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Implications of chlorhexidine use in burn units for wound healing[☆]

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ABSTRACT

Chlorhexidine is known to be a potent antiseptic with evidence of a beneficial role in burn care. Nevertheless, several *in vitro* studies have reported cytotoxicity on cultured cells, while *in vivo* and clinical data seem to show more controversial results. In the frame of this work, we aimed to evaluate the use of chlorhexidine in burn units worldwide by sending a survey to professionals of the field. We associated survey results to those perspectives reported in the literature to update recommendations for the use of chlorhexidine in specific protocols for burn management. The survey results showed that there is no clear consensus on the use of chlorhexidine regarding the concentrations, the type of excipient and the cleansing after application. Literature searches showed evidence that the skin of premature infants appears to be more sensitive to chlorhexidine than adult skin, with more reported cases of adverse effects. It was also determined that aqueous formulations of chlorhexidine do not appear to be necessarily less efficient than with alcohol as an excipient, and that lower concentrations are as efficient as higher concentrations. In view of this study, we have adjusted our protocols for the use of aqueous formulations at low concentrations and investigated further the role of washing after application in order to standardize the indication of chlorhexidine and minimize the probability of adverse effects.

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1. Introduction

Skin is the main physical and chemical barrier against pathogens, notably by producing antimicrobial peptides [1]. This barrier is destroyed by burns rendering the body more prone to infections due to a lack of vascularity, immune deficiency and repeated surgery [2]. Infections can inhibit wound healing by invasion and dissemination of microorganisms, which can extend the inflammatory phase with an increase of pro-inflammatory cytokines and proteases, inducing disproportionate granulation tissue degradation associated with impaired healing [3]. With a prevalence of infection in burn units of

approximately 66% and more than 11 million people affected annually by burn injuries worldwide [4], wound infection has become the major cause of mortality, morbidity and wound healing delay [5,6]. Furthermore, rate of mortality in burn patients is three times higher in patients who are infected by pathogens [7]. Therefore, infection still remains a major challenge of wound care in burn units.

Clinically, infection can be seen by a discoloration of the wound, sloughing of burned tissue, increased edema or particular odor, and is usually characterized by a load of more than 10⁵ microorganisms per gram of tissue [8]. Microorganisms that infect burn wounds are heterogeneous depending on the anatomical site and time after injury and they can include bacteria,

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virus and fungi [9,10]. Most of the time, *Staphylococcus* and *Pseudomonas* are responsible for infections and sepsis in burn cases [11]. Commonly, antiseptics are used in order to significantly reduce bacterial load of the skin or mucous membranes [12].

Reference to antiseptic substances can be traced back to the time of ancient Egyptians, who used coniferous resin for antimicrobial effect in the process of embalming mummies [13]. Also, in early medical practices, the anti-bacterial effects of honey, vinegar and wine were well known [14,15]. However, major developments for antiseptics took place from the 19th century to the 20th century. Briefly, Bernard Courtois, discovered iodine in 1811 [16], which is presently a commonly used antiseptic agent. Bromine, carbolic acid and sodium hypochlorite were established to be effective in treating gangrene during the Civil War (1861–1865) [17]. In 1897, Joseph Lister, inspired by the work of Louis Pasteur on bacteria, discovered the antiseptic properties of phenol (carbolic acid) in surgery [18]. During the First World War, irrigation of wounds with Dakin solution (composed of sodium hypochlorite) was initiated. Later during the Vietnam war, several studies against infections permitted the development of Mafenide acetate and silver sulfadiazine, two topical antimicrobials still used routinely today [17].

The mechanisms of action and effects of the contemporary antiseptic agents are currently not totally determined and understood. In particular, Chlorhexidine has been used since 1954 and studied for wound care only in the last 20–30 years. While it is a potent antiseptic, chlorhexidine has been reported in relation to serious burn injuries under certain circumstances [19]. Nowadays, specific guidelines for the use of chlorhexidine in burn units is of benefit. The state of the literature for Chlorhexidine reports numerous concentrations and in different excipients for the same indication. We therefore evaluated the worldwide use of chlorhexidine in burn units and associated this information into perspective with the effects reported in the literature. Overall, this allows an update for recommendations of specific protocols for burn patient care.

2. Methods

In order to evaluate the use of Chlorhexidine in burn units, a survey was sent worldwide to 213 professionals of burn care. The survey encompassed questions about the performed practice in burn wound management and associated concentrations of antiseptics containing Chlorhexidine. The survey was sent twice in the same year at an interval of 5 months in order to obtain a maximum number of responses. We compared the responses of the external medical units with the internal protocols of our hospital, as the Burn Center of the Lausanne University Hospital (CHUV) was among the first burn units to receive certification from the European Burns Association. Data were also compared to the existing literature on patient care involving Chlorhexidine. For more details on the survey questions and criteria for the literature review, please refer to the Supporting Information.

3. Results

3.1. Survey

In order to have a worldwide overview of the use of Chlorhexidine in burn units, a survey was sent out to 213 professionals of burn care, among which 36 were filled, thus representing a participation rate of 17%.

The health care category, medical practice and geographical region of the participants who completed the survey are presented in Fig. 1. In summary, the majority of the responses came from physicians (77%) and nurses (23%), working in Burn Care (53%) and Plastic Surgery (38%), mainly in Europe (67%) followed by the Middle East (24%).

Participants acknowledged the use of Chlorhexidine on burn wounds by 54%, with Chlorhexidine concentrations varying from 0.02% to 4% (Fig. 2a–b). The most common Chlorhexidine concentrations used in burn care were found to be 0.05% (31% of the participants) and 4% (23% of the participants), which represents a concentration difference of 100-fold. Also, for approximately 31% of the responses, the practitioner did not know the Chlorhexidine concentration used (no specific response). As an alternative substance instead of Chlorhexidine, Betadine® was the most used disinfectant (40%), followed by saline solution (11%), soap and water (6%) and hydrogen peroxide (3%). Overall, 40% of survey participants did not answer this specific question (Fig. 2c).

The survey participants were also asked if they washed the burn wounds after disinfection, with 60% of the participants responding positively (Fig. 3a); this question was asked as we postulated that rinsing the patient after disinfection may reduce side effects. Nevertheless, 63% of the participants reported the observations of side effects (Fig. 3b), such as skin irritation, dryness, inhibition of wound healing and pseudomonas contamination. Moreover, the results have revealed different shower frequencies depending on the hospitals; only three hospitals reported to not use shower systems. Shower frequency shows two trends of either a daily shower (35%) or only when indicated (22%). In addition, other practice was found, such as a shower twice a week of every other day (Fig. 3c).

Reported protocols for burn wound cleaning varied between the different hospitals. Among the responses received, some even reported that they have no Standard Operating Procedures (SOPs) in place and they transfer the patient directly to specialized centers. However, for a majority, one or the other of the following SOP's is implemented in routine: (i) Disinfection with Betadine® only or Betadine® wiped afterward with saline solution. In case of allergy of Betadine®, washed only with saline water. (ii) Disinfection with Chlorhexidine at concentration 0.05% and 4%. Some of them used only Chlorhexidine or after a first wash with Betadine® and normal saline solution. Others used Chlorhexidine at first and then washed with soapy water, normal saline water or betadine®. (iii) Application of MEBO® ointment on the burn. Thereafter, old ointment removed and apply the new layer three times per day. (iv) Application of Flamazine® directly on the

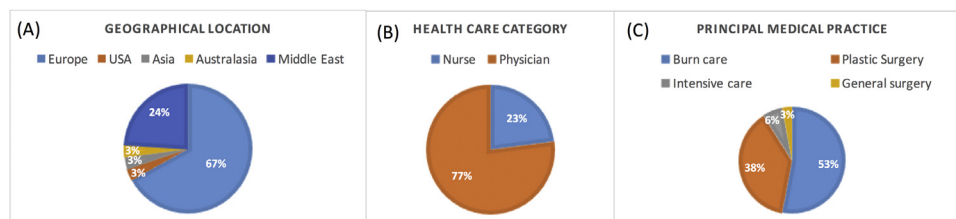


Fig. 1 – Survey results: (A) geographical location of the survey participants, (B) health care category as physician or nurse, and (C) field of practice of the participants.

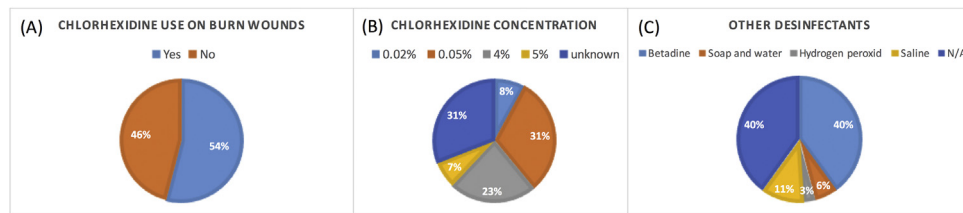


Fig. 2 – Survey results: (A) The fraction of survey participants that use Chlorhexidine, (B) the used concentrations of Chlorhexidine in burn care, and (C) other disinfectants used in burn care.

wound. Also used to remove the eschar and then clean with normal saline solution. (v) Bath or wash with soapy water and wiped with saline water.

Results regarding the type of cover or dressing used and if cellular therapy was routinely used showed that no specific type of dressing is more frequently used than others (Fig. 4a). Among the 33% of other employed wound covers, mentioned included Mebo ointment[®], Flamazine[®], Flaminal[®], Silver sulfadiazine, hypochlorite solution for some infected wounds, dressings Mepitel[®], Mepiplex[®], Acticoat[®] or Urogotul SSD[®], Polyfax[®] and Biobrane[®]. Likewise, the majority of the survey participants (60%) did not answer if they used specific cellular therapy techniques (Fig. 4b).

3.2. Literature review on the use of Chlorhexidine for burns and in wound care

As previously mentioned, burn wounds are subject to infections because the pathophysiology of burns implies loss of physical barrier, blood vessel damage and a subsequent immunosuppressed state, hence the use of antiseptics such as Chlorhexidine in burn management. Following a burn, the wound is sterile except for the presence of some microorganisms deep in the sebaceous glands and hair follicles [20]. Therefore, recommendations to use Chlorhexidine have been reported in the literature to keep burn wounds sterile and to prevent colonization from microorganisms [21,22]. Nevertheless, there are inconsistent results regarding the indication. One article advises use only on large burns to prevent sepsis [23] while two other publications suggest use only for superficial burns as a disinfectant [21,24]. Other indications were reported included use within dressings or embedded in surgical scrub-brushes during strong debridement procedures [9,20].

Contradictory results can be found in the literature regarding Chlorhexidine effect on wound healing, as Wasiak et al. reported in their review article that Chlorhexidine dressings do not reduce the time of burn wound healing compared to hydrocolloid dressings [25]. On the other hand, avoidance of disinfectants such as Chlorhexidine has been advised due to inhibitory effects on wound healing [26–28]. Notably, the majority of adverse effects reported due to Chlorhexidine concerned premature newborns [29–34]. Extremely low birth weight populations seemed to be very susceptible to Chlorhexidine and adverse skin reactions appeared mostly by burns [29]. Also, in comparison to silver sulfadiazine,

Chlorhexidine dressings used in clinics did show less interference with wound reepithelialization [25,35].

In animals, results are similar to clinical data, as Chlorhexidine was also found to inhibit the healing process compared to saline water [36]. At a concentration of 4% Chlorhexidine, the effect was more pronounced than at 0.05%, as expressed in a delay of the formation of the granulation tissue and tissue thickness decrease. On the other hand, authors of another report studied the effect of 0.05% Chlorhexidine on wounds and concluded that Chlorhexidine was more beneficial than normal saline solution [37], and it was reported that the concentration of Chlorhexidine which is cytotoxic in vitro is not cytotoxic in vivo. Finally, neutral effects on wound healing have also been stated, as some authors have reported that either Chlorhexidine does not interfere with the reepithelialization of the wound [38] and that no difference in toxicity of Chlorhexidine on wound healing [39] nor on the delay in the wound healing process were noted [40,41].

3.3. Lausanne University Hospital (CHUV) internal data

Chlorhexidine is an antiseptic largely used in the CHUV for cleansing or for disinfection of hands, skin, wounds or materials. Concentrations vary from 0.02% to 4% and Chlorhexidine can be found to be used in alcoholic or aqueous solution. Table 1 summarizes the use of Chlorhexidine in the different protocols of the CHUV. From the different protocols in use at the CHUV, what appeared relevant is that Chlorhexidine is mainly present for disinfection of skin before surgery and for hand wash procedures. In burn care at CHUV, disinfection with 0.05% Chlorhexidine or Betadine for a duration of 10min is a required step prior to any skin grafting procedure. Indeed, prior to a skin autograft procedure Betadine 10% is employed for 10min. on both, the wound and the donor site. However, if a topical or a dressing containing silver is also applied on the wound, such as Ialugen plus or Aquacel Ag+Extra; in that case Chlorhexidine 0.05% is preferred. If the autograft procedure involves a cell therapy, such as CEA, Chlorhexidine 0.05% for 10min. is also preferred. Interestingly, from 2009 to 2015, about 11.5 million units of chlorhexidine in alcoholic solution were used at CHUV, corresponding to nearly 4 million liters. In comparison, only 450,000 liters were in aqueous solution, which represents 10-fold less (Table 2). The yearly overall use of Chlorhexidine corresponds to 750,000 liters (Fig. 5).

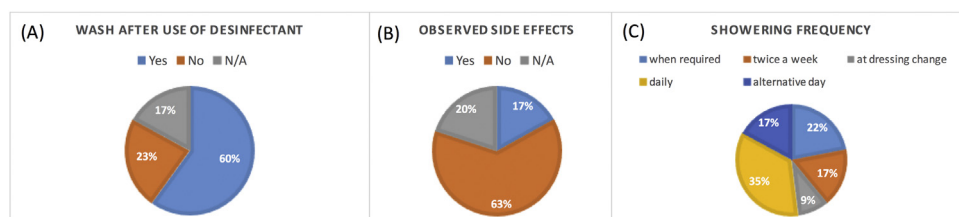


Fig. 3 – Survey results: (A) fraction of the survey participants that shower their burn patients after Chlorhexidine use, (B) the fraction of observed side effects after Chlorhexidine use, and (C) and showering frequency of the burn patients.

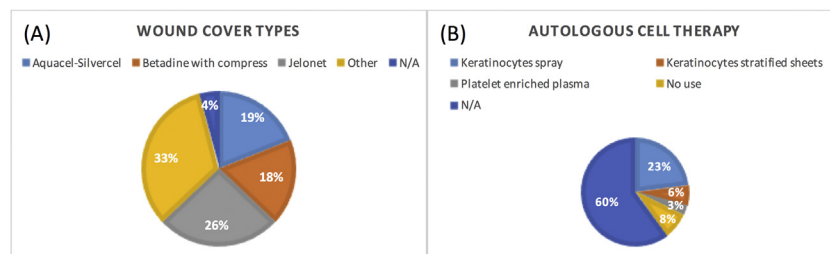


Fig. 4 – Survey results: (A) different types of wound covers used by the survey participants for the burn care, (B) different types of cell therapies used by the survey participants for the burn care.

4. Discussion

In the frame of this study, the first aim was to provide an overview of the use of Chlorhexidine in burn care by sending out a survey to professionals in the field concerning their practice regarding Chlorhexidine use. Overall, the majority of the responses came from European practitioners, and most of them use Chlorhexidine in concentrations varying from 0.02% to 5%. Approximately 20% of side effects were reported when using Chlorhexidine such as skin irritation, dryness, inhibition of wound healing and contamination with *Pseudomonas*. Nevertheless, we were not able, from the received answers, to determine a dose-dependent correlation with observed side effects and if the side-effects were due to the association of alcohol with Chlorhexidine. Strikingly, most of the participants did not know the concentration of Chlorhexidine used, indicating a lack of consensus in the concentration to use. Interestingly, 60% of the professionals who responded to the survey wash the patient after the use of a disinfectant, while this practice is typically not recommended in the literature. This could illustrate that healthcare professionals have the assumption that washing may reduce potential adverse effects. Nevertheless, efficacy of this procedure of post-disinfection wash has to be investigated to be proven. Importantly, it should be investigated if a post-disinfection wash would cancel the antiseptic effect of the Chlorhexidine, especially it has been shown that disinfection efficacy can be improved to some extent by omitting the preceding washing step and by awaiting the evaporation of the alcohol [42].

Another lack of consensus was observed for the frequency of showering of the burn patients, which varied from daily to three times a week. This observation was already reported in the literature, as wound cleansing frequency is based rather on ritualized patterns and preferences of the healthcare staff rather than on evidence-based practice [43,44].

The frequency of wound cleansing should be dictated by several factors, including the amount of exudation, the presence of debris/necrotic tissues, and the half-life of the wound dressing active component when present [43]. A too frequent cleansing may be destructive to the newly formed tissue and alter the wound healing process, namely by removing the exudate which could be essential to keep the wound moist and also which may contain growth factors supporting wound healing [43,45].

Regarding the use of Chlorhexidine related in the literature, we investigated the reports of potential adverse effects at two levels, in vivo studies and clinical case reports, since the in vitro cytotoxicity of Chlorhexidine is well documented [45–48]. The in vivo studies revealed controversial effects of Chlorhexidine related to the healing process of wounds, which is similar to results documented for povidone-iodine [49]. These contradictory results raise several questions that still remain unexplored, such as: (i) why there is a significant difference in the toxicity results of Chlorhexidine between in vitro and in vivo studies and what are the mechanisms underlying these differences? (ii) why products containing Chlorhexidine for clinical disinfection are at a concentration well above effective concentrations against microorganisms and proven to be cytotoxic in vitro? (iii) Does the concentration have an effect on germs selection such as

Table 1 – Different indication of Chlorhexidine use at CHUV.

Chlorhexidine concentration	Clinical use
0.02%	Vesical wash.
0.05%	Disinfection of wounds on ear-nose-throat area.
	Disinfection of the external urethral orifice before placing a urinary catheter or vulval cleansing if prescribed.
0.5%	Cleansing and dressing of burned patient.
	Disinfection of surgery field or intact skin before an invasive surgery, blood sample or injection.
	Disinfection of central venous catheter and venous catheter site by oncologic patients.
	Disinfection of the skin before introduction of a pacemaker.
2%	Disinfection of intravenous connections, gloves, taps.
	Replacement of one-way valve of veinous catheter.
	Desinfection of parenteral feeding field.
	Impregnated gloves for cleansing.
	Disinfection of skin before connection on hemodialysis fistula.
	Hand wash.
4%	Impregnated dressings for intensive care of burn patients.
	Hand wash.
	Preoperative patient wash whether or not colonized by multidrug-resistant germs.
	Entire cleansing of neutropenic patient.

Table 2 – Quantities of Chlorhexidine-containing solutions produced at CHUV (namely its in-house pharmacy) between 2009-2015 for disinfection purposes. The overall quantity corresponds to nearly 4.5 million liters.

Product	Quantity (units)
Chlorhexidine Alcoolique Colorée Braun sol 2% 1 flac 100mL	632, 200.00
Chlorhexidine Alcoolique Colorée Braun sol 2% 1 flac 500mL	3, 589, 000.00
Chlorhexidine Alcoolique Incolore sol 2% 1 flac 250mL	7, 519, 750.00
Chlorhexidine Aqueuse Bichsel sol 0.100% 1 flac 100mL	465, 700.00
Chlorhexidine Aqueuse Braun sol 0.500% 1 flac 100mL	133, 200.00
Chlorhexidine Aqueuse CHUV sol 0.050% 1 flac 500mL	787, 500.00
Chlorhexidine Aqueuse CHUV sol 2% 1 flac 100mL	69, 900.00
Chlorhexidine Incolore Braun teinture 0.500% 1 flac 500mL	10, 000.00
Hibidil Stérile sol 0.050% 5 flac 15 mL	1, 157, 475.00
Hibiscrub sol 4% 1 flac 250mL	1, 250.00
Lifo-Scrub sol 4% 1 flac 100mL	1, 168, 400.00

Quantity of Chlorhexidine produced at CHUV in kilo Liters

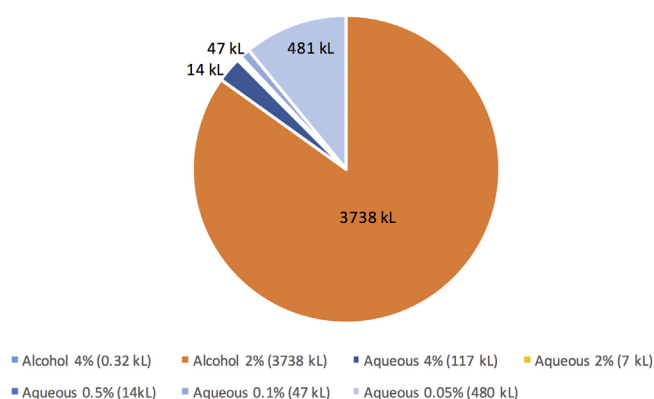


Fig. 5 – Overall quantities in liters of Chlorhexidine-containing solutions produced at CHUV between. 2009-2015.

Pseudomonas? (iv) is there a synergistic effect of alcohol with Chlorhexidine on disinfection and on side-effects?

Regarding the clinical cases reported in the literature, adverse effects were observed for adult patients but most of the adverse effects concerned neonatal cases. There could be multiple reasons why most of the burns by Chlorhexidine were on neonate infants, but the most probable reason is the different and more sensitive skin type, as neonates have a thinner stratum corneum and reduced dermo-epidermal cohesion implying a higher skin permeability [50]. In several case reports [30–33,51,52], authors mentioned the use of alcohol in the preparation on premature infant skin as the cause for irritation. Alcohol is well known for its antibacterial properties and is probably enhancing the disinfection when associated with Chlorhexidine. However, alcohol solutions and povidone-iodine with alcohol are also known to induce burns [31,31,32,33,53–56], which might be another explanation that the alcoholic excipient can be a factor of adverse effect. These types of formulations should therefore be avoided in the neonatal population.

High concentrations of Chlorhexidine often used are not proven to be more effective than lower concentrations [57], while its toxicity is dose dependent. Therefore, there is no reason to use Chlorhexidine at higher concentrations especially on fragile skin such as on burn wounds. An interesting element worth to note is that povidone-iodine and Chlorhexidine are rarely used simultaneously notwithstanding that the incompatibility of these two agents is not evident. Some studies suggest a synergistic antiseptic

effect of these two compound when used together [58,59], without necessarily implying further adverse effect of the combination. Nevertheless, this needs to be confirmed by a randomized trial.

In summary, case reports found in the literature mention skin reactions, burns and allergic reactions mainly on extremely low birth weight infants but these adverse effects also can occur on adults.

Dose dependent toxicity of Chlorhexidine is well demonstrated in vitro, but in vivo results are rare and seem contradictory. Due to the toxicity of Chlorhexidine, its effects on wound healing and specifically on burn wound healing should appear to be harmful but are not really known. Opinions of authors are heterogeneous in the literature [60], though the role of Chlorhexidine in the prevention and treatment of infections have been clearly demonstrated. Finally, further studies are required on the effects of Chlorhexidine on burns and adult population.

Based on the literature review and the results of the survey, minimal changes may diminish adverse reactions and we therefore recommend: (i) inform the medical workers that Chlorhexidine can be harmful if not used properly; (ii) use Chlorhexidine in an aqueous solution at a low concentration (0.05%), especially on fragile skin; (iii) different packaging design and color between aqueous and alcoholic solutions could be implemented in order to avoid confusions.

5. Conclusions

In conclusion, the role of Chlorhexidine in burn care is still a controversy. Effects on wound healing and reepithelization are still contradictory. On the other hand, its large spectrum of action and its role in the treatment of bacterial-resistant infections is well established. As a topical solution, within dressings or brushes and with different solutions could prevent or treat infections of burn wounds. We report herein that there is no clear consensus on the use of Chlorhexidine regarding the concentrations, the type of excipient and the cleansing after application. Literature searches showed evidence that the skin of premature infants appears to be more sensitive to Chlorhexidine than that of adult skin, with more reported adverse effects seen for neonatal skin. Aqueous formulations of Chlorhexidine as well as lower concentrations do not appear to be necessarily less efficient than with alcohol as the excipient. Therefore, we recommend to use lower concentrations, within an aqueous solution and investigate the role of washing after application in order to standardize the indication of Chlorhexidine and minimize the probability of adverse effects for overall burn care.

Conflict of interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.burns.2019.12.008>.

REFERENCES

- [1] Schaubert J, Gallo RL. Antimicrobial peptides and the skin immune defense system. *J Allergy Clin Immunol* 2009;124:R13–8.
- [2] Fournier A, Eggimann P, Pagani JL, Revelly JP, Decosterd LA, Marchetti O, et al. Impact of the introduction of real-time therapeutic drug monitoring on empirical doses of carbapenems in critically ill burn patients. *Burns* 2015;41:956–68.
- [3] McCarty SM, Percival SL. Proteases and delayed wound healing. *Adv Wound Care (New Rochelle)* 2013;2:438–47.
- [4] Peck MD. Epidemiology of burns throughout the world. Part I: distribution and risk factors. *Burns* 2011;37:1087–100.
- [5] Bloemsma GC, Dokter J, Boxma H, Oen IM. Mortality and causes of death in a burn centre. *Burns* 2008;34:1103–7.
- [6] Cumming J, Purdue GF, Hunt JL, O'Keefe GE. Objective estimates of the incidence and consequences of multiple organ dysfunction and sepsis after burn trauma. *J Trauma* 2001;50:510–5.
- [7] Alp E, Coruh A, Gunay GK, Yontar Y, Doganay M. Risk factors for nosocomial infection and mortality in burn patients: 10 years of experience at a university hospital. *J Burn Care Res* 2012;33:379–85.
- [8] Bowler PG. The 10(5) bacterial growth guideline: reassessing its clinical relevance in wound healing. *Ostomy Wound Manage* 2003;49:44–53.
- [9] Church D, Elsayed S, Reid O, Winston B, Lindsay R. Burn wound infections. *Clin Microbiol Rev* 2006;19:403–34.
- [10] Plichta JK, Gao X, Lin HY, Dong QF, Toh E, Nelson DE, et al. Cutaneous burn injury promotes shifts in the bacterial microbiome in autologous donor skin: implications for skin grafting outcomes. *Shock* 2017;48:441–8.
- [11] Appelgren P, Bjornhagen V, Bragderud K, Jonsson CE, Ransjö U. A prospective study of infections in burn patients. *Burns* 2002;28:39–46.
- [12] Bowler PG, Duerden BI, Armstrong DG. Wound microbiology and associated approaches to wound management. *Clin Microbiol Rev* 2001;14:244–69.
- [13] Buckley SA, Evershed RP. Organic chemistry of embalming agents in Pharaonic and Graeco-Roman mummies. *Nature* 2001;413:837–41.
- [14] Daglia M, Papetti A, Grisoli P, Aceti C, Dacarro C, Gazzani G. Antibacterial activity of red and white wine against oral streptococci. *J Agric Food Chem* 2007;55:5038–42.
- [15] Yagnik D, Serafin V, JS A. Antimicrobial activity of apple cider vinegar against *Escherichia coli*, *Staphylococcus aureus* and *Candida albicans*; downregulating cytokine and microbial protein expression. *Sci Rep* 2018;8:1732.
- [16] Chapman EM. The history of the discovery of iodine and its many uses. *Ala J Med Sci* 1987;24:216–9.
- [17] Manring MM, Hawk A, Calhoun JH, Andersen RC. Treatment of war wounds: a historical review. *Clin Orthop Relat Res* 2009;467:2168–91.
- [18] Lister J. Antiseptic principle in the practice of surgery. *Br Med J* 1967;2:9–12.
- [19] Sivathanan N, Ramamurthy NK, Pabla RS. Chemical burns associated with chlorhexidine-alcohol solution: an avoidable complication? *J Burn Care Res* 2010;31:833.
- [20] Tiwari VK. Burn wound: How it differs from other wounds? *Indian J Plast Surg* 2012;45:364–73.
- [21] D'Avignon LC, Saffle JR, Chung KK, Cancio LC. Prevention and management of infections associated with burns in the combat casualty. *J Trauma* 2008;64:S277–86.
- [22] Snelling CF, Inman RJ, Germann E, Boyle JC, Foley B, Kester DA, et al. Comparison of silver sulfadiazine 1% with chlorhexidine digluconate 0.2% to silver sulfadiazine 1% alone in the prophylactic topical antibacterial treatment of burns. *J Burn Care Rehabil* 1991;12:13–8.
- [23] Waitzman AA, Neligan PC. How to manage burns in primary care. *Can Fam Phys* 1993;39:2394–400.
- [24] DeSanti L. Pathophysiology and current management of burn injury. *Adv Skin Wound Care* 2005;18:323–32 quiz 32–4.
- [25] Wasiak J, Cleland H, Campbell F. Dressings for superficial and partial thickness burns. *Cochrane Database Syst Rev* 2008;CD002106.
- [26] Morgan ED, Bledsoe SC, Barker J. Ambulatory management of burns. *Am Fam Phys* 2006;62(2015) 29–30, 32.
- [27] Paunio KU, Knuttila M, Mielitynen H. The effect of chlorhexidine gluconate on the formation of experimental granulation tissue. *J Periodontol* 1978;49:92–5.
- [28] Niedner R, Schopf E. Inhibition of wound healing by antiseptics. *Br J Dermatol* 1986;115(Suppl. 31):41–4.
- [29] Kutsch J, Ottinger D. Neonatal skin and chlorhexidine: a burning experience. *Neonatal Netw* 2014;33:19–23.
- [30] Bringué Espuny X, Soria X, Sole E, Garcia J, Marco JJ, Ortega J, et al. Chlorhexidine-methanol burns in two extreme preterm newborns. *Pediatr Dermatol* 2010;27:676–8.
- [31] Watkins AM, Keogh EJ. Alcohol burns in the neonate. *J Paediatr Child Health* 1992;28:306–8.
- [32] Reynolds PR, Banerjee S, Meek JH. Alcohol burns in extremely low birthweight infants: still occurring. *Arch Dis Child Fetal Neonatal Ed* 2005;90:F10.
- [33] Mannan K, Chow P, Lissauer T, Godambe S. Mistaken identity of skin cleansing solution leading to extensive chemical burns in an extremely preterm infant. *Acta Paediatr* 2007;96:1536–7.
- [34] Lashkari HP, Chow P, Godambe S. Aqueous 2% chlorhexidine-induced chemical burns in an extremely premature infant. *Arch Dis Child Fetal Neonatal Ed* 2012;97:F64.
- [35] Patel PP, Vasquez SA, Granick MS, Rhee ST. Topical antimicrobials in pediatric burn wound management. *J Craniofac Surg* 2008;19:913–22.
- [36] Saatman RA, Carlton WW, Hubben K, Streett CS, Tuckosh JR, DeBaecke PJ. A wound healing study of chlorhexidine digluconate in guinea pigs. *Fundam Appl Toxicol* 1986;6:1–6.
- [37] Sanchez IR, Swaim SF, Nusbaum KE, Hale AS, Henderson RA, McGuire JA. Effects of chlorhexidine diacetate and povidone-iodine on wound healing in dogs. *Vet Surg* 1988;17:291–5.
- [38] Dai T, Huang YY, Sharma SK, Hashmi JT, Kurup DB, Hamblin MR. Topical antimicrobials for burn wound infections. *Recent Pat Antiinfect Drug Discov* 2010;5:124–51.
- [39] Brennan SS, Foster ME, Leaper DJ. Antiseptic toxicity in wounds healing by secondary intention. *J Hosp Infect* 1986;8:263–7.
- [40] Fumal I, Braham C, Paquet P, Pierard-Franchimont C, Pierard GE. The beneficial toxicity paradox of antimicrobials in leg ulcer healing impaired by a polymicrobial flora: a proof-of-concept study. *Dermatology* 2002;204 (Suppl. 1):70–4.
- [41] Popp JA, Layon AJ, Nappo R, Richards WT, Mozingo DW. Hospital-acquired infections and thermally injured patients: chlorhexidine gluconate baths work. *Am J Infect Control* 2014;42:129–32.
- [42] Hubner NO, Kampf G, Kamp P, Kohlmann T, Kramer A. Does a preceding hand wash and drying time after surgical hand disinfection influence the efficacy of a propanol-based hand rub? *BMC Microbiol* 2006;6:57.
- [43] Blunt J. Wound cleansing: ritualistic or research-based practice? *Nurs Stand* 2001;16:33–6.
- [44] Koh S. Wound care. Dressing practices. *Nurs Times* 1993;89(80) 4, 6.

- [45] Atiyeh BS, Dibo SA, Hayek SN. Wound cleansing, topical antiseptics and wound healing. *Int Wound J* 2009;6:420–30.
- [46] Tatnall FM, Leigh IM, Gibson JR. Comparative study of antiseptic toxicity on basal keratinocytes, transformed human keratinocytes and fibroblasts. *Skin Pharmacol* 1990;3:157–63.
- [47] Thomas GW, Rael LT, Bar-Or R, Shimonkevitz R, Mains CW, Slone DS, et al. Mechanisms of delayed wound healing by commonly used antiseptics. *J Trauma* 2009;66(82) discussion -1.
- [48] Liu JX, Werner J, Kirsch T, Zuckerman JD, Virk MS. Cytotoxicity evaluation of chlorhexidine gluconate on human fibroblasts, myoblasts, and osteoblasts. *J Bone Jt Infect* 2018;3:165–72.
- [49] Norman D. The use of povidone-iodine in superficial partial-thickness burns. *Br J Nurs* 2003;12:S30–6.
- [50] Garland JS, Alex CP, Mueller CD, Cisler-Kahill LA. Local reactions to a chlorhexidine gluconate-impregnated antimicrobial dressing in very low birth weight infants. *Pediatr Infect Dis J* 1996;15:912–4.
- [51] Palmanovich E, Brin YS, Laver L, Nyska M, Kish B. Third-degree chemical burns from chlorhexidine local antisepsis. *Isr Med Assoc J* 2013;15:323–4.
- [52] Sanders TH, Hawken SM. Chlorhexidine burns after shoulder arthroscopy. *Am J Orthop (Belle Mead NJ)* 2012;41:172–4.
- [53] Liu FC, Liou JT, Hui YL, Hsu JC, Yang CY, Yu HP, et al. Chemical burn caused by povidone-iodine alcohol solution—a case report. *Acta Anaesthesiol Sin* 2003;41:93–6.
- [54] Lowe DO, Knowles SR, Weber EA, Railton CJ, Shear NH. Povidone-iodine-induced burn: case report and review of the literature. *Pharmacotherapy* 2006;26:1641–5.
- [55] Supradeeptha C, Shandilya SM, Naresh A, Satyaprasad J. Aqueous based Povidone-iodine related chemical burn under the tourniquet (a case report) and literature review. *J Orthop* 2013;10:152–4.
- [56] Rees A, Sherrod Q, Young L. Chemical burn from povidone-iodine: case and review. *J Drugs Dermatol* 2011;10:414–7.
- [57] Gunjan K, Shobha C, Sheetal C, Nanda H, Vikrant C, Chitnis DS. A comparative study of the effect of different topical agents on burn wound infections. *Indian J Plast Surg* 2012;45:374–8.
- [58] Anderson MJ, Horn ME, Lin YC, Parks PJ, Peterson ML. Efficacy of concurrent application of chlorhexidine gluconate and povidone iodine against six nosocomial pathogens. *Am J Infect Control* 2010;38:826–31.
- [59] Davies BM, Patel HC. Does chlorhexidine and povidone-iodine preoperative antisepsis reduce surgical site infection in cranial neurosurgery? *Ann R Coll Surg Engl* 2016;98:405–8.
- [60] Norman G, Christie J, Liu Z, Westby MJ, Jefferies JM, Hudson T, et al. Antiseptics for burns. *Cochrane Database Syst Rev* 2017; CD011821.