Application of Ultrasound in Diagnosis of Prosthesis Loosening and Infection After Total Hip Arthroplasty

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Research Article

Keywords: Infection, Aseptic loosening, Ultrasound, Hip arthroplasty

Posted Date: February 23rd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-222251/v1

Abstract

Objective: To explore the diagnostic efficiency of ultrasound for the identification of periprosthetic joint infection (PJI) and aspetic loosening.

Methods: 50 patients with joint pain after total hip arthroplasty, who were all clinically diagnosed as aseptic prosthesis loosening or PJI, were examined by ultrasonography combined with C-reactive protein, erythrocyte sedimentation rate, bacterial culture and pathology.

Results: Thirty-eight of the 50 cases were PJI (group A) , and twelve cases were aseptic loosening (group B) . Fourteen patients with extra-capsular effusion were diagnosed as PJI, while none appeared extra-capsular effusion effusion in group B. 34 cases PJI obtained joint fluid, which was more than group B (7/11) ($P < 0.05$). The average depth of joint effusion of group B (19.83 ± 8.9mm), was significantly less than group A (25.97±15.25mm) ($P < 0.05$). In group A , 21 cases (55.26%) had grade 2-3 synovial blood flow signal,which was higher than group B (8.3%) ($P < 0.05$). Under the circumstance that PJI was diagnosed: (1) There was a sinus tract or extra-capsular effusion; or (2) Joint fluid depth was ≥ 17.0 mm; or (3) Grade 2-3 synovial blood flow signal was detected,the positive predictive value of ultrasound diagnosis of PJI was 92.1% (35/38)，and the accuracy of aseptic loosening was 83.3% (10/12) ($P < 0.05$).

Conclusions: Ultrasound has significant value in the differential diagnosis of PJI and aspetic loosening.

Background

Aseptic loosening and periprosthetic joint infection (PJI) are the most common complications after joint replacement. It is very difficult to identify infection and loosening ,for they are very similar both histologically and clinically, but the differences in management and prognosis between the two are so significant that it is such important to distinguish PJI from aseptic loosening [1, 2]. Current studies have found that no serological examination has sufficient sensitivity and specificity for the identification of the two [1]. Arthrocentesis and intraoperative sample removal are the main methods for the identification, both of which are traumatic ,and strict with the requirements for surgical conditions and sampling, while the false negative and false positive rates are still high [3–6].How to diagnose PJI and aseptic loosening preoperation accurately is particularly important. Other cross-sectional imaging diagnostic procedures (CT, MRI) are associated with artefacts caused by metal implants[7–9].The existing research data related to radiological diagnostic procedures such as PET and 99mTc bone scintigraphy are so inconsistent, that the value of nuclear medicine examination is still unclear [10, 11]. Ultrasonography has been observed to distinguish intra-articular effusion, synovium and pericortical lesions, while power doppler can be used for detecting the blood flow in synovium sensitively,that is easy to operate, and has the advantages of real-time dynamic and non-invasive. At present, there are few studies that report the role of ultrasonography identifing of PJI and aseptic loosening. Accordingly, the purpose of this study was to determine the efficacy of sonography in detecting infection in patients with loosened hip prostheses.

Materials And Methods

Research objects: Fifty patients who had total hip arthroplasty were clinically diagnosed as aseptic prosthesis loosening or PJI from 2017.1 to 2020.10. Thirty-eight of the 50 cases were PJI, and twelve cases were aseptic loosening. The time of postoperative pain was from 3 months to 11 years.

Laboratory diagnostics: Serum C-reactive protein and erythrocyte sedimentation rate were measured in all patients within one week before ultrasonography. Conventional culture of joint fluid or periprosthetic tissues were performed after ultrasonography.

Ultrasonography: GE logic E9 with a curved linear-array 2.8-5 MHz transducer and a linear-array 8–11 MHz transducer was used throughout the study. The studies were performed by one sonographer.According to the guidelines of European Society of Musculoskeletal Radiology. Musculoskeletal Ultrasound Technical Guidelines IV. Hip[12], All ultrasound examinations were done using a systematic approach to assess the anterior, medial, lateral and posterior hip regions. The acoustic window in and around the articular cavity were detected by gray-scale ultrasound, the depth of effusion was measured,and the blood flow of synovium was observed by power Doppler. It had been suggested that adistance between the anterior hip joint capsule and the femur of more than 10 mm was indicative of a hip effusion[13]. According to the semi-quantitative scoring standard proposed by szkudlarek in 2003, the synovial blood flow signals were divided into 0–3 grades. In accordance with Douis H,Dunlop DJ, synovial tissue was identified when blood flow signal appeared, while it was not easy to distinguish joint fluid and synoviam by gray-scale ultrasound [14]Fig. 1 was the schematic drawing of a normal anterior longitudinal sonographic appearance of a hip prostehsis.

Clinical diagnostics: The diagnosis of periprosthetic infection refered to the diagnostic criteria established by the American Musculoskeletal Infection Society (MSIS) [15]: (1) There was a sinus tract communicating with the prosthesis; or (2) A pathogen was isolated by culture from at least two separate tissue or fluid samples obtained from the affected prosthetic joint; or (3) Four of the following six criteria existed: (a) Elevated serum erythrocyte sedimentation rate (ESR) and serum C-reactive protein (CRP) concentration, (b) Elevated synovial leukocyte count, (c) Elevated synovial neutrophil percentage (PMN%), (d) Presence of purulence in the affected joint, (e) Isolation of a microorganism in one culture of periprosthetic tissue or fluid, or (f) Greater than five neutrophils per high-power field in five high-power fields observed from histologic analysis of periprosthetic tissue at 9400 magnification.

Aseptic loosening was directly confirmed by intraoperative findings: the surrounding tissues were normal, the synovial fluid was clear, the bacterial culture was negative, and there was no obvious neutrophil infiltration in the intraoperative and postoperative pathology.

Statistical analysis: Version 18.0 of the Statistical Package for the Social Sciences (SPSS, Chicago, IL, USA) were employed for the statistical analyses (mean, median, range, standard deviation, and significance of group differences). X^2 test was used to compare the data of gender, joint fluid, echo of effusion and synovial blood flow signal between the two groups, two independent samples t-test was

used to compare the age and depth of effusion. All tests were two-sided, and p values < 0.05 were considered significant. A receiver operating characteristic (ROC) curve analysis was employed to discriminatory accuracy of effusion depth on the basis of the area under the curve (AUC) and to determine the optimal cut-off to distinguish between PJI and aseptic loosening patients.

Results

1. The basic informations of the two groups is shown in Table 1.

Table 1
Basic information of the cases

		Aspetic loosening **n = 12**	**PJI** **n = 38**	**P value**
Sex (Male/female)		18/20	6/6	0.874
Age (years)		45.17 ± 15.42(28–63)	56.32 ± 11.05(31–76)	0.035
Extraarticular fluid		0	14	——
Intraarticular effusion	Yes	7	34	0.044[a]
	No	5	4	
Deep of Intraarticular effusion		19.83 ± 8.9mm(0-20mm)	25.97 ± 15.25mm(0-50.8mm)	0.000
Acoustic window	optimal	4	5	0.031[b]
	Poor	3	29	
Synovial blood flow signal	grade 0–1	11	17	0.012[a]
	grade 2–3	1	21	
a: Continuity correction; b: Fisher's exact test				

From Table 1, it can be seen that the ratios of male to female were both roughly 1 in the aseptic loosening group and PJI group, while the age of PJI group was older than that of the aseptic loosening group ($P < 0.05$). All the fourteen patients with extra-capsular effusion were diagnosed as PJI, then there was no extra-capsular effusion in the aseptic loosening group (Fig. 2). The depth of effusion in PJI group (Fig. 3) was greater than that of aseptic loosening group (P < 0.01), and 94.1% of the effusion in PJI group had poor acoustic window, which was more than that in the aseptic loosening group. Meanwhile, PJI group had more severe synovial thickening with abundant blood supply (Fig. 4) (P < 0.01).

2. The effect of fluid volume on the diagnosis of PJI.

From the above results, it was seen that joint effusion increased when the prosthesis was loose or infected, and it was more obvious when there had the presence of infection. ROC curve of fluid volume on the diagnosis of PJI was drawn(Fig. 5).It was highly significant for clinical practice to diagnose and treat PJI early, so the value with high sensitivity was selected as the cut-off to distinguish PJI from aseptic loosening under the condition of high enough specificity. When we appointed 17.0 mm as the cut-off, the sensitivity was 71.1%, and the specificity was 83.3%, in other words, it was more likely to be PJI when the effusion depth was not less than 17.0 mm.

3. The comprehensive diagnostic efficiency of ultrasound: In our study, all of the 14 cases that with extracapsular effusion or sinus were found by ultrasoundwere diagnosed as PJI,and the accuracy rate of ultrasound was 100%.In the aseptic loosening group, there were 2 cases of joint capsule effusion depth ≥ 17.0 mm, one of them had grade 2 synovial blood flow signal. In PJI patients without extracapsular effusion or sinus, there were 18 cases with joint effusion depth more than 17.0 mm and poor acoustic window, while 16 cases with hypertrophic synovium and grade 2–3 synovial blood flow signal, and 13 cases meeting with the two requirements.Under the circumstance that PJI was diagnosed when one of the above conditions was met,the positive predictive value of ultrasound diagnosis of PJI was 92.1% (35/38),and the accuracy of aseptic loosening was 83.3% (10/12).

Discussion

The main causes of prosthesis loosening are osteolytic prosthesis loosening caused by wear particles, infection, prosthesis placement error, traumatic mechanical loosening, bone structure decay of patients, etc. Aseptic loosening caused by biological debris reaction is the most common complication with long-term, slow and slight inflammation, while PJI is the most serious with severe inflammatory reactionsgenerally, which include inflammatory exudation, synovial reaction, pus formation and even joint capsule rupture. The inflammatory reaction of PJI is generally more obvious. In this study, ultrasonography could reveal all of PJI with extracapsular effusion or sinus, simultaneously PJI group had large amount of effusion, poor acoustic window, and hypertrophic synovium with rich blood flow signal. The area under ROC curve of effusion depth in the two groups was 0.82 (0.7–0.9), which could explain the reference value of effusion depth in the judgment of disease better. There were all PJI when the patients with effusion volume ≥ 25.5mm (sensitivity 53.5%, specificity 100%) or with extracapsular effusion or sinus. The positive predictive value of ultrasound in the diagnosis of PJI could be as high as 95% when 17.0 mm was carried as the cut-off value of fluid volume (sensitivity 71.1%, specificity 83.3%), combined with hypertrophic synovium with flow signal. The results of this study indicated that ultrasound played an important role in the differential diagnosis of PJI and aseptic loosening.

Guidelines recommend that white blood cell (WBC) count, C-reactive protein (CRP) level, and erythrocyte sedimentation rate (ESR) be determined as non-invasive methods, however, no laboratory test is sensitive or specific enough to confirm or rule out a periprosthetic joint infection definitively[15, 16]. Current studies [17, 18] have found that MRI is associated with artefacts caused by metal implants,although ultrasound and MRI both have enough high sensitivity and specificity for the soft tissue.Takashi Nishii MD and his

team[18] had showed that there were 9 cases of MRI found abnormity but US missed, 8 of 9 cases were located in the lateral area, while 11 cases of US picked up abnormal echography but MRI could not detect. Ultrasound and MRI had certain limitations for the specific area in metal-on-metal THA, however,MRI could not be used as a routine examination tool ,since MRI was more expensive, time-consuming, and there were many contraindications. The artifacts of prosthesis severely degrade the image quality and decrease the diagnostic value of CT, and dual-energy CT technique alone does not sufficiently remove the artifacts either[19, 20].Bone scintigraphy and FDG-PET are less specific, leukocyte scintigraphy has only moderate specificity，and the existing research data related to radiological diagnostic procedures such as PET and 99mTc bone scintigraphy are inconsistent, so further validation of the value of nuclear medicine examination is needed [21]. As a new diagnostic mode, SPECT/CT combines the sensitivity of bone imaging with the high specificity of CT [22, 23], but there is still limited literature on its efficacyand clinical validity. Ultrasound has the characteristics such as total reflection and attenuation, so the lesions with deep location and covered by bone or metal prosthesis are easy to be missed for the loss of sound beam. On the other hand, ultrasound can clearly show the situation of effusion, synovium and other soft tissues ,since it has enough high resolution and can be scanned dynamically from multiple angles. When necessary, different auxiliary skills or changing body position in real time can be used,and adjusting the energy output, frequency and other conditions timely according to the situation of different patient can improve the probability of finding abnormal signs. In the past, it was thought that infection and aseptic loosening were difficult to distinguish. Our research found that the accuracy of ultrasound was 100% for extra-articular capsule infection. Meanwhile, in the part of the situation that PJI containing large effusion (greater than 17mm) and obvious synovial hyperplasia, the detection rate of ultrasound was also high. Therefore, it could be cautiously optimistic that ultrasound could better distinguish the two.

In clinical work, ultrasound is not only used to routinely observe joint and prosthetic peripheral lesions, but also to guide joint aspiration. Many researchers such as Randelli F[24] had found that joint aspiration guided by ultrasound could provide direct vision when the articular fluid volume was relatively less in the early stage of inflammation. Sonicated fluid could significantly improve the positive rate of joint fluid culture where required. Some studies [25, 26] compared the capabilities of culture and broad-range polymerase chain reaction (PCR)using joint fluid (JF), periprosthetic tissue (PT), and sonicated fluid(SF) for the diagnosis of periprosthetic joint infection(PJI),the results showed that the specificity and sensitivity of sonicated fluid culture were not lower than other methods, and SF culture had theadvantage of detecting polymicrobial or fungal infections.

Our study had some limitations: In some cases the blood flow signals of the synoviam of obese patients were not easy to display, and it was difficult to distinguish synoviam from effusion because of the deep location of hip joint, which might affect the results; it was not suitable to classify hyperplastic synovium according to Szkudlarek semi standard for evaluation for the joint structure changing after operation; In addition, some studies had shown that aseptic loosening usually occured long after operation, but we were unable to further group on this aspect due to the limited number of cases in this study, which did not

affect the utility of ultrasonography. We need to strengthen the cooperation with clinical in the future and make further efforts to accumulate experience.

Abbreviations

PJI: periprosthetic joint infection; MSIS: Musculoskeletal Infection Society; JF: joint fluid; PT: periprosthetic tissue; SF: sonicated fluid.

Declarations

Acknowledgements

Not applicable

Authors’ contributions

WW and SC designed the report; LX, LH and WL collected the patient’s clinical data;YG collected the figure; WW and XH analyzed the clinical data and drafted the paper. All authors read and approved the final manuscript.

Funding

Fujian Medical University sailing Fund Project, 2018QH1086

Ethics approval and informed consent approved by the institutional medical ethics committee of The First Afilliated Hospital of Fujian Medical University, □2016□117

Fujian Medical University sailing Fund Project, 2019QH1111

Availability of data and materials

All data generated or analysed during this study are included in this published article [and its supplementary information files].

Ethics approval and consent to participate

The study was conducted in accordance with the principles of the Declaration of Helsinki, and approved by the institutional medical ethics committee of The First Afilliated Hospital of Fujian Medical University □2016□117. Written informed consent was obtained from each patient included in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no financial or other conflicts of interest.

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Figures

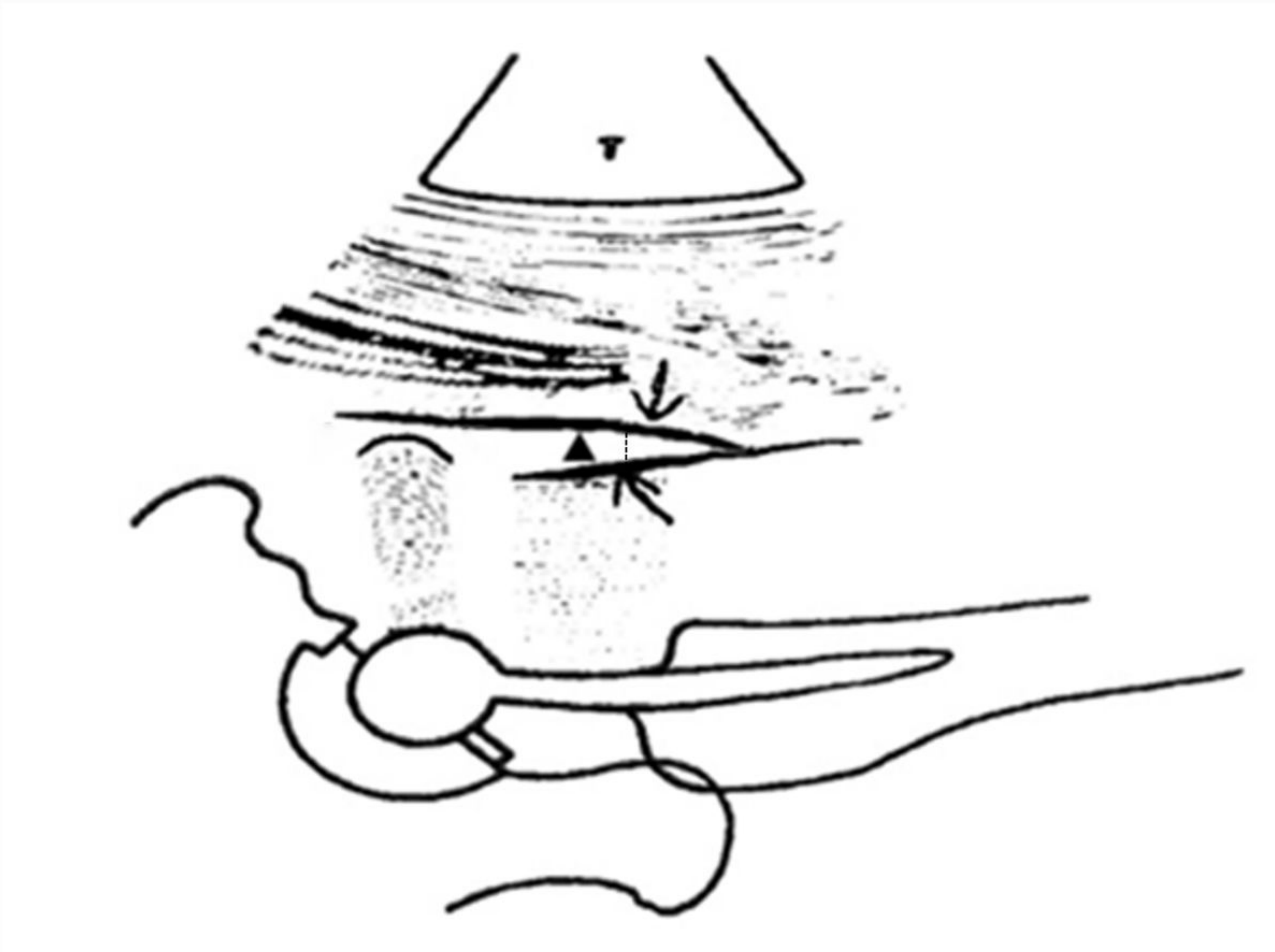

Figure 1

Schematic drawing : Normal anterior longitudinal sonographic appearance of a hip prostehsis. Curved linear-array transducer(T) was positioned over anterior part of thigh, joint cavity (triangle), joint effusion measurement (dotted line), pseudocapsule (arrow) had been marked.

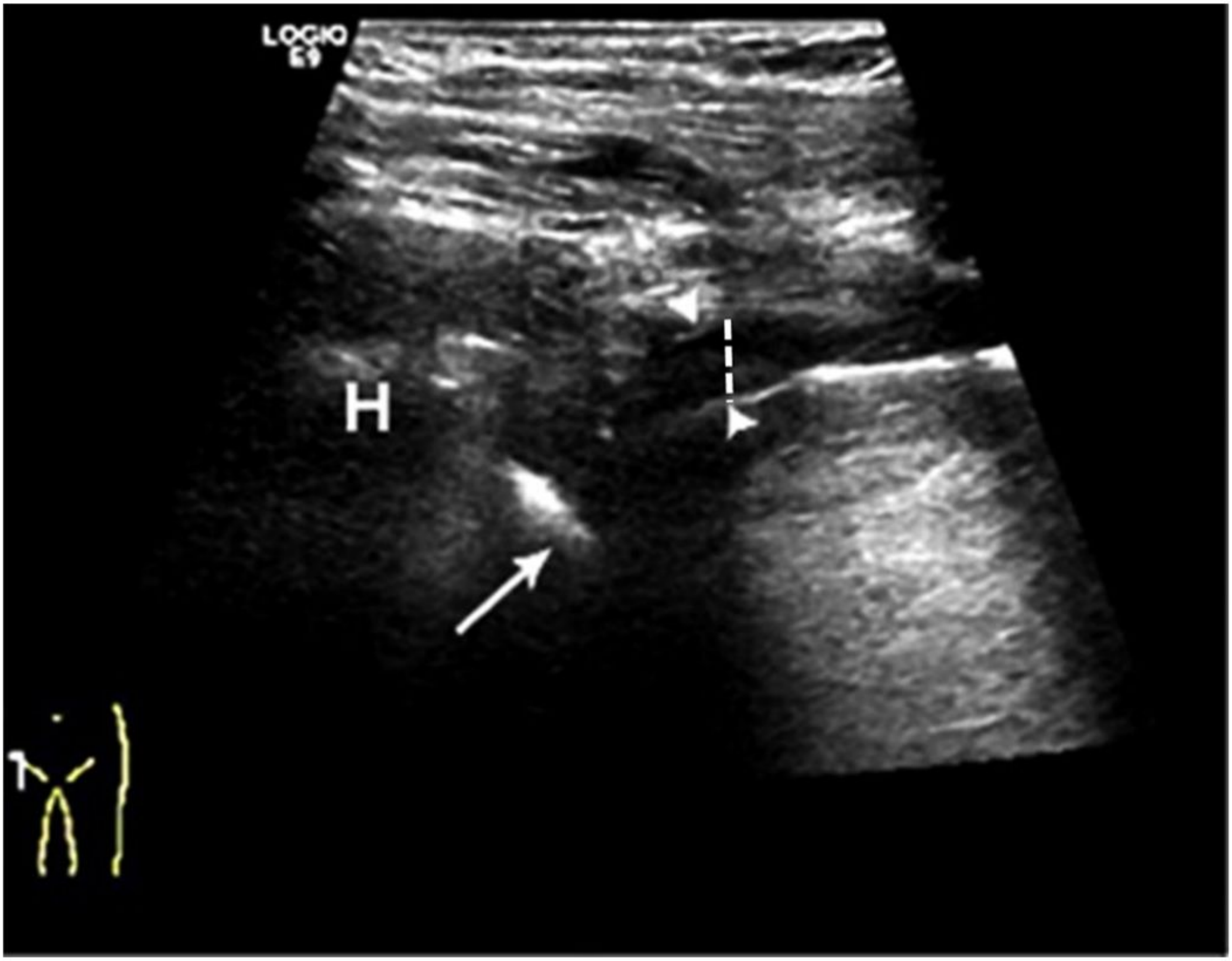

Figure 2

Aseptic loosening of the right hip prosthesis: Prosthetic femoral head（H）, Femoral neck (arrow), pseudocapsule(triangle) and a small amount of effusion in the joint had been marked，Pseudocapsule-to-bone distance(dotted-line) was measured.

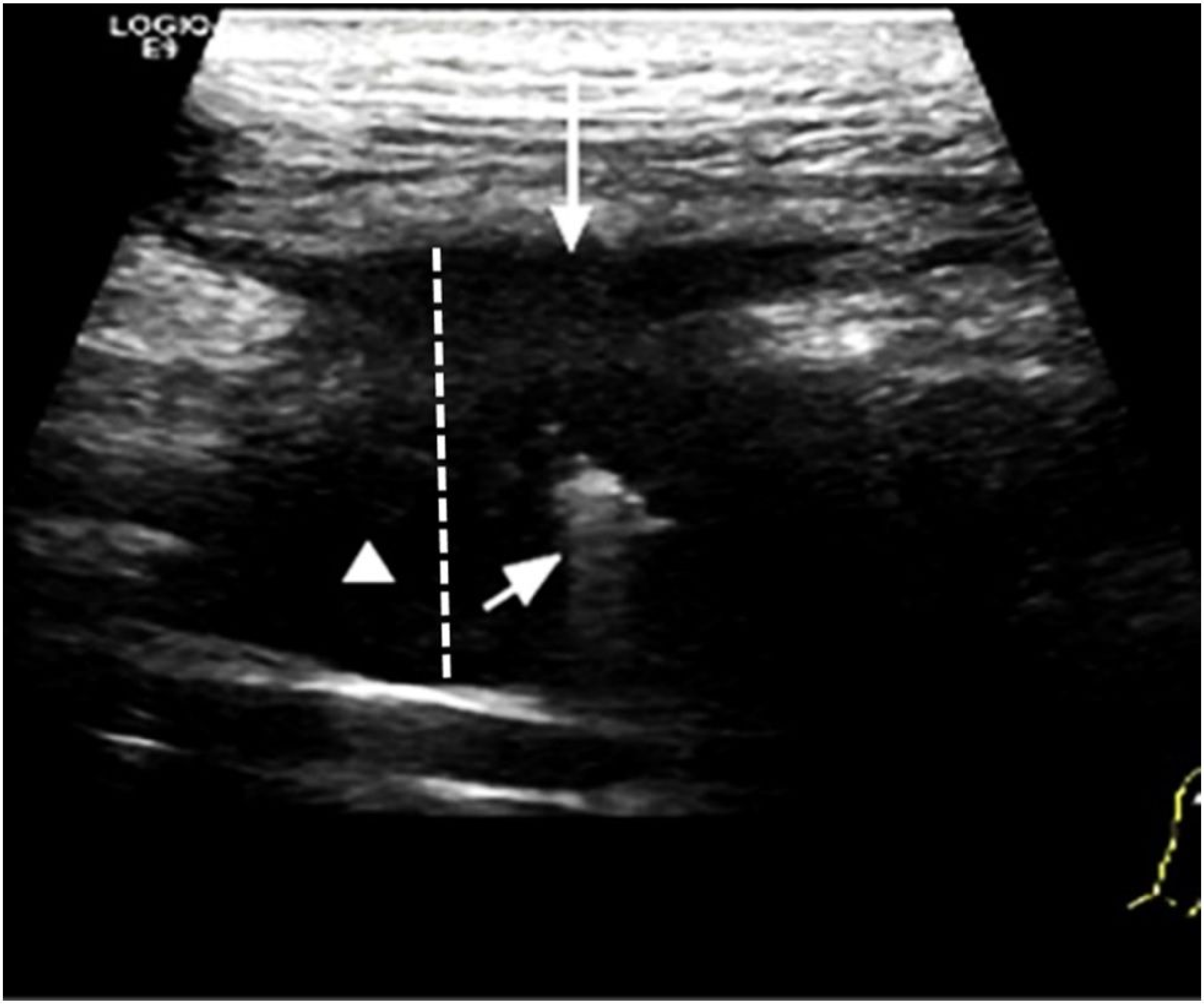

Figure 3

PJI after right hip prosthesis: Longitudinal image demonstrating echolessa fluid collection adjacent to the neck of the prosthesis consistent with an effusion(triangle)，needle，arrowhead，and anterior limit of the effusion (arrow) were illustrated. Pseudocapsule-to-bone distance(dotted-line) was measured.

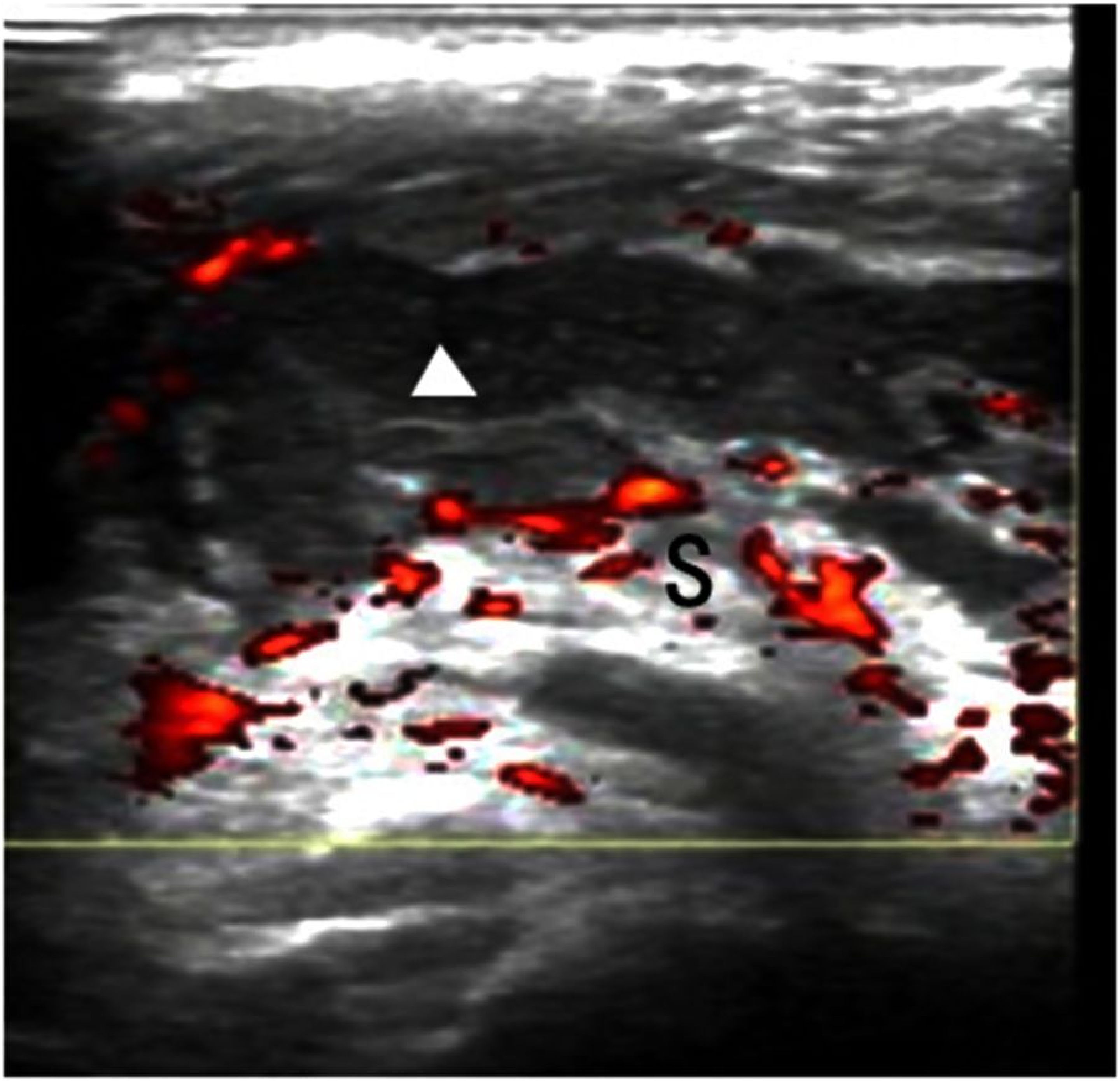

Figure 4

PJI after left hip prosthesis，joint effusion（triangle）and proliferative synovium with grade3 blood flow singnal（S）were indicated.

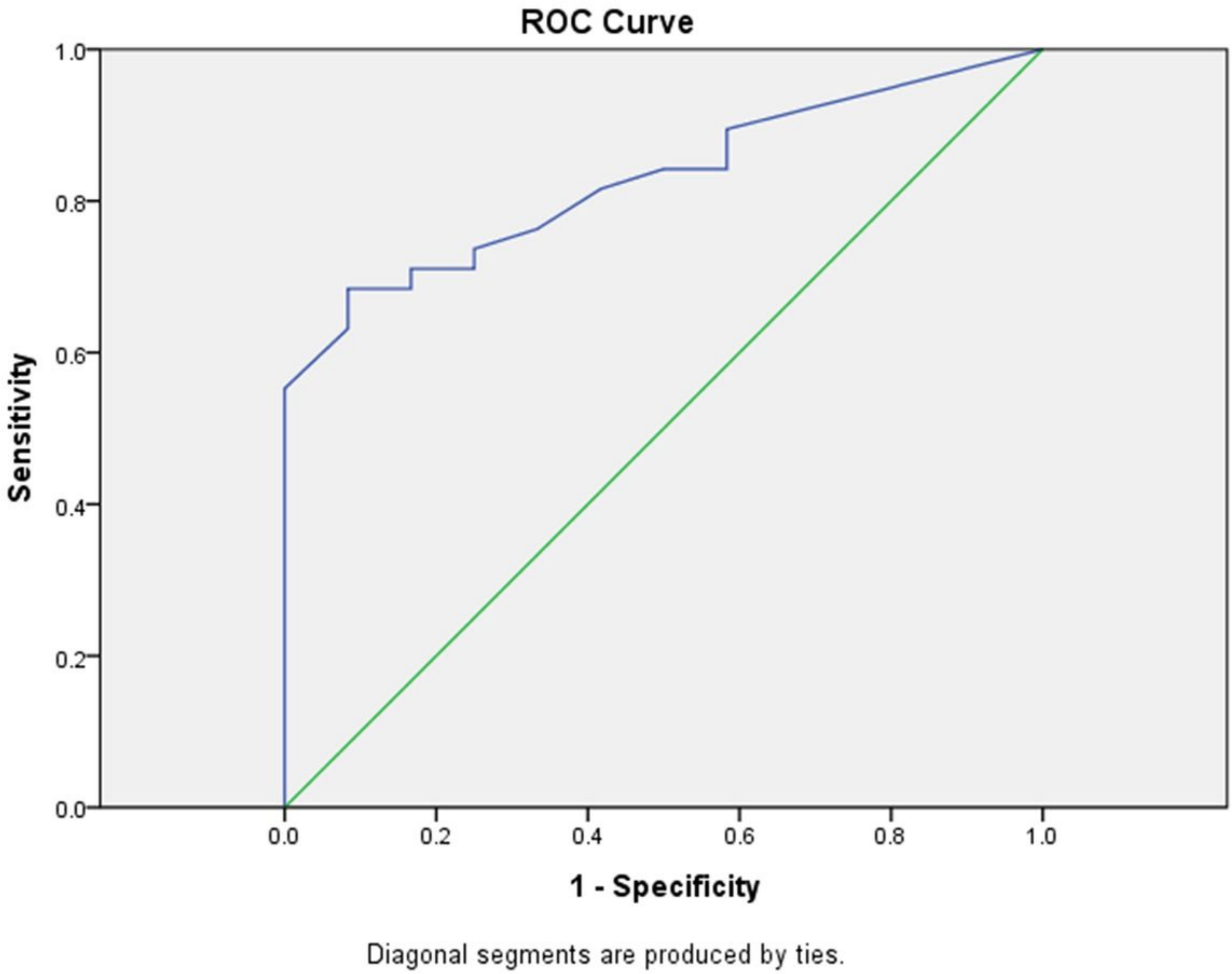

Figure 5

ROC curve of joint fluid volume The area under ROC curve was 0.828±0.057 (Sig.b0.001).