Effectiveness of surgical hand antisepsis using chlorhexidine digluconate and parachlorometaxylenol hand scrub

Cross-over trial

Ricardo Becerro de Bengoa Vallejo, PhD, DPM, DHLa, David Sevillano Fernandez, PhDb, Luis Alou Cervera, PhDb, Laura Martín Aragón, PhDb, Marta Elena Losa Iglesias, PhDb,c, Luis Rodolfo Collado Yurrita, MD, PhDb, Daniel Lopez Lopezd

Abstract

Background: Chlorhexidine and parachlorometaxylenol (PCMX) are antiseptics recommended for surgical hand antisepsis. To our knowledge, PCMX has not been evaluated for bactericidal efficacy in vivo.

Methods: We conducted a randomized, double-blind, controlled crossover trial to compare the bacterial loads on fingertips and fingernails under laboratory conditions after use of antiseptic test products, including chlorhexidine digluconate 4%, PCMX 3%, and a reference solution of propan-1-ol 60% (P-1). We assessed bacterial load after a prewash with soft soap, immediately after application of an antiseptic, and 3 hours after application and wearing of sterile, powder-free gloves. Our procedures followed those specified by European Norm (EN) 12791 for evaluating surgical hand antiseptics and using cotton swab for fingertips and fingernails.

Results: Chlorhexidine digluconate 4% and PCMX 3% did not decrease bacterial load on the hands. The bactericidal performances of chlorhexidine digluconate 4% and PCMX 3% did not differ significantly. Chlorhexidine digluconate 4% and PCMX 3% increased bacterial load on the fingertips after participants had worn gloves for 3 hours. Fingernails had greater bacterial loads than skin on the fingertips.

Conclusions: Chlorhexidine digluconate 4% and PCMX 3% had similar bactericidal efficacy, but they failed to meet the EN 12791 efficacy standard. Fingernails should be a particular focus of antiseptic in preparation for surgery.

The trial was registered at ClinicalTrials.gov (ID: NCT02500758).

Abbreviations: CHG = chlorhexidine gluconate, EN = European Norm, P-1 = propan-1-ol 60%, PCMX = parachlorometaxylenol, PVI = povidone iodine.

Keywords: antisepsis, randomized controlled trial, surgical site infection

1. Introduction

Surgical site infections (SSI) are among the most common hospital-acquired infections worldwide despite significant developments in surgical technique. Surgical hand antisepsis has long been used to prevent SSI. Intact surgical gloves are the most important barrier to the bi-directional migration of microorganisms between the hands of surgical team members and the patient. However, undetected perforations of surgical gloves are common and increase in frequency with duration of glove wear. The risk of glove defects is related to the type of surgery, ranging from 7% in urologic surgery to 65% in cardiothoracic surgery. Surgical hand antisepsis is also essential for preventing chronic infections associated with contaminated implants.

The 5 main products currently marketed for preoperative antisepsis are alcohol, chlorhexidine, iodine/iodophors, parachlorometaxylenol (PCMX), and triclosan with povidone iodine (PVI) and chlorhexidine gluconate (CHG) the most commonly used for skin preparations. They are available in aqueous and alcoholic preparations and in different concentrations. PVI and CHG are effective against a wide range of gram-positive and Gram-negative bacteria, viruses, and fungi, though CHG has greater residual antiseptic activity on the skin after application and superior efficacy in bacterial reduction. Although PCMX is a recommended antiseptic to prevent SSI, we are aware of no formal in vivo evaluations of its bactericidal power.

We compared the efficacy of a PCMX 3% formulation with CHG 4% in surgical hand antisepsis. We used an standard approach for assessing anti-bacterial efficacy: European Norm (EN) 12791 to determine bactericidal efficacy in vivo during...
surgical hand scrub preparations\cite{19,20} and cotton swab to determine bacterial load from fingertips and fingernails independently.

2. Methods

We conducted a randomized, double-blind, controlled crossover trial to compare the number of colony forming units per mL (CFU/mL) on the fingertips, fingernails, and web spaces between fingers under laboratory conditions after use of antiseptic test products, including CHG, PCMX, and a reference solution. The study was performed from January to June, 2016, at Universidad Complutense de Madrid (Spain).

2.1. Participants

Twenty-five healthy participants of last courses in the health sciences were assessed for eligibility. Twenty participants completed the study, aged 25 to 55 years old, mean 29, 95 ± 9, 02, median 28. They participated in the study after giving written informed consent.

These participants met the inclusion criteria of having short and clean fingernails, no cuts/abrasions on their fingers, no history of skin disorders, including allergies to any ingredient in tested solutions, no recent antibiotic/antimicrobial use, no recent use of medicated soap or cream on hands, and no painted nails\cite{17} at least 1 week before the study. All participants received formal training on standard surgical hand scrubbing (with non-antimicrobial soap) and sterile gloving.\cite{21} The ethics committee of the Hospital Clínico San Carlos, Madrid, Spain, approved this study (ID: 14/186-TFM) and the trial was registered at ClinicalTrials.gov (ID: NCT02500758).

The sample size was calculated with the software from Unidad de Epidemiología Clínica y Bioestadística. Complexo Hospitalario Universitario de A Coruña. Universidade A Coruña (www. fisterra.com) to detect a difference in bacterial load reduction equal to that observed previously between CHG and PVI were 0.94 ± 1.11 log10 and 0.15 ± 1.11 log10, respectively\cite{18} with 80% statistical power (α = 0.05, 2-tailed test), at least 18 participants are required. Our inclusion of 20 participants surpasses this limit and meets the EN 12791 sample size requirement\cite{20} Furthermore, assuming a loss to follow up rate of 25%, at least 25 participants were included in the study.

2.2. Experimental design

Experimental procedures followed those specified by EN 12791 for assessing surgical hand scrubs, with propan-1-ol 60% (P-1) as a reference control.\cite{21} Participants were randomly assigned to 1 of 2 groups (n = 10 each), a “Latin-square design” is used. In 1 group, participants first used P-1. In the second and third test sessions, participants in this group used CHG and PCMX, respectively. In the other group, participants used PCMX, P-1, and CHG in the first, second, and third test sessions, respectively (Fig. 1). Between test sessions, there was a washout period of at least 1 week to allow normal skin flora to reconstitute.\cite{18,21} Random assignments were based on computer generated randomization routine using EpiData software version 3.02 (EpiData Association, Odense, Denmark) and allocations were concealed with sealed, numbered, tamperproof, opaque envelopes that were opened only after participants consented to participate. Participants were blinded to CHG and PCMX administration, but not P-1 administration because it was applied with a sterile syringe according to EN 12791. The laboratory assessor of bacterial load outcomes was blinded to participants’ allocations.

2.3. Materials

The soft soap used in pre-antisepsis scrubbing was composed of 50 parts linseed oil, 0.5 parts potassium hydroxide, 7 parts 96% ethanol (volume concentration), and up to 1000 grams distilled water that had been sterilized in a autoclave at 121°C for 15 minutes. The CHG formulation included CHG 4%, propan-2-ol 1% to 5%, lauryldimethylamine oxide 1% to 5%, and glycerol 1% to 5% (Dispomedic Scrub C, CV Medica, Sarral, Tarragona, España). The PCMX formulation included PCMX 3%, water, sodium laureth sulfate, triethyleneglycol, cocamide propylbeta-taine, chloroxylenol, aloe barbadensis, lanolin, parfum, methylchloroisothazolinone, and methylisothiazolinone (Dispomedic Aloe PCMX, CV Medica, Sarral, Tarragona, España). The P-1 formulation included propan-ol-1 60% (volume concentration). Participants wore powder free sterile surgical gloves (Peha-Taft Classic, Bastos Medical, S.L., Barcelona, Spain) after application of test antiseptics.

2.4. Procedures

2.4.1. Antiseptic application and bacterial sampling.

Our procedures strictly followed norm EN12791.\cite{20} For each test session, samples for bacterial counts were taken immediately after a prewash (before application of the test antiseptic), immediately after application of the test antiseptic, and 3 hours after application.

For the prewash, soap was poured into cupped hands and rubbed vigorously on to the skin up to the wrists. The hands were then rinsed with running tap water and dried thoroughly with clean disposable paper towels. Immediately after drying, the 5 fingertips were rubbed for 1 minute on the base of a 90 mm diameter sterile petri dish containing 10 mL of trypticase soy broth (TSB) without neutralizer. A separate petri dish was used for each hand. To isolate the source of any bacteria found, we also scrubbed cotton-tipped swabs (Copa Italiana S.p.A., Brescia, Italy) for 10 seconds in the medial nailfold at the subungual aspect of the free border of the nail of the thumb, and from the fingertip of the thumb, respectively. Cotton-tipped swabs have been used for bacterial sampling on skin of the foot and ankle previously.\cite{23–26} Next, the test antiseptics were applied. For P-1, 3 mL of P-1 was poured into participants’ cupped dried hands. Participants then rubbed the liquid vigorously into the skin up to the wrists according with the standard handrub procedure.\cite{22} When hands were nearly dry, additional 3 mL aliquots of P-1 were applied until the hands had been wet for 3 continuous minutes. 10 cc of P-1 was used by each participant. CHG and PCMX were applied according to the manufacturer’s instructions. Fingernails were brushed with a sterile brush, and hands and forearms were washed over a period of 3 minutes. After washing, hands were rinsed with running tap water for 15 seconds and dried with a sterile disposable towel. As soon as participants’ hands were dry after antiseptic application, we used the same bacterial sampling procedure as after the prewash described above, but for 1 randomly selected hand only, taking care to avoid contamination of the other hand.

Participants then donned gloves. After participants had worn the gloves for 3 hours, according to the reference surgical hand disinfection procedure described in norm EN 12791.\cite{20} The
gloves were removed and the bacterial sampling were repeated again, this time for the hand not sampled immediately after the antiseptic application.

2.4.2. Microbiologic processing. For preswash samples, 1:10 and 1:100 dilutions were prepared in TSB. For each dilution, 0.1 mL was spread over trypticase soy agar (TSA) in 2 Petri dishes with a sterile glass spatula. No more than 5 minutes elapsed between sampling and seeding. Dishes were incubated for 24 hours at 37 ± 2°C. After an initial count of the CFU, Petri dishes were incubated for another 24 hours to detect slow-growing colonies.[20] For both rounds of samples after application of antiseptics, 1.0 mL and 0.1 mL of undiluted solution and a 1:10 dilution of it were plated, incubated, and assessed as for the preswash samples. The mean number of CFU per mL (log10 values) in duplicate dishes was calculated after correction for the dilution factor.

The nail and skin swabs were resuspended in 2 mL of 0.9% sodium chloride and diluted 10-fold. At least 3 dilutions of each sample were spread onto TSA (20 μL in each plate). Plates were incubated at 35°C, and colonies were counted (log10 values per cm² of skin) after 24 to 48 hours. The limits of detection in the nailfold and skin tests were $1.33 \times 10^2$ and $1 \times 10^2$ CFU/cm², respectively.[24–26] The laboratory investigator was blinded to the antiseptic test products individual participants had received.

2.5. Outcome measures

The primary outcome measures were the log10 CFU values for the different sample types at the 3 assessment points (preshwash, immediate post-application, and 3 hours post-application) and the immediate and 3-hour reduction factors (preshwash—immediate and preswash—3 hours, respectively).

Secondary outcome measures were adverse effects participants reported about the different antiseptics.

2.6. Statistical analysis

We computed means and standard deviations for the primary outcomes. These variables were not normally distributed.
3. Results

Assessed according UN12791, P-1 reduced bacterial load substantially, at both immediate and 3-hour post-application assessments (Table 1). CHG and PCMX, however, did not change bacterial load appreciably at the immediate assessment (P > .05), and they both actually increased bacterial load by 3-hours post-application (P < .001). P-1 had significantly greater bactericidal efficacy reductions factors than CHG and PCMX at immediate and 3-hours (P = .0002) and PCMX at immediate and 3-hours (P < .001). The reduction factors for CHG and PCMX were not significantly different from each other at either immediate and 3-hours (P = .614 respectively).

Bacterial loads collected with swab were higher from fingernail samples (Table 2) than for fingertips and P-1 reduced bacterial load considerably from fingernail (P < .0001), but the reductions for CHG and PCMX were very small (P > .05). P-1 had significantly greater bactericidal efficacy than CHG and PCMX at immediate and 3-hours (P = .0001 and .0004 respectively), and the reduction factors for CHG and PCMX were not significantly different at each other immediate and 3-hours (P = .614 and .6951 respectively).

Collected with swab the fingertips (Table 3) had lower bacterial loads than fingernails. P-1 still decreased bacterial load at this location at both immediate and 3-hours (P = .0007 and .0011 respectively), but CHG and PCMX produced only negligible changes in bacterial load at both immediate and 3-hours (P > .05). P-1 was a significantly better antiseptic power than PCMX (P < .01) and showed similar bactericidal power with CHG (P = .177). The bactericidal performances of CHG and PCMX were not significantly different at fingernails at immediate and 3-hours effect (P > .05)

There were no adverse effects.

4. Discussion

We evaluated the bactericidal efficacy of CHG and PCMX in surgical hand antisepsis, following the procedures specified in EN 12791.[20] To our knowledge, PCMX has not previously been evaluated in this context, although the US Centers for Disease Control and Prevention have recommended it to prevent SSI[10,11].

In our randomized, double-blind, controlled, crossover trial, CHG, and PCMX did not decrease bacterial load on the fingertips and fingernails after surgical hand antisepsis. The bactericidal performances of CHG and PCMX did not differ significantly. However, the reference antiseptic, P-1, reduced bacterial loads substantially at immediate effect and maintained these reductions even after participants had worn sterile, powder-free surgical gloves for 3 hours. CHG and PCMX actually produced a modest increase in bacterial load after participants had worn gloves for 3 hours. Consequently, neither CHG nor PCMX met the EN12791 criteria for non-inferiority relative to P-1 in our study.

The increase in bacterial load 3 hours after the application of CHG and PCMX is a paradoxical effect similar to that previously described after surgical hand antisepsis and use of powdered gloves.[21]

Our participants, however, wore sterile, powder-free gloves. Unlike P-1, the CHG and PCMX antiseptic products both have excipients, which might counteract their antibacterial effects. Edmonds and colleagues[28,29,31] showed that excipients can influence bactericidal efficacy in antiseptics. If the paradoxical effect we observed is replicated, this and other possible explanations merit investigation.

The lack of bactericidal efficacy we observed for CHG is consistent with research showing CHG’s poor antiseptic

| Table 1 | Immediate and 3-hour bactericidal effects of antiseptic products using European Norm 12791. |
| --- | --- |
| | Immediate effect (log 10 CFU/ml) means±SD | 3-hour effect (log 10 CFU/ml) means±SD |
| | Prewash | Immediate | Post-application | RFI | P value | RFI | Prewash | 3-hours | Post-application | RFI | P value | RFI |
| CHG 4% | 3.71±0.58 | 3.87±0.58 | 0.076 | -0.16±0.62 | CHG/P-1 0.0002 | 3.9±0.48 | 4.05±0.8 | 0.001 | -0.75±0.32 | CHG/P-1 0.0002 |
| PCMX 3% | 4.07±0.63 | 3.96±0.39 | 0.254 | 0.11±0.60 | PCMX/P-1 0.0016 | 3.89±0.75 | 4.54±0.62 | 0.001 | -0.65±0.67 | PCMX/P-1 0.0001 |
| P-1 60% | 3.47±1.13 | 2.08±1.00 | 0.001 | 1.38±1.20 | CHG/PCMX .162 | 3.68±1.20 | 2.37±1.00 | 0.001 | 1.32±0.84 | CHG/PCMX .614 |

*CFU = colony-forming units, CHG = chlorhexidine gluconate, P-1 = propan-1-ol 60%, PCMX = parachelornemethylend, RFI = reduction factor 3-hours effect expressed by decimal logarithms of log prevalue 3 hours minus log “postvalue 3 hours”, RFI = reduction factor Immediate effect expressed by decimal logarithms of log “prevalue immediate” minus log “postvalue immediate”. |

| Table 2 | Immediate and 3-hour bactericidal effects of antiseptic products on fingernails using cotton swab. |
| --- | --- |
| | Immediate effect (log 10 CFU/mL) means±SD | 3-hour effect (log 10 CFU/mL) means±SD |
| | Prewash | Immediate | Post-application | RFI | P Value | RFI | Prewash | 3-hours | Post-application | RFI | P Value | RFI |
| CHG 4% | 4.78±0.88 | 4.60±0.79 | 0.18±0.71 | CHG/P-1 0.0001 | 4.55±1.04 | 3.99±1.20 | 0.0349 | 0.56±1.03 | CHG/P-1 0.0004 |
| PCMX 3% | 4.05±0.92 | 4.82±0.75 | 0.12±0.77 | PCMX/P-1 0.0001 | 4.45±1.28 | 4.15±1.24 | 0.2197 | 0.30±1.20 | PCMX/P-1 0.0004 |
| P-1 60% | 4.98±0.84 | 2.28±0.64 | 0.001 | 2.68±1.03 | CHG/PCMX .5628 | 4.98±1.02 | 2.34±0.83 | 0.0001 | 2.64±1.34 | CHG/PCMX .6951 |

*CFU = colony-forming units, CHG = chlorhexidine gluconate, P-1 = propan-1-ol 60%, PCMX = parachelornemethylend, RFI = reduction factor 3-hours effect expressed by decimal logarithms of log prevalue 3 hours minus log “postvalue 3 hours”, RFI = reduction factor Immediate effect expressed by decimal logarithms of log “prevalue immediate” minus log “postvalue immediate”.
performance in surgical preparation hand[18] and toenail
scrubs.[24,25,30] However, Marchetti and colleagues found that
hand-rubbed CHG (Hisbiscrub) was an effective antiseptic and
failed to meet the EN 12791 standards.

Pre-operative surgical hand antisepsis using CHG or PCMX do
not reduce significantly, but not eradicate, the resident flora
on the fingertips and fingernails, and thus it does not eliminate
the risk of contamination of microorganisms into the surgical site
if the integrity of the glove is breached. Based on our findings
and those of others.[3,14]

We recommend further research adding before or after a hand
wash with alcohol solution when using these antiseptics to
increase its efficacy for surgical hand antisepsis

We found that the fingernails had greater bacterial loads than
skin on the fingertips and the first web spaces of the hand. This
suggests that fingernails should be a particular focus of antisepsis
in preparation for surgery.

Moreover, CHG and PCMX is the only recommended antiseptic products that did not meet the EN 12791 requirements because some alcohol-based hand rubs recommended by the World Health Organization for both hygienic and pre-surgical hand treatment with formulations based on ethanol 80% v/v and 2-
propanol 75% v/v[22] also failed to meet the EN 12791 criteria.[10] These and other results, in combination with our
own, underline the need for further rigorous evaluation of surgical hand antisepsis products.

A limitation of the study is that the European Standard Norm EN 12791 specifies a test method simulating practical conditions for establishing whether a product for surgical hand antisepsis reduces the release of hand flora according to its requirements when used for the antisepsis of the clean hands of volunteers, so further research is needed in an operating theatre environment or
clinical setting.

In conclusion, as surgical hand antisepsics, CHG 4% and
PCMX 3% had similar bactericidal efficacy, but failed to meet the
EN 12791 efficacy standard. PCMX did not show paradoxical
overcolonization at immediate effect as showed by CHG and
fingernails had high bacterial load and thus should be a particular
focus of pre-surgical antiseptic.

Author contributions

Conceptualization: Ricardo Becerro de Bengoa Vallejo, David
Sevillano Fernandez, Luis Alou Cervera, Marta Elena Losa
Iglesias.

Data curation: Ricardo Becerro de Bengoa Vallejo, Laura Martín
Aragón.

Formal analysis: Ricardo Becerro de Bengoa Vallejo, David
Sevillano Fernandez, Luis Alou Cervera, Marta Elena Losa
Iglesias.

Investigation: Ricardo Becerro de Bengoa Vallejo, David
Sevillano Fernandez, Luis Alou Cervera, Laura Martín
Aragón.

Methodology: Ricardo Becerro de Bengoa Vallejo, David
Sevillano Fernandez, Luis Alou Cervera.

Supervision: Ricardo Becerro de Bengoa Vallejo, Marta Elena
Losa Iglesias, Luis Collado Yurrita.

Validation: Ricardo Becerro de Bengoa Vallejo, David Sevillano
Fernandez, Luis Alou Cervera, Marta Elena Losa Iglesias, Luis
Collado Yurrita, Daniel Lopez Lopez.

Writing – original draft: Ricardo Becerro de Bengoa Vallejo,
David Sevillano Fernandez, Luis Alou Cervera, Marta Elena
Losa Iglesias.

Writing – review & editing: Ricardo Becerro de Bengoa Vallejo,
David Sevillano Fernandez, Luis Alou Cervera, Laura Martín
Aragón, Marta Elena Losa Iglesias, Luis Collado Yurrita,
Daniel Lopez Lopez.

Marta Elena Losa Iglesias orcid: 0000-0001-7588-2069.

Table 3
Immediate and 3-hour bacterial effects of antiseptic products on
fingertips using cotton swap.

| Immediate and 3-hour bacterial effects of antiseptic products on fingertips using cotton swap. |
|---------------------------------------------------------------|
| **Immediate effect (log 10 CFU/ml) means ± SD** | **3-hour effect (log 10 CFU/ml) means ± SD** |
| CHG 4% | 2.55 ± 0.85 | 2.29 ± 0.72 | 2.762 ± 0.28 ± 0.81 | CHG/P-1 | 0.177 |
| PCMX 3% | 2.77 ± 1.21 | 2.78 ± 1.11 | 6.008 ± 0.00 ± 0.79 | PCMX/P-1 | 0.010 |
| P-1 60% | 2.35 ± 0.69 | 1.71 ± 0.24 | 0.007 ± 0.64 ± 0.27 | CHG/PCMX | 0.270 |
| | | | | | |
| Prewash | Post-application | P value | RFI | Prewash | Post-application | P value | RFI |
| CHG 4% | 2.33 ± 0.81 | 2.23 ± 0.76 | 0.5905 ± 0.11 ± 0.05 | CHG/P-1 | 0.116 |
| PCMX 3% | 2.53 ± 0.82 | 2.41 ± 0.73 | 0.2397 ± 0.12 ± 0.07 | PCMX/P-1 | 0.025 |
| P-1 60% | 2.28 ± 0.64 | 1.65 ± 0.15 | 0.0111 ± 0.63 ± 0.64 | CHG/PCMX | 0.7038 |

CFU= colon-forming units, CHG = chlorhexidine gluconate, P-1 = propan-1-ol 60%, PCMX = parachlorometaxylenol, RFI = reduction factor 3-hours effect expressed by decimal logarithms of log prevalue 3
hours minus log "postvalue 3 hours", RFI = reduction factor 3-hours effect expressed by decimal logarithms of log "prevalue immediate" minus log "postvalue immediate".

References

[1] Rosenhalh WD, Maki DG, Jamulitrat S, et al. International Nosocomial Infection Control Consortium (INICC) report, data summary for 2003–2008, issues June 2009. Am J Infect Control 2010;38:

[2] Hübner N, Goerd t A. Bacterial migration through punctured surgical gloves under real surgical conditions. BMC Infect Dis 2010; 10;0:5.

[3] Harnoss JC, Partecke LJ, Heidecke CD, et al. Concentration of bacteria passing through puncture holes in surgical gloves. Am J Infect Control 2010;38:154–8.

[4] Partecke LJ, Goerd t A-M, Langner I, et al. Incidence of microperforation for surgical gloves depends on duration of wear. Infect Control Hosp Epidemiol 2009;30:409–14.

[5] Ekholm AM, Ojaarvi J, Laitinen K, et al. Glove punctures and postoperative skin flora of hands in cardiac surgery. Ann Thorac Surg 2002;74:149–53.

[6] Mistek H, Weber WP, Reck S, et al. Surgical glove perforation and the risk of surgical site infection. Arch Surg 2009;144:553–9.

[7] Kuroyanagi N, Nagao T, Sakuma H, et al. Risk of surgical glove perforation in oral and maxillofacial surgery. Int J Oral Maxillofac Surg 2012;41:1014–9.

[8] Kojima Y, Ohashi M. Unnoticed glove perforation during thoracoscopic and open thoracic surgery. Ann Thorac Surg 2005;80:1078–80.

[9] Peters G, Locci R, Pulverer G. Microbial colonization of prosthetic devices. II. Scanning electron microscopy of naturally infected intravenous catheters. Zentralbl Bakteriol Mikrobiol Hyg B 1981;173:293–9.

[10] Mangram AJ, Horan TC, Pearson ML, et al. Guideline for prevention of surgical site infection, 1999. Hospital infection control practices advisory committee. Infect Control Hosp Epidemiol 1999;20:250–78.

[11] Mangram AJ, Horan TC, Pearson ML, et al. Guideline for prevention of surgical site infection, 1999. Centers for disease control and prevention (CDC) hospital infection control practices advisory committee. Infect Control Hosp Epidemiol 1999;97–132.

[12] Dunville J, McFarlane E, Edwards P, et al. Preoperative skin antisepsis for prevention of surgical wound infections after clean surgery. Cochrane Database Syst Rev 2013;53:CD003949–69.
[13] Noorani A, Rabey N, Walsh SR, et al. Systematic review and meta-analysis of preoperative antisepsis with chlorhexidine versus povidone-iodine in clean-contaminated surgery. Br J Surg 2010;97:1614–20.
[14] Queensland Government Department of Health. Surgical Skin Antisepsis Guideline. 2015. [cited 2014 July 9]. Available at: https://www.health.qld.gov.au/__data/assets/pdf_file/0020/444422/skin-disinfection.pdf.
[15] Maiwald MCE. The forgotten role of alcohol: a systematic review and meta-analysis of the clinical efficacy and perceived role of chlorhexidine in skin antisepsis. PLoS One 2012;7:e44277.
[16] Lai KW, Foo TL, Low W, et al. Surgical hand antisepsis—a pilot study comparing povidone iodine hand scrub and alcohol-based chlorhexidine gluconate hand rub. Ann Acad Med Singapore 2012;41:12–6.
[17] Marchetti MG, Kampf G, Finzi G, et al. Evaluation of the bactericidal effect of five products for surgical hand disinfection according to prEN 12054 and prEN 12791. J Hosp Infect 2003;54:63–7.
[18] Barbadoro P, Martini E, Savini S, et al. In vivo comparative efficacy of three surgical hand preparation agents in reducing bacterial count. J Hosp Infect 2014;86:64–7.
[19] Labadie JC, Kampf G, Lejeune B, et al. Recommendations for surgical hand disinfection—requirements, implementation and need for research. A proposal by representatives of the SFHH, DGHM and DGKH for a European discussion. J Hosp Infect 2002;51:312–5.
[20] European Norm EN 12791: Chemical disinfectants and antiseptics. Surgical hand antisepsis. Test method and requirement (phase 2/step 2). [Internet]. Brussels: 2005. [cited 9 June 2014]. Available from: https://standards.globalspec.com/std/9992696/en-12791.
[21] Assadian O, Kramer A, Ourel K, et al. Suppression of surgeons’ bacterial hand flora during surgical procedures with a new antimicrobial surgical glove. Surg Infect (Larchmt) 2013;14:53–5.
[22] Pittet D, Allegranzi B, Boyce J. The World Health Organization guidelines on hand hygiene in health care and their consensus recommendations. Infect Control Hosp Epidemiol 2009;30:611–22.
[23] Ostrander RV. Efficacy of surgical preparation solutions in foot and ankle surgery. J Bone Jt Surg 2003;85:980–5.
[24] Becerro de Bengoa Vallejo R, Losa Iglesias ME, Cervera LA, et al. Preoperative skin and nail preparation of the foot: comparison of the efficacy of 4 different methods in reducing bacterial load. J Am Acad Dermatol 2009;61:986–92.
[25] Becerro de Bengoa Vallejo R, Losa Iglesias ME, Cervera LA, et al. Efficacy of preoperative and intraoperative skin and nail surgical preparation of the foot in reducing bacterial load. Dermatologic Surg 2010;36:1258–65.
[26] Becerro de Bengoa Vallejo R, Losa Iglesias ME, Cervera LA, et al. Efficacy of preoperative and intraoperative skin and nail surgical preparation of the foot in reducing bacterial load. Dermatologic Surg 2010;36:1258–65.
[27] Boyce JM, Pittet D. Guideline for hand hygiene in health-care settings: recommendations of the healthcare infection control practices advisory committee and the HICPAC/SGA/APIC/IDSA hand hygiene task force. Infect Control Hosp Epidemiol 2002;23:S3–40.
[28] Suchomel M, Rotter M, Wenzel M, et al. Glycerol significantly decreases the three hour efficacy of alcohol-based surgical hand rubs. J Hosp Infect 2013;83:284–7.
[29] Rotter ML, Kampf G, Suchomel M, et al. Population kinetics of the skin flora on gloved hands following surgical hand disinfection with 3 propanol- based hand rubs: a prospective, randomized, double- blind trial. Infect Control Hosp Epidemiol 2007;28:346–50.
[30] Suchomel M, Kundi M, Allegranzi B, et al. Testing of the World Health Organization-recommended formulations for surgical hand preparation and proposals for increased efficacy. J Hosp Infect 2011;79:115–8.
[31] Edmonds SL, Macinga DR, Mays-Suko P, et al. Comparative efficacy of commercially available alcohol-based hand rubs and World Health Organization-recommended hand rubs: Formulation matters. Am J Infect Control 2012;40:521–5.