Evidence and Trends in Burn Wound Debridement: An Evidence Map

Les données probantes et les tendances en matière de débridement des brûlures : la cartographie des données probantes

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Abstract

Treatment of the burn wound is crucial in care of severely burned patients. Surgical strategies differ in technique and timing of wound excision and are considered to have an impact on morbidity and mortality of burn patients. Most techniques and strategies have been established during the last century and are still standard of care. Nonetheless, several newer techniques have been presented and evaluated recently. To summarize the evidence and trends for eschar removal by burn wound debridement currently available, an evidence map as variant of the systematic review, was prepared. For this purpose, a systematic literature search was performed in the PubMed databases until December 2016. While overall evidence in this domain is low, recent publications focus on optimal timing of wound excision, enzymatic debridement, and hydrosurgery. Several studies report the benefit of an early wound excision in terms of shorter hospital stay, lower wound infection rate, and reduction of postburn metabolic changes. Enzymatic debridement has been shown to be an effective tool for early eschar removal and in addition reduces the need for autografting of the debrided burn wound with a relatively high level of evidence (LoE 2-). Wound debridement by means of hydrosurgery is more precise compared to conventional wound excision and preserves viable dermis, but a positive effect on wound healing or scar formation could not been shown (LoE 2). Furthermore, rarely reported techniques comprise larvae therapy, debridement by laser, and other technical adjuncts, but the level of evidence is limited (LoE 4-5).

Résumé

Il est crucial de traiter les plaies des grands brûlés. Les stratégies chirurgicales et le moment d'exciser les plaies dépendent de diverses techniques, qui sont considérées comme ayant des répercussions sur la morbidité et la mortalité des patients brûlés. La plupart des techniques et des stratégies ont été mises au point au cours du dernier siècle et représentent encore la norme des soins. Plusieurs nouvelles techniques ont toutefois été présentées et évaluées récemment. Pour résumer les données probantes et les tendances en matière d'élimination des escarres par débridement, les chercheurs ont préparé une variante de l'analyse systématique, sous forme de cartographie des données probantes. Ils ont ainsi effectué une analyse bibliographique dans les bases de données de PubMed jusqu'en décembre 2016. Les données probantes globales sont faibles dans ce domaine, mais de récentes publications portent sur le moment optimal de procéder à l'excision des plaies, au débridement enzymatique et à l'hydrochirurgie. Plusieurs études soulignent les avantages d'une excision rapide des plaies pour raccourcir le séjour hospitalier, abaisser le taux d'infection et réduire les changements métaboliques après la brûlure. Il a été démontré que le débridement enzymatique est un outil efficace pour éliminer rapidement les escarres et limiter le recours aux autogreffes de la plaie débridée, et la qualité de

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preuves qui y est reliée est relativement élevée (QdP 2-). Le débridement des plaies par hydrochirurgie est plus précis que l'excision classique et permet de préserver le derme viable, mais n'a pas d'effet positif démontré sur la guérison ou la cicatrisation des plaies (QdP 2). Certaines techniques sont peu déclarées, telles que la larvothérapie, le débridement au laser et des techniques auxiliaires, mais la qualité des preuves s'y rapportant est limitée (QdP 4-/5).

Keywords

burn wound debridement, systematic review, evidence map, enzymatic debridement, hydrosurgery

Introduction

Appropriate treatment of the burn wound is a major objective in the care of every burn patient. It is crucial for achieving good functional and aesthetic outcomes and is vitally important in major burn injuries. As a prolonged time to wound closure increases, the risk of infectious complication might influence mortality; timely and effective burn wound debridement are necessary prior to safe and fast wound closure with a prognostic relevance.

The first historical description of early burn wound excision by Ambroise Pare is found in 16th century, but eschar removal evolved mainly during the middle of the 20th century.¹ To date, tangential excision as described by Dr Janzekovic,² and deep epifascial excision for deep burns and increased extend of the burnt surface area³ are predominantly performed and accepted as gold standard in most burn centers worldwide.

Despite the frequent use of these techniques in daily routine, a systematic evaluation of the efficiency of the reported techniques is lacking and the level of evidence of burn wound debridement remains unclear. In addition, several new tools to debride the burn wound have been developed and established in clinical practice during the last decades. Although some of them were validated via animal experiments and clinical studies and are gaining more acceptance in many burn centers, a systematic evaluation and validation of the described techniques for burn wound debridement and an evidence-based recommendation for surgical or non-surgical wound excision is not available to date.

This evidence map was conducted to summarize the evidence and efficiency for burn wound debridement and intends to find an evidence-based recommendation for treatment of these burns.

Methods

We have prepared an evidence map as a new variant on the classical systematic review. It visualizes the available primary studies and systematic reviews and ranks them according to their level of evidence. The evidence map is particularly appropriate to investigate a broad field and to reveal gaps and further need for research.⁴ We performed a systematic literature search in the PubMed databases (December 2016) for studies investigating debridement of burn wounds by searching for wound cleaning and debridement, necrosectomy or eschar removal in combination with burn, scald, or electric injury. The used query to search the database is shown in Table 1. Preclinical studies

and animal studies were excluded. Only systematic reviews, randomized controlled trials (RCTs), cohort studies, case-control studies, and case series were included. The systematic search was limited to articles published between 2000 and 2016. All articles that were related to debridement of burn wounds were included. Only articles in English or German were considered for inclusion. Articles that were unavailable in full text in several university libraries were also excluded from the review. All titles and abstracts and, afterward, all potentially relevant full-text articles were screened regarding their relevance for burn wound treatment by an experienced burn surgeon. Study type was assigned by an experienced methodologist.

References of all full-texts were cross-checked for further relevant articles. For all studies included in the evidence map, the level of evidence was classified according to the Oxford Centre for Evidence-Based Medicine⁵ considering study type and methodological quality. All data were extracted in standardized tables including demographic data, setting/country, study type, study size, and results for patient important outcomes. Rating of the quality of evidence and data extraction was performed by an experienced methodologist. The resulting data were arranged by clinical topic and quality of evidence to provide a comprehensive overview of the available evidence on debridement of burn wounds and to identify research gaps.

Results

The PubMed search resulted in 988 potentially relevant articles. Out of these studies, 63 articles were classified as relevant. Based on cross-references of the identified literature, 5 further relevant studies were identified. Nineteen unsystematic reviews and 3 in vitro studies were excluded from further analysis. Thus, 46 studies were included in the analysis (Figure 1), including 1 systematic review, 5 RCTs, 7 comparative cohort studies, 2 intra-individual comparison studies, 20 case series, and 10 case reports. While the included systematic review investigated the use of honey in burn wound treatment, 2 RCTs investigated the effectiveness of enzymatic debridement, 2 RCTs compared hydrosurgery to conventional tangential excision, and 1 other RCTs compared different methods of blister removal on burn wounds. All included studies were published in English language.

Most studies had a low level of evidence.

Table 1. Search Query.

(debridement[MeSH Terms] OR debrid*[tiab] OR
 necrosectom*[tiab] OR (necrotic[tiab] OR necrotizing[tiab] AND
 (remove*[tiab] OR excis*[tiab] OR clean*[tiab])))
AND (burns[MeSH Terms] OR burn*[tiab] OR "thermal injury"[tiab]
 OR "burns, electric"[MeSH Terms] OR "electric injury"[tiab] OR
 "burns, chemical"[MeSH Terms])
NOT (animals [MeSH Terms Terms] NOT humans [MeSH Terms
 Terms])
AND ("2000"[Date - Publication]: "3000"[Date - Publication])

Figure 1. Flowchart of systematic literature search.

Timing of Debridement

Timing of the first escharectomy was investigated by 6 cohort studies, 3 case series/reports, and 1 unsystematic review (Table 2). One cohort study showed reduced bacterial colonization ($P < .05$) and lower infection rate ($P = .001$) after acute wound excision within 24 hours compared to delayed excision (level of evidence [LoE] 3-).⁷ In addition, Saaq et al could show a significant better graft take and a significant shorter hospital stay after early excision within 7 days and grafting in another cohort study (LoE 3-).⁹ A better graft take after early excision and autologous grafting could also be confirmed by Ayaz et al in a further cohort study, while this group found a difference in length of hospital stay that was not of significance (LoE 3-).⁶

Another study could show comparable results in children with significant lower rates of invasive infection, sepsis, and shorter length of hospital stay after early debridement within 2 days after injury. However, no significant difference could be shown in mortality, pneumonia, acute respiratory distress syndrome, pulmonary edema, and amount of blood transfusion between early and late wound debridement in children (LoE 3-).¹⁰

A positive immunomodulatory effect of early escharectomy within 72 hours after trauma has been shown by the marker of a

significant lower insulin resistance ($P < .01$) induced by major burn injury (LoE 4).¹²

A further aspect of timing of burn wound debridement was investigated in a cohort study by Elmasry et al who compared a single-stage escharectomy and early grafting with sequential smaller escharectomies. Both cohorts had a similar extend of burn with a Total body surface area (TBSA) of 31% in the single-stage escharectomy group and 30% in the sequential escharectomy group. Although shorter operating time in staged excisions could be observed, no difference in patient-related outcome could be shown (LoE 3-).⁸

Enzymatic Debridement

One randomized control trial compared enzymatic debridement ($n = 74$) and surgical excision ($n = 81$) and could show a significant shorter time to complete escharectomy ($P < .0001$), lesser need for surgical excision ($P < .0001$) and autografting ($P = .0099$), and less blood loss ($P = .0061$) after enzymatic debridement. Time to complete wound closure, scar quality, need for scar revision, and general health status were not significantly different between enzymatic debridement and conventional surgical excision (LoE 2-).¹⁶ Of note, this study was funded by the producer of the investigated enzyme, Medi-wound, Israel. Ozcan et al investigated the use of the collagenase clostridiopeptidase A (Novuxol) in a collective of burned children and compared enzymatic debridement ($n = 49$) with surgical debridement ($n = 41$) and the consecutive use of both methods. They could show a significantly lower rate of blood transfusion ($P < .001$), a shorter length of hospital stay ($P < .001$), and lesser need for autografting ($P < .001$; LoE 3-).¹⁷ A local debridement could be also observed by using a collagenase gel (Iruexol) for 14 days on burn wounds ($n = 33$) in a RCT by Xiaobing et al.¹⁸ Compared to dressings with Vaseline ($n = 29$), the collagenase treatment showed a significant higher removal of necrotic tissue (LoE 2-). Treated wound area and TBSA of patients were not described by the authors.

Another agent used for enzymatic debridement containing papain was investigated in an intra-individual comparison against silver sulfadiazine. Due to major adverse effects, nearly all patients could not complete the trial and no efficacy of the enzymatic debridement could be attested.¹⁹

In addition, numerous case series describe enzymatic debridement of the burn wound by bromelain and other agents (LoE 4 or lower; Table 3).

Hydrosurgery

In the last decades, burn wound debridement by hydrosurgery has been claimed to allow a more precise, selective, and gentle wound excision (Table 4). This could be confirmed in an RCT comparing wound debridement with Versajet ($n = 25$) against conventional tangential wound debridement ($n = 27$). The authors could show a significant lower loss of vital dermis ($P = .02$) in the hydrosurgery group by histological examination with a lower postoperative infection rate ($P = .05$).

Table 2. Timing of Debridement.

Study	Patients (IG/CG)	Intervention	Comparison	Outcomes (IG/CG)	Study type	Country/ setting	LoE
Ayaz et al ⁶	Burn <15% TBSA Age (mean): 21.9/ 20.1 Female: 38.5%/40.7% TBSA: 6.3%/5.29%	n = 27 Early excision and grafting (referred to centre less than 14-day post-injury)	n = 27 Delayed excision and grafting (not consented for early excision or were referred to the hospital more than 14 days post-injury)	<ul style="list-style-type: none"> Length of hospital stay (days, mean): 7.92/9.38 ($P = .654$) Graft success (6 months): 96.8/92.8 ($P = .033$) Itching (5D-itch scale, 6 months): 8.61/ 8.9 ($P = .977$) Appearance of scar (Vancouver scar scale, 6 months): 0.38/0.55 ($P = .393$) Bacterial colonization (6 days): IG < CG ($P < .05$) Bacterial counts (6 days): IG < CG ($P = .001$) Infection rates (6 days): IG < CG ($P = .001$) 	Cohort study	Iran, level I burn centre	3-
Barret and Herndon ⁷	Thermal injuries Age (mean): 7.5/7.2 Female: 36%/47% TBSA: 34%/42%	n = 12 Acute excision (within 24 hours)	n = 8 Delayed excision	<ul style="list-style-type: none"> Bacterial colonization (6 days): IG < CG ($P < .05$) Bacterial counts (6 days): IG < CG ($P = .001$) Infection rates (6 days): IG < CG ($P = .001$) 	Cohort study	United States, University hospital	3-
Elmasry et al ⁸	Burns Age (median): 31.5/47 Female: 15.3%/8.5% TBSA: 31%/30%	n = 62 Early and total excision of full thickness burns followed by immediate autograft	n = 107 Sequential smaller excisions and delayed coverage with an autograft	Length of hospital stay/TBSA (days, mean): 1.6/1.9 ($P = 0.21$)	Cohort study	Sweden, NR	3-
Saaliq et al ⁹	Burns up to 40% TBSA Age (mean): 29.1/ 28.8 Female: 24/23 TBSA: 30.6%/ 30.5%	n = 60 Early excision (within 4-7 days of sustaining burn injury)	n = 60 Delayed excision (within 1-4 weeks post-burn)	<ul style="list-style-type: none"> Poor graft take (<80%); 1.6%/21.6% ($P < .05$) Length of hospital stay $\leq$ 7 days: 90.0%/21.66% ($P < .05$) 	Cohort study	Pakistan, burn centre	3-
Xiao-Wu et al ¹⁰	Acute burns Children TBSA > 40% 10% full-thickness burns Age (mean): 5.4/8.5/5.5 Female: 32.7%/45.2%/31.0% TBSA: 62.2%/60.3%/59.8%	Early debridement (day 0-2)	Intermediate debridement (3- 6 days) Late debridement (7-14 days)	<ul style="list-style-type: none"> Mortality: 15.1%/9.5%/10.3% (ns all comparisons) Invasive infection: IG < CGs (statistical significant higher in both late groups) Sepsis: IG < CGs (statistical significant higher in both late groups) Adult respiratory distress syndrome: 8.1%/19.0%/10.3% (ns all comparisons) Pneumonia: 15.1%/21.4%/13.8% (ns all comparisons) Pulmonary edema: 38.4%/42.9%/41.4% (ns all comparisons) Total blood transfusion (mean): 1.83/1.97/1.67 (ns all comparisons) Length of hospital stay (mean, days per TBSA): 0.66/0.71/0.79 (statistical significant between early and late group) 	Cohort study	United States, children hospital	3-
Al-Qattan and Pitkanen ¹¹	n = 15 Alkali drain cleaner burns Age (mean): 27 years Women: 5 TBSA: 2%	Delayed primary excision and grafting (7-9 days)	NA	<ul style="list-style-type: none"> Grip strength (1 year): 85–105% of the contralateral hand Range of motion (1 year): 14 Colour and texture of the grafted skin (1 year): excellent = 0; satisfactory = 12; poor = 3 Insulin Sensitivity Index (5 days): IG < CG ($P < .01$) Infused Rate of Total 20% Glucose (5 days): IG < CG ($P < .01$) 	Case series	Saudi Arabia, University hospital	4
Chen et al ¹²	Major burn Age (mean): 29/30 Female: 25%/23.3% TBSA: 58%/55%	Removal of dead devitalized tissue and allografting in escharotomy within 72	Removal of dead devitalized tissue and allografting after about 7 days		Cohort study	China, University hospital	4
Bhat ¹³	Chemical burns n = 300	Early excision of chemical burns within 48h	NA	NR	Case series	Saudi Arabia, hospital	4-
Tang et al ¹⁴	Deep facial burns TBSA (range): 8%-30%	Early escharotomy and concurrent composite razor-thin skin autografting and acellular dermal matrix scaffold for treating deep facial burns	NA	Take rat (day 12): 97.3 Haemorrhage or Henatoma: 0	Case series	China, department of burns	4-
Zhang et al ¹⁵	n = 5 Burned by para-Chloronitrobenzene Female: 0	Early and thorough wound debridement	NA	NR	Case report	China, department of burns	5

Ordered by LoE, significant results marked in bold, unsystematic reviews are listed but were excluded from further analysis (IG: intervention group; CG: control group; NA: not applicable; NR: not reported; ns: not statistical significant ($P > .05$); TBSA: total body surface area; LoE: level of evidence)

Table 3. Enzymatic Debridement.

Study	Patients (IG/CG)	Intervention	Comparison	Outcomes (IG/CG)	Study type	Country/ setting	LoE
Rosenberg et al ¹⁶	Deep burns Age (mean): 32.4/29.3 Female: 23.8%/24.7% TBSA: 11.3%/11.0%	n = 74 Enzymatic debridement with NexoBrid	n = 81 Excisional debridement followed by autografting	<ul style="list-style-type: none"> Time to complete eschar (mean, days): 2.2/8.7 ($P < .0001$) Wounds requiring surgical excision 24.5%/70.0% ($P < .0001$) Autograft: 17.9%/34.1% ($P = .0099$) Time to complete wound closure (days): 32.8/29.2 ($P = .1197$) Blood loss-change in hemoglobin (mean, mmol/L): 0.52/1.04 ($P = .0061$) Scar quality (mean, Modified Vancouver Scar Scale, 2-4years): 3.12/ 3.38 ($P = .88$) Scar revision/reconstructive surgery (2-4years): 3.7%/8.6% ($P = .6547$) General health (mean SF-36, 2-4years) – physical score (patients) 51.1 /51.3 ($P = .68$) Adverse events: ns differences Debridement efficacy very good or good in 90.99%/0% ($P < .05$) Pain (median, 10 days): 3/7 	RCT	Israel	2-
Xiaobing et al ¹⁸	Burn wounds n = 30 Major burn Age (range): 9-80 Females: 18 TBSA (range): 20%-60%	n = 33 Treatment with collagenase gel (14 days) Enzymatic debridement with Debridase (papain and urea)	n = 29 Vaseline (14 days) Silver sulphadiazine	<ul style="list-style-type: none"> Complete removal of eschar (mean, days): 7.8 / 8 / 7 (ns) Blood transfusion: 1/18/30 ($P < .001$ [enzymatic only vs. both other groups]) Hospital stay (mean, days): 12.5/20.7/20.2 ($P < .001$ [enzymatic only vs. both other groups]) Autografting: 1/28/33 ($P < .001$ [enzymatic groups vs. surgery]) Wound infection: 0/17/7 ($P > .05$ [enzymatic groups vs. surgery]) Pain (3 months, Patient-Related) Wrist Evaluation Score: 23/100 Disabilities of the Shoulder, Arm and Hand: 22/100 Scar quality (3 months, Vancouver Scar Scale): 6/14 Side effects (during hospital stay): 0 Wound infections (during hospital stay): 0 Complete wound closure (mean, days): 17 (surgery), 23 (no surgery) Surgical escharotomy: 0 Permanent damage: 0 Significant adverse events: 0 	RCT	China, hospital	2-
Langer et al ¹⁹	Major burn Age (range): 9-80 Females: 18 TBSA (range): 20%-60%	n = 29 Enzymatic debridement with collagenase clostridiopeptidase A	n = 29 Enzymatic debridement with collagenase clostridiopeptidase A followed by surgical debridement	<ul style="list-style-type: none"> Complete removal of eschar (mean, days): 7.8 / 8 / 7 (ns) Blood transfusion: 1/18/30 ($P < .001$ [enzymatic only vs. both other groups]) Hospital stay (mean, days): 12.5/20.7/20.2 ($P < .001$ [enzymatic only vs. both other groups]) Autografting: 1/28/33 ($P < .001$ [enzymatic groups vs. surgery]) Wound infection: 0/17/7 ($P > .05$ [enzymatic groups vs. surgery]) Pain (3 months, Patient-Related) Wrist Evaluation Score: 23/100 Disabilities of the Shoulder, Arm and Hand: 22/100 Scar quality (3 months, Vancouver Scar Scale): 6/14 Side effects (during hospital stay): 0 Wound infections (during hospital stay): 0 Complete wound closure (mean, days): 17 (surgery), 23 (no surgery) Surgical escharotomy: 0 Permanent damage: 0 Significant adverse events: 0 	Non-randomized intra individual comparison	India, tertiary referral centre	3-
Özcan et al ¹⁷	Children with partial-thickness burns Age (mean): 2.8/3.4/3.4 Female: 17/9/15 TBSA: 12%/12%/13%	n = 49 Enzymatic debridement with collagenase clostridiopeptidase A	n = 41 Surgical debridement	<ul style="list-style-type: none"> Complete removal of eschar (mean, days): 7.8 / 8 / 7 (ns) Blood transfusion: 1/18/30 ($P < .001$ [enzymatic only vs. both other groups]) Hospital stay (mean, days): 12.5/20.7/20.2 ($P < .001$ [enzymatic only vs. both other groups]) Autografting: 1/28/33 ($P < .001$ [enzymatic groups vs. surgery]) Wound infection: 0/17/7 ($P > .05$ [enzymatic groups vs. surgery]) Pain (3 months, Patient-Related) Wrist Evaluation Score: 23/100 Disabilities of the Shoulder, Arm and Hand: 22/100 Scar quality (3 months, Vancouver Scar Scale): 6/14 Side effects (during hospital stay): 0 Wound infections (during hospital stay): 0 Complete wound closure (mean, days): 17 (surgery), 23 (no surgery) Surgical escharotomy: 0 Permanent damage: 0 Significant adverse events: 0 	Cohort study	Turkey, paediatric burn unit	3-
Cordts et al ²⁰	Full-thickness upper extremity burns Age (mean): 47.8 Females: 31.2% TBSA: 20.1%	n=16 Enzymatic debridement	NA	<ul style="list-style-type: none"> Complete removal of eschar (mean, days): 7.8 / 8 / 7 (ns) Blood transfusion: 1/18/30 ($P < .001$ [enzymatic only vs. both other groups]) Hospital stay (mean, days): 12.5/20.7/20.2 ($P < .001$ [enzymatic only vs. both other groups]) Autografting: 1/28/33 ($P < .001$ [enzymatic groups vs. surgery]) Wound infection: 0/17/7 ($P > .05$ [enzymatic groups vs. surgery]) Pain (3 months, Patient-Related) Wrist Evaluation Score: 23/100 Disabilities of the Shoulder, Arm and Hand: 22/100 Scar quality (3 months, Vancouver Scar Scale): 6/14 Side effects (during hospital stay): 0 Wound infections (during hospital stay): 0 Complete wound closure (mean, days): 17 (surgery), 23 (no surgery) Surgical escharotomy: 0 Permanent damage: 0 Significant adverse events: 0 	Case series	Germany, Burn Intensive Care Unit	4
Krieger et al ²¹	Deeply burned hand TBSA: 1.4%	Selective enzymatic debridement	NA	<ul style="list-style-type: none"> Complete removal of eschar (mean, days): 7.8 / 8 / 7 (ns) Blood transfusion: 1/18/30 ($P < .001$ [enzymatic only vs. both other groups]) Hospital stay (mean, days): 12.5/20.7/20.2 ($P < .001$ [enzymatic only vs. both other groups]) Autografting: 1/28/33 ($P < .001$ [enzymatic groups vs. surgery]) Wound infection: 0/17/7 ($P > .05$ [enzymatic groups vs. surgery]) Pain (3 months, Patient-Related) Wrist Evaluation Score: 23/100 Disabilities of the Shoulder, Arm and Hand: 22/100 Scar quality (3 months, Vancouver Scar Scale): 6/14 Side effects (during hospital stay): 0 Wound infections (during hospital stay): 0 Complete wound closure (mean, days): 17 (surgery), 23 (no surgery) Surgical escharotomy: 0 Permanent damage: 0 Significant adverse events: 0 	Case series	Israel, Hospital (burn unit)	4-
Rosenberg et al ²²	Deep second degree and third degree burns Age (mean): 18.6 Female: 48.5% TBSA < 10%: 66%	n = 130 Enzymatic debridement with Bromelain-derived debridement agent	NA	<ul style="list-style-type: none"> Complete removal of eschar (mean, days): 7.8 / 8 / 7 (ns) Blood transfusion: 1/18/30 ($P < .001$ [enzymatic only vs. both other groups]) Hospital stay (mean, days): 12.5/20.7/20.2 ($P < .001$ [enzymatic only vs. both other groups]) Autografting: 1/28/33 ($P < .001$ [enzymatic groups vs. surgery]) Wound infection: 0/17/7 ($P > .05$ [enzymatic groups vs. surgery]) Pain (3 months, Patient-Related) Wrist Evaluation Score: 23/100 Disabilities of the Shoulder, Arm and Hand: 22/100 Scar quality (3 months, Vancouver Scar Scale): 6/14 Side effects (during hospital stay): 0 Wound infections (during hospital stay): 0 Complete wound closure (mean, days): 17 (surgery), 23 (no surgery) Surgical escharotomy: 0 Permanent damage: 0 Significant adverse events: 0 	Case series	Israel, Hospital	4-

Abbreviations: CG, control group; IG, intervention group; LoE, level of evidence; NA, not applicable; ns, not statistically significant; TBSA, total body surface area.

Table 4. Hydrosurgery.

Study	Patients (IG/CG)	Intervention	Comparison	Outcomes (IG/CG)	Study type	Country/ setting	LoE
Hyland et al ²³	Partial thickness burns Children ≤16 years Age (median): 2.2/2.9 TBSA: 3%/4%	n = 25 Debridement using the Versajet II Exact	n = 27 Conventional tangential burn wound debridement using a Goulian knife	<ul style="list-style-type: none"> • Viable dermis lost (median, μm): 35/325 ($P = .02$) • Infection (postoperative): 30%/35% ($P = .05$) • Graft take (mean, day 10): 92%/94% ($P = .9$) • Time to healing (median, days): 1.3/13 ($P = .6$) • Scar quality (6 months, Vancouver Scar Scale score): 1.7/2.1 ($P = .1$) 	RCT	Australia, children's hospital (burn unit)	2
Gravante et al ²⁴	Thermal injuries requiring debridement Age (mean): 46/50 Female: 17/20 TBSA: 25%/30%	n = 42 Versajet system	n = 45 Hand-held dermatome escharectomy	<ul style="list-style-type: none"> • Pain (postoperative, VAS): 4.3/4.6 (ns) • Complete healing (mean, days): 11/13 (ns) • Contractures (6 months): 14/16 (ns) 	RCT	Italy, Burn Centre	2-
Duteille and Perrot ²⁵	Intermediate 2nd-degree burns on at least 15% of the face and no life-threatening prognosis Age (mean): 40.5 TBSA: 27.75 Female: 5 n = 20 Burns	Early excision was performed (day 5–10) using the Versajet System Porcine xenograft was applied afterwards	NA	<ul style="list-style-type: none"> • Satisfaction score (mean, 3–12 months): 7.84 • Healing duration (mean days): 13.4 	Case series	France, hospital	4
Gravante et al ²⁶	Adults n = 70 IIb/III thermal burns Age (mean): 61/48 Women: 12 n = 50 Burn wound	Versajet system	NA	NR	Case series	Italy, hospital	4-
Kawecki et al ²⁷	Children Age (median): 2.4 TBSA: 5%	Versajet	NA	• Complete healing: 47%	Case series	Poland, burns Center	4-
Kimble et al ²⁸	Burn wound n = 50 Children	Versajet hydrosurgery system	NA	NR	Case series	NR	4-
Klein et al ²⁹	n = 44 Age (range): 3 months–83 years	Versajet hydrosurgery system	NA	Repeated grafting: 0 Graft loss: 0 NR for burn patients	Case series	United States, burn centre	4-
Matsumura et al ³⁰	n = 21 burns	Versajet	NA		Case series	Japan, surgical centres	4-
Rennekampff et al ³¹	n = 10 Age (range): 7–80 TBSA (range): 0.5%–40%	Versajet	NA	<ul style="list-style-type: none"> • Surgical complications: 0 • Postoperative infections: 0 	Case series	Germany, burn Center	4-
Tenenhaus et al ³²	n = 13 Depth face and neck burns	Versajet	NA	• Scar revision: 0	Case series	Germany/United States, hospitals	4-
Yang et al ³³	n = 10 Thermal injuries Age (mean): 37.8 TBSA (range): 3%–40%	Versajet	NA	NR	Case series	Taiwan, hospital	4-
Cubison et al ³⁴	Pediatric burns	Versajet hydrosurgery system	NA	NR	Case report	United Kingdom, burn centre	5
Gumus et al ³⁵	Chemical burn	Water jet	NA	NA	Case report	Turkey, hospital	5
Shafer et al ³⁶	n = 1 Partial-thickness hand burns	Hydrosurgical tangential excision	NA	NR	Case report	NR	5
Yeh et al ³⁷	n = 1 Age: 43 Male TBSA: 20%	Versajet hydrosurgery system	NA	NR	Case report	Taiwan, medical centre	5

Abbreviations: CG, control group; IG, intervention group; LoE, level of evidence; NA, not applicable; NR, not reported; ns, not statistically significant; TBSA, total body surface area.

Table 5. Miscellaneous Debridement Methods.

Study	Patients (IG/CG)	Intervention	Comparison	Outcomes (IG/CG)	Study type	Country/ setting	LoE
Dessy et al ³⁸	n = 20 Partial thickness burn of trunk or extremities Age (range): 20 to 64 Female: 11 TBSA (range): 1-6% Burns	Lubricant and razor debridement	Debridement by scraping the roof off with a sterile gauze	Pain during debridement (mean) 2.5/5.2 Wound healing: in all patients within 12-21 days	RCT	NR	2-
Vandamme et al ³⁹	Burns	Honey for burns	NA	Debriding effect: of 5 studies no found a statistical significant effect	Systematic review	NA	2-
Mohammadi et al ⁴⁰	n = 49 Chronic-colonized burn wounds in both limbs Age (mean): 26.44 TBSA: 28.3% Burns n = 44	Debridement and wound cleansing with 2% hydrogen peroxide	Debridement and curetting the surface layer of chronic granulations combined with simple normal saline lavage which followed by skin grafting	Graft take (mean, 21 days): 82.85%/65.61% ($P < .05$) Adverse effects: 0/NR	Non-randomized intra individual comparison	Iran, hospital	3
Blanke and Hallern ⁴¹	Burns n = 44	Lidocaine-prilocaine cream for sharp debridement Doses ranging from 3 to 150 g for 45-60 min Topical methylene blue to facilitate precise surgical debridement	NA	NR for burn patients	Case series	Germany, NR	4
Dorafshar et al ⁴⁷	Unclear	Escharectomy	NA	NR	Case series	Germany, NR	4-
Han et al ⁵⁸	n = 25 Major burn Age (mean): 40.9 Female: 5 TBSA: 42.9% n = 64 Major burn Male	Extensive escharectomy and auto-microskin graft	NA	NR	Case series	China, hospital (burn unit)	4-
Pidcoke et al ⁶⁰	Age (mean): 41.24 TBSA: 74.16% Burns n = 36	Burn and soft tissue excisions	NA	Received blood products: 32	Case series	United States: Army Institute of Surgical Research Burn Center	4-
Akhtar et al ⁴²	n = 3 Mixed depth burn NA	Larvae therapy to debride full thickness burns	NA	NR	Case report	United Kingdom, hospital	5
Brusselaers et al ⁶¹	n = 3	Different therapeutic options	NA	NA	Expert survey	Belgium, NA	5
Mitsukawa et al ⁴⁶	Large burn wounds n = 1 Burn	Cautery knife equipped with an air spray	NA	NR	Case report	Japan, hospitals	5
Namias et al ⁴³	n = 1	Maggot debridement therapy with the larvae of <i>Phaenicia sericata</i>	NA	NR	Case report	United States, burn Center	5
Reynolds et al ⁴⁵	n = 1 Full thickness and deep dermal burn	Debridement via erbium: YAG laser	NA	NR	Case report	United Kingdom, Bristol	5
Wu et al ⁴⁴	Severe infected burn n = 1	Maggot therapy	NA	NR	Case report	China	5

Abbreviations: CG, control group; IG, intervention group; LoE, level of evidence; NA, not applicable; NR, not reported; ns, not statistical significant; TBSA: total body surface area.

However, no significant difference could be shown in success of autografting ($P = .9$), time to heal ($P = .6$), and scar quality ($P = .1$) between the treatment groups (LoE 2).²³ These results match the second available RCT investigating hydrosurgery that could not show a significant advantage in postoperative pain, time to complete healing, and long-term contractures in comparison of Versajet ($n = 42$) and conventional escharectomy ($n = 45$; LoE 2-).²⁴

Miscellaneous Debridement Methods

Numerous studies, reviews, and case reports report miscellaneous techniques and adjuncts in burn wound debridement (Table 5). An RCT by Dessy et al compared blister removal in intermediate burns by lubricant (KY-Jelly) supported razor debridement ($n = 10$) and blister removal by scraping of the roofs with a sterile gauze ($n = 10$). The authors found a reduced level of pain during razor debridement but could not report a significant difference (LoE 2-).³⁸ Vandamme et al presented a systematic review on honey in wound care that includes 5 studies investigating the debriding effect of honey but could not found a significant effect (LoE 2-).³⁹ In contrast, a significant better graft take (82, 85% vs 65, 61%) in chronic-colonized burn wounds could be shown in an intra-individual comparison ($n = 49$) after wound cleansing with 2% hydrogen peroxide compared with conventional debridement with curetting and lavage with saline (LoE 3).⁴⁰ Several case reports describe miscellaneous topics such as topical anesthesia for wound debridement,⁴¹ larvae therapy to debride full-thickness or infected burn wound,⁴²⁻⁴⁴ burn wound debridement via erbium: YAG laser,⁴⁵ the equipment of a cautery knife with an air spray to maintain better sight on bleeding wound areas,⁴⁶ or wound dyeing with methylene blue to facilitate adequate debridement⁴⁷ (LoE 4 or lower).

Discussion

The present evidence map summarizes the available evidence on burn wound debridement published between 2000 and 2016. During the investigated period, the literature with a high LoE focuses on 3 major topics: Timing of debridement, enzymatic debridement, and hydrosurgery.

Timing of Debridement

To determine the best timing for eschar removal, several cohort studies have been conducted. Xiao-Wu et al investigated the impact of timing of the first step of excision in 157 children and could show a significant increase in wound infection, a longer hospitalization, and a higher incidence of sepsis after delayed wound excision after 7 to 14 days. Although an effect on mortality could not be shown, an excision within 48 hours can be recommended based on the results of this study.¹⁰ Comparable results in terms of significant shorter hospital stay and decreased wound infection have been presented earlier⁴⁸ in a collective of burned children.

A shorter length of hospital stay after early excision in general could be shown in adult burn patients repeatedly since the 1980s^{49,50} establishing early burn wound excision as a standard of care. These results could be confirmed recently by Saaiq et al in a cohort study including 120 patients. Furthermore, these authors found a significant better graft take rate after autologous skin grafting following early wound excision.⁹ A better graft take rate after early wound excision was found in another cohort study including 54 patients by Ayaz et al. Contrarily, this smaller study could not confirm a significant effect of timing of wound excision on the length of hospital stay.⁶

Reduced bacterial colonization and decreased infection rates after early wound excision could be shown by Barret et al.⁷ Although case count in this recent study was fairly low with 12 respectively 8 cases per group, results are statistically significant. While infectious complications such as sepsis are responsible for many lethal courses in burn patients, reduced bacterial colonization might be regarded as a key reason for reduced mortality after early burn wound excision that has been reported before.⁵¹

Chen et al reported significantly reduced insulin resistance after early eschar removal within 72 hours compared to delayed escharectomy after 7 days.¹² While extensive postburn metabolic changes with impaired insulin sensitivity have been described and maintenance of low blood glucose levels is a major goal that might improve morbidity and mortality,⁵² these findings help to understand the underlying mechanisms and emphasize the importance of early burn wound debridement.

While the previously mentioned studies could attest benefits of early wound excision, Elmasry et al recently investigated the effect of sequential smaller burn wound excision compared with a single one-stage excision. After including 169 cases in a cohort study, the authors concluded that splitting of the burn wound excision in several smaller operations is not of significance in terms of patient-related outcome parameters.⁸ Nonetheless, splitting of burn wound excisions can be necessary in patients that are not stable enough to undergo major excisions.

Enzymatic Debridement

The second major topic of increasing LoE in recent burn literature is enzymatic burn wound debridement. Different agents have been described to either clean the burn wound from coating debris or to perform an entire enzymatic eschar removal as an alternative to conventional surgical wound excision. The latter has been investigated by Rosenberg et al in a multicenter RCT comparing 74 cases treated with bromelain-based (Nexobrid) enzymatic eschar removal with 81 cases of conventional wound excision. Both groups showed similar severity of injury and no significant difference in demographics. While no significant difference in scar quality and time to wound closure could be reported, a significant lower number of wounds as well as a lower percentage of wound area required surgical excision and autografting. Also, total blood loss was significantly lower in the enzymatic treatment group.¹⁶ Although there was no difference in overall health status between groups, enzymatic debridement leads to a significantly shorter time to

complete eschar removal. In that way, enzymatic escharectomy could be beneficial in severely burned patients by avoiding adverse effects of delayed wound excision and lead to a reduced mortality as discussed above. Several case series on enzymatic wound debridement with Nexobrid²⁰⁻²² support the RCT and report the feasible application of this therapy.

Comparable results have been presented for a cohort study by Özcan et al. The authors used clostridiopeptidase A as enzymatic agent (Novuxol) and showed significant lower blood loss and reduced need for autografting compared to conventional wound excision. The group could also show a shorter hospital stay in patients undergoing enzymatic eschar removal without the need for further surgical intervention.¹⁷

A second recent RCT on enzymatic debridement investigated the effectiveness of a collagenase ointment (Iruexol) for removal of necrotic tissue on burn wounds.¹⁸ The authors missed to define the depth of the treated burn wounds but the use of vaseline ointment as the control group suggest the use in partial thickness burns without the need for surgical intervention. Furthermore, the outcome is defined by surgeons rating of the debridement efficiency which limits the provided evidence. Nonetheless, collagenase ointments seem to be useful to remove coating fibrin remnants or small amounts of residual necrotic tissue in partial thickness burn wounds.

Another investigated agent for wound debridement in recent literature is papain-urea (Debridace). Since nearly all participants in the study group could not complete the trial due to severely adverse effects like high fever or excruciating pain, it will not play a further role in clinical appliance.¹⁹

Hydrosurgery

Burn wound excision by use of an accelerated water jet, also referred to as hydrosurgery (Versajet), is another technique that has recently been validated with a remarkable level of evidence (LOE 1-) for eschar removal. It has been first described by Klein et al who presented a case series of 44 patients and underwent hydrosurgical tangential burn wound excision.²⁹ Subsequently, a series of case reports and case series stated the feasibility of the VersaJet procedure.^{25-28,30-37,53} Gravante et al conducted an RCT to compare tangential excision by VersaJet with tangential excision by knife. Although they included 47 patients in their study, they could not show a significant difference in complete healing time, postoperative pain, and development of scar contractures in both groups. Only when debriding particular "difficult" areas such as hands, genitals, or face, the operating time using hydrosurgery was significantly shorter while on limbs or trunk conventional tangential excision was faster,²⁴ which is mainly associated with the reduced excisional area of the device. A second recent RCT presented by Hyland et al could prove a significantly lower loss of viable tissue by hydrosurgery investigated through histological examination of punch biopsies prior to and after tangential excision. Nonetheless, they could not show benefits of the apparently more preserving hydrosurgical technique on graft take, wound infection rate, or healing time. Even evaluation of scarring after

3 and 6 months did not show a significant benefit due to a more accurate debridement using VersaJet.²³

While most of the listed publication investigate recent techniques in burn surgery, the classic tangential burn excision as introduced by Janzekovic in 1970² is only described by one unsystematic review included in this review.⁵⁴ Due to its limitation on literature since 2000, the evidence map does not include many publications of the last decades of the past millennium that investigated surgical techniques of excision by knife or diathermia.^{51,55-57} Nonetheless, classical tangential or epifascial excision can still be considered as the standard of care and is the predominant modality of burn wound debridement in most countries worldwide.

Establishing evidence-based treatment principles in burn medicine is a difficult undertaking. The caseload, compared to other injuries or diseases, is low and in addition, changing burn size and depths result in different demand in burn wound treatment and patients with different burn extent cannot be reasonably compared. Due to these circumstances, available studies often lack the necessary standardized population to present significant results. From this angle, the relatively high LoE provided for the aforementioned debridement techniques is quite remarkable.

Conclusion

This evidence map has shown a limited LoE for timing of burn excision (LoE 3-) and a remarkable LoE for enzymatic eschar removal (LoE 2-) and hydrosurgery (LoE 2). In matters of timing of excision, early burn excision seems to be superior to delayed excision. Enzymatic debridement as second trend in burn wound debridement on the other hand has also been investigated repeatedly. For this technique, some benefits in patient-related outcomes have already been shown but further research is necessary to prove its supremacy in comparison to standard of care. While the feasibility of the use of the hydrosurgery system VersaJet has been shown, an impact on patient-related outcomes could not be proved to date. Standard of care in terms of classical excision has not been systematically evaluated in the investigated time frame. Further research is necessary to provide evidence-based strategies for burn wound debridement.

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Key messages with level of evidence

- Rates of bacterial colonization and infectious complications are lower after early burn wound excision within 24 hours. (LoE 3-)⁷
- Graft take and length of hospital stay is improved after early wound excision within 7 days. (LoE 3-)⁹
- Incidence of invasive infection and sepsis is lower and length of hospital stay is shorter after early burn wound excision within 2 days in children. (LoE 3-)¹⁰
- Time to complete eschar removal, need for surgical excision, need for autografting, and blood loss after enzymatic debridement using Nexobrid® is lower compared to surgical excision. (LoE 2-)¹⁶
- Blood loss, need for autografting and length of hospital stay is reduced after enzymatic debridement with collagenase (Novuxol®) compared to surgical excision alone. (LoE 3-)¹⁷
- Loss of viable dermis is lower using VersaJet® hydro-surgery system while there is no significant difference in healing time, graft take, and long-term scar quality compared to conventional surgical excision. (LoE 2/2-)^{23,24}

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