Scratching beneath the surface: innovative treatment modalities for burn patients

Kwa, K.A.A.

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Debridement and wound management

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A systematic review on surgical and nonsurgical debridement techniques of burn wounds

Kelly A.A. Kwa*
Harold Goei*
Roelf S. Breederveld
Esther Middelkoop
Cornelis H. van der Vlies
Margriet E. van Baar

*authors contributed equally

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Abstract

Objective
to provide a complete overview of all burn debridement techniques studied in recent literature and to find the best evidence with regard to efficiency and safety.

Method
a systematic review was performed. Searches were conducted in electronic databases such as PubMed, Embase, Cochrane, CINAHL, Web of Science, and Academic Search Premier. All studies published from 1990 onwards, on the efficiency and/or safety of burn debridement techniques in patients with thermal burn injuries of any age, were included. Primary outcomes were time to complete wound healing and time to complete debridement. Randomized trials were critically appraised.

Results
twenty-seven studies, including four randomized clinical trials, were included. Time to wound healing in the conventional tangential excision (seven studies), hydrosurgery (eight studies), enzymatic debridement (eleven studies) and shock waves group (one study) ranged from 13–30, 11–13, 19–33 and 16 days, respectively. Time to complete debridement ranged from 5–10, 4–23 and 1–9 days, respectively. Furthermore, secondary outcomes (including grafting, mortality and scar quality) were compared between the debridement categories.

Conclusion
Convincing evidence in favor of any of these techniques is currently lacking. Future studies regarding (new) debridement techniques need to use standardized and validated outcome measurement tools to allow improved standardization and comparisons across studies.

Introduction

Debridement of burn wounds is defined as the (surgical) removal of all lacerated, devitalized, or contaminated tissue, also called eschar, that is incompatible with healing.[1] In traditional burn care, eschar was treated by awaiting spontaneous separation from the underlying layer of viable tissue.[2] In 1970, Zora Janzekovic introduced the early removal of eschar by tangential excision.[3]

Major advancements in burn care, with regard to significant reduction in mortality and a shorter hospital stay are linked to early excision of burn wounds.[4,5] According to Herndon, nutritional support, sepsis control and management of inhalation injury also contributed, but to a lesser degree.[2] Presently, excision is applied in virtually every full-thickness or deep dermal burn wound that is unlikely to heal within 14-21 days post-burn to shorten wound healing time, thereby reducing length of hospital stay and infection rate and improving functional outcome and scar quality.[2] Burn wound excision is primarily performed with sharp instruments.[2] In recent decades various surgical and nonsurgical techniques for the excision of eschar have been proposed to improve selective debridement and minimize blood loss. In a recent Cochrane review, Gethin et al.[6] described several techniques for the debridement of venous leg ulcers. They distinguished six different forms of debridement, namely sharp, mechanical, autolytic, enzymatic, biosurgical and surgical debridement. This subdivision can also apply to the different debridement techniques of burn wounds. The choice of the debridement technique depends on the burn center, the expertise and availability of professionals and the type of burn wound, but techniques are often interchangeably used. It is not known if this choice is of influence on the final result of the wound healing. Two reviews on debridement techniques of burn wounds were previously published.[7,8] Both reviews were narrative reviews and limited to nonsurgical debridement techniques. Makepeace et al.[8] described case-reports of patients who were exclusively treated with enzymatic debridement. The review of Klasen et al.[7] described several techniques but did not systematically report outcomes. Since the publication of these reviews, several new commercially available debridement techniques became available on the market.[9,10]

A comprehensive systematic review that discusses all the available burn wound debridement techniques is lacking. More specifically, the efficiency and safety of the various methods are not well established. The objective of this paper was to conduct a systematic search to provide a complete overview of all surgical and nonsurgical debridement techniques described in recent literature (≥1990) and to find the best available evidence with regard to efficiency and safety outcomes in burn patients with thermal injuries.

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Methods

Protocol
This systematic review is protocol-driven according to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement.[11] Our protocol was developed and registered in PROSPERO (CRD42016039301), the international prospective register of systematic reviews.[12]

Selection criteria
The following criteria were met when conducting the search:

- Type of patients:
  - No age limit
  - Burn etiology of thermal origin
- Study design:
  - Regarding outcome efficiency: all studies, excluding case-reports (<5 patients)
  - Regarding outcome safety: all studies
- Publication date was restricted to articles published from 1990 onwards
- Language restriction: articles not written in English were taken into account only for randomized controlled clinical trials (RCT) and controlled clinical trials (CCT)

Search strategy
The following electronic databases were searched on May 8, 2017: PubMed, Embase, Cochrane, CINAHL, Web of Science and Academic Search Premier. The search terms included burn*, debridement, excision, and surgery. For complete electronic search strategy, see Appendix 1.

Selection procedure
The selection procedure was performed according to the Cochrane Handbook for Systematic Reviews of Interventions and carried out by two reviewers (KK and HG).[13] Disagreement between the reviewers about eligibility was solved through discussion and, in case of consistent disagreement, by a third reviewer (MB). This screening process was conducted with the use of the web-based software platform Covidence (www.covidence.org), which has been selected as a preferred tool by the Cochrane Collaboration.

Data-extraction
Data were extracted (KK and HG) using a standardized data-extraction form that included study characteristics (study design, sample size per group, study setting, and type of debridement), patient characteristics (age, gender, burn depth,

median burned TBSA, and etiology) and our outcome parameters. Our primary outcome parameters were time to complete wound healing and time to complete debridement, which are both parameters regarding efficiency. Our secondary outcome parameters regarding efficiency included excision procedure time, time from accident to start debridement, need for grafting, precision of debridement (assessed by any available method), graft take, re-operations, length of hospital stay, scar quality, reconstructions, and costs. Our secondary outcome parameters regarding safety included mortality and adverse events (AEs).

Risk of bias (quality) assessment

The "Risk of bias tool" from the Cochrane Handbook for Systematic Reviews of Interventions was used to assess the quality in the included RCTs.[14] The criteria were assessed independently by the two review authors.

Strategy for data synthesis

Taking into account the probable differences in reporting outcomes amongst studies, we anticipated to be restricted to a narrative description of outcomes. When possible, data were pooled to perform quantitative analysis.

Results

Literature search

The literature search yielded 4213 records. After removal of duplicates, 2254 articles remained. After title screening, 145 articles were left to be screened by abstract, which resulted in 41 articles eligible to read full text, and finally 14 papers were excluded (see flowchart shown in Figure 1). The search resulted in a total of 27 articles that were used for data extraction.

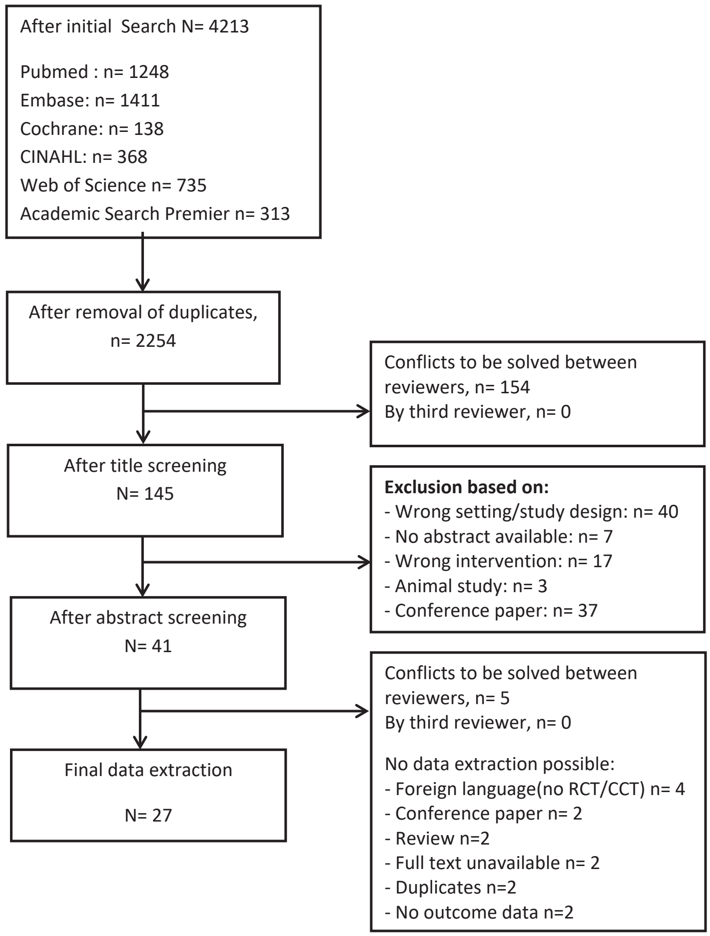

Figure 1. Flowchart

Description of debridement techniques

The debridement techniques used in the full text analysis (n=27) covered four out of the six debridement techniques described in literature.[6] We subdivided the debridement techniques into four categories: (1) conventional tangential excision (CTE),[3] (2) hydrosurgery (HS),[15] (3) ED,[10] and (4) shock waves (SW).[16] No studies were included in the debridement categories autolytic and biosurgical (i.e., maggots). CTE is defined as sharp tangential excision with the use of hand-held knives. HS is a debridement tool that produces a high-pressure jet of water across an aperture in an angled hand piece with a vacuum that removes surface debris that is sucked into the machine. ED in our review consisted of debridement with either collagenase, bromelain [NEXOBRID®, Mediwound Ltd., Yavne, Israel] or papain. SW therapy is thought to act by producing an acoustic energy that optimizes cellular and molecular microenvironments.

Strategy for data synthesis
The outcome parameters were defined differently between studies. For example, our primary outcome “time to wound healing”, had several definitions including >95% re-epithelialization or last wound dressing. We aimed to use the most widely accepted definition.

Study characteristics
Table 1 shows an overview of the study characteristics of the included articles. The study designs mostly consisted of cohort studies (22/27), with four randomized controlled studies and one case-series (<10 participants). Studies involving the more recent debridement techniques, including HS, ED, and SW were predominantly published from 2005 onwards (17/20), whereas the CTE studies were mostly published before 2005 (4/7). The burn severity had a wide range, except in the CTE group, in which all seven studies included patients with a more than 20% mean TBSA burned. Age categories varied largely, but consisted predominantly of adults or participants of all ages. The number of participants was less than 30 in a substantial part of the studies (11/27), with only six studies including more than 100 participants.

Table 1. Overview study characteristics

	CTE n=7	HS n=8	ED n=11	SW n=1	Total n=27
Study design					
Randomized controlled trial*	1	2	1		4
Cohort study	6	5	10	1	22
Case-series		1			1
Publication date					
<2005	4		3		7
≥2005	3	8	8	1	20
TBSA burned					
<5%		3	2	1	6
5-20%		2	6		8
≥20%	7	3	2		12
Not described			1		1
Age category					
Children (<18 years)		2	1		3
Adults	2	5	3	1	11
All ages	4	1	5		10
Not described	1		2		3
Number of participants					
<30	1	5	4	1	11
30-100	4	3	3		10
≥100	2		4		6

CTE = conventional tangential excision. HS= hydrosurgery. ED= enzymatic debridement. SW= shock wave therapy. TBSA = total body surface area. *RCT's comparing either HS versus CTE or ED versus CTE were classified in respectively HS or ED category.

Primary outcomes

Table 2 presents the primary outcomes. The data of time to complete wound healing were available in 12/27 of the studies. The definition of time to complete wound healing was described in 8/14 studies and usually defined as 'complete epithelialization' or 're-epithelialization of more than 90-95% of the wound'. The time to complete wound healing in the CTE-group had a range of 13-30 days. In the HS-group 4/5 studies had a range of 11-13 days, while the fifth study had a range of 18-64 days.[9] The ED group had a range of 19-33 days. There was no significant difference in time to wound healing in the two RCTs in the HS group and the one RCT in the ED group, that compared their technique to various conventional debridement techniques, including CTE, HS and dermabrasion. The data of time to complete debridement were available in 10/27 studies. The ED group had the shortest time to complete debridement with a range of 1-9 days. The HS group had a range of 4-23 days and the CTE-group had a range of 5-10 days. There was a significantly shorter time to complete debridement in the ED group patients in the RCT comparing ED to various conventional debridement techniques (CTE, HS, dermabrasion), while the RCT in the HS group showed no difference. Pooling of the data was not possible due to heterogeneity of the data. For a detailed overview of the primary outcomes per study, refer to Appendix 2.1.

Table 2. Primary outcomes

Debridement technique	Time to complete wound healing *days (SD, range)*	Time to complete debridement *days (SD, range)*
Conventional tangential excision (CTE)		
Early CTE vs. C[17] –RCT	-	4.8 vs. 18.3, n.r.
CTE vs. HS[21] –RCT *	13 (2) vs. 11 (2), NS	10 (3) vs. 9 (3), NS
CTE vs. HS[9] – RCT*	30.4 (16-70) vs. 32.6 (18-64), NS	-
(Early) CTE vs. Col[40]*	-	CTE 7 (2.9), Col+CTE 8 (3.6), Col 7.8 (2.8), NS
Hydrosurgery (HS)		
HS vs. CTE[21] – RCT*	11 (2) vs. 13 (2), NS	9 (3) vs. 10 (3), NS
HS vs. CTE[9] – RCT*	32.6 (18-64) vs. 30.4 (16-70), NS	-
Hydrosurgery[41]	13.4 (3.2, 8-19)	-
Hydrosurgery[42]	-	23 (5-78)
Hydrosurgery[43]	13.4 (2.1, 10-18)	7.6 (1.7, 5-11)
Hydrosurgery[44]	-	8.4 (8.5, 1-32)
Hydrosurgery[45]	-	4.4 (7.6, 1-25)
Hydrosurgery[30]	11.8 (8.1, 5-21)	-

Table 2. Continued.

Debridement technique	Time to complete wound healing *days (SD, range)*	Time to complete debridement *days (SD, range)*
Enzymatic debridement		
B vs. CDT[10] –RCT	32.8 (17) vs. 29.2 (16.1), NS	2.2 (1.4) vs. 8.7 (5.7), $p<0.0001$
Col vs. SSD[46]	19.0 vs. 22.1, NS	9.3 vs. 11.6, NS
Col vs. early CTE[40]*	-	Col: 7.8 (2.8), Col+CTE: 8 (3.6), CTE: 7 (2.9), NS
Bromelain[47]	23 (15.8, 4-60), SG-patients: 17 (13.1, 0-40), n.r.	-
Collagenase[48]	22.3	-
Bromelain[49]	29.2 (12.2, 11-54)	1.7 (2.5, 1-12)
B vs. CTE[19]	19.9 (6.0) vs. 42.2 (18.7), $p=0.002$	0.9 (0.3, 0-1) vs. 4.9 (6.2, 0-18), NS
Bromelain[33]	28 (9-49)	-
Shock wave therapy		
Shock waves[16]	15.6 (5.1, 10-29)	-

*These studies (n=3) are mentioned twice, because they compared two different debridement techniques.
CTE = conventional tangential excision; C = conservative treatment; RCT = randomized clinical trial; n.r. = not reported; HS = hydrosurgery; NS = none significant; Col = Collagenase; B = Bromelain; CDT = conventional debridement techniques (CTE, hydrosurgery, dermabrasion; SSD = Silver Sulfadiazine; SG = skin graft.

Secondary outcomes

Table 3 presents an overview of the secondary outcomes in each debridement category, from top to bottom, most reported to least reported. The most reported (>40%) secondary outcomes are described below, except AEs which are presented in Appendix 2.3 (found online doi: *10.1016/j.bjps.2019.07.006*) due to the heterogeneity of the assessments.

Need for grafting

The need for grafting was 100% in all five CTE studies that reported the need for grafting and lowest in the ED group with a range of 2-60% of the patients. Three studies in the ED group, including one RCT, showed a significantly lower need for grafting in ED patients than for CTE patients.

Adverse events

AEs were frequently reported (14/27 studies), but the reported AEs varied greatly. AEs were reported in 5/7 studies in the CTE group and mainly consisted of infections/positive wound cultures. There was no difference between postoperative pain (one study) and infection (one study) when comparing HS with CTE. In the ED group, the most frequently described AEs were pain (two studies), fever (two studies) and infection (two studies). The SW study had no AEs.

Mortality

Mortality was highest in the CTE group, with a range of 2-57%. One cohort study showed no difference in mortality when comparing CTE with conservative treatment[17]. Another cohort study showed that early (48-72 hours) compared to delayed excision (7-10 days) led to a significantly lower mortality.[18] In 6/7 HS and ED studies the mortality was 5% or lower.

Time from accident to first debridement

This was reported in 12/27 studies. It was generally shortest in the ED group which ranged from 1 to 2 days and highest in the HS group with a range of 3-23 days. However, there was no significant difference in the cohort study that compared ED (bromelain) with CTE.[19]

Scar quality

The definition of scar quality differed between the studies, see Table 4. Scar quality was described in three studies in the CTE group, where it appears that early CTE prevented scar problems (e.g., contractures, impairment) compared to late CTE, and scars after CTE were rated poorer than those after conservative treatment. Furthermore, three studies found no difference, of which two compared HS to CTE and one compared ED to various conventional debridement techniques (CTE, HS, dermabrasion).

Table 3. Overview of incidence of reports on secondary outcomes

Secondary outcomes	CTE (n=7)	HS (n=8)	ED (n=11)	SW n=1
Need for grafting	■■■■■	■■■■■■	■■■■■■■■	■
Adverse events	■■■■■	■■	■■■■■■	■
Mortality	■■■■■	■■■	■■■■	
Time accident – 1st debridement	■	■■■■■	■■■■■	■
Scar quality	■■■	■■■■	■■■■	■
Re-operation	■■	■■■■	■■■■	
Length of hospital stay	■■■■■■■		■■	
Excision time	■■	■■■		
Graft take	■■■	■■		
Reconstructions		■■	■	
Precision of debridement		■	■■	
Costs			■	

CTE = conventional tangential excision. HS= hydrosurgery. ED= enzymatic debridement. SW= shock wave therapy. The number of studies which report a specific outcome parameter is indicated by the number of grey boxes, e.g., the need for grafting was reported in 5 out of 7 CTE studies, 6 out of 8 HS studies, 8 out of 11 ED studies and in 1 out of 1 SW study.

Table 4. Scar quality outcomes

Debridement technique	Scar quality assessment method	Results
Early CTE vs. C[22]	3-point scale, not validated	8 excellent, 14 good, 2 fair vs. 12 excellent/good, p<0.01
Early CTE: early admittance <1 week and later admittance[32]	3-point scale, not validated	Major problems: 2 vs. 4; Moderate problems: 6 vs. 8; Minor problems: 18 vs. 4, n.r.
Early CTE <5 days vs. start conservative treatment + later SG (CSG)[31]	Hypertrophy and contracture, not validated	CTE group: hypertrophy 3/7, minor contractures 3/7; CSG: no follow up patients
HS vs. CTE[21]	Contractures 6 months post-burn, not validated	33.3% vs. 35.6%, NS
HS vs. CTE[9]	Vancouver Scar Scale (VSS) at 3 and 6 months, validated	At 6 months: mean scores 1.7 vs. 2.1, NS
Hydrosurgery[43]	Grading satisfaction scale (0 -10), not validated	7.8 (range 5-9, SD 1.0)
Hydrosurgery[30]	Hypertrophy, not validated	In 4/7 patients it was specifically mentioned that they did not develop hypertrophy, 3/7 no data mentioned
B vs. CTD[10]	Modified VSS (0-13), validated	3.1 (SD 2.6) vs. 3.4 (SD 2.6), NS
Bromelain[49]	Limiting range of motion, VSS, validated	5% (N=1)
B vs. CTE[49]	Patient and Observer Scar Assessment Scale and VSS, not validated	Several POSAS items were superior in ED group or not significant compared to CDT. VSS: no differences
Bromelain[19]	VSS at 3 months, validated	8 patients left for follow-up, average score: 6/14 (4-8) points
Shock waves[16]	Hypertrophy, not validated	5% of the patients

CTE = conventional tangential excision; C = conservative treatment; n.r. = not reported; CSG = conservative + later skin graft; HS = hydrosurgery; NS = none significant; VSS = Vancouver Scar Scale; SD = standard deviation; B = Bromelain; CDT = conventional debridement techniques (CTE, hydrosurgery, dermabrasion).

The following secondary outcomes were reported in less than 40% of the studies.

Reoperations

Ten studies reported the average number of operations per patient, how many patients required an additional operation, or the number of operations performed to reach complete debridement. One of the two CTE studies found the number of operations needed until complete debridement to be higher in the staged excision group than in the excision and immediate autografting group[20]. One out of four ED studies showed that a significantly higher number of operations were needed in the CTE group than in the ED group (bromelain)[19].

Length of hospital stay (LOHS)

LOHS was reported in all the CTE studies but only in two ED studies and not reported in the HS or SW studies. In 2/3 CTE studies, in which CTE was compared to conservative treatment, the LOHS was significantly shorter in the CTE group.

Excision time

This entails the time it takes to debride a burn wound in a debridement session that leads to complete eschar removal (e.g., in the operating theater). It is not applicable in the ED group, because the ED has a fixed duration of application. In the HS group, one of the three studies showed a significantly shorter excision time when debriding particular areas (e.g., hands), but a longer excision time in larger areas (e.g., limbs, trunk) than that taken for CTE.[21]

Graft take

Graft take ranged between 85 and 100% in the CTE and HS studies, with the exception of one CTE study with a range of 40-100%.[22]

Reconstructions

The number of reconstructions was reported only in three studies. The RCT (between ED and standard of care) showed no difference.[10]

Precision of debridement

One HS study used biopsies to determine the precision of debridement and showed that the CTE group lost more viable dermal tissue than the HS group.[9] Two ED studies used a visual assessment classification system.

Costs

costs were compared in one ED study, which was in favor of the ED compared to various other conventional debridement techniques (CTE, HS, and dermabrasion).[23]

For detailed overview of all the secondary outcomes per study, see Appendix 2.2 (found online doi: *10.1016/j.bjps.2019.07.006*).

Risk of bias was assessed in four included RCTs

Allocation (selection bias)

in 3/4 RCTs, randomization was adequately described and performed using computer-generated closed envelopes[9, 21] or constrained block allocation.[10] One study reported that patients were randomly assigned to either of the intervention groups but did not specify the method used.[22]

Blinding (performance and detection bias)

Performance: In all four RCTs, blinding of the surgeons performing the procedure was not possible given the nature of the intervention.

Detection

None of the studies explicitly reported blinding of the primary outcomes. In the Bromelain RCT[10], long-term outcomes (such as scar quality and quality of life) were assessed by blinded assessors. In one HS RCT[9] some secondary outcomes (graft take) were assessed by a blinded assessor.

Incomplete outcome data (attrition bias)

one of the HS RCTs primary outcome was dermal preservation as determined by biopsies.[9] These biopsies were not available in 8/30 cases in the HS group and 7/31 cases in the control group. In the other HS RCT[21], no lost to follow up was reported.

In the bromelain study[10] one patient in the Bromelain group was withdrawn from the study due to noncompliance in the early phase of the study. In the CTE study[22], no patients were lost to follow-up. However, one patient died in the CTE group and 3 patients died in the group treated with honey dressing.

Other potential bias (conflicts of interest)

In the two HS RCT's[9, 21], the authors declared no conflict of interest or financial affiliation with the manufacturer of the hydrosurgical instrument [VERSAJET, Smith and Nephew Plc., London, UK]. The Bromelain RCT was funded by Mediwound, the manufacturer of NEXOBRID® (bromelain).[10] Thus, potential conflict of interest cannot be excluded for this study. In the CTE study of Subrahmanyam[22], there was no mention of possible conflicts of interest.

Discussion

Our study shows that there is scarce evidence of the efficiency and safety of burn wound debridement techniques. Twenty-seven studies met our inclusion criteria and addressed four out of six debridement categories. Four studies had a randomized controlled study design, addressing three debridement categories. Risk of bias in these RCTs was limited, mainly related to absent or unclear blinding of surgeons and outcome assessors.

Because of heterogeneity in primary outcome parameter definition and patient groups, we were unable to conduct a meta-analysis of the primary outcomes, i.e., time to wound healing and time to complete debridement data. Furthermore, comparative studies were conducted only between HS or ED in comparison to CTE. For these reasons, no definitive conclusions could be drawn regarding outcomes between HS and ED. Nevertheless, some trends can be noted.

The time to complete wound healing tended to be longer in the ED group than in the HS group. An explanation can be that the use of autograft, which facilitates wound healing, was postponed in the treatment trajectory in the ED studies to reduce the eventual need for grafting. A longer time to wound healing is associated with a decline in scar quality.[24, 25] Although ED is associated with a longer time to wound healing, we hypothesize that this may not necessarily lead to lower scar quality. Eschar maintains an ongoing acute inflammation locally in the burn wound that can lead to poorer outcome of wound healing and thus, an earlier and more selective removal of eschar might improve wound healing and allow spontaneous healing.[26]

Time to complete debridement seemed to be shortest in the ED group. This is often inherent to the way ED is performed, namely, rapidly after admission. Early complete eschar removal with enzymes is associated with increased spontaneous healing due to preservation of dermis and, herewith, a reduced need for excision and autografting.[10] A shorter time to complete debridement could allow spontaneous healing of a vital dermal wound bed and is thought to decrease the inflammatory response accompanied by the presence of eschar.[27] It may therefore be desirable to achieve complete debridement as soon as possible.

The content of our secondary study outcomes might reflect a general shift in focus from survival to quality of life in burn patients. The older studies using conservative treatment and CTE primarily focused on mortality and length of hospital stay, whereas currently, outcomes with regard to time to wound healing, need for grafting, and scar quality are considered to be of equal or even higher importance. The evolution of burn care has caused a decrease in mortality.[2, 28] This decrease is noted when comparing earlier studies using CTE to more recent studies using HS or ED. However, this higher mortality in the CTE group can be partly attributed to the more severely burned patients in this group as reflected by the higher TBSA burned. The decrease in need for grafting, seen in the HS and the ED group, can be explained by the more precise and controlled manner of debridement with these tools which leads to dermis preservation and more spontaneous epithelialization.

AEs were reported relatively frequently, but the type of events differed considerably between studies. The most frequently described AEs included infection, pain and blood loss, although none of the studies describe all these AEs together. Thus, there is no agreement between which types of AEs are considered most relevant. Length of hospital stay was reported in all of the CTE studies, but in the studies involving modern debridement techniques, it was fairly underreported. An explanation might be that the parameter LOHS is not predictive of the final outcome in terms of scar quality and quality of life and therefore deemed less relevant nowadays. Another remarkable finding is the limited attention for costs. Although burn care is known as an expensive type of care[29], only one study compared costs between two debridement techniques.[23]

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Although most of our outcome parameters were described by more than one study, the definition of certain parameters, including time to complete wound healing and precision of debridement remained either unclear or differed between studies. This also applied to the definition of scar quality. Some studies used a very narrow definition of scar quality as just the presence of hypertrophy, contractures or (dis)satisfaction with the scar at follow-up.[16, 30-32] Other studies used a validated scar assessment scale (Vancouver Scar Scale), but did not include the patients' perspective or objective scar measurement tools.[9, 10, 33] Due to the use of non-validated tools and the heterogeneity of assessments, it was not possible to compare the outcomes between studies or to draw definite conclusions regarding scar quality.

The strength of this review was the systematic method we used during the entire process, which conforms to established guidelines on the conduct and reporting of systematic reviews.[11] Moreover, our literature search was performed in all major databases and was updated (until May 8, 2017) during the writing of this review to ensure the inclusion of the most recent studies. This update resulted in seven new eligible studies, which were included in our analysis. This emphasizes the relevance of this review topic in present day burn care research. Furthermore, we included parameters without predefined definitions (e.g., scar quality) to formulate comprehensive definitions of our outcomes on efficiency and safety. This enabled us to include more studies to extract data than would have been the case when more narrow definitions were used.

Our study has some limitations. First, no meta-analysis was performed because of limited available data: only four studies, including two RCTs, provided data on a two-group comparison including an estimate of variance. Second, we did not include studies before 1990. We choose this strategy because we anticipated to find no or only few appropriate studies for the purpose of this review, as the emphasis of burn care research was different before this time. Third, we chose not to score the quality of the observational studies as we did with the RCTs. However, their level of evidence is limited due to their study design and lack of comparison between treatments. Lastly, not all debridement techniques can or will be universally applied to wounds of every burn depth. For instance, HS cannot debride full-thickness burn wounds. This makes it impossible to make a universal claim as to which debridement technique is "best" for every burn wound. More data in different burn depth categories would be necessary to perform stratification in the analysis.

We recommend that future studies regarding (new) debridement techniques use the design of a randomized clinical trial or high-quality prospective cohort study. Recently, Beks et al.[34] underscored the added value of nonrandomized studies especially in the field of surgery. Observational studies revealed similar estimates of treatment effects as those of RCTs.[35] Thus, high-quality observational studies on excision techniques in burns can contribute to the evidence of these techniques. Moreover, uniform definitions of outcome parameters, either frequently described or clinically most relevant, and validated measurement tools should be used. Such measurement tools are available and often validated specifically in burn wound patients. These include tools for scar assessment[36], quality of life[37] and functioning.[38] It is important to keep in mind the more clinically relevant outcome assessments of modern-day burn care with a special focus on scar quality and (subsequent) quality of life after burns. Furthermore, we recommend a follow-up period of at least one year, to approach final scar results.

Recently, a systematic review focusing on burn excision tools of randomized and nonrandomized trials has been published.[39] There are some differences in our review, including the use of the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement in our review. Most importantly, we used predefined outcome measures. In general, we do agree with the conclusion drawn by these authors that modern techniques are upcoming and may lead to better long-term scar quality and quality of life.

In conclusion, to the best of our knowledge this is the first comprehensive review that, following the PRISMA statement, systematically included all available literature from 1990 onwards of both surgical and nonsurgical debridement techniques of thermal burn injuries. Although CTE is considered the gold standard for burn debridement, we found limited evidence on efficiency and safety of this technique. More recently, several relatively new debridement techniques (HS and ED) have been described in studies of increasingly methodological quality. These studies show promising results with regard to relevant modern burn wound outcomes such as need for grafting and scar quality. At this point, convincing evidence on efficiency and safety in favor of any of these techniques for any particular burn wound is lacking. Unfortunately, we only found studies that compared these more selective debridement techniques to CTE, while it seems more relevant to compare these modern debridement techniques to each other.

In the future, studies regarding (new) debridement techniques need to use standardized and validated outcomes measurement tools to allow improved standardization and comparisons across studies.

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Conflict of interest

The authors declare no direct conflict of interest.

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Appendix 1. complete electronic search strategy

((((“Burns”[majr:noexp] AND (“Debridement”[majr] OR “debridement”[ti] OR debride*[ti] OR “operation”[ti] OR operation*[ti] OR “excision”[ti] OR excision*[ti] OR hydrosurg*[ti] OR hydro surg*[ti] OR “grafting”[ti] OR grafting*[ti] OR “surgery”[ti] OR “Skin Transplantation”[majr] OR “skin transplantation”[ti] OR skin transplant*[ti] OR skin graft*[ti] OR “surgical procedure”[ti] OR surgical procedure*[ti] OR “versajet”[ti] OR “enzymatic debridement”[ti] OR scalpel*[ti] OR “autolytic debridement”[ti] OR “mechanical debridement”[ti] OR “necrotomy”[ti] OR necrotom*[ti] OR “escharotomy”[ti] OR escharotom*[ti] OR “nettoyage”[ti] OR nettoyag*[ti] OR “Surgical Procedures, Operative”[majr:noexp] OR surg*[ti])) OR ((“burn”[ti] OR “burns”[ti] OR “burned”[ti] OR thermal injur*[ti] OR scald*[ti] OR burn*[ti]) NOT (Chemical Burn*[ti] OR Electric Burn*[ti] OR Inhalation Burn*[ti] OR “Smoke Inhalation”[ti] OR Eye Burn*[ti] OR Sunburn*[ti] OR burnout*[ti]) AND (“Debridement”[majr] OR “debridement”[ti] OR debride*[ti] OR “operation”[ti] OR operation*[ti] OR “excision”[ti] OR excision*[ti] OR hydrosurg*[ti] OR hydro surg*[ti] OR “grafting”[ti] OR grafting*[ti] OR “surgery”[ti] OR “Skin Transplantation”[majr] OR “skin transplantation”[ti] OR skin transplant*[ti] OR skin graft*[ti] OR “surgical procedure”[ti] OR surgical procedure*[ti] OR “versajet”[ti] OR “enzymatic debridement”[ti] OR scalpel*[ti] OR “autolytic debridement”[ti] OR “mechanical debridement”[ti] OR “necrotomy”[ti] OR necrotom*[ti] OR “escharotomy”[ti] OR escharotom*[ti] OR “nettoyage”[ti] OR nettoyag*[ti] OR “Surgical Procedures, Operative”[majr:noexp] OR surg*[ti]))) NOT (“Animals”[mesh] NOT “Humans”[mesh]) NOT (“comment”[ptyp] OR (“case reports”[ptyp] NOT “case series”[tw])) AND english[la]) **OR** (((“Burns”[majr:noexp] AND (“Debridement”[majr] OR “debridement”[ti] OR debride*[ti] OR “operation”[ti] OR operation*[ti] OR “excision”[ti] OR excision*[ti] OR hydrosurg*[ti] OR hydro surg*[ti] OR “grafting”[ti] OR grafting*[ti] OR “surgery”[ti] OR “Skin Transplantation”[majr] OR “skin transplantation”[ti] OR skin transplant*[ti] OR skin graft*[ti] OR “surgical procedure”[ti] OR surgical procedure*[ti] OR “versajet”[ti] OR “enzymatic debridement”[ti] OR scalpel*[ti] OR “autolytic debridement”[ti] OR “mechanical debridement”[ti] OR “necrotomy”[ti] OR necrotom*[ti] OR “escharotomy”[ti] OR escharotom*[ti] OR “nettoyage”[ti] OR nettoyag*[ti] OR “Surgical Procedures, Operative”[majr:noexp] OR surg*[ti])) OR ((“burn”[ti] OR “burns”[ti] OR “burned”[ti] OR thermal injur*[ti] OR scald*[ti] OR burn*[ti]) NOT (Chemical Burn*[ti] OR Electric Burn*[ti] OR Inhalation Burn*[ti] OR “Smoke Inhalation”[ti] OR Eye Burn*[ti] OR Sunburn*[ti] OR burnout*[ti]) AND (“Debridement”[majr] OR “debridement”[ti] OR debride*[ti] OR “operation”[ti] OR operation*[ti] OR “excision”[ti] OR excision*[ti] OR hydrosurg*[ti] OR hydro surg*[ti] OR “grafting”[ti] OR grafting*[ti] OR “surgery”[ti] OR “Skin Transplantation”[majr] OR “skin transplantation”[ti] OR skin transplant*[ti] OR skin graft*[ti] OR “surgical procedure”[ti] OR surgical procedure*[ti] OR “versajet”[ti] OR “enzymatic debridement”[ti] OR scalpel*[ti] OR “autolytic debridement”[ti] OR “mechanical debridement”[ti] OR “necrotomy”[ti] OR necrotom*[ti] OR “escharotomy”[ti] OR escharotom*[ti] OR “nettoyage”[ti] OR nettoyag*[ti] OR “Surgical Procedures, Operative”[majr:noexp] OR surg*[ti]))) NOT (“Animals”[mesh] NOT “Humans”[mesh]) NOT (“comment”[ptyp] OR (“case reports”[ptyp] NOT “case series”[tw])) NOT english[la] AND (“Epidemiologic Studies”[Mesh] OR “Clinical Trial”[Publication Type] OR “Trial”[tw] OR “RCT”[tw] OR random*[tw] OR “study”[tw])))