. 2 Calculation of the $b = 1000 \text{ s/mm}^2$ image
 a) DWI ($b = 1000 \text{ s/mm}^2$ image) through the largest area of the lesion is used for the ROI measurement.
 b) The segmented VOI on $b = 1000 \text{ s/mm}^2$ image is shown.
 c) ADC map with high intensity area on $b = 1000 \text{ s/mm}^2$ image is shown.
 d) Histogram with high intensity area from $b = 1000 \text{ s/mm}^2$ image.

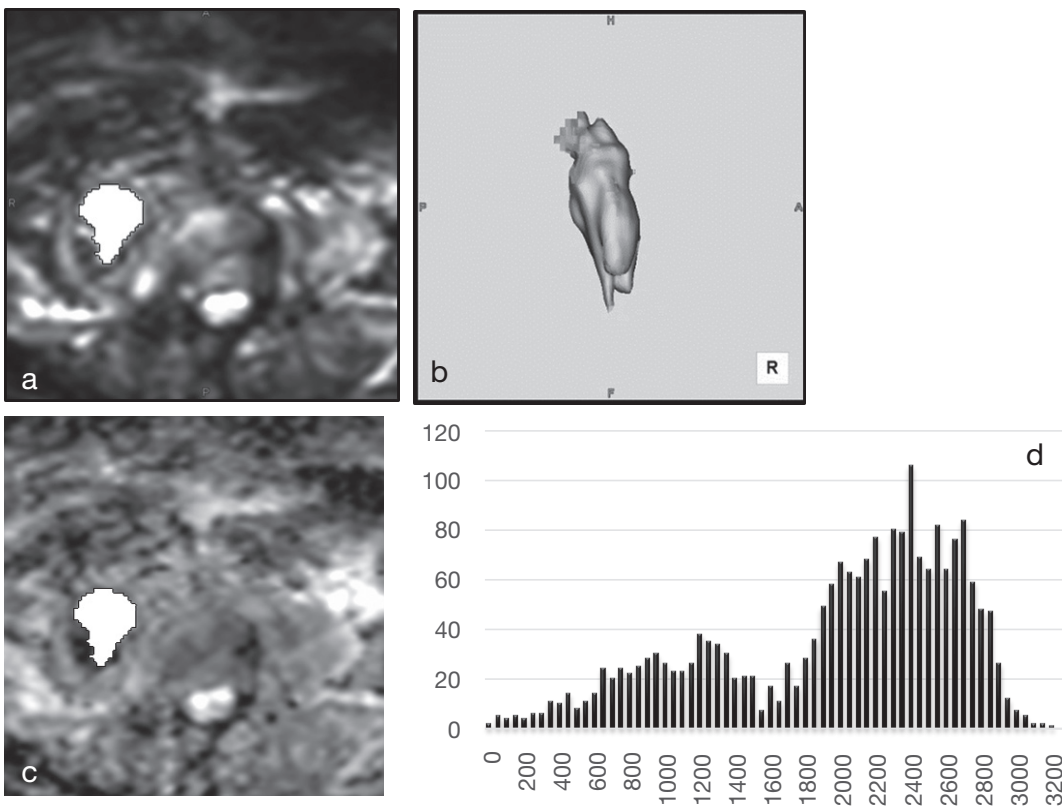


Fig. 3 Calculation of the $b = 0 \text{ s/mm}^2$ image
 a) DWI ($b = 0 \text{ s/mm}^2$ image) through the largest area of the lesion is used for the ROI measurement.
 b) The segmented VOI on $b = 0 \text{ s/mm}^2$ image.
 c) ADC map with high intensity area on $b = 0 \text{ s/mm}^2$ image is shown.
 d) Histogram with high intensity area from $b = 0 \text{ s/mm}^2$ image.

Table 1 The results of Pearson's R for the correlation between the measurements and CRP level on $b = 0$ s/mm² image

$b = 0$ s/mm ²	ROI (area)	ROI mean ADC	VOI (volume)	VOI mean ADC	%ADC	Skewness	Kurtosis
Pearson's R	0.586	0.771	0.535	0.782	0.705	0.557	-0.599
P	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.017	< 0.01

Table 2 The results of Pearson's R for the correlation between the measurements and CRP level on $b = 1000$ s/mm² image

$b = 1000$ s/mm ²	ROI (area)	ROI mean ADC	VOI (volume)	VOI mean ADC	%ADC	Skewness	Kurtosis
Pearson's R	0.422	0.428	0.324	0.665	0.582	-0.183	-0.04
P	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.96	0.37

= 0.71, $P < 0.01$). The ROI areas at b -values of 0 s/mm² showed a moderate correlation with CRP levels (Pearson's $R = 0.59$, $P < 0.01$), and at 1000 s/mm² showed moderate correlation (Pearson's $R = 0.42$, $P < 0.01$); the volumes of the VOI at b -values of 0 s/mm² showed moderate correlation with CRP levels as well (Pearson's $R = 0.54$), and at 1000 s/mm² showed weak correlation (Pearson's $R = 0.32$, $P < 0.01$). Regarding the ADC histogram analysis, a higher correlation with CRP level was observed at ADC threshold of 1.8×10^{-3} mm²/s (Pearson's $R = 0.71$, $P < 0.01$) at b -value of 0 s/mm² than with 1.2×10^{-3} mm²/s (Pearson's $R = 0.58$, $P < 0.01$) at b -value of 1000 s/mm².

There was moderate or no significant correlation between skewness and CRP level at $b = 0$ or $b = 1000$ s/mm² (Pearson's $R = 0.56$, $P = 0.02$ and $R = -0.18$, $P = 0.96$, respectively), or between kurtosis and CRP level at $b = 1000$ s/mm² (Pearson's $R = -0.04$, $P = 0.37$). There was a strong negative correlation between kurtosis and CRP level at $b = 0$ s/mm² (Pearson's $R = -0.60$, $P < 0.01$).

DISCUSSION

Diffusion is sensitive to the random Brownian motion of water molecules, which is thought to depend mainly on limitations from interactions with cell membranes and macromolecules in biological tissues [6, 7, 12, 13]. Therefore, malignant lesions frequently show high intensity on DWI because of their relatively high cellular density and lower level of extracellular space. On the other hand, abscesses also show high intensity on DWI, but due to a different mechanism. Abscesses consist of inflammatory cells, a matrix of proteins, cellular debris, and bacteria in high-viscosity pus, which results in low ADC values [6–8, 14].

Cartes-Zumelzu *et al.* [13] reported that brain abscess cavities demonstrated high signal intensity on DWI, and after treatment with antimicrobials or surgical drainage, the abscesses had low signal intensity on high b -value DWI with high ADC value. Yoshizako *et al.* [7] reported that active perianal fistulas had lower ADC values than inactive perianal fistulas, although there was a considerable overlap in ADC values between the two groups. Oto A *et al.* reported that an

abdominopelvic abscess demonstrated high signal on DWI, and the ADC value at 2.0×10^{-3} mm²/s was the optimal threshold to differentiate between an abscess and non-infected ascites [5].

In this report, abscess cavities showed high signal on DWI as well ($b = 1000$ s/mm²). The mean ADC value in ROI and VOI of the high-intensity area on images at b -value of 0 s/mm² were positively correlated with CRP levels. However, several abscess cavities had areas that only showed high signal at $b = 0$ s/mm²; hence, examining both areas should be considered to evaluate the whole abscess cavity. Furthermore, before the start of this study, we speculated that we should consider the VOI analysis as a better approach rather than a simple ROI analysis.

A strong correlation between the mean ADC value and CRP level was not produced by the ROI/VOI delineation at b -value of 1000 s/mm². Unexpectedly, strong correlations were observed for the ROI/VOI delineation at b -value of 0 s/mm². Regarding the three datasets (ROI, VOI, and ADC histogram), the strongest correlation was observed for the mean ADC value in the VOI (Pearson's $R = 0.78$, $P < 0.01$), followed by the mean ADC value in ROI (Pearson's $R = 0.77$, $P < 0.01$), and %ADC for ADC threshold of 1.8×10^{-3} mm²/s (Pearson's $R = 0.71$, $P < 0.01$). Because there was only small difference and the ROI analysis is simpler than the VOI analysis, the ROI analysis may be the most practical approach for this purpose. Our results seem to contradict previous studies that showed a tendency for active inflammatory process to have low ADC values [5, 7, 13] because our mean ADC data were positively correlated with the CRP level. One possible explanation is that previous studies made comparisons between "non-active" and "active" inflammatory groups. Another explanation is that the areas were extracted from $b = 0$ s/mm² images. One explanation is that active abscesses contain more exudative fluid than less active abscesses, and as a result, the former would have a larger high signal area on $b = 0$ s/mm² images, which would lead to high ADC value. To our knowledge, this is the first study that has showed the importance of performing an ADC measurement based on the ROI/VOI delineation on $b = 0$ s/mm²

image to evaluate the inflammatory activity of a body abscess cavity.

Regarding the ADC histogram analysis, the highest correlation was seen at an ADC threshold of 1.8×10^{-3} mm²/s (Pearson's $R = 0.71$, $P < 0.01$) at b-value of 0 s/mm², and at 1.2×10^{-3} mm²/s (Pearson's $R = 0.58$, $P < 0.01$) at b-value of 1000 s/mm². However, there was no additional advantage in performing a more complicated histogram analysis over calculating the mean ADC value for the assessment of inflammatory activity.

Histogram analysis was reported to be helpful for the determination of the efficiency of chemotherapy in malignant tumors [16, 17], although the skewness and kurtosis did not show stronger correlations with the CRP level than the mean ADC value in the ROI/VOI. Therefore, we may omit a histogram analysis to evaluate the inflammatory activity of abscesses.

Our study has several limitations. The major limitation is that our analysis was a retrospective, single-institution study. Therefore, a referral bias could exist. Second, our sample size was small, and among the 23 patients, 18 patients had previously received antimicrobials either orally or intravenously because of their highly febrile state, while the other patients did not receive medical treatment. This difference may have influenced the results, especially with regard to the amount of exudative fluid and low-viscosity pus present. However, in our study, found no significant difference in all of the data sets between medicated and non-medicated patients (including the mean ADC value for the ROI/VOI at $b = 0$ s/mm²) that were assessed using an unpaired t-test. In daily clinical practice, the majority of patients undergoing the MRI examination for scrutiny of the abscess have previously received some medication (e.g., antimicrobial or anti-inflammatory agents) at the first contact with a doctor who make a diagnosis of some sort of infectious disease based on the symptoms and laboratory examinations (blood screening, ultrasonography, or a CT scan). All for these reasons, it may be practical to investigate patients with and without a history of medical treatment. Third, the affected region and causative organism of these abscesses varied. However, Henning *et al.* [18] reported that the mean ADC value of abscess for several organs (i.e., muscle, liver, spleen, and kidney) showed little difference, with the exception of a tuberculous soft tissue abscess. Fourth, the sequence that we used is a popular single-shot spin-echo EPI sequence, which inherently suffers from the effects of distortion. This distortion may cause inaccurate values for ADC calculations because of differences in distortion between $b = 0$ and $b = 1000$ mm²/s images.

CONCLUSION

The mean ADC value in the ROI or VOI encompassing an abscess at b-value of 0 s/mm² was positively correlated with the CRP level. Overall our results suggest that because of its simplicity, the ROI measurement may be the best way to assess the associated inflammatory activity of an abscess in daily practice.

ACKNOWLEDGEMENTS

The authors thank Mr. Takayuki Saso for his technical assistance.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

- 1) Weledji EP, Ngowe MN. The challenge of intra-abdominal sepsis. *Int J Surg*. 2013; 11: 290-5.
- 2) Lardièrè-Deguelte S, Ragot E, Amroun K, Piardi T, Dokmak S, Bruno O, *et al.* Hepatic abscess: Diagnosis and management. *J Visc Surg*. 2015; 152: 231-43.
- 3) Mizushima T, Yoshida H, Ohi Y, Ishikawa M, Hirahara F. Evaluating the risk factors for developing resistance to parenteral therapy for tubo-ovarian abscess: a case-control study. *J Obstet Gynaecol Res*. 2013; 39: 1019-23.
- 4) Demirtas O, Akman L, Demirtas GS, Hursitoglu BS, Yilmaz H. The role of the serum inflammatory markers for predicting the tubo-ovarian abscess in acute pelvic inflammatory disease: a single-center 5-year experience. *Arch Gynecol Obstet*. 2013; 287: 519-23.
- 5) Oto A, Schmid-Tannwald C, Agrawal G, Kayhan A, Lakadamyali H, Orrin S, *et al.* Diffusion-weighted MR imaging of abdominopelvic abscesses. *Emerg Radiol*. 2011; 18: 515-24.
- 6) Morani AC, Elsayes KM, Liu PS, Weadock WJ, Szklaruk J, Dillman JR, *et al.* Abdominal applications of diffusion-weighted magnetic resonance imaging: Where do we stand. *World J Radiol*. 2013; 5: 68-80.
- 7) Yoshizako T, Wada A, Takahara T, Kwee TC, Nakamura M, Uchida K, *et al.* Diffusion-weighted MRI for evaluating perianal fistula activity: feasibility study. *Eur J Radiol*. 2012; 81: 2049-53.
- 8) Kwee TC, Takahara T, Ochiai R, Nievelstein RA, Luijten PR. Diffusion-weighted whole-body imaging with background body signal suppression (DWIBS): features and potential applications in oncology. *Eur Radiol*. 2008; 18: 1937-52.
- 9) Kyriazi S, Collins DJ, Messiou C, Pennert K, Davidson RL, Giles SL, *et al.* Metastatic ovarian and primary peritoneal cancer: assessing chemotherapy response with diffusion-weighted MR imaging--value of histogram analysis of apparent diffusion coefficients. *Radiology*. 2011; 261: 182-92.
- 10) Chou CP, Chiou SH, Levenson RB, Huang JS, Yang TL, Yu CC, *et al.* Differentiation between pelvic abscesses and pelvic tumors with diffusion-weighted MR imaging: a preliminary study. *Clin Imaging*. 2012; 36: 532-8.
- 11) Nadal Desbarats L, Herlidou S, de Marco G, Gondry-Jouet C, Le Gars D, Deramond H, *et al.* Differential MRI diagnosis between brain abscesses and necrotic or cystic brain tumors using the apparent diffusion coefficient and normalized diffusion-weighted images. *Magn Reson Imaging*. 2003; 21: 645-50.
- 12) Le Bihan D. Molecular diffusion nuclear magnetic resonance imaging. *Magn Reson Q*. 1991; 7: 1-30.
- 13) Koç O, Paksoy Y, Erayman I, Kivrak AS, Arbag H. Role of diffusion weighted MR in the discrimination diagnosis of the cystic and/or necrotic head and neck lesions. *Eur J Radiol*. 2007; 62: 205-13.
- 14) Park HJ, Kim SH, Jang KM, Lee SJ, Park MJ, Choi D. Differentiating hepatic abscess from malignant mimickers: Value of diffusion-weighted imaging with an emphasis on the periphery of the lesion. *J Magn Reson Imaging*. 2013; 38: 1333-41.
- 15) Cartes-Zumelzu FW, Stavrou I, Castillo M, Eisenhuber E, Knosp E, Thurnher MM. Diffusion-weighted imaging in the assessment of brain abscesses therapy. *Am J Neuroradiol*. 2004; 25: 1310-7.
- 16) Downey K, Riches SF, Morgan VA, Giles SL, Attygalle AD, Ind TE, *et al.* Relationship between imaging biomarkers of stage I cervical cancer and poor-prognosis histologic features: quantitative histogram analysis of diffusion-weighted MR images. *Am J Roentgenol*. 2013; 200: 314-20.
- 17) Pope WB, Kim HJ, Huo J, Alger J, Brown MS, Gjertson D, *et al.* Recurrent glioblastoma multiforme: ADC histogram analysis predicts response to bevacizumab treatment. *Radiology*. 2009; 252: 182-9.
- 18) Neubauer H, Platzer I, Mueller VR, Meyer T, Liese J, Koestler H, *et al.* Diffusion-weighted MRI of abscess formations in children and young adults. *World J Pediatr*. 2012; 8: 229-34.