BURNS 40 (2014) 177–190

Available online at www.sciencedirect.com

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journal homepage: www.elsevier.com/locate/burns

Review

Optimal treatment of partial thickness burns in children: A systematic review

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ARTICLE INFO

Article history:
Accepted 10 September 2013

Keywords:
Burns
Children
Wound treatment
Systematic review
Partial thickness burns
Paediatric burns

ABSTRACT

A large part of the patient population of a burn centre consists of children, most of whom are younger than four years. The majority of these young children suffer from superficial and deep partial thickness scald burns that may easily deepen to full thickness burns. A proper wound therapy, that prevents infection and ensures a moist wound condition, might prevent the deterioration of the wound.

Therefore, we performed a systematic review of wound management and dressing materials to select the best treatment option for children with burns.

A search in Medline and Embase revealed 51 articles for a critical appraisal. The articles were divided into randomized controlled trials, cohort studies and a group of case-reports. Total appraisal did not differ much amongst the groups; the level of evidence was highest in the randomized controlled trials and lowest in the case-reports.

In 16 out of 34 comparative studies, silver sulfadiazine or a silver sulfadiazine/chlorhexidine-gluconate combination was the standard of wound care treatment. The competitor dressing was Biobrane® in six studies and amnion membrane in three. Tulle gauze, or tulle gauze impregnated with an antibacterial addition were the standard of care treatment in seven studies.

In general, membranous dressings like Biobrane® and amnion membrane performed better than the standard of care on epithelialization rate, length of hospital stay and pain for treatment of partial thickness burns in children. However, hardly any of the studies investigated long-term results like scar formation.

Contents

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0305-4179/$36.00.
http://dx.doi.org/10.1016/j.burns.2013.09.016

1. Introduction

In most burn centres in the world, a large part of the patient population consists of children. In the Netherlands, about 45% of the patients admitted to a Burn Centre is below 17 years of age. Between 1995 and 2007, 2682 children have been admitted to a Dutch burn centre. Almost 70% of these children are younger than four years. They suffer from scald burns in more than 84% of the cases. For children between 5 and 17 years of age the aetiology of the burns is about the same as for adults: roughly 60% are flame burns and 20% are scalds. The majority of scald burns is partial thickness similar to the group of children younger than four years of age [1]. Recent studies that have been conducted in Western Australia and the Czech Republic showed similarly high frequencies of scald burns in the group of young children [2,3].

Compared to adults, children, especially those between 0 and 4 years old, have a thin skin. Because of their thin skin even a small quantity of hot fluid, such as a cup of tea or a mug of soup, may inflict a serious burn. Moreover, burns in children often affect anatomically important areas such as the face, neck, shoulder and hands. Dewar et al. found that in scalds caused by hot beverages in children, the anterior torso was affected in 65%, the upper limbs in 51%, the head and neck in 39% and the legs in 26% [4].

Infection prevention and the promotion of a moist wound environment to prevent deepening of the wound nowadays form the basis of the wound treatment in children [5]. The choice of a wound dressing for a child with burns should meet these requirements. However, most wound dressings that are currently available on the market are originally developed for the treatment of chronic wounds. These wounds differ from burn wounds in level of exudate, inflammatory status and healing potential [6]. Therefore, dressings designed for chronic wounds may not possess optimal characteristics for burn treatment and vice versa.

Since there is abundant choice of different dressing materials and topical treatment modalities, it is not easy to determine which materials should be preferred for a specific wound type. Because of the thin skin in children and the different physiology and specific aetiology of the injury, some dressing materials may be better suited for the treatment of burns in the younger age group. We performed a literature search to investigate paediatric burns, their treatment and the dressing used in these treatments.

2. Methods

2.1. Search strategy

In April 2011, we conducted a structured literature search in Medline (1996 to present) and Embase. Our search *domain* was defined as patients less than 18 years of age with burns accompanied by the *determinant*, which was defined as a topical wound dressing. The *outcome* was defined as (re)epithelialization (short term) and scar formation (long term). Synonyms and syntax structure including the *domain* and *determinant* are shown in Fig. 1. In total, 3455 articles were found. After excluding duplicates ($n = 1500$), an independent title/abstract screening was performed by two reviewers based on the following inclusion criteria, the presence of our previously described domain and determinant. If no abstract was available the full text was included, based on the title. Seventeen articles were irretrievable and 70 articles were excluded for not containing our third and last criterion for relevance: *outcome*. Finally, 51 articles remained for a critical appraisal.

2.2. Critical appraisal

We performed a critical appraisal based on the Centre for Evidence-Based Medicine (Toronto) guidelines (CEBM) by determining items to score for relevance and validity [7]. Relevance was scored on articles only concerning children, and only children under the age of 4 years old, only partial thickness burns, time post burn of the first application of treatment material and at least one item describing the outcome.

As partial thickness scald burn in children under the age of four are most common, and as these children have a thin skin that makes them vulnerable for thermal lesions, we added children under the age of four to the domain.

Partial thickness burns are prone to deepening, also known as conversion, but a wound dressing might be able to influence and prevent this process [5,8]. We therefore defined the

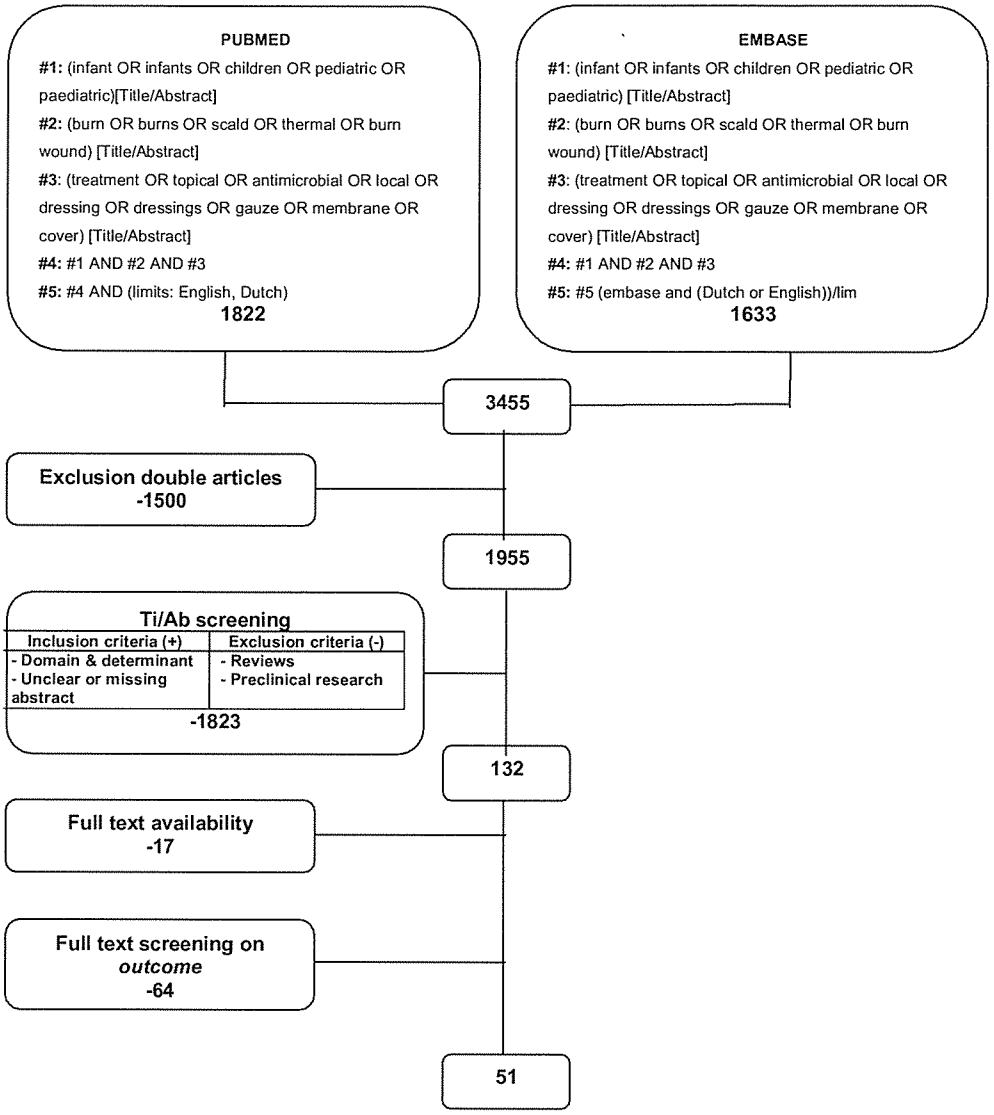

Fig. 1 – Flow diagram for the selection of the studies.

treatment modality and the time of application as the determinant. As scar formation in children is a major problem, follow-up was evaluated as an outcome parameter, with specific attention to long-term follow up (Table 1).

Our primary interest was in the outcome results; therefore most points were allocated to short and long-term outcomes. Short-term outcome results were considered as days of hospital stay, time to re-epithelialization, need for grafting and complications such as infection or pain at dressing changes. Long-term results were scar formation and contractures that required reconstructive surgery.

Validity was scored at study design, number of patients, blinding, selection bias, length of follow-up and loss-to follow-up (Table 1). As the study design determines for a large part the level of evidence and thereby the quality of the study, we arranged the studies in four groups, A–D (Table 2). Subsequently, for all studies the level of evidence was determined according to the CEBM 'Levels of Evidence 1' document [9].

3. Results

Fig. 1 shows the steps that were taken for the identification and selection of the studies. In the end, the search yielded 51 articles on the treatment of partial and full thickness burns in children.

In 41 out of the 51 studies a statement on possible conflict of interest was not included in the text. Eight authors stated no conflict of interest and in two studies a conflict of interest was mentioned [10,11].

As expected, there was great heterogeneity between the included studies. None of the studies had the same age groups.

Table 1 – Critical appraisal based on the Centre for Evidence-Based Medicine (Toronto) guidelines [8].

Relevance (domain, determinant, outcome)
1. Patients
   a. Children (<18 years) → 1
   b. Adults and children → 0
2. Children
   a. All children under the age of 4 years → 2
   b. All children, ages mentioned → 1
   c. All children, ages not mentioned → 0
3. Burns
   a. Only scald burns or only partial thickness burns → 2
   b. Partial and full thickness burns, other treatment mentioned for full thickness burns → 1
   c. Differences between treatment of partial and full thickness burns not mentioned → 0
4. Time to application of topical treatment or dressing
   a. Within 48 h post burn → 1 point
   b. Not mentioned or >48 h post burn → 0 points
5. Short term outcome; hospital stay, re-epithelialization, need for grafting, complications (infection and pain scores)
   a. 4/4 → 3
   b. 3/4 → 2
   c. 2/4 → 1
   d. <2 → 0
6. Long term outcome
   a. Scar formation and evaluation → 3
   b. No long term outcomes → 0

Total relevance: max 12 points

Validity
1. Study design
   a. Randomized controlled trial → 2
   b. Cohort study → 1
   c. Other design → 0
2. Number of included patients
   a. ≥25 patients → 1
   b. <25 patients → 0
3. Blinding
   a. Yes → 1
   b. No → 0
4. Allocation concealment?
   a. Method of randomization mentioned → 1
   b. Unclear or not applicable → 0
5. Follow-up
   a. ≥1 year → 1
   b. <1 year → 0
6. Loss to follow-up
   a. ≤20% → 1
   b. >20% → 0

Total validity: max 8 points

In fifteen studies on paediatric patients the age was not specified, in 29 studies young (0–5 years) and older (6–18) children were included and 17 studies concerned children below the age of 5 years.

Total Body Surface Area (TBSA) of subjects and outcomes and study designs varied. For these reasons, pooling was impossible. Based on their designs, the studies were divided in four groups: randomized controlled trials (group A), comparative cohort studies (group B), non-comparative cohort studies (group C) and a group with case reports (group D) (Table 2). Both groups of cohort studies were subdivided in prospective studies and retrospective studies (Tables 2b and 2c).

Total appraisal scores for groups A–C and group D differed little; mean values were 9.8, 8.3, 9.0 and 9.0 respectively. As could be expected, the level of evidence was highest in group A (1b–2b), lower in group B (2b–4) and C (2b–4) and lowest in group D (5). Despite the low level of evidence in this last group, total appraisal was relatively high since long-term results were evaluated specifically on children with burns. However no comparisons of treatments were included.

An overview of the treatment modalities is given in Table 3.

3.1. *Randomized controlled trials (group A)*

The search revealed 12 randomized controlled trials (Table 2a) [10–21].

For all but one study the depth of the burns was estimated by clinical judgement only while in one study, the trial of Kumar et al. [10] the depth of the burn was determined by laser Doppler imaging measurement (LDI). One study was on partial and full thickness burns [12] and 11 were on partial thickness burns only. Silver sulfadiazine (SSD) is considered a standard treatment for burns in children in many burn centres, as in 8 out of 12 articles it was compared to varying types of membranous dressings [10,13–17,19,20] or a local therapeutic [21] in one study. In two studies SSD was compared with Biobrane® and in two other studies it was compared to Mepitel® [14–17]. In one study SSD was compared to Jelonet® and Opsite® [13] and in another study it was compared to amnion membrane [20]. In the final study it was compared to collagenase [21].

Silvazine®, a combination of SSD cream with 0.5% chlorhexidine, was compared to two membranous dressings, Transcyte® and Biobrane® in one study [10]. In all studies combined, a total of 268 patients were treated with SSD or Silvazine.

However, most notably was the observation that in almost all of the studies which compared SSD or Silvadene® to another wound treatment, the alternative treatment showed better results on parameters such as eschar formation, length of hospital stay (LOS), healing time, pain score and need for analgesics, nurses' preference, and need for autografting. In the comparison of SSD with collagenase no differences in outcome were found [21].

Two membranous dressings, DuoDERM® and Biobrane® were compared in one study: there were no differences in clinical parameters but DuoDERM® was less expensive [18].

3.2. *Cohort studies (groups B and C)*

The 35 cohort studies were divided into 22 comparative and 13 non-comparative cohort studies (Tables 2b and 2c).

3.2.1. *Comparative cohort studies (group B)*

Seven out of twenty-two studies were prospective [22–28], 15 were retrospective [29–43].

Within the entire group the type of treatment varied extensively. SSD or Silvazine® was considered standard treatment in eight studies, with a total of 1227 patients [23,27,31–33,37,39,43]. In two studies SSD gave similar results as impregnated gauze dressing and other antiseptics respectively [23,33]. SSD gave better results than the comparator, tulle gauze with an antibacterial addition, in one study [32]. In the other five studies, the alternative to SSD treatment

Table 2a – Group A, randomized controlled trials.

Study	Study design	Number of patients (wounds)	Age in months	Burn depth	TBSA (%)	Type of treatment	Best outcome	Difference	Total appraisal out of 20	Level of evidence
Marichy [12]	RCT	49/50	Mean 45	PT and FT	BUS index 14.9/15.1	Solcoseryl®/Acexamic acid or tulle gras or placental extract ointment	Solcoseryl®	Higher cure rate LOS Less septicaemia	8	2b
Cockington [13]	RCT	13/12/14	Not specified	SPT	<10	SSD/Jelonet®/Opsite®	Opsite®	Nurses preference Infection in Jelonet group	5	2b
Bugmann [14]	RCT	30/36	3–180	PT	2.1	SSD/Mepitel®	Mepitel®	Healing time	7	1b
Gotschall [15]	RCT	33/30	<144	PT	<15	SSD/Mepitel®	Mepitel®	Healing time Less eschar formation Less pain Less costs	10	1b
Lal [16]	RCT	48/41	Mean 3.1	SPT	11.6	SSD/Biobrane®	Biobrane®	LOS Time to healing	12	1b
Barret [17]	RCT	10/10	Mean 3.4	PT	8.4	SSD/Biobrane®	Biobrane®	Pain Pain medication requirement LOS Wound healing time	10	1b
Cassidy [18]	RCT	37/35	36–216	SPT and MPT	<10	Duoderm®/Biobrane®	No difference	Duoderm less expensive	9	1b
Glat [19]	RCT	12/12	2–216	SPT and MPT	1–10	SSD/SilvaSorb Gel®	SilvaSorb Gel®	Reepitheliasation < 21 days in more cases Less pain	9	1b
Mostaque [20]	RCT	51/51	<144	SPT and DPT	12.2	SSD/amnion membrane	Amnion membrane	Time to epithelialization LOS Less dressing changes	9	1b
Wood [11]	RCT	4/4/5	Mean 43.0	PT	Mean 5.9	Various/Biobrane/ Biobrane + ReCell	Biobrane/ Biobrane + ReCell	n.s.	16	1b
Ostlie [21]	RCT	50/50	Mean 60	PT	9.7	SSD/collagenase	None	None	11	1b

TBSA: Total Body Surface Area, PT: partial thickness, SPT: superficial partial thickness, FT: full thickness, MPT: mid-partial thickness, DPT: deep partial thickness, BUS: burned body surface + (3× surface of FT), SSD: silver sulfadiazine, LOS: length of stay and SSG: split skin graft.

Table 2b – Group B, cohort studies (comparative).

Study	Study design	Number of patients (wounds)	Age in months	Burn depth	TBSA (%)	Type of treatment	Best outcome	Difference	Total appraisal out of 20	Level of evidence
Walker [22]	Prospective	37/73	Mean 55.2	PT and FT	Not specified	Amnion membrane/ furacin	Amnion membrane	Fewer split skin graft Shorter LOS	8	3b
Waymack [23]	Prospective	10/10	12–180	PT	4–23	Aquaphor gauze/SSD	None	No difference	8	3b
Özcan [24]	Prospective	49/29/41	38.4	PT	12.3	Enzymatic debridement/enzymatic debridement + surgical excision/early tangential excision	Enzymatic debridement	Shorter LOS Less need for surgery Less need for blood transfusion	8	3b
Rab [25]	Prospective	22/14	27.7	PT and FT	18.0	Allogeneic cultured keratinocytes/ autologous skin graft	Allogeneic cultured keratinocytes	Less blood volume substituted, higher number of children without transfusion TBSA covered with SSG VSS better	11	3b
Akita [26]	Prospective	10/10	8–36	SPT and DPT	Mean 7.0 (2–14)	Basic fibroblast growth factor/ointment impregnated gauze	Basic fibroblastic growth factor	Less scarring Well organized stratum corneum	11	3b
Hosseini [27]	Prospective	51/35	1–180	PT and FT	<5	Xenoderm®/SSD	Xenoderm®	Lower mortality, shorter LOS, less dressing changes	6	2b
Zajicek [28]	Prospective	43/43	Mean 20 (15–290)	SPT	Mean 7 (4–10)	Xe-Derma®/Askina® THINSite®	XeDerma®	Lower number of reapplications	8	2b
Burke [29]	Retrosp.	100/100	4–180	Not specified	<65%	$AgNO_3$ 0.5%/primary excision	Primary excision	Mortality and morbidity Time to wound closure LOS	4	4
Piserchia [30]	Retrosp.	10/12	7–132	SPT	Mean 21.8	Amnion membrane/ Sofra tulle®	Amnion membrane	Less need for analgesics Shorter LOS Less wound infection	8	3b
Tjong [31]	Retrosp.	74/50	< 156	Not specified	Mean 6.7/6.5, < 15	SSD or early tangential excision and autografting/allograft skin	Allograft skin	Less hypertrophic scarring	10	4
Kudlácková [32]	Retrosp.	56/89	Not specified	DPT and FT	Mean 12.5 (4–35)	SSD/tulle gauze + chloramine	SSD	Reduced bacterial contamination	6	4
Lloyd [33]	Retrosp.	53/31/16	<144	Not specified	<20%	Aserbine/Daromide/SSD	None	None	8	4
Rose [34]	Retrosp.	27/30	Not specified	PT	Mean 31 (20–75)	Allograft/topical antimicrobial therapy	Allograft skin	More rapid re-epithelialization, increased patient comfort	12	3b
Delatte [35]	Retrosp.	43/130/57	Mean 5.5/5.6/4.9	PT	Mean 9.3/4.5/13.9	Beta-glucan collagen/ standard treatment/ split thickness skin graft	None	None	8	4

Lukish [36]	Retrosp.	20/20	37.2 ± 9.6	PT	14.3 ± 1.4/12.7 ± 1.3	Antimicrobial gent + hydrotherapy/ TransCyte®	Transcyte®	Shorter LOS	8	3b
Cuttle [37]	Retrosp.	241/328	5.2/48.8	PT and FT	Mean 5.2/4.4	Acticoat®/Silvazine®	Acticoat®	Shorter time to re-epithelialization for non-grafted group Lower need for skin graft Lower percentage requiring long term scar treatment	5	2b
Kazmierski [38]	Retrosp.	25/31/33/19/17	3–216	DPT	3–40	Excision and grafting/ mechanical dermabrasion/ duoderm/enzymatic dressing/Aquacel Ag®	Mechanical dermabrasion in burns <10% TBSA, excision and grafting in burns >20%	Various reasons	10	2c
Paddock [39]	Retrosp.	39/40	Not specified	FT	<22	Aquacel Ag®/SSD	Aquacel Ag®	Shorter LOS	6	2b
Martin [40]	Retrosp.	109/139	50.9(1–180)	PT	9.4 (0.5–40)	Duoderm®/Jelonet®	Duoderm®	Less debridement and autologous split skin grafting	10	2b
Saba [41]	Retrosp.	10/10	Mean 41.5 (3–180)	PT	Mean 16.0 (5–30)	Aquacel Ag®/ petrolatum gauze with bacitracin zinc ointment	Aquacel Ag®	Shorter LOS Less nursing time Less pain Faster re-epithelialization	9	3b
Lesher [42]	Retrosp.	235/43	1–72	PT	Mean 6.5 (0–35)	Biobrane/beta-glucan collagen	Biobrane	Faster epithelialization	8	2b
Dokter [43]	Retrosp.	338/164/302	Mean 15.6/15.6/13.2	PT	5.3/4.9/5.1	SSD before HFD/SSD after HFD/HFD	HFD	Reduction in skin grafting	10	2b

TBSA: Total Body Surface Area, Retrosp.: retrospective, PT: partial thickness, SPT: superficial partial thickness, FT: full thickness, MPT: mid-partial thickness, DPT: deep partial thickness, SSD: silver sulfadiazine, LOS: length of stay, SSG: split skin graft, VSS: Vancouver Scar Score and HFD: hydrofiber dressing.

Table 2c – Group C, cohort studies (non-comparative).

Study	Study design specified	Number of patients (wounds)	Age in months	Burn depth	TBSA (%)	Type of treatment	Outcome	Total appraisal out of 20	Level of evidence
Lobe [44]	Prospective	10	Not specified	SPT and DPT	Not specified	Polyurethane film	'Comfortable, fewer dressing changes Faster epithelialization in many cases'	8	4
Thomson [45]	Prospective	14	Mean 74.4 (2.4–192)	FT	Mean 39 (1–81)	Amnion membrane	Cost effective Acceptable as an intermediate dressing	6	4
Siim [46]	Prospective	10	Mean 18 (10–144)	Not specified	Mean 6.9 (2–15)	Omiderm®	No advantages or disadvantages over conventional exposure treatment	7	4
Yanaga [47]	Prospective	43	Mean 5.1 (4–17)	DPT	Mean 30.7 (5–75)	Cryopreserved cultured epidermal allografts	'Early closure of the wound and good functional outcome'	12	2b
Letouze [53]	Prospective	77	12–144	SPT and DPT	Mean 42.4 cm^2	Lipidocolloid dressing	Efficacious and well tolerated	8	2b
Borsuk [54]	Prospective	15	Not specified	ST and DPT	8	Silver-coated nylon dressing (Silverleaf®)	As effective as other silver dressings, less traumatic, less costly than silver sulfadiazine, absence of dressing residue	10	2b
Gravante [51]	Prospective	300	Mean 55.7 (SD 50.9) 12–192	SPT and DPT	17.7 (SD13) 4–50	Hyalomatrix PA after dermabrasion	'Dermabrasion combined with a dermal substitute could be a good and reasonable approach for the treatment of PT burns'	13	2b
Highton [48]	Prospective	33	Mean 29 (5–132)	PT	Mean 4 (1–13)	Suprathel®	Effective as dressing for PT; behaves like a biologic dressing, but not animal derived.	13	4
De Mey [52]	Retrospective	725	<60	PT and FT	Mean 7.8	SSD		6	2b
Gonzalez [55]	Retrospective	153	Not specified	PT and FT	Not specified	Abrasion	'Early assessment of depth and extension of the wound, removal of necrotic tissues, thus avoiding the production of toxins, decreases loss of fluids and reduction of infection risk, rapid wound healing'	10	4
Ou [49]	Retrospective	106	Mean 35	PT	11.4 ± 9	Biobrane®	Suitable for PT burns	7	4
Lang [50]	Retrospective	84	Mean 38.4 ± 34.8	PT	Not specified	Biobrane®	Effective, less traumatic for superficial burns	12	2b
Bauer [56]	Not indicated	13	Mean 40 (0.5–10)	Not specified	40 (25–75)	$AgNO_3$ 10%	Pain relief, reduction of circulatory instability, simply to apply and economical	5	4

TBSA: Total Body Surface Area, PT: partial thickness, SPT: superficial partial thickness, FT: full thickness, MPT: mid-partial thickness, DPT: deep partial thickness and SSD: silver sulfadiazine.

Table 2d – Group D, case reports.

Study	Study design specified	Number of patients or wounds	Age in months	Burn depth	TBSA (%)	Type of treatment	Outcome	Total appraisal out of 20	Level of evidence
Williams [57]	Case reports	2	24 and 96	PT	12 and 10	Mepitel®	Hypopigmentation in interstices of dressing	6	5
Ahmadi [58]	Case report	1	216	PT	16	Biobrane®	Scars corresponding to pores of dressing	10	5
Ahmadi [59]	Case report	1	36	PT	5	Furacin and Mepitel®	Scars corresponding to pores of dressing	12	5
Al-Ahdab [60]	Case reoprt	1	0.5 days	PT	18	Fusidic acid and Aquacel Ag®	Spontaneous healing	9	5

TBSA: Total Body Surface Area, PT: partial thickness, SPT: superficial partial thickness, FT: full thickness, MPT: mid-partial thickness, DPT: deep partial thickness, SSD: silver sulfadiazine, LOS: length of stay and na: not applicable.

modality scored better [27,31,37,39,43]. This involved 987 out of the 1227 patients, and included comparisons to two silver containing dressings (Aquacel Ag® and Acticoat®), two biological dressings (allograft skin and Xenoderm®) and a hydrofiber dressing (Aquacel®).

3.2.2. *Non-comparative cohort studies (group C)*

Although the individual treatments varied greatly, there was some consensus in the type of dressing; seven out of 13 studies included a membranous dressing [44–50], four of which can be considered of biological or semisynthetic origin [45,47,49,50]. These studies are mainly descriptive in nature and provide little quantitative data on outcome parameters such as rate of wound closure, LOS and scarring. Gravante [51] and De Mey [52] included a large number of patients, but due to the heterogeneity in the patient groups such as types of burn and extent and depth of the burns, only general conclusions were drawn. Siim [46] investigated Omiderm®, a polyurethane film dressing, as an alternative to allograft skin for the treatment of scalds in children. When compared retrospectively to exposure treatment of scalds, no advantages were found. Highton reports on the treatment of partial thickness burns with a new synthetic dressing, Suprathel®, in 33 children [48]. This material is considered to behave like a biologic dressing, but has the advantage that it is not animal derived. Finally, Bauer described a small group of children with extensive burns treated by tanning with a 10% solution of $AgNO_3$ [56].

3.3. *Case reports (group D)*

Of the four articles in group D, three evaluate long term adverse reactions concerning scars related to the texture of the wound dressing, two on Mepitel® and one on Biobrane® [57–60]. Al-Ahdab claims the first publication on the treatment of a 16-year old baby with deep partial thickness burns with fusidic acid and Aquacel-Ag® [60].

4. Discussion

Fifty-one studies were included in this review after critical appraisal according to the guidelines published by the Centre for Evidence-Based Medicine, Toronto. The reasons for the authors of these studies to do a study on the treatment of burns in children were various. An obvious reason to study

Table 3 – Frequency of treatment modalities in 51 studies.

	Treatment modality	Number of studies
Topical antiseptics	SSD/Silvazine® (SSD + chlorhexidine)	16/2
	Furacin	2
	$AgNO_3$ 0.5%	1
	$AgNO_3$ 10% (tanning)	1
	Daromide	1
	Other topical antiseptics	2
Other topical products	Acexamic acid	1
	Aserbine	1
	Basic fibroblast growth factor	1
	Placental extract ointment	1
	Solcoseryl	1
Biological dressings	Amnion membrane	4
	Allogeneic cultured keratinocytes	2
	Allograft skin	2
	Beta glucan collagen	2
	Xe-derma®/Xenoderm®	2
Semisynthetical dressings	Biobrane®	9
	Biobrane + ReCell	1
	Transcyte®	2
Silver containing dressings	Aquacel Ag®	4
	Acticoat®	1
	Silverleaf®	1
Synthetic dressings	Tulle gauze/Aquaphor®	5
	Duoderm®/Askina® THINsite®	4
	Mepitel®	4
	Tulle gauze with antibacterial addition	3
	Opsite®	2
	Aquacel®	1
	Lipocolloid dressing (Urgotul)®	1
	Omiderm®	1
	SilvaSorb gel	1
	Suprathel®	1
Enzymatic debridement	Enzymatic substance/enzymatic dressing	2
	Surgical excision + enzymatic debridement	1
Surgical	Surgical excision/dermabrasion	3
	Tangential excision and grafting	3
	Hyalomatrix after dermabrasion	1

only children was because the study was performed in a children's hospital or a paediatric burns centre. More often epidemiological reasons were given. Burns in children are a common type of injury. By far the majority of burns in children under four years are partial thickness scald burns, and while for full thickness burns the established opinion since long is that early wound excision and grafting is the standard accepted procedure [61–63], for partial thickness burns there is no consensus on the optimal treatment modality.

In many clinics SSD or tulle gauze, with or without an antiseptic are the standard of treatment [64]. With these treatment modalities, daily (painful) dressing changes with wound exposure may lead to disruption of newly formed epithelium, wound colonization, subsequent wound infection and deepening of the burn [13,32,40,41]. These clinical findings are supported by an in vitro study, by Hoekstra et al. [65]. These authors showed that tulle gauze became embedded in the wound bed and were associated with a disturbed pattern of epithelial outgrowth. Moreover, these dressing changes are considered time consuming and costly [15].

4.1. *Scars and long term follow up*

Partial thickness burns in children may cause permanent scars, but better wound treatment with faster healing and fewer infections has been shown to reduce the severity of scarring [66–69].

It is therefore remarkable that only in one of the RCT's the results of long term follow up are included in the study: in Cockington's study, comparing treatment of partial thickness burns with SSD, Jelonet® and Op-site®, only in a few children a three-month-post-reepithelialization follow up was performed and no significant differences were found [13]. Tjong et al., in a retrospective cohort study, showed that treatment with allograft skin was associated with less hypertrophic scarring than treatment with SSD or early tangential excision [31]. In three case reports long term skin abnormalities after uncomplicated wound healing were mentioned. Williams et al. described two children with scalds that were successfully treated with Mepitel®, an open structured siliconized dressing [57]. Both children had a fenestrated pigmentation pattern that corresponded to the pores in the dressing. Ahmadi et al. noticed a mesh pattern that corresponded to the Mepitel® structure in the healed skin, two years post burn [59]. The same authors presented a patient, who, at almost three years post burn, had scars that corresponded to the pores of the Biobrane® dressing [58].

In the group of 20 comparative cohort studies (Table 2b), long-term results were shown in only two prospective studies [24,25] and four retrospective studies [30,34,37,40]. Rab et al. compared two groups of children with scald burns who underwent a surgical excision [25]. The group that was subsequently treated with allogeneic keratinocytes had a significantly lower Vancouver Scare Score (VSS) [70] one year post burn than the group that was treated with an autologous skin graft. Akita et al. covered superficial and deep partial thickness burns of children with bFBF spray (basic fibroblast growth factor) in one group and applied ointment-impregnated gauze in the control group. Better scarring based on the VSS one year post burn was found in the group treated with bFBF spray as was a well as a well-organized stratum corneum based on moisture metre analysis [26].

In general no conclusive recommendation can be given on the best treatment modality to reduce scarring in the paediatric burn patient, since most of the studies have not reported this systematically.

4.2. *Topicals versus membranous dressings*

We found a total of 45 trials in this category and SSD or Silvazine® was one of the treatment modalities in 11 of them [10,13–17,19,20,27,39,43]. In these studies SSD was the standard treatment that was compared to a newer treatment modality, in most cases a biological or synthetic membranous dressing. Three RCT's provided a direct comparison between SSD and Biobrane® [10,16,17]. All three reported superiority for Biobrane® with regard to wound healing time and LOS.

Besides Biobrane® as a semisynthetic dressing, biological dressings were used as well. Membranous dressings, creating a moist wound environment, may be favourable in treating partial thickness burns in children. Reducing the number of dressing changes, pain, the number of wound infections and deepening of the wound have been reported by the authors as beneficial effects in the studies on biological dressings. Walker et al. were the first to study a biological dressing, amnion membrane, in comparison with a gauze dressing impregnated with furacin, a topical antiseptic [22]. In this study amnion membrane proved to be superior with respect to the need for split skin autografting and LOS. Bacterial counts were low, loss of fluids and proteins was minimized and pain was reduced. Two other studies on amnion membrane showed similar results [20,30]. The choice for amnion membrane as a biological dressing may be driven by geographical circumstances, as many of the clinics that use these materials are located in developing countries, where amnion membrane is cheap and readily available. The study by Thomson et al. on amnion membrane mainly focussed monitoring, banking and bacterial safety [45]. In this study amnion membrane was used in 14 paediatric patients as a dressing over partial thickness burns, while in 22 other patients it was used over meshed split skin autografts and over freshly excised burns, with favourable results. In their recent article, Mostaque et al. describe an oven-dried, radiation sterilized human amnion membrane that is considered safe with regard to the risk of transmission of HIV [20]. With proper harvesting and preparation, amnion membrane dressings still are a safe and cheap treatment modality for acute burns in children.

In this review only two studies were identified on another biological dressing, human allograft skin. The studies by Rose et al. and Tjong et al. are both on partial thickness scald burns [31,34]. Rose et al. compared the allograft treatment with topical antimicrobials, whereas Tjong et al. compared human allograft treatment with early excision and subsequent autografting or, if the wound proved to be superficial after excision, with subsequent treatment with SSD. Roses' study showed a faster epithelialization and increased patient comfort in the allograft group; in Tjong's study the need for secondary excision and grafting was reduced and a remarkable reduction in hypertrophic scarring after allograft treatment was observed.

A remarkably high number (9) of studies included Biobrane®; five out of seven are in the RCT-group [10,11,16–18,42,49,50,58]. Biobrane® is a bilaminar synthetic membrane, consisting of a nylon mesh bonded with porcine collagen, covered with a silicone membrane. It has been commercially available for the treatment of burn wounds since 1979.

In a study by Kumar, three different wound treatments were compared: Biobrane®, Silvazine® and Transcyte®, a human fibroblast-derived temporary skin substitute [10]. Transcyte® was superior with regard to the number of dressing changes, faster healing and fewer autografting procedures.

When Biobrane® was compared to another membranous dressing, DuoDERM®, there were no differences except for the cost of the treatment, which was lower in the DuoDERM®-group [18].

In two studies in the RCT-group SSD was compared to Mepitel®, a silicone net dressing. Healing time was shorter for Mepitel® treated wounds [14,15]. Gottschall also found less eschar formation, less pain and lower costs for the Mepitel® treatment [15].

In 8 comparative studies, SSD or Silvazine was compared to a membranous dressing, that adheres to the wound surface and creates a moist wound environment such as Biobrane [10,16,17] amnion membrane [20], Xenoderm® [27], Askina® Thinsite® [28] and Aquacel (Ag)® [39,43]. Superior outcome was reported for all the membranous dressings, mostly on shorter LOS [16,17,20,27,39], shorter healing time [10,16,17,20], fewer dressing changes [10,20,27,28], less pain [17], lower mortality [27], but also in the need for surgery [10,43]. These findings support the opinion that the creation of a moist wound-healing environment, the prevention of crust formation and the physical protection of the wound against mechanical disturbances play a significant role in an undisturbed wound healing. Pain reduction may also play a role in the enhanced wound healing [71].

In only one of the comparative studies SSD treatment offered the best outcome, but in this case the comparator was tulle gauze with chloramine [32]. SSD treatment reduced the bacterial contamination and in a higher percentage of wounds the swabs were sterile. Although the outcome of the treatment with SSD is inferior to the other treatment modalities in most studies, SSD is still widely used in burn wound treatment in many hospitals [72]. Ignorance of recent literature on burn wound treatment may be an explanation, but the antimicrobial properties of the cream, in combination with a good safety profile, most likely are major arguments for the use of SSD as well [72]. Moreover the use of SSD is very versatile, while many of the dressings that were compared to SSD were deemed not suitable for body areas like the face and neck, hands and feet and buttocks and genitals.

Nevertheless, some negative aspects associated with SSD treatment in wound healing are commonly accepted:

1. Treatment modality: SSD cream is usually applied on gauze-like material. This may cause ingrowth of dressing material and disruption of newly formed epithelium during dressing changes; the application technique of SSD might cause these disadvantages rather than the cream itself. This disadvantage may be avoided by applying SSD on a non-adhesive dressing [73,74].
2. The cream base itself causes a very moist wound environment which may be beneficial early in the wound healing process by promoting necrolysis. However at a later stage this may limit epithelial outgrowth by causing maceration [75,76]. This aspect could be solved by application of SSD in another material [73,74] or through shortening the period of usage by switching to an ointment based antiseptic [77] or another topical therapeutic [78].
3. Toxicity of silver component to keratinocytes: this is firmly established in in vitro experiments [79,80]. Shorter duration of application might prevent this effect to some extent. In a recent publication on the application of a nanosilver wound dressing in a rat study, Bidgoli found mild hepatotoxic effects [81]. When using silver containing dressings, toxic effects of silver must be considered, especially with regard to the extend of the burn and the duration of treatment. This applies in particular for wounds treated with epithelial cultures.

4.3. *Dressings containing silver*

Silver containing dressings, which release silver in a more or less controlled way, are a relatively recent development in wound care.

Three recent studies on Aquacel Ag®, a carboxymethyl cellulose dressing in which sodium ions are replaced by silver ions, are in the non-randomized controlled trial-group [38,39,41]. Kazmierski et al. studied five treatment modalities in children with deep partial thickness scalds [38]. According to the authors, Aquacel Ag® was considered 'a dressing suitable for superficial partial thickness burns and some deep partial thickness burns'. Paddock et al., in a cohort study comparing SSD and Aquacel Ag® found a shorter LOS in the Aquacel Ag® group [39]. Compared to petrolatum gauze impregnated with Bacitracin®, the Aquacel® group showed less nursing time, less pain, shorter time to re-epithelialization and a reduced LOS in a study by Saba [41].

A widely used dressing for burn treatment, Acticoat®, appeared only in one comparative study in paediatric patients [37]. It was used in 241 patients, performed better than SSD with regard to healing time and was shown to reduce the need for grafting. In a non-comparative trial, Borsuk et al. treated 15 children with a silver-coated nylon dressing, Silverleaf® [54]. The author considered this dressing equally effective as other silver containing dressings used for paediatric burns. No conclusion can be drawn as to which silver-releasing dressing would perform better, since no direct comparative studies amongst the different silver containing dressings could be identified. This corresponds with the outcome of the recent Cochrane review on topical silver for preventing wound infection [82].

4.4. *Tulle gauze dressings as standard of care treatment*

In seven studies a tulle gauze dressing was used as the control treatment [12,13,26,30,32,40,41]. The different types of tulle gauze dressings included Jelonet dressings [13,40], tulle gras [12], tulle gauze with chloramine [32], Sofratulle [30], ointment impregnated gauze [26], and petrolatum gauze with bacitracin

zinc ointment [41]. In most studies these were considered the conventional dressing for the treatment of partial thickness burns in children. Some adverse effects of this type of treatment, such as adherence to the wound bed, thereby damaging the wound and newly formed epithelium during the dressing change, painful and frequent dressing changes and low antimicrobial properties were mentioned. The comparator materials were very diverse; seven different types of dressings were studied. However, in all studies the impregnated gauze dressings performed worse than the competitor. Waymack et al. [23] compared a fine cellulose acetate mesh dressing, impregnated with petrolatum, mineral oil, mineral wax and wool wax with SSD. Compared to a tulle gauze dressing, this material is supposed not to adhere to the wound bed. No differences were found between the two treatments. A more recently developed lipidocolloid dressing, consisting of a polyester mesh carrier covered with hydrocolloid particles and petroleum does not adhere to wound surfaces. In a non-comparative multicentre study is was efficacious and well tolerated [53].

4.5. *Limitations*

To be able to assess the outcome of a study, not only the dressing itself, but also the proper application, dressing protocol and frequency of dressing change is important. In 41 out of 51 studies a dressing protocol and frequency of dressing changes was described; in two studies a brief protocol was given and in eight studies no protocol was mentioned at all.

A limitation of reviewing studies is a reporting bias, as it is less likely that negative study results will be published. However some of the studies reviewed for this article reported no advantages of the 'newer' dressing. In two RCT's no significant differences were seen between treatments. Wood [11] did not find differences between the treatment with Biobrane® or Biobrane® + ReCell and Ostlie [21] found no of improvement of collagenase over SSD in the treatment of partial thickness burns.

In three comparative cohort studies none of the investigated treatment protocols proved to be superior. Delatte [35] studied the differences between Beta-Glucan Collagen, their "standard treatment" and split thickness skin graft in partial burns in children. In the study of Waymack and Lloyd Aquaphor gauze and respectively Aserbine and Daromide did not perform better than SSD [23,33].

Finally in a non-comparative cohort study Siim [46] did not show advantages of Omiderm® over exposure treatment of scalds in children.

Although 18 studies were found on SSD or Silvazine, four studies on amnion membrane and seven on Tulle gauze dressings, no meta analysis on outcome parameters of these studies was possible due to the high variation in and lack of definition on outcome parameters. Furthermore, only studies on children were included in this literature review.

5. Conclusion and recommendation

Despite the high level or variations in study design and outcome parameters, some general conclusions can be drawn from the systematic analysis of studies on the treatment of partial thickness burns in children. Analysis of the comparative studies provides enough evidence to conclude that membranous dressings perform better on various wound-healing parameters than cream based topical antiseptics or tulle gauze treatments. Among the advantages mentioned are reduced LOS, reduced healing time and reduced pain. At the same time, application of membranous dressings is difficult on some anatomic locations, such as hands, face and neck and genitals. This represents a limitation of the applicability. This may be one of the reasons that SSD is still widely used since it is a very versatile material, which easily can be applied on all body areas. However since other treatment options, such as membranous dressings, have many advantages, these dressings should be considered prior to applying SSD to a partial thickness burn wound in a child.

Within the group of membranous dressings, the group of biological dressings such as amnion membrane or allograft skin is still important. Particularly amnion membrane is abundantly available in developing countries and safe for the treatment of burns in children. Synthetic variants of membranous dressings are silicone containing materials such as Biobrane® or Mepitel®, or a cellulose based material such as Aquacel Ag®.

Direct comparisons between different types of membranous dressings are scarce. Therefore, no indication can be given as to which membranous dressings would be best for the treatment of partial thickness burns in children. Furthermore, there is a lack of studies describing the outcome of the wound healing process in terms of scar formation.

Conflict of interest

None.

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