ORIGINAL ARTICLE

Ultrasound Transducer Infection Control in Emergency Department: Bacterial Load and Effectiveness of Different Cleaning Methods

Maryam Abu Bakar[1], Afifah Sjamun Sjahid[1], Siti Suraiya Md Noor[2,3], Mimi Azliha Abu Bakar[1], Nadia Binti Sa'at[4]

[1] Department of Emergency Medicine, Universiti Sains Malaysia, School of Medical Sciences, Kubang Kerian, Kelantan, Malaysia
[2] Infection Control and Epidemiology Unit, Universiti Sains Malaysia
[3] Department of Microbiology and Parasitology, School of Medical Sciences, Universiti Sains Malaysia
[4] Unit of Biostatistics and Research Methodology, School of Medical Sciences, Universiti Sains Malaysia

ABSTRACT

Introduction: Point-of-care ultrasonography (POCUS) is increasingly used across medical fields, highlighting the need to prevent cross-contamination through ultrasound probes. This study aims to assess bacterial contamination on ultrasound probes and evaluate the effectiveness of different cleaning methods. **Methods:** A prospective cross-sectional study was conducted in the emergency department of a hospital in Kelantan from August 2023 to February 2024. Pre- and post-cleaning samples were collected from ultrasound probes meeting the inclusion criteria. Three cleaning methods were compared: 4% chlorhexidine (CHD), quaternary ammonium compound, and clean papers. Results were measured in colony-forming units per millilitre (CFU/ml). **Results:** A total of 99 samples were collected, with equal distribution among the three cleaning methods. Most probes (83.8%) were used in non-trauma cases, and 99% of gross contamination was from wet gel, with blood accounting for 1%. Curvilinear probes showed the highest bacterial growth, with a median of 3450 CFU/ml (range: 0–7.2 × 10^5). All cleaning methods significantly reduced bacterial contamination ($p<0.001$), with 4% CHD showing the greatest reduction. No other factors were significantly associated with bacterial load. **Conclusion:** Ultrasound probes are prone to bacterial contamination, but proper cleaning methods, particularly using 4% CHD, can significantly reduce contamination levels.
Malaysian Journal of Medicine and Health Sciences (2026) 22(2): 1-7.doi:10.47836/mjmhs.v22.i2.1542

Keywords: Bacterial load, Ultrasonography, Chlorhexidine, Quarternary ammounium compounds, Emergency service

Corresponding Author:
Afifah Sjamun Sjahid, MD
Email: afifahkk@usm.my
Tel: +6017-9805054

INTRODUCTION

The use of point-of-care ultrasound (POCUS) have become increasingly popular across various fields of medicines, including emergency medicine. POCUS helps to improve diagnostic accuracy, procedural safety, and timeliness of care(1). Furthermore, it can be conveniently performed at the bedside. Most importantly it is relatively safe, as it does not expose patients or operators to neither contrast agents nor radiation.

The surface of the probes that we use come into contact with patients' skin, blood, and other bodily fluids, that can lead to cross-contamination between patients and operators. Therefore, employing a proper cleaning method is very crucial after each examination. A study showed that cultures taken from a public toilet and bus pole had lower bacterial loads in comparison to ultrasound probes which do not undergo proper cleaning processes(2). Most operators only clean the ultrasound probes using a dry towel without any disinfection wipes(2). This happens to be a common practice in most healthcare centres in Malaysia. However, due to the lack of studies regarding this practice in Malaysia, we do not have sufficient data to support this statement.

A study conducted in Thailand by Lenghong K et.alfound that cleaning using a dry paper towel alone turned out to be the worst cleaning method among others (3). An earlier study by Mirza et al.compared three different cleaning methods namely tissue papers, saline and soap wipes. This study found that tissue papers were the least effective method(4). Although all three methods of cleaning can reduce the pathogenic bacterial count to certain extent, the soap wipes technique was identified as the best and most cost-effective method(4).

Apart from probes, cords and gels were found to be potential sources of bacterial contamination. Heated gel provides a conducive environment for bacterial growth (5). Older studies have shown that gel can be heavily contaminated with potentially pathogenic organisms like Staphylococcus aureus and Enterococcus faecalis. However, no multi-resistant organisms were identified (6).

This study aims to ascertain the extent of bacterial contamination on ultrasound probes, factors affecting bacterial contamination, and the effectiveness of different cleaning methods. By utilising the data gathered from the present research, we may enhance healthcare services for patients by minimising the risk of bacterial infections.

MATERIALS AND METHOD

This was a prospective cross-sectional study conducted in the emergency department (ED) of Hospital Universiti Sains Malaysia from August 2023 to February 2024. It involved all ultrasound machines available in the ED. Samples were collected from all probes, but the transcavitary probes were excluded. The inclusion criteria were post-examination of non-critical transducers (e.g., external use linear, curvilinear, and phased array transducers) in the ED. The exclusion criteria included transcavitary transducers and any ultrasound-guided procedures.

After each ultrasound examination performed in the ED that fulfilled the inclusion and exclusion criteria, the first sample was taken by the primary investigator. A swab technique was used to extract the sample from a previously used and unclean probe. The sample was then sent to the laboratory and underwent a serial dilution technique before being cultured on agar. All the serial dilutions, plating and counting of bacterial colonies were done in the microbiology laboratory by the expert personnel in the field. Proper swabbing technique was emphasised in this study and a proper training had been provided by the infection control unit to ensure a correct swabbing technique. Once the first swab sample had been obtained, the probes ware cleaned using a randomly assigned cleaning method. The three different cleaning methods include clean dry paper, 4% chlorhexidine without alcohol and a quaternary ammonium compound. Each of the reagents was colour coded into green (clean dry paper), yellow (4% chlorhexidine) and red (quaternary ammonium compound), respectively and sealed in 99 separate envelopes which composed of 33 reagents from each respective group. Each envelope contained one of the three cleaning methods. After the cleaning process was completed and the probe was left to dry for approximately five minutes, the second sample was taken using the same technique. The second sample could only be taken once the probe was completely dry. Both samples were cultured and the results were interpreted in the form of colony-forming units per millilitre (CFU/ml). Based on the results obtained, the bacterial load was further subdivided into three groups of no growth, moderate growth and numerous growths. Plates showing no bacterial growth at all were classified as no growth. Plates with colonies too dense to count even after multiple dilutions, were classified as numerous growths. Plates with countable colonies were classified as moderate growths. The flowchart of the process is simplified in Figure 1.

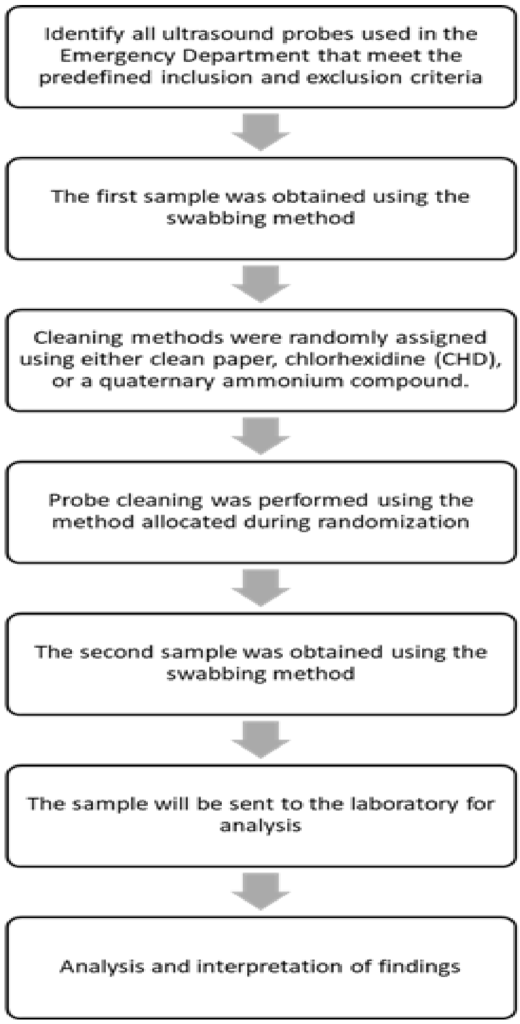

Figure 1: Study flowchart

In this study, descriptive statistics were employed for selected variables. The findings were then presented based on the type and distribution of the data. Categorical data were presented as frequencies and percentages, while numerical data were presented as medians and minimum and maximum values, as the data were not normally distributed.

Comparison of the effectiveness between conventional cleaning method (clean paper) and low-level disinfection (LLD) was analysed using the Wilcoxon Signed Rank test. Factors affecting bacterial load of ultrasound probes in the emergency department were analysed using Fisher's exact test. A level of significance (p-value) of less than 0.05 was considered statistically significant.

RESULTS

A total of 99 samples were collected in this study. The samples were subsequently divided into three different cleaning methods with 33.3% allocated to 4% CHD, 33.3% to Quaternary Ammonium Compound and 33.3% to clean papers. Most of the samples taken were obtained from non-trauma cases (83.8%). The number of patients in the zone always exceeded 50%. Only 5.1% of cases involved zones with patient counts of less than 50% at the time of sampling. Other details and a summary of the sample obtained in this study are presented in Table I.

Table I: Summary of data distribution.

Variables	n	%
Trauma		
Yes	16	16.2
No	83	83.8
Type of probe		
Curvilinear	38	38.4
Linear	25	25.3
Phase array	36	36.4
Working shift		
AM	34	34.3
PM	32	32.3
Night	33	33.3
Zone		
Red zone	42	42.4
Yellow zone	57	57.6
No. of patients currently in the zone		
<50%	5	5.1
51% - 80%	9	9.1
>80%	63	63.6
Full	22	22.2

The bacterial load was measured according to the number of bacterial colonies cultured (CFU/ml). Curvilinear probe showed the highest number of bacterial growths before cleaning, with a median of 3450 (0, 7.2 Ч 105). The cultured bacterial colonies were categorised into three groups of no growth, moderate growth and numerous growths. Most of the time, for all probe types, moderate growth was observed (Table II).

Table II: Bacterial load according to number of bacterial colonies on different types of probes in emergency department before cleaning.

Type of Probe	CFU/ml Median (Min, Max)	No Growth n (%)	Moderate n (%)	Numerous n (%)
Curvilinear	3450 (0,720000)	1 (2.6)	32 (84.2)	5 (13.2)
Linear	700 (0, 15200)	5 (20.0)	20 (80.0)	0
Phased array	2800 (0, 250000)	3 (8.3)	30 (83.3)	3 (8.3)

Table III shows that all the three different cleaning methods had a significant difference in bacterial colony counts pre- and post-cleaning process (p<0.001). The 4% CHD achieved the greatest reduction in bacterial growth compared to other methods as it had the lowest post-cleaning bacterial growth (Table III). According to Fisher's Exact test, there was a significant association between cleaning methods and the percentage of bacterial growth reduction (p<0.001) for all three cleaning methods. The highest reduction in bacterial colonies at 100% was observed with 4% CHD (75.8%) when comparing pre- and post-cleaning, in contrast to dry clean paper (42.4%) and quaternary ammonium compound (63.6%). Based on these results, 4% CHD was identified as the preferred cleaning method (Table IV).

Table III: The effectiveness between conventional cleaning method (clean papers) and low-level disinfection (LLD).

Type of Cleaning Methods	Pre-Cleaning Bacterial Load (CFU/ml) Median (Min, Max)	Post-Cleaning Bacterial Load (CFU/ml) Median (Min, Max)	z-score	p-value*
Dry clean paper	3100 (200, 720000)	100 (0, 20000)	-5.012	<0.001
4% Chlorhexidine without alcohol	1500 (0, 150000)	0 (0, 200)	-4.459	<0.001
Quaternary ammonium	2200 (0, 250000)	0 (0, 1500)	-4.861	<0.001

*Wilcoxon Signed Ranks Test

Table IV: Percentage of bacterial growth reduction between different cleaning methods.

Percentage of bacterial growth reduction	Type of cleaning method			P-value*
	Dry clean paper n (%)	4% CHD n (%)	Quaternary ammonium n (%)	
0%	0 (0%)	7 (21.2%)	2 (6.1%)	
1% - 99%	19 (57.6%)	1 (3.0%)	10 (30.3%)	<0.001
100%	14 (42.4%)	25 (75.8%)	21 (63.6%)	

*Fisher's Exact Test

None of the involved factors were significantly associated with the bacterial load of the ultrasound probes in this study (Table V).

Table V: The factors affecting bacterial load of ultrasounds probes in emergency department.

Variables	No growth n (%)	Moderate n (%)	Numerous n (%)	p-value*
PPE				
Apron	0 (0.0%)	1 (1.2%)	0 (0.0%)	
Glove	1 (11.1%)	2 (2.4%)	0 (0.0%)	0.688
Both	0 (0.0%)	2 (2.4%)	0 (0.0%)	
None	8 (88.9%)	77 (93.9%)	8 (100.0%)	
Working shift				
AM	1 (11.1%)	31 (37.8%)	2 (25.0%)	
PM	6 (66.7%)	25 (30.5%)	1 (12.5%)	0.100
Night	2 (22.2%)	26 (31.7%)	5 (62.5%)	
Zone				
Red zone	5 (55.6%)	34 (41.5%)	3 (37.5%)	0.723
Yellow zone	4 (44.4%)	48 (58.5%)	5 (62.5%)	
Bed occupancy in the zone				
<50%	1 (11.1%)	3 (3.7%)	1 (12.5%)	
51% - 80%	0 (0.0%)	8 (9.8%)	1 (12.5%)	0.099
>80%	8 (88.9%)	49 (59.8%)	6 (75.0%)	
Full	0 (0.0%)	22 (26.8%)	0 (0.0%)	
Type of probe				
Curvilinear	1 (11.1%)	32 (39.0%)	5 (62.5%)	
Linear	5 (55.6%)	20 (24.4%)	0 (0.0%)	0.081
Phase array	3 (33.3%)	30 (36.6%)	3 (37.5%)	
Gross contamination				
Blood	0 (0.0%)	1 (1.2%)	0 (0.0%)	1.000
Wet gel	9 (100.0%)	81 (98.8%)	8 (100.0%)	
Trauma				
Yes	4 (44.4%)	12 (14.6%)	0 (0.0%)	0.054
No	5 (55.6%)	70 (85.4%)	8 (100.0%)	

*Fisher's Exact Test

DISCUSSION

Point-of-care Ultrasounds (POCUS) has become an increasingly sought-after modality among clinicians these days. It is convenient for patients, non-invasive, rapid, and can be performed at the bedside without exposing the patient to any radiation(7). Their easy to carry and portability make it convenient for clinicians to move between patients. However, these characteristics also increase the risk of contamination and cross-transmission between patients(7–9). Numerous previous research has demonstrated that not just common flora, but also pathogenic organisms have been cultured from ultrasound probes (10–12). Among these organisms are Staphylococcus coagulase-neg, Pseudomonas spp., Bacillus spp., Micrococcus spp., Corynebacterium, and Burkholderia cepacia (3,8). Some researchers have even found fungi, methicillin-sensitive Staphylococcus aureus (MSSA) and methicillin-resistant Staphylococcus aureus (MRSA), cultured from the probes(10,12–15). However, despite the various organisms cultured, there is still insufficient evidence to establish that probe colonisation plays a causative role in human infection(14).

Ultrasound probes are used for various purposes. According to the guidelines released by the American College of Emergency Physicians (ACEP), a probe is classified as a noncritical device if it is only used on the intact skin without coming into contact with the mucous membrane(16). Such devices will only require LLD after each use(17). In our study, we found that curvilinear probes harboured the highest bacterial load (3450 CFU/ml) compared to linear probes (700 CFU/ml) and phased array probes (2800 CFU/ml). However, no other studies were found to compare our findings. This could be due to curvilinear probes having the widest interface or footprint in comparison to the other two probes. Besides that, the curvilinear probes had the highest usage rate in the emergency department, accounting for 38.4% compared to phased array probes at 36.4% and linear probes at 25.3%. Due to their highest usage rate, they are more prone to contamination and contribute to the highest load of bacterial contamination. This study reveals that clinicians in emergency departments prefer curvilinear probes due to their high usage rates.

To date, all the present studies show that the bacterial contamination of ultrasound probes is significantly high. According to a survey conducted in the United States, the emergency department had the third-highest rate of ultrasound usage, following the radiology department and the obstetrics and gynaecology departments, with poor reprocessing and significant noncompliance with existing guidelines(18). Another separate study conducted in France, specifically targeting emergency physicians, noted that the overall rate of compliance to guidelines was 66%. While this is acceptable, there is still considerable room for improvement(19). Thus, it is important for us clinicians to ensure that probes are properly cleaned before being used on other patients. The Canadian Association of Emergency Physicians recommends the use of LLD effective against mycobacteria and blood-borne viruses for POCUS disinfection(20). In this study, we aim to compare the most conventionally used method in the emergency department, which is clean paper with LLD. The LLD we used were 4% CHD without alcohol and a quaternary ammonium compound. All three methods tested showed a significant reduction in bacterial growth post-cleaning ($p<0.001$). The most efficient method with the highest percentage of 100% reductions post-cleaning was 4% CHD without alcohol, which accounted for 75.8%. The quaternary ammonium compound showed 63.6% while clean paper was only 42.4%. This finding is similar with a study conducted in Thailand(3).

CHD can easily be found in all emergency departments. It belongs to a group called antiseptic and antibacterial agents. Generally, CHD is widely used as a disinfectant(21). It exists in different formulations such as patient bathing, skin antiseptic, mouth care and hand washing or rubs(22). It can also be diluted into different concentrations, tailored to our needs and suitability at that time. CHD can be prepared by the pharmacist according to the respective hospital protocols and this is a very crucial aspect to ensure that no alcohol is added to the preparations, as alcohol is well known to cause degradation of piezoelectric crystals in ultrasound transducers, especially those of linear type(23). Furthermore, CHD is cost-effective and readily available in most hospitals. Supported by findings from other studies, the author found out that LLD is noninferior to HLD in terms of disinfecting ultrasound transducers contaminated by skin microorganisms(24).

In this study, several factors had been analysed to determine whether there were any significant associations between those factors and the bacterial load of ultrasound contamination. Among those factors analysed were the use of personal protective equipment (PPE) while performing ultrasound examinations, zone involved (red or yellow zone), working shift, bed occupancy in the zone, type of probes, gross contamination and lastly, trauma case or non-trauma case. However, none of the factors showed a significant association, with the lowest p-value being 0.054. A previous study sought to ascertain the correlation between the frequency of contamination and the time of day or working shift and it turned out to be statistically non-significant as well(25). Besides that, we couldn't find any other similar studies regarding the associated factors that we looked into. As the results showed no significant associations, we could confidently say that regardless of the ultrasound's surroundings, it will not affect the bacterial load of our probes. Thus, in other words, it reflects a good and proper cleaning method with a suitable reagent is what we need to decontaminate and prevent cross-transmission between patients and operators. This will improve patients' safety as it reduces the risk of contamination and cross-infections in hospital settings.

This study has several limitations that should be acknowledged. First, it was conducted at a single centre and specifically limited to the emergency department setting. As such, the findings may not be generalizable to other hospital departments or institutions with different patient populations, workflows, or environmental factors. Multi-centre studies would be necessary to validate these results across various healthcare settings.

Second, due to funding constraints, we were unable to perform microbiological analyses to identify specific bacterial species present on the surfaces. This limits our understanding of the spectrum and clinical significance of the pathogens potentially involved, and it restricts our ability to correlate specific bacterial types with the effectiveness of the disinfection agents used.

Lastly, our centre does not currently have access to advanced disinfection technologies, such as ultraviolet (UV) sterilisation systems or hydrogen peroxide vapour systems. This limited our ability to compare the efficacy of these more modern technologies against the low-level disinfectants (LLDs) evaluated in our study. Including such comparisons in future studies would provide a more comprehensive assessment of disinfection strategies in healthcare environments.

CONCLUSION

According to this study, ultrasound probes are highly contaminated, and applying a proper cleaning technique can significantly reduce bacterial contamination. Based on the outcome of this study, we would like to suggest the use of 4% CHD as the cleaning method of choice in the ED. Further efforts can be done to develop a proper cleaning protocol or booklet to educate all user regarding a proper cleaning technique and its importance.

ACKNOWLEDGEMENT

The authors would like to express our utmost gratitude from the bottom of our hearts to all members of the Emergency Department, Hospital Universiti Sains Malaysia, who helped in the completion of this study.

REFERENCES

1. American College of Emergency Physicians. Guideline for ultrasound transducer cleaning and disinfection. 2018. p. 2–7.
2. Sartoretti T, Sartoretti E, Bucher C, Doert A, Binkert C, Hergan K, et al. Bacterial contamination of ultrasound probes in different radiological institutions before and after specific hygiene training: do we have a general hygienical problem? Eur Radiol. 2017;27(10):4181–7. doi: 10.1007/s00330-017-4812-1
3. Lenghong K, Kleebbuakwan K, Apiratwarakul K, Phungoen P, Gaysonsiri D, Bhudhisawasdi V. Comparison of Cleaning Methods for Ultrasound Probes at an Emergency Department in a Resource-Limited Country Correspondence to: Comparison of Cleaning Methods for Ultrasound Probes at an Emergency Department in a Resource-Limited Country. Vol. 103, Article in Journal of the Medical Association of Thailand = Chotmaihet thangphaet. 2020.
4. Mirza WA, Imam S, Salim KM, Aslam M, Ali S, Masroor I, et al. Cleaning methods for ultrasound probes. ecommons.aku.edu [Internet]. 2008 [cited 2023 Mar 19];18(5):286–9. Available from: https://ecommons.aku.edu/pakistan_fhs_mc_radiol/104/
5. Westerway SC, Basseal JM, Brockway A, Hyett JA, Carter DA. Potential infection control risks associated with ultrasound equipment – a bacterial perspective. Ultrasound Med Biol. 2017;43(2):421–6. doi: 10.1016/j.ultrasmedbio.2016.09.004
6. Mattar EH, Hammad L. University Hospital in Saudi Arabia Article in Journal of Clinical and Diagnostic Research [Internet]. 2010. Available from: https://www.researchgate.net/publication/235943923
7. Heldeweg MLA, Berend K, Cadenau L, Rosingh A, Duits AJ, van Mansfeld R, et al. Bacterial Contamination of Ultrasound and Stethoscope Surfaces in Low- and High-Resource Settings. American Journal of Tropical Medicine and Hygiene. 2022 Aug 1;107(2):463–6.
8. Genc O, Umay S. Can ultrasound probes and gels be the source for opportunistic bacterial infections? Medicine Science | International Medical Journal. 2020;(0):1.
9. Van Kalsbeek D, Enroth K, Lyden E, Rupp ME, Smith CJ. Improving hospital-based point-of-care ultrasound cleaning practices using targeted interventions: a pre–post study. Ultrasound Journal. 2021 Dec 1;13(1).
10. Miyague AH, Mauad FM, Martins W de P, Benedetti ACG, Ferreira AEG de MT, Mauad-Filho F. Ultrasound scan as a potential source of nosocomial and crossinfection: A literature review. Vol. 48, Radiologia Brasileira. Colegio Brasileiro de Radiologia; 2015. p. 319–23.
11. Koibuchi H, Kotani K, Taniguchi N. Ultrasound probes as a possible vector of bacterial transmission. Med Ultrason. 2013;15:41–4. doi: 10.11152/mu.2013.2066.151.hk1upp2
12. Mullaney PJ, Munthali P, Vlachou P, Jenkins D, Rathod A, Entwisle J. How clean is your probe? Microbiological assessment of ultrasound transducers in routine clinical use, and cost-effective ways to reduce contamination. Clin Radiol [Internet]. 2007 Jul;62(7):694–8. Available from: https://linkinghub.elsevier.com/retrieve/pii/

S0009926007000293
13. Sanz GE, Theoret J, Liao MM, Erickson C, Kendall JL. Bacterial contamination and cleanliness of emergency department ultrasound probes. Canadian Journal of Emergency Medicine. 2011 Nov;13(6):384–9.
14. Dos Santos FD, Merlin MA. Emergency department ultrasound probe infection control: challenges and solutions. Open Access Emergency Medicine [Internet]. 2015 Jan;7:1. Available from: http://www.dovepress.com/emergency-department-ultrasound-probe-infection-control-challenges-and-peer-reviewed-article-OAEM
15. Ohara T, Ltoh Y, Ltoh K. M Ultrasound instruments as possible vectors of staphylococcal infection. Vol. 40, journal of Hospital Infection. 1998.
16. American College of Emergency Physicians. Guideline for Ultrasound Transducer Cleaning and Disinfection [Internet]. 2018 [cited 2024 May 24]. p. 2–7. Available from: https://www.acep.org/patient-care/policy-statements/guideline-for-ultrasound-transducer-cleaning-and-disinfection
17. Rutala WA, Weber DJ. Guideline for Disinfection and Sterilization in Healthcare Facilities, 2008.
18. Carrico RM, Furmanek S, English C. Ultrasound probe use and reprocessing: Results from a national survey among U.S. infection preventionists. Am J Infect Control. 2018 Aug 1;46(8):913–20.
19. Andolfo A, Maatoug R, Peiffer-Smadja N, Fayolle C, Blanckaert K. Emergency ward ultrasound: clinical audit on disinfection practices during routine and sterile examinations. Antimicrob Resist Infect Control. 2021 Dec 1;10(1).
20. Bell C, Sheppard G, Andani R, Katz N, Kim DJ. Canadian association of emergency physicians emergency ultrasound committee best practice recommendations on point-of-care ultrasound disinfection. Canadian Journal of Emergency Medicine. 2024 Mar 1;26(3):145–7.
21. Noor SSSE, Pradeep. Chlorhexidine: Its properties and effects. Res J Pharm Technol. 2016;9(10):1755.
22. Van den Poel B, Saegeman V, Schuermans A. Increasing usage of chlorhexidine in health care settings: blessing or curse? A narrative review of the risk of chlorhexidine resistance and the implications for infection prevention and control. Vol. 41, European Journal of Clinical Microbiology and Infectious Diseases. Springer Science and Business Media Deutschland GmbH; 2022. p. 349–62.
23. Koibuchi H, Fujii Y, Kotani K, Konno K, Matsunaga H, Miyamoto M, et al. Degradation of ultrasound probes caused by disinfection with alcohol. Journal of Medical Ultrasonics. 2011 Apr 23;38(2):97–100.
24. Peters N, Williamson F, Bauer MJ, Llewellyn S, Snelling PJ, Marsh N, et al. Comparison of low-level to high-level disinfection in eliminating microorganisms from ultrasound transducers used on skin: a noninferiority randomized controlled trial. J Ultrasound Med. 2023;42(11):2525–34. doi: 10.1002/jum.16286
25. Kiraly A, Stedford A, Awad E, Adam G, Besserer F. Evaluation of portable ultrasound machine contamination in a community emergency department. Med Res Innov. 2020;4(1).