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Effectiveness of ultrasonic debridement on reduction of bacteria and biofilm in patients with chronic wounds: A scoping review

Yukie Kataoka[1] | **Mao Kunimitsu**[1,2] | **Gojiro Nakagami**[1,3] | **Sofoklis Koudounas**[3] | **Carolina D. Weller**[4] | **Hiromi Sanada**[1,3]

[1]Department of Gerontological Nursing/Wound Care Management, Graduate School of Medicine, The University of Tokyo, Tokyo, Japan

[2]Japan Society for the Promotion of Science, Tokyo, Japan

[3]Division of Care Innovation, Global Nursing Research Center, Graduate School of Medicine, The University of Tokyo, Tokyo, Japan

[4]Monash Nursing and Midwifery, Monash University, Clayton, Victoria, Australia

Correspondence
Prof. Hiromi Sanada, Department of Gerontological Nursing/Wound Care Management, Graduate School of Medicine, The University of Tokyo, Faculty of Medicine Building 5-307, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan.
Email: hsanada-tky@umin.ac.jp; hsanada@g.ecc.u-tokyo.ac.jp

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Abstract

Chronic wounds are defined as "hard-to-heal" wounds that are caused by disordered mechanisms of wound healing. Chronic wounds have a high risk of infection and can form biofilms, leading to the release of planktonic bacteria, which causes persistent infections locally or remotely. Therefore, infection control and removal of the biofilm in chronic wounds are essential. Recently, ultrasonic debridement was introduced as a new method to reduce infection and promote the healing of chronic wounds. This scoping review aimed to evaluate the effectiveness of ultrasonic debridement on the changes in bacteria and biofilms, and consequently the wound healing rate of chronic wounds. A total of 1021 articles were identified through the database search, and nine papers were eligible for inclusion. Findings suggest that non-contact devices are useful for wound healing as they reduce the inflammatory response, although the bacterial load is not significantly changed. Ultrasonic debridement devices that require direct contact with the wound promote wound healing through reduction of biofilm or bacterial load. The optimum settings for ultrasonic debridement using a non-contact device are relatively consistent, but the settings for devices that require direct contact are diverse. Further studies on ultrasonic debridement in chronic wounds are required.

KEYWORDS

foot ulcer, leg ulcer, pressure ulcer, ultrasound, wound healing

1 | INTRODUCTION

Chronic wounds occur as a result of disordered mechanisms of wound healing,[1,2] and include pressure ulcers, diabetic foot ulcers (DFUs), venous leg ulcers (VLUs), and arterial ulcers. Chronic wounds are experienced by 1% to 2% of the population in developed countries, and as many as 4.5 million people are estimated to suffer from chronic wounds in the US.[3,4] Recently, a meta-analysis showed a pooled prevalence of 2.21 per 1000 individuals for chronic wounds of mixed etiologies and an estimated prevalence of 1.51 per 1000 individuals for chronic leg ulcers.[5] As chronic wounds are a high-risk factor for infections,[6] which increases the probability of limb

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amputation and death, the infection control of chronic wounds is essential.

A previous study demonstrated that biofilms were detected by confocal and electron microscopy in 60% of the biopsies from chronic wounds that required sharp debridement.[7] Biofilms are composed of extracellular polysaccharides regulated by a quorum-sensing system, and a cell density-dependent gene expression mechanism, which protects bacterial cells from antibiotics, antiseptics, and host immunity.[8,9] Additionally, a biofilm releases planktonic bacteria, thereby causing persistent infections locally or remotely.[10] Thus, the presence of biofilms plays a crucial role in the development of infection in chronic wounds.[11]

The international guidelines for pressure ulcers recommend identification and removal of biofilms at the wound site.[12] Furthermore, an anti-biofilm treatment approach for all chronic wounds is essential to heal them.[13] Debridement is one of the most important treatment strategies against biofilms. Wound debridement includes sharp debridement, autolytic debridement, chemical debridement, biological debridement, and mechanical debridement.[14] Sharp debridement is an effective way to help remove biofilm, while there is limited evidence for other types of debridement.[15] However, sharp debridement requires surgical skills and techniques that must be performed by a medical professional,[16] and can only be performed on wounds with visible necrotic tissue. Additionally, sharp debridement is a highly invasive and painful procedure that can result in bleeding.[17] Therefore, non-invasive methods that can remove biofilms in wounds with or without necrotic tissue are required.

Recently, debridement performed using low-frequency (20–40 kHz) ultrasonic waves that promote elimination and destruction of devitalized soft tissue by the cavitation effect has been introduced as a new method to treat chronic wounds.[17] As a consequence, several ultrasonic devices for wound debridement have been developed. However, indications regarding wound size and type for ultrasonic debridement and the optimum settings, such as ultrasonic irradiation time and frequency of irradiation, have not been elucidated. Additionally, the effects of ultrasonic debridement on the bacteria and biofilm, with regards to healing, of chronic wounds have not been clarified thus far.

1.1 | Scoping review question

The specific question that guided this scoping review was: "Do ultrasonic debridement techniques contribute to biofilm removal, reduction of bioburden, and wound healing in patients with chronic wounds?"

Key Messages

- This scoping review provides a summary of the effects of ultrasonic debridement on biofilm or bacterial load with regards to the healing of chronic wounds.
- Changes in bacterial load after ultrasonic debridement are different between non-contact and contact devices.
- The optimum settings for ultrasonic debridement using non-contact devices are summarised.

1.2 | Scoping review objective

The objectives of this study were: (a) to summarise the available evidence on the changes of bacteria and biofilm in chronic wounds affected by ultrasonic debridement, and (b) to organise the settings of ultrasonic devices in these summarised evidences. This scoping review will be of use to clinicians involved in the management of chronic wounds and researchers who plan to conduct clinical trials using ultrasonic debridement.

2 | METHODS

2.1 | Protocol and registration

A review protocol was not published. This scoping review was performed according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist.[18]

2.2 | Eligibility criteria

We limited our search to articles published in English, regardless of clinical setting, including inpatient settings and home care settings, and publication year. We included studies involving participants of all ages with chronic wounds (as outlined above) that had undergone ultrasonic debridement. Published original articles and case reports written in English were included in this scoping review. Proceedings, conference abstracts, letters to the editor, editorials, guidelines, protocols, literature reviews, and meta-analysis were excluded.

2.3 | Information sources

The following bibliographic databases were searched on January 2020: Medline, PubMed, CINAHL, and Cochrane Central.

2.4 | Search

Search terms and Medical Subject Heading terms related to ultrasonic debridement, chronic wounds, and biofilm were used and combined using the Boolean operator "AND". The search strategy used was as follows: (1. chronic wound*, 2. pressure ulcer*, 3. pressure injur*, 4. diabetic foot ulcer*, 5. venous leg ulcer*, 6. arterial ulcer*) AND (1. ultraso*, 2. debridement) AND (1. bacteria*, 2. biofilm).

2.5 | Selection of sources of evidence

Search results were imported into Rayyan (Qatar Computing Research Institute, Doha, Qatar), and duplicates were removed.[19] Titles and abstracts were screened by two researchers (Y.K. and M.K.) independently, and those that clearly did not fit the inclusion criteria were excluded. Potentially eligible full-text articles were screened for inclusion by two independent reviewers (Y.K. and M.K.), according to the inclusion criteria. In particular, the articles lacking outcomes for bacteria and biofilm in patients with chronic wounds were excluded, because in this scoping review, we focused on how ultrasonic debridement affected bacteria and biofilm in chronic wounds. Disagreements on study selection were resolved through discussion.

2.6 | Data-charting process

A data-charting form was developed by one author (Y.K.) to determine which variables to extract. Data were extracted by a single author (Y.K.) and verified by co-authors (M.K. and G.N.). Discrepancies in the extracted data were resolved through discussion between the three authors.

2.7 | Data items

The following information was extracted: (a) study authors, year of publication, and country, (b) study design/participants, (c) wound type, (d) name of ultrasonic debridement device used, (e) settings of ultrasonic debridement, (f) main outcome, (g) outcome related to bacteria and biofilms, (h) outcome related to wound healing, (i) conclusion, (j) reported quality of evidence and limitations, and (k) suggestions for future studies.

3 | SYNTHESIS OF RESULTS

Extracted data from the included studies are summarised. The ultrasonic settings according to the way the ultrasonic debridement device was used, by direct contact or non-contact with the wound, were reported.

4 | RESULTS

4.1 | Selection of sources of evidence

The initial search yielded 1021 studies. Following removal of duplicates (n = 114), 907 articles remained. Through the title and abstract screening, 889 papers were excluded. Among the 18 remaining papers, nine papers were excluded through the full-text screening: one study did not investigate outcomes of ultrasonic debridement for bacteria and biofilm, and eight studies were ineligible due to publication type. A total of nine articles were included in this scoping review.[20-28] A PRISMA flowchart of the current review is shown in Figure 1.

4.2 | Characteristics of sources of evidence

The characteristics of the included studies are provided in Table 1. Among the nine studies included in this scoping review, six represented original papers and three were case studies. One RCT, involving DFUs, was conducted in the US and Canada, and was published in 2005,[21] and

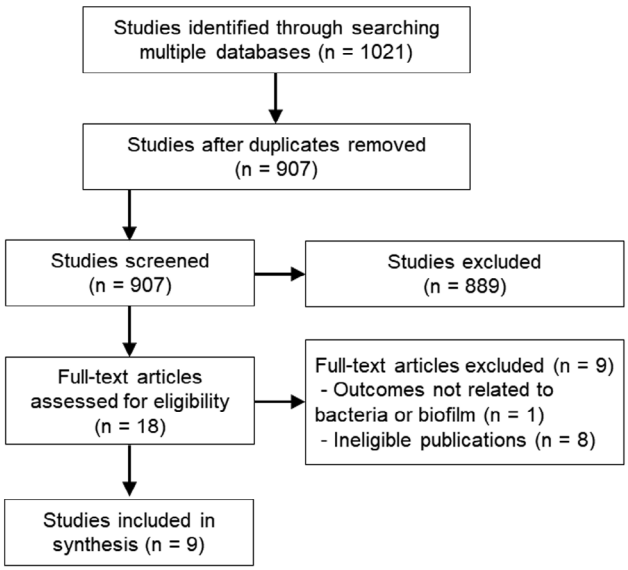

FIGURE 1 Flow chart of this scoping review. A PRISMA flowchart of the current review is shown. Finally, a total of nine articles were included in this scoping review

TABLE 1 Summary of collected data in this scoping review

Study author/ year/ country	Study design/ participants	Wound type	Ultrasonic debridement device	Settings of ultrasonic debridement	Theme	Outcome related to bacteria/ biofilm	Outcome related to wound healing	Conclusion
Breuing et al, 2005, USA[20]	Case study: N = 17	Venous stasis ulcers (n = 5), arterial insufficiency–related ulcers (n = 2), diabetic ulcers (n = 3), pressure ulcers (n = 3), sickle cell anaemia (n = 1), and nonhealing surgical wounds (n = 4).	Söring Sonoca Ultrasonic Debridement Device, Sonoca 180 (Söring, Inc, Germany)	The ultrasonic amplitude is preferably set at 80–100% and a frequency of 25 kHz. All wounds were treated for 20 seconds per cm^2.	Wound healing, and bacterial existence after debridement with contact device.	In case 1, qualitative wound biopsy cultures grew 4+ MRSA, 4+ *Stenotrophomonas maltophilia*, and 4+ *corynebacterium* species before ultrasonic treatment. Final qualitative wound cultures grew 2 + MRSA only, and soft-tissue biopsy showed granulation tissue after ultrasonic debridement.In case 2, qualitative wound biopsy cultures revealed 3+ *E. coli*, 2+ *Serratia marcenscens*, and 2+ *β hemolytic streptococcus* before ultrasonic debridement. Cultures taken after the initial ultrasonic treatment showed 1+ *E. coli*, 1+ *β hemolytic streptococcus*, and 2+ *Serratia*.	Nine of the wounds (53%) healed primarily or with the aid of a skin graft. Six additional patients (35%) experienced a wound-size reduction of at least 50%.	Ultrasonic debridement has long been regarded as a technique that enhances wound healing.
Ennis et al, 2005, USA and Canada[21]	Prospective, randomised, double-blinded, controlled, multicenter study: inclusion N = 133 (analysis N = 55)	DFU	MIST™ therapy system (Celleration Inc., Eden Prairie, MN)	A 4- minute treatment was conducted holding the device perpendicular to the wound bed and moving the device in an up-and-down pattern across the wound bed. Treatment times had been calculated as 4 minutes in duration for wounds measuring <15 cm^2.	Proportion of wounds healed and adverse events after debridement with non-contact device.	The initial, post-debridement quantitative culture biopsies taken at enrollment showed that 86% of wound cultures in the group randomised to ultrasound treatment had >100 000 colonies/ g of tissue compared to 93% in the sham group. These	Overall, 40.7% of wounds in the ultrasound therapy, compared to 14.3% in the shamtreatment group, healed ($P = .0366$, Fisher's exact test). Time to healing differed significantly between the two treatment groups.	Ultrasound therapy is a useful adjunct to standard of care for the treatment of diabetic foot ulcers.

(Continues)

TABLE 1 (Continued)

Study author/ year/ country	Study design/ participants	Wound type	Ultrasonic debridement device	Settings of ultrasonic debridement	Theme	Outcome related to bacteria/ biofilm	Outcome related to wound healing	Conclusion
						differences were not statistically significant.		
Escandon et al, 2012, USA[22]	A prospective pilot study: N = 10 (analysis samples for bacteria, n = 9)	VLU	MIST™ therapy system (Celleration Inc., Eden Prairie, MN)	The treatment time depended on the size of the wound that is set in the entry screen in the machine, for example for a wound size 10– 20 cm^2 the irrigation time will be 4 minutes. The same physician operated the machine every time and placed the leading edge about 2 cm away from the wound.	Wound area, bacterial load, inflammatory cytokines profile, correlation between healing and cytokine expression change, and pain level after debridement with non-contact device.	*Staphylococcus aureus* was the most prevalent species, being present in 9/ 9 samples, *Pseudomonas aeruginosa* was found in 6/ 9 samples and Kocuria kristinae was present in 5/ 9 samples. These last two bacteria had a reduction in their mean value, but this was not statistically significant in this group of patients. The overall bacterial profile was unchanged over the trial period.	Wound size mean area was 38.3 cm^2 at the baseline, and it was reduced to 29.0 cm^2 at last follow-up visit. There was a statistically significant reduction (45% mean reduction) ($P = .0039$).	1. Wound size reduction and decreased inflammatory cytokines expression were correlated despite a non-significant decrease in bacterial count.2. Pain was decreased after treatment with non-contact ultrasound and compression therapy in refractory venous leg ulcers.
Hiebert et al, 2016, USA[23]	RCT: N = 17	Chronic open wounds of PU, DFU, and VLU.	Misonix low-frequency ultrasound (SonicOne OR, Ultrasonic Debridement System, Misonix Inc., Farmingdale, NY)	Not described.	Wound closure and bacterial bioburden reduction after debridement with contact device.	Patients treated with hypochlorous acid irrigation showed sustained suppression of bacterial growth. However, patients treated with saline irrigation showed growth of bacteria to near predebridement levels at 7 days.	More than 80% of patients in the saline group had postoperative closure failure compared with 25% of patients in the hypochlorous acid group.	1. Ultrasound debridement is an effective method to lower tissue bacterial counts in chronic wounds. 2. Hypochlorous acid is more effective than saline as an irrigant with ultrasonic debridement for maintaining wounds post–initial debridement until wound closure can be performed.
Esposito et al, 2017, Italy[24]	Cohort study: N = 32, n = 128	Skin and soft tissue infections, including infected trophic ulcer (N = 16), infected post-traumatic ulcer (N = 8), and diabetic	Ultrasonic debridement (Sonic One, Misonic, Inc)	About 5 min (average) at 5000– 7000 Hz.	Bacterial species isolated, percentages of concordance, and bacterial load after debridement with contact device.	Bacterial load yield by the culture of biopsy is significantly lower than that of a superficial swab after	Not described.	Ultrasonic debridement significantly reduced bacterial load or even suppressed bacterial growth.

TABLE 1 (Continued)

Study author/ year/ country	Study design/ participants	Wound type	Ultrasonic debridement device	Settings of ultrasonic debridement	Theme	Outcome related to bacteria/ biofilm	Outcome related to wound healing	Conclusion
		foot infection ulcer (N = 8).				ultrasonic debridement.		
Wiegand et al, 2017, Germany[25]	RCT: N = 36	VLU	MIST™ therapy system (Celleration Inc., Eden Prairie, MN)	Subjects randomised to NLFU treatment continued with the standardised protocol of care plus NLFU therapy of 3 times per week for a total of 12 treatments.	Reduction of wound area, evaluation of bacteria population, and detection of mediator profiles after debridement with non-contact device.	*Peptoniphilus* abundance significantly decreased more in the NLFU treatment group relative to standard of care for both swab (P = .007) and tissue biopsy samples (P = .01). The abundance of *Proteus* was found to decrease in both groups over the 4 week (P = .01).	Higher mean wound area reduction was observed in the NLFU treatment group (67.0%) compared to the control group receiving standard of care (41.6%) (P < .05).	NLFU improves wound healing by equally inhibiting abundant levels of proinflamma-tory cytokines as well as by reducing the overall bacterial burden.
Vallejo et al, 2018, Australia[26]	Case study: N = 4, n = 5	VLU	low-frequency ultrasonic debridement device, but the detailed information is not described.	LFUD was applied weekly in the clinic until it was deemed unnecessary. This was determined when the wound bed demonstrated signs of red, healthy granulation, an epithelial wound edge advancement and wound size reduction.	Biofilm suspected sign, bacterial existence, time to heal, pain level, and qualitative interview after debridement.	1. The wound history and wound behaviour were also consistent with chronic wound infection and the presence of biofilm, which were presumptively diagnosed by the clinician. 2. These signs included: long duration of non-healing; failure of multiple doses of antibiotic treatment to improve wound outcomes; persistent inflammation; regular presence of exudate; and unhealthy, friable granulation tissue. 3. Pseudomonas aeruginosa was diagnosed in all wounds via a swab culture prior to attending the clinic for all four participants.	All of the wounds healed within 16 weeks.	Chronic wounds with suspected biofilm have the potential to heal if treatment is multifactorial. The combination of techniques used in case series was acceptable to patients and shows promise as an effective treatment, as it may have assisted the healing process.

(Continues)

TABLE 1 (Continued)

Study author/ year/ country	Study design/ participants	Wound type	Ultrasonic debridement device	Settings of ultrasonic debridement	Theme	Outcome related to bacteria/ biofilm	Outcome related to wound healing	Conclusion
						Additionally, *Escherichia coli* was identified in the wound of one patient.		
Lázaro-Martínez et al, 2018, Spain[27]	Case study: N = 24, n = 18	DFU	SONOCA 185 device (Söring GmbH, Germany)	For most wounds, a two-minute treatment with 40% intensity was performed by holding the sonotrode in contact mode, perpendicular to the wound bed, and moving it across in an up-and-down pattern. For wounds measuring >15cm^2, the debridement procedure was increased to 3 minute. Ultrasound-assisted wound debridement was conducted every week during a six-week treatment period.	Wound size, wound bioburden, and correlation of reduced bacterial load after debridement with contact device.	The mean number of bacterial species per culture determined at week zero and at week six was 2.53 ± 1.55 and 1.90 ± 1.16, respectively ($P = .023$). Seventeen (70.9%) polymicrobial cultures at week zero versus seven (38.8%) at week six were observed ($P < .001$).	Wound healing progressed well, with significant wound surface area reductions observed during the treatment period. Mean wound sizes were 4.45 cm^2 (range: 2– 12.25) at week zero, and 2.75 cm^2 (range: 1.67–10.70) at week six ($P = .04$).	1. The process reduced bacterial load, thereby improving wound conditions and promoting healing. 2. Bacterial load reduction was independent to the bacterial species, with the ultrasound-assisted wound debridement device acting in the same way against all bacteria, including antibiotic resistant bacteria strains. 3. Sequential wound debridement with an ultrasound-assisted wound debridement device could avoid the unnecessary use of antimicrobials and reduce the risk of bacteria emerging with enhanced resistance levels.
Mori et al, 2019, Japan[28]	Study 1, cross-sectional study: inclusion N = 67, n = 217 (analysis N = 48, n = 114); Study 2, retrospective cohort study: inclusion N = 77, n = 105 (analysis N = 65, n = 80).	Study 1, PU; Study 2, PU, DFU, VLU, and AU.	Qoustic Wound Therapy System (Arobella Medical, LLC, Minnetonka, MN)	Study 1: low-frequency ultrasonic waves of 35 kHz and saline with 50– 100% of power levels using a 10- mm curette probe for 30 seconds to 2 minutes; Study 2: 60% power level for 1 to 10 minutes according to the size of the wound.	Study1: proportion of biofilm removal, and Study2: wound healing within 90 days after debridement with contact device.	Study1: proportion of biofilm removal; 38.9% (12.9– 68.0%) without ultrasonic debridement, 65.2% (41.1– 78.8%) with ultrasonic debridement, $P = .009$.	Study2: adjusted hazard ratio for the implementation of ultrasonic debridement in wound healing within 90 days, 4.5 (95% confidence interval, 1.3– 15.0; $P = .015$).	1. Ultrasonic debridement was effective for removing biofilms of pressure ulcers. 2. The novel approach using biofilm-based wound care system including both biofilm detection by wound blotting as a point-of-care testing and

TABLE 1 (Continued)

Study author/ year/ country	Study design/ participants	Wound type	Ultrasonic debridement device	Settings of ultrasonic debridement	Theme	Outcome related to bacteria/ biofilm	Outcome related to wound healing	Conclusion
								ultrasonic debridement can be a promising therapeutic strategy for promoting healing in chronic wounds.

Abbreviations: AU, arterial ulcer; DFU, diabetic foot ulcer; N, number of patients; n, number of wounds; NLFU, non-contact low-frequency ultrasonic debridement; PU, pressure ulcer; VLU, venous leg ulcer.

a small prospective pilot study for VLU which measured cytokines was published in 2012 from the US.[22] A small RCT for chronic open wounds using hypochlorous acid irrigation was published in 2016 from the US,[23] and an RCT for VLU conducted in Germany was published in 2017.[25]

Among the nine papers in this scoping review, the wound types of all nine papers included DFU or VLU, and pressure ulcer and arterial ulcer were included in three papers.

4.3 | Synthesis of results

4.3.1 | Effects of ultrasonic non-contact devices

In three studies, the MIST™ therapy system (Celleration Inc., Eden Prairie, MN), was used which represented a non-contact ultrasound device.[21,22,25] One RCT demonstrated that ultrasonic therapy resulted in reduced bacterial colonies, as evidenced by quantitative culture biopsies, but without statistical significance, while more than 40% of the treated DFUs were healed after 12 weeks of care, and this was statistically significant compared to the wounds treated with a "sham device", which delivered saline without the use of ultrasound.[21] Another study reported that the expression of inflammatory cytokines, such as tumour necrosis factor-α and interleukins, was decreased in correlation with decreasing wound size, although there was no significant decrease in bacterial numbers, and that a reduction in pain intensity was also observed, using a visual analog scale, from baseline.[22] Additionally, findings from another RCT demonstrated that ultrasonic debridement improved the wound healing of VLUs by inhibiting the release of inflammatory cytokines and by reducing the overall bacterial counts.[25] Although bacterial counts did not differ between treatments, these findings suggest that non-contact devices can be useful for wound healing by attenuating inflammatory responses and decreasing pain. There were no studies using non-contact devices that investigated the effect on biofilms.

4.3.2 | Effects of ultrasonic devices that require direct contact with wounds

Two case studies used the Söring Sonoca Ultrasonic Debridement Device (Söring, Inc, Germany),[20,27] which is an ultrasonic-assisted wound treatment device that can be used by direct contact with or bubbling over the wound.[29] One study demonstrated that bacterial counts reduced in

DFUs and this reduction was independent of bacterial species, with the device acting in the same manner against all bacteria, including antibiotic-resistant bacteria strains. This process significantly reduced bacterial load, thereby improving wound conditions and promoting healing.[27]

A small RCT and an observational study on DFUs, VLUs, and pressure ulcers reported on the Misonix low-frequency ultrasound (SonicOne OR, Ultrasonic Debridement System, Misonix Inc., Farmingdale, NY) device.[23,24] Findings from these studies demonstrated that this device significantly reduced bacterial load or suppressed bacterial growth. Furthermore, findings from our previous study demonstrated that another device (Qoustic Wound Therapy System [Arobella Medical, LLC, Minnetonka, MN]) contributed to the removal of biofilms and promoted wound healing in patients with DFUs, VLUs, arterial ulcers, and pressure ulcers.[28] However, other studies, which used devices that require direct contact with wounds, did not investigate the effect on biofilms.

These findings suggest that ultrasonic debridement devices that can be used through direct contact with the wound can contribute to wound healing through biofilm removal and reduction of bacterial load or growth.

4.3.3 | Settings of ultrasonic debridement

Regarding ultrasonic non-contact devices, the optimum settings with the MIST™ therapy system (Celleration Inc.) can be summarised as follows: 2 to 5 minutes per session for wounds of <10 to 20 cm^2, and an additional several minutes for those with larger wounds, for around 3 times a week.[21,22,25] However, for the three types of ultrasonic devices that could be used through direct contact with the wound, the settings of ultrasonic debridement varied among the studies, as shown in Table 1, and it was difficult to determine the optimum settings.

4.4 | Arrangement of irrigation solution for ultrasonic debridement

One study demonstrated that hypochlorous acid irrigation enhanced the suppression of bacterial growth by ultrasound debridement more efficiently than the suppression observed with saline alone.[23] Saline is generally used with ultrasonic debridement, but this study suggests the importance of future investigations into irrigation solutions other than saline.

5 | DISCUSSION

5.1 | Summary of evidence

This scoping review not only focused on the changes in bacteria and biofilm after ultrasonic debridement in chronic wounds but also clarified the optimal settings for the devices. To date, this evidence has not been summarised before. The final count of articles was nine, and only one paper demonstrated the changes of biofilm after ultrasonic debridement, suggesting there is a paucity of relevant literature in this field. The results of these nine articles suggested a promising healing effect from ultrasonic debridement on chronic wounds.

5.1.1 | Bacteria and biofilm following ultrasonic debridement

Ultrasonic debridement by non-contact devices improved wound healing rates by decreasing the levels of inflammatory cytokines. Additionally, a reduction in wound size correlated with a decrease in the expression of inflammatory cytokines.[22,25] On the contrary, the ultrasonic debridement devices that require direct contact with the wound promoted the wound healing process by reducing bacterial counts or bacterial growth. These findings suggest that direct contact devices can directly remove bacteria, and that the effectiveness of non-contact devices to remove bacteria is low compared to that of direct contact devices; however, a significant reduction of bacteria is not necessarily required for wound healing.

Furthermore, changes in biofilm after ultrasonic debridement were reported in one study,[28] in which a direct contact device was used. Thus, there has been no evidence regarding the changes of biofilm after ultrasonic debridement using non-contact devices in patients, whereas the effectiveness against in vivo model of wound biofilm by ultrasonic debridement using a non-contact device has been reported.[30]

5.1.2 | Implications for practice

This scoping review clarified that clinical evidence demonstrating the effectiveness of ultrasonic debridement on the healing process of pressure ulcers and arterial ulcers is limited compared to DFUs and VLUs. In this respect, findings from the current scoping review support the effectiveness of ultrasound as an adjunctive therapy for treatment of DFUs and VLUs. In addition, the optimum settings for ultrasonic debridement using non-contact

devices in clinical practice have been reported in this scoping review.

5.1.3 | Future perspectives

This scoping review provides important implications for future studies on ultrasonic debridement. The settings concerning ultrasonic debridement using devices that require direct contact with the wound were found to be diverse. The optimum settings for contact devices are expected to be determined in future studies. Additionally, the RCTs identified in this scoping review were performed in the US, Canada, and Germany, and this highlights the need for future studies involving patients with varied characteristics, such as racial background. Such variations may influence the effectiveness of ultrasonic debridement and will need to be explored in the future.

Furthermore, there was only one clinical study which explored the association between ultrasonic debridement and biofilms,[28] and this study targeted the wounds whose depth was deeper than the dermis, of which 94% contained necrotic tissue. Therefore, future studies exploring the association between ultrasonic debridement and biofilms in superficial wounds, wounds without necrotic tissue, and wounds whose healing is inhibited by biofilms, such as wounds with critical colonisation, are needed. Additionally, a future study to investigate biofilm reduction by ultrasonic debridement using non-contact devices is also desirable.

6 | LIMITATIONS

This scoping review had some limitations. We did not extract information on the quality of evidence provided by the authors nor was the quality of the study assessed systematically in this scoping review. Additionally, we used "biofilm" or "bacteria" as search terms; however, the specific bacterial names of major components in biofilms were not used. Furthermore, we cannot rule out the possibility that the articles on mixed-aetiology ulcers were not included, if these articles did not have the terms used in the search strategy. These processes might affect the selection results of the evidence.

7 | CONCLUSIONS

This scoping review summarised the evidence regarding the effectiveness of ultrasonic debridement on the changes in bacteria and biofilm, in association with promoting wound healing. Ultrasonic debridement using non-contact devices improved wound healing by attenuating inflammatory responses, although the bacterial load did not change significantly, and the optimum settings could be summarised as follows: 2–5 minutes per session for wounds of <10 to 20 cm^2, and an additional several minutes for larger wounds, for around 3 times a week. On the contrary, the devices that required direct contact with the wound promoted wound healing by reducing bacterial load or bacterial growth. However, the settings for these devices were diverse. Further studies using ultrasonic debridement on chronic wounds are needed, as the relevant literature remains sparse.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this scoping review article, as no new data were created or analyzed in this study.

ORCID

Yukie Kataoka https://orcid.org/0000-0002-7201-7253
Gojiro Nakagami https://orcid.org/0000-0002-9650-2464
Sofoklis Koudounas https://orcid.org/0000-0002-3915-2322
Carolina D. Weller https://orcid.org/0000-0002-8016-1060
Hiromi Sanada https://orcid.org/0000-0003-1912-1251

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