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Original article

BedBiopsy: Diagnostic performance of bedside ultrasound-guided bone biopsies for the management of diabetic foot infection

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ABSTRACT

Objective: We aimed to assess the feasibility and diagnostic performance of ultrasound-guided bone biopsies at the bedside of diabetic patients admitted for suspected foot osteitis not requiring surgery.
Research Design and Methods: In this retrospective monocentric study, we compared the performance of ultrasound-guided (n = 29 consecutive patients, Dec.2020-Oct.2022) versus surgical (n = 24 consecutive patients, Jan.2018-Nov.2020) bone biopsies at confirming or ruling out diabetic foot osteitis (primary outcome).
Results: Patient characteristics were similar in the two intervention groups, including arteritis prevalence (62.3 %), SINBAD score, and wound location (phalanges 36 %, metatarsus 43 %, and calcaneus 21 %). However, the ultrasound-guided group was older (67 ± 11 versus 60 ± 13 years respectively, $P = 0.047$) and had more type 2 diabetes (97 % versus 75 %, $P = 0.038$). Diagnostic performance (i.e., capacity to confirm or rule out suspected osteitis) was similar for ultrasound-guided (28/29 cases: 25 confirmations, 3 invalidations) and surgical (24 confirmations/24) biopsies, $P = 0.358$. No biopsy-related side effect or complication was observed for either intervention, even for patients on antiaggregation and/or anticoagulation therapy. The mean (± standard deviation) time necessary to perform the biopsy was shorter in the ultrasound-guided group (2.6 ± 3.0 versus 7.2 ± 5.8 days, respectively, $P < 0.001$) and wound evolution at three months was more favorable (83.3 versus 41.2 %, $P = 0.005$) (94.4 % versus 66.7 %, respectively, patients with new surgical procedure within six months excluded; $P = 0.055$). Even though not statistically significant, healing rates in terms of wound and osteitis at six months were also better in the ultrasound-guided group (wound: 40.9 % versus 36.8 %; $P = 0.790$, and osteitis: 81.8 vs 55.6 % $P = 0.071$).
Conclusion: In diabetic patients with suspected foot osteitis not requiring surgery, bedside ultrasound-guided bone biopsies may constitute a promising alternative to surgical biopsies. This intervention provided excellent tolerance and microbiological documentation, short lead-times, and more favorable wound prognosis.

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Introduction

Diabetes is one of the major public health problems of the 21st century; physicians face many related treatment challenges, especially complications associated with diabetic foot infections. Fifteen percent of diabetic patients have a related foot infection during their lifetime. These infections are the leading cause of non-traumatic amputation worldwide and are responsible for prolonged hospitalizations and long-term care [1–5].

Important risk factors for the development of osteitis in cases with diabetic foot infection include the presence of sensory neuropathy, association with arteriopathy of the lower limbs (peripheral arterial disease impairs the blood flow necessary for the proper diffusion of antibiotics and healing) and poor glycemic control (hyperglycemia impairs neutrophil function and reduces host defenses) [6–8].

The prognosis of diabetic foot osteitis in patients depends on appropriate early antibiotic therapy [9]. Multiple problems can delay treatment, the first and most important being confirmation of the diagnosis. Often this implies performing at least one X-ray or scan or better still (but less accessible) a magnetic resonance imaging (MRI) scan [10]. Confirming which bacteria are or are not implicated in the osteitis can also be challenging. International recommendations emphasize the importance of early microbiological documentation to allow appropriate antibiotic therapy to be provided as quickly as possible [11].

Nevertheless, performing biopsies in the operating theater is often delayed because of organizational issues (access to the theater, issues related to anesthesia, etc.). Consequently, probabilistic antibiotic therapy is often urgently started to avoid soft tissue damage. This implies the need for a 14-day window without antibiotherapy before the biopsy can be performed, which in turn delays adequate management of osteitis.

Ultrasound has revolutionized the management of chronic inflammatory rheumatism, in particular thanks to earlier and more sensitive detection of bone erosion than X-ray imaging [12,13]. As the elementary lesion (erosion) in inflammatory rheumatism and infectious osteitis is the same, performing a bedside ultrasound-guided biopsy is an attractive alternative to surgical biopsies. It provides early detection of bone erosions, precise identification of the region to be biopsied with real-time control of the gesture, and ease of access even for small bones thanks to high spatial resolution [14–17].

Several studies have already focused on the performance of non-surgical bone biopsies, which, depending on structural aspects, can be easier to obtain [18,19]. Féron *et al.* recently showed the non-inferiority of bedside blind bone biopsies compared to surgical and radiological biopsies [20]. It is also now widely agreed that taking a skin swab from a wound should no longer be used because it does not accurately predict the bacterial species incriminated in osteitis, and that it is better to proceed through an area of healthy skin to perform the bone biopsy [21,22]. Thanks to its precision, ultrasound makes it possible to move into a healthy zone while precisely targeting the infected bone where the biopsy must be performed.

To our knowledge, this is the first study to report on ultrasound-guided bone biopsies for diabetic foot osteitis.

Research design and methods

Patient selection

This was a pilot, monocentric, retrospective study which consecutively recruited patients living with diabetes admitted to our department in Avicenne hospital (suburb of Paris, France) for a suspected foot infection. We only included patients with no indication for additional surgery (i.e., need for amputation, abscess to be drained, etc.) who underwent either a classic surgical bone biopsy for osteitis between January 2018 and October 2020 or an ultrasound-guided bone biopsy between December 2020 and October 2022. As per expert recommendations, patients undergoing a biopsy (either type) could not be on antibiotherapy in the two weeks preceding the procedure.

In Avicenne hospital, as in the other hospitals within the *Assistance Publique des Hôpitaux de Paris* network, all patients are informed at admission that their medical records may be used for research unless they indicate their opposition. Data were analyzed anonymously. A local ethics committee validated the study (CLEA-2022–273) and no patient indicated opposition. Data were extracted from patients' medical records and collected anonymously in a secure health database.

Outcomes

Our primary endpoint was the percentage of biopsies confirming or rejecting suspected osteitis. Diagnosis was confirmed when clinical (presence of bone contact through the wound, visible bone) or imaging-based (i.e., *either* presence of erosion on X-ray/scan *or* inflammation on MRI scan) suspected osteitis plus *either* anatomopathology *or* bacteriology tests returned positive. Diagnosis was rejected if the bacteriology and anatomopathology tests returned negative despite positive clinical and/or imaging-based tests.

Secondary endpoints were as follows: time between the indication for a bone biopsy and its realization (excluding patients who needed a 14-day antibiotherapy window, and including patients at least 14 days after the end of their probabilistic antibiotherapy to treat soft tissue infection); empirical large spectrum antibiotic consumption; favorable evolution of the initial wound at 3 and 6 months; healing rate of the wound and of osteitis at 6 months; serious complications in the 6 months following the biopsy (i.e., appearance of multi-resistant bacteria, *Clostrioides difficile* infection, sepsis, further surgical intervention needed, amputation, and death). Wound evolution was considered 'favorable' if its surface was smaller, and 'healed' if it was closed and covered by healthy skin. Osteitis was considered 'healed' when the wound was healed and/or imagery results highlighted an improvement/no deterioration at least one month after the end of antibiotherapy. We also analyzed the tolerance of both biopsy procedures and recorded any adverse events.

The following data were also collected:

- general data within 24 h of hospital admission: sex, age, current tobacco consumption, use of blood pressure-lowering agents, statins, antiaggregant and anticoagulant drugs.
- diabetes-related data: diabetes type and duration, HbA1c (high performance liquid chromatography variant), routine treatment before admission and complications. Retinopathy was defined as any medical argument for a retinopathy; renal failure was estimated as creatinine clearance < 60 ml/min (serum creatinine was measured by colorimetry, Kone Optima, Thermolab System, Paris La Défense, France and creatinine clearance was estimated using the Chronic Kidney Disease-Epidemiology Collaboration equation); microalbuminuria (urinary albumin/creatinine excretion rate ratio ≥ 3 mg/mmol (measured by laser immunonephelometry, BN100, Dade-Behring, Paris, France)); neuropathy (defined as any sign or symptom of polyneuropathy); history of coronary arterial disease and peripheral macrovascular disease (peripheral artery occlusive disease, 50 % stenosis measured by ultrasound examination).
- wound data: as per validated international recommendations, we used the SINBAD (Site, Ischaemia, Neuropathy, Bacterial infection and Depth) classification to grade patients' foot wounds [23]. The following biological parameters were collected at diagnosis: white blood cell count, neutrophils, C-reactive protein levels (Cobas 6000 analyzer, Roche diagnostics).
- biopsy data: location, antiaggregation and/or anticoagulation therapy at the time of biopsy and procedure-related adverse events.

Table I
Patients' characteristics.

		Ultrasound-guided biopsy ($n = 29$)	Surgical biopsy ($n = 24$)	*P*-value
Demographics at hospital admission				
Male gender		24 (82.8)	21 (87.5)	0.631
Age (years)		67.2 ± 11.2	60.0 ± 12.8	0.047
Tobacco consumption (current or past)		15 (51.7)	14 (58.3)	0.63
Blood pressure-lowering agents		23 (79.3)	20 (83.3)	0.709
Statins		20 (69)	15 (62.5)	0.621
Antiaggregant drugs		22 (75.9)	14 (58.3)	0.174
Anticoagulation therapy		3 (10.3)	2 (8.3)	0.803
Diabetes relatives data at admission				
Type 2 diabetes		28 (97)	18 (75)	0.038
Diabetes duration (years)		19.8 ± 12.8	18.7 ± 14.2	0.665
HbA1c (%)		8.5 ± 2	8.6 ± 2.21	0.920
Insulin		21 (72.4)	22 (91.7)	0.075
GLP1 analogues		1 (3.4)	1 (4.2)	0.891
Gliflozins		1 (3.4)	0 (0)	0.358
Other oral glucose-lowering agents		11 (37.9)	9 (37.5)	0.974
Retinopathy		18 (72)	18 (78.3)	0.617
Microalbuminuria		14 (56)	15 (65.2)	0.514
Creatinine clearance (ml/min)	> 60	21 (72.4)	17 (70.8)	0.899
	30–60	5 (17.2)	4 (16.7)	0.956
	< 30	3 (10.3)	3 (12.5)	0.805
Neuropathy		29 (100)	21 (87.5)	0.05
Coronaropathy		17 (58.6)	8 (33.3)	0.066
Peripheral macrovascular disease		18 (62.1)	15 (62.5)	0.974
Revascularization procedures in the 6 months following biopsies		**3 (10.3)**	**2 (8.3)**	**0.99**
Foot characteristics at admission				
Bone biopsy site	phalanx	10 (34.5)	9 (37.5)	0.82
	metatarsus	13 (44.8)	10 (41.7)	0.817
	calcaneus	6 (20.7)	5 (20.8)	0.99
SINBAD wound grade	3	4 (13.8)	1 (4.2)	0.233
	4	10 (34.5)	12 (50)	0.254
	5	11 (37.9)	9 (37.5)	0.974
	6	4 (13.8)	2 (8.3)	0.532
CRP (mg/L)		38.9 ± 56.2	34.9 ± 55.4	0.637
WBC (G/L)		7580 ± 2507	8471± 3960	0.920
PNN (G/L)		5033 ± 2171	5396± 3267	0.962
Antiaggregation therapy during biopsy		22 (75.9)	14 (58.3)	0.174
Preventive anticoagulation therapy during biopsy		22 (75.9)	18 (75)	0.942
Curative anticoagulation therapy during biopsy		3 (10.3)	2 (8.3)	0.803

Data are n (percentage) or mean ± standard deviation.
CRP: C-reactive protein; GLP1: glucagon-like peptide 1; PNN: polynuclear neutrophils; WBC: white blood cells.

Ultrasound-guided and surgical biopsies

We separated the patients into two groups described below:

i) patients who underwent an ultrasound-guided bone biopsy between December 2020 and October 2022. The procedure for this biopsy was as follows: after carrying out meticulous disinfection at the patient's bedside, an osteo-articular ultrasound was performed under sterile conditions to identify the area showing signs of osteitis (erosion). A local anesthesia was then performed followed by a bacteriological swab of the skin outside the wound (where the trocar needle was going to be introduced) for quality control. Four biopsies were performed under ultrasound guidance using a Madison™ Bone Biopsy Mini kit. Three samples were sent for bacteriological analyses in Portagerm® and one was fixed in formalin and sent to the hospital's pathology laboratory. Bacteriological samples were cultivated for 5 days on solid growth culture and 15 days on enriched liquid growth culture. It is important to note that these patients did not have to fast prior to the biopsy.
ii) patients who underwent a classic surgical bone biopsy between January 2018 and November 2020. Bacteriological samples were treated in the same way as for the ultrasound-guided group but without a skin swab culture.

Care for wounds

The care strategy in our department for patients admitted for suspected foot osteitis not requiring surgery was similar throughout the study period (2018–2022). However, the practice of beside ultrasound-guided biopsy only started in December 2020. Foot infections were initially managed during hospitalization, then at home. Care management included a podiatrist and/or vascular surgeon when necessary, as well as visits by the multidisciplinary medical team every one to two weeks [11,24].

Statistical analyses

Data were expressed as means (standard deviation: SD) for continuous variables and numbers (%) for categorical variables. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) software platform to compare the two groups using the chi-square test for non-normal binary variables and the Mann-Whitney-Wilcoxon test for non-normal numeric variables. A P-value < 0.05 was deemed significant.

Results

Participants and their characteristics

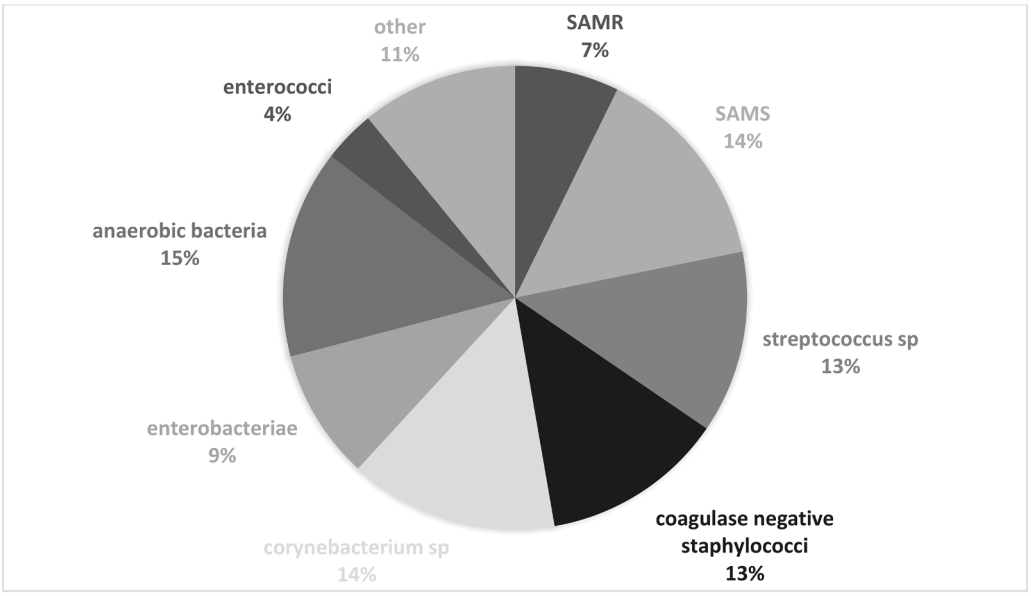
Twenty-nine patients underwent ultrasound-guided biopsies

Table II
Bacteriological and pathological analyses of bone biopsies.

	Ultrasound-guided biopsy ($n = 29$)		Surgical biopsy ($n = 24$)		*P*-value
	Available data (n)	n (percentage)	Available data (n)	n (percentage)	
Clinical osteitis	29	27 (93.1)	24	23 (95.8)	0.669
Radiological osteitis **(including ultrasonic osteitis)**	28	28 (100)	24	20 (83.3)	0.025
Ultrasound osteitis	29	29 (100)	NA	NA	NA
Positive bone bacterial culture	29	25 (86.2)	24	22 (91.7)	0.532
Positive skin bacterial culture	29	28 (96.6)	NA	NA	NA
Bacteria different between bone and skin	29	25 (86.2)	NA	NA	NA
Osteitis confirmed in anatomopathology	24	23 (95.8)	21	21 (100)	0.344
Diagnosis of osteitis confirmed	29	26 (89.7)	24	24 (100)	0.105
Diagnosis of osteitis ruled out	29	2 (6.9)	24	0 (0)	0.19
Diagnosis of osteitis confirmed or ruled out	29	28 (96.6)	24	24 (100)	0.358

NA: not available.

A



B

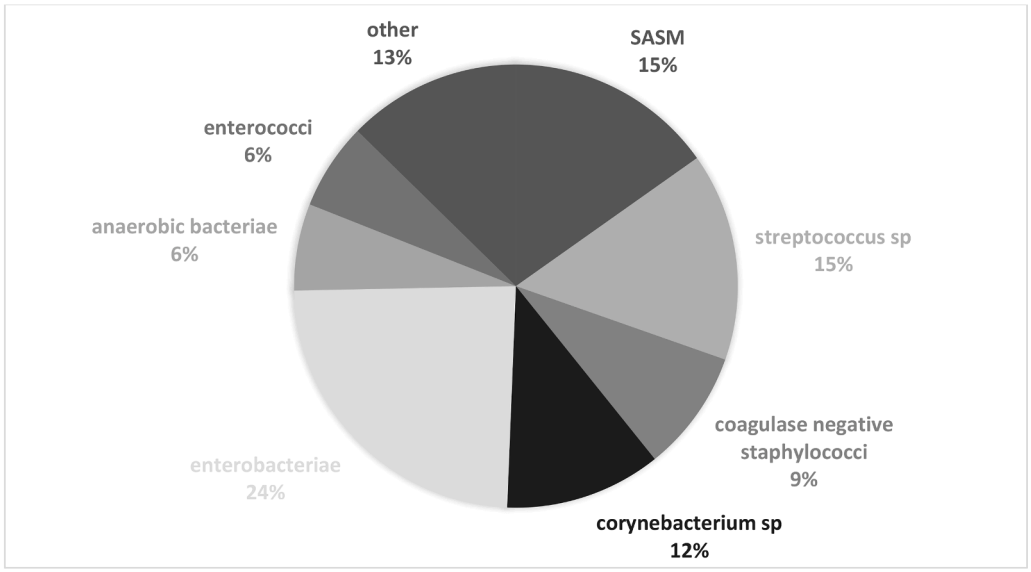


Fig. 1. Bacteria found in bone biopsies
Panel A: ultrasound-guided bone biopsies; Panel B: surgical bone biopsies
SAMR: Staphylococcus aureus methicillin-resistant; SAMS: Staphylococcus aureus methicillin-sensitive.

between December 2020 and October 2022, and 24 had classic surgical biopsies between January 2018 and November 2020. Table 1 shows that both groups had similar characteristics, except that ultrasound-guided group was older (67.2 ± 11.2 versus 60.0 ± 12.8 years, respectively, $P = 0.047$) and had more type 2 diabetes (97 % versus 75 %, $P = 0.038$).

All patients had a SINBAD wound level of at least 3; biopsies were performed in the phalanx ($n = 19$), the metatarsus ($n = 23$) or the calcaneum ($n = 11$) (Table I). Over 90 % of the patients in both groups had clinical osteitis (Table II).

Main outcome

Table 2 shows that the diagnosis of osteitis was confirmed by the ultrasound-guided biopsy in 26 patients and invalidated in 2 patients. Therefore, in terms of diagnostic performance, ultrasound-guided biopsies confirmed or ruled out osteitis diagnosis in 28/29 patients. The bone biopsy bacteriology result for the remaining patient was negative, and pathology was not interpretable. By error, he was treated with antibiotherapy for 6 weeks for the germ found in the skin swab (the evolution was favorable). Accordingly, we could not conclude whether he had osteitis or not.

In the surgical biopsy group, osteitis was confirmed in all 24/24 patients. The difference in the proportion of biopsies confirming or ruling out suspected osteitis (96.6 % versus 100 %; $P = 0.358$) (Table II) was not significant between the two methods. The germs found in bone samples are shown in Fig. 1.

Table III
Prognosis of diabetic foot infection in both groups.

	Ultrasound-guided biopsies (n = 29)		Surgical biopsies (n = 24)		P-value
	Available data (n)	Result	Available data (n)	Result	
Mean time between indication and biopsy					
including antibiotherapy window (days)	29	4.5 ± 4.9	24	8.4 ± 5.9	0.005
not including antibiotherapy window (days)	25	2.6 ± 3.0	22	7.2 ± 5.8	< 0.001
Probabilistic broad-spectrum antibiotherapy	29	6 (20.7)	24	11 (45.8)	0.051
Favorable evolution of the wound					
at 3 months **(all patients included)**	24	20 (83.3)	17	7 (41.2)	0.005
At 3 months (patients with new surgical procedure within 6 months excluded)	**18**	**17 (94.4 %)**	**9**	**6 (66.7)**	**0.055**
at 6 months **(all patients included)**	22	16 (72.7)	19	11 (57.9)	0.346
At 6 months (patients with new surgical procedure within 6 months excluded)	**15**	**13 (86.7)**	**12**	**9 (75)**	**0.438**
Prognosis at 6 months					
Healing of the wound **(all patients included)**	22	9 (40.9)	19	7 (36.8)	0.790
Healing of the wound (patients with new surgical procedure within 6 months excluded)	**15**	**8 (53.3)**	**12**	**6 (50)**	**0.863**
Healing of osteitis **(all patients included)**	22	18 (81.8)	18	10 (55.6)	0.071
Healing of osteitis (patients with new surgical procedure within 6 months excluded)	**15**	**14 (93.3)**	**11**	**9 (81.8)**	**0.364**
Outcomes at 6 months					
Onset of multi-resistant bacteria	22	1 (4.5)	21	1 (4.8)	0.973
Clostrioides difficile infection	22	0 (0)	21	0 (0)	NA
Sepsis	19	1 (5.3)	20	1 (5)	0.970
New surgical procedure	22	7 (31.8)	19	8 (42.1)	0.495
Amputation	22	6 (27.3)	19	4 (21.1)	0.644
Death	25	1 (4)	22	0 (0)	0.343

Data are n (percentage) or mean ± standard deviation.
NA: not available.

Other outcomes

No adverse event was reported for either group, including patients on anticoagulation and/or antiaggregation therapy.

Table III shows that the delay between indication for the biopsy and its realization was significantly shorter for the ultrasound-guided group than the surgical group, irrespective of whether the biopsies were performed after an antibiotic therapy window (4.5 ± 4.9 versus 8.4 ± 5.9 days, respectively; $P = 0.005$) or not (2.5 ± 3.0 versus 7.21 ± 5.8 days respectively; $P < 0.001$). Furthermore, wound evolution was more likely to be favorable in the ultrasound-guided biopsy group at 3 months (83.3 % versus 41.2 %, respectively; $P = 0.005$) (94.4 % versus 66.7 %, respectively, patients with new surgical procedure within 6 months excluded; $P = 0.055$) but not at 6 months (72.7 % versus 57.9 %, respectively; $P = 0.346$) (86.7 % versus 75 %, respectively, patients with new surgical procedure within 6 months excluded; $P = 0.438$). Table III also shows that the percentages of the other secondary outcomes were similar in both groups. There was no difference between the two groups regarding the frequency of revascularization procedures in the 6 months following the biopsy (3/29 and 2/24 respectively; $P = 0.99$).

Conclusions

In this retrospective pilot study which included consecutive patients with diabetes admitted for a foot infection with suspected osteitis without indication for complementary surgery or amputation, we found that the diagnostic performance of bedside ultrasound-guided biopsies (2020–2022) for osteitis was similar to that for classic surgical biopsies (2018–2020). Moreover, ultrasound-guided biopsies were safe; no biopsy-related complication was observed in either group, even for patients on antiaggregation or anticoagulation therapy. In addition, the time between indication and an ultrasound-guided biopsy was shorter than for a surgical biopsy. Furthermore, a more favorable healing rate was observed at three months in the ultrasound-guided biopsy group.

Taking good quality microbiological samples is of major importance in the management of diabetic foot infections. Moreover, as the recommendations for osteitis diagnosis are not clear, expert consensus is often difficult to obtain. Accordingly, the largest possible number of inputs is needed in order to diagnose the condition [1,4,5]. Due to an often substantial delay between indication and biopsy, in part due to organizational constraints, a growing number of hospital teams are considering performing biopsies at the patient's bedside [18,21,25]. Recently, a study by Féron *et al.* showed significantly lower effectiveness of percutaneous bone biopsies in clinical landmarks compared to surgical biopsies, despite a lack of any significant difference between the two groups on wound healing at one year [22]. In comparison, the diagnostic performance of surgical biopsies in our study was much higher (100 % versus 77.3 % in the article by Féron et al.). Moreover, in their study, there were no anatomopathological examination samples. In line with data from the literature [26], we showed that such samples are crucial to accurately diagnose osteitis (in our study, three patients who underwent an ultrasound-guided biopsy and two who underwent a surgical biopsy had a diagnosis of osteitis based on an anatomopathological examination). Moreover, the differences we found between the germs found in skin swabs and those found in bone biopsies confirm two points: first, antiseptic procedures were performed correctly, and second, skin flora are definitely different from pathogens responsible for osteitis and therefore should not be treated; the latter finding is consistent with previous findings in the literature [21,22]. Thanks to the excellent precision of ultrasound imaging, it is therefore easy to avoid the wound and take a sample directly from the infected bone, with no skin contamination.

The excellent cost-effectiveness of ultrasound-guided biopsies goes hand in hand with a significant shortening of the time required to obtain microbiological documentation, thus shortening patient care duration, which is an important issue in the current changing health context (Covid-19, policies, etc.). The rate of wound healing at three months in our study tended to be better in the ultrasound-guided biopsy group than in the surgical biopsy group, despite the patients in the former group being older. This result may be because of a shorter time before beginning targeted antibiotherapy. Furthermore, age and associated comorbidities may limit surgical procedures because of anesthetic-related

issues. Neither general nor regional anesthesia is needed for an ultrasound- guided bone biopsy, which is a major advantage for aging persons with diabetes.

The two main strengths of our study are the relatively large number of patients and the long-term follow-up period. We found that osteitis ultrasound-guided bone biopsy diagnostic performance was not inferior to the 100 % performance found for our surgical bone biopsy group; this highlights the excellent diagnostic performance of ultrasound-guided bone biopsy. In addition, bacteriologic and pathological analyses were exhaustive. Finally, to our knowledge, this is the first study to report on ultrasound-guided bone biopsy for diabetic foot osteitis diagnosis. The main limitations are the retrospective nature, possibly leading to memory bias, and the fact that it was only a feasibility study. Plus, even if protocols and procedures especially for wound caring were the same from 2018 to 2022 we cannot exclude a possible bias. Since our study was not randomized we also observed a difference in the frequency of type 2 diabetes between the two groups. Randomized studies could confirm our results but are unrealistic in the setting of routine hospital activities.

In a context where bacterial resistance to antibiotherapy is increasing due to overconsumption, and despite the fact that we did not observe higher levels of multi-resistant bacteria in the surgical biopsy group, the substantially lower use of empirical broad-spectrum antibiotic consumption in our ultrasound-guided biopsy group (20.7 % versus 45.8 % in the classic surgical group; $P = 0.051$) highlights the importance of obtaining prompt bacterial documentation in order to reduce empirical broad-spectrum antibiotic consumption [27,28].

It is important to note that there are organizational barriers to the implementation of bedside ultrasound-guided biopsy on a larger scale, including the provision of ultrasound equipment and in particular, trained personnel in bone ultrasounds, like any ultrasound modality, the main limitation of echography remains the echographist.

To conclude, in hospitalized patients with suspected diabetic foot osteitis, bedside ultrasound-guided bone biopsies are a promising alternative to surgical biopsies thanks to their excellent microbiological cost-effectiveness, their accessibility to small bones, their safety even in patients on antiaggregation/anticoagulation therapy, and finally, the short indication-biopsy lead time, which probably translates into improved wound prognosis.

CRediT authorship contribution statement

Nolan Hassold: Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization. **Hélène Bihan:** Data curation. **Yolène Pambo Moumba:** Data curation. **Isabelle Poilane:** Supervision. **Frédéric Méchaï:** Supervision. **Nabil Assad:** Supervision. **Véronique Labbe-Gentils:** Supervision. **Meriem Sal:** Supervision. **Omar Nouhou Koutcha:** Supervision. **Antoine Martin:** Supervision. **Dana Radu:** Supervision. **Emmanuel Martinod:** Supervision. **Hugues Cordel:** Supervision. **Nicolas Vignier:** Supervision. **Sopio Tatulashvili:** Supervision. **Narimane Berkane:** Supervision. **Etienne Carbonnelle:** Supervision. **Olivier Bouchaud:** Supervision. **Emmanuel Cosson:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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