Comparison of the Results of Operative and Conservative Treatment of Deep Dermal Partial-Thickness Scalds in Children

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Abstract
Deep dermal partial-thickness scalds remain one of the most common types of injuries in childhood. Local treatment of those wounds, alternatively described as IIb degree, is still very controversial. Some authors advise conservative treatment of such wounds, pointing to their ability to self-reepithelialise, which is possible but significantly prolonged. Other investigators postulate operative treatment, i.e., tangential necrectomy and split-thickness autologous skin grafting, which may shorten the time of wound healing. Arguments call forth contra-arguments, and the problem still seems to be unresolved. There is indeed a lack of acceptable standardisation of the local treatment for deep dermal partial-thickness scalds in the paediatric population. The results of both conservative and operative treatment of 114 children aged between 3 months and 17 years, treated for deep dermal partial-thickness scalds from 1997 to 2004 are presented. The treatment of five groups of patients, divided into groups based on the extent of their burn wounds, is evaluated. The patients were treated by tangential necrectomy and skin grafting, mechanical dermabrasion, Granuflex® (manufacturer info?) hydrocolloid dressings, IruxoMono® (manufacturer info?) enzymatic dressings, or Aquacel Ag® (manufacturer info?) hydrofibre dressings with silver ions. A number of parameters of wound healing were analysed. The results of this paper encouraged us to present and discuss a proposition for the standardisation of local treatment of deep dermal partial-thickness burn wounds in the paediatric population, according to the extent of injury.

Introduction
Thermal burns remain one of the biggest problems in paediatric surgery and traumatology. According to different statistics, 0.8 to 1 % of persons in each population suffer from burn injuries every year, and 50 or even 80% of them are children. Paediatric burns have been found to be entirely different from adult thermal injuries with respect to aetiology, diagnostics, treatment and the possibility of complications. The difference in children’s physiology as well as in the pathophysiology of paediatric burn wounds results in the need for a separate standardisation for the therapy of paediatric burn injuries.

Scalds are the most common type of paediatric burns (85%). Most of them are described as non-extensive, up to 25% of Total Body Surface Area (TBSA), mixed and deep dermal partial-thickness wounds. Deep dermal partial-thickness (DDPT) burns, alternatively described as IIb degree, are still very controversial in terms of both diagnostics and management. Even if most of the dermis is destroyed, the characteristic of that type of wound is that some vital stem-cell keratinocytes remain in the deepest recesses of the epidermal appendages. The number of such appendages is calculated to be about 10/cm². Thanks to this fact DDPT burns retain their ability to heal and epithelialise from the bottom of the wound, as happens easily in cases of superficial partial-thickness (SPT) burns. Such self-reepithelialisation of DDPT wounds is however significantly prolonged and may last from 21 to 35 days when the wound is treated conservatively. Superficial necrosis is always present in cases of DDPT burns, which does not allow any healing process to begin in such wounds until it has been demarcated. When infected, DDPT burns may easily turn into full thickness (FT) wounds, with all the consequences. Puchała [19] has claimed that fluid loss and met-
abolic disturbances are the same in the case of DDPT and of FT burns.

Many different opinions exist in the literature concerning the best methods for the local treatment of DDPT burns. Many authors claim that there is a danger of hypertrophic scarring and burn shock in cases of DDPT burns in paediatric patients, and the treatment of such wounds should be the same as that for all necrotic wounds, i.e. early excision and grafting. However, another group of authors maintain that it is important to focus on the differences between DDPT and FT burns, especially in the case of scalds in children, and propose a conservative treatment of DDPT paediatric scalds for at least the first two weeks after the injury. Controversies regarding the local treatment of DDPT and mixed scalds, as well as the lack of an acceptable standardisation of management of such wounds in paediatric patients, induced us to seek for an optimal therapy method and to try to propose a suitable standardisation.

Material and Methods

Structure of the group of patients

The material consisted of 114 children, 74 boys (65%) and 40 girls (35%), aged from 3 months to 18 years, treated in our Department between the years 1999 and 2004. The scald wounds were DDPT as well as mixed DDPT/SPT and DDPT/FT. The extent of the burn wounds varied between 3 and 40% of TBSA. The location of the injury affected all anatomical areas, but special sites (face, armpits, palms, feet, cubital and popliteal fossa, crotch) were excluded from this analysis. The examined group of patients was divided into five study groups (A, B, C, D, E) (Table 1). A different protocol for the local treatment of the burn wound was performed in each group.

Estimation of burn wound depth

The depth of the burn wound was estimated according to the clinical signs known to be typical for DDPT wounds. Clinical observation was performed every day after admission, and the final decision concerning the burn wound depth was undertaken on day 5 post trauma. All wounds that did not blister on the day of injury were recognised as DDPT. DDPT wounds were found to be hyposthetic when compared to the surrounding healthy skin. This project included all patients, who on the fifth day after the injury, had burn wounds which were either DDPT, mixed SPT/DDPT or DDPT/FT. In the case of mixed DDPT/FT wounds, the area of full-thickness necrosis was never bigger than 3% of TBSA. In the case of the mixed SPT/DDPT burns, the DDPT zone had to cover at least 50% of the described burn wound.

Initial wound management

At the time of admission standard wound debridement as well as appropriate general treatment were carried out. The wound was primarily covered with Op-site Flexigrid® foil dressing. Clinical observation of the wound was carried out at every change of dressing and the final decision whether or not to include the patient in the study was taken on day 5.

Operative treatment

On the 5th day after the injury, tangential excision to the bleeding points with an electrical dermatome, followed by split-thickness autologous skin graft (STASG) was performed in each case. The thickness of the skin graft was between 0.1 and 0.25 mm. Donor sites depended on the localisation of injury: mostly buttocks, thighs, shanks, abdomen and the back. In 88% of the cases (n = 22) non-meshed STASG, and in 12% of the cases (n = 3) 1 : 1.5 meshed STASG were performed. The graft was covered with a Jelonet® dressing and tulle gauze that was first changed 4–6 days after the operation. The donor site was covered with Op-site Flexigrid® (manufacturer info?) foil dressing. The dressing was removed 6–7 days after the procedure.

A sparing technique of the mechanical dermabrasion

The procedure was routinely performed on the 5th day after the injury. During the procedure, controlled abrasion with rotating diamond stones (up to 20 000 rpm) was performed in order to gently remove superficial necrosis from the surface of the wound (Fig. 1a). The dermabrasion stones were continuously cooled with a sterile 0.9% saline solution kept at room temperature to avoid secondary burns. The procedure was continued until at least 95% of the superficial necrosis was removed. Dermal papillae were observed at the bottom of the hyperemic wound. Bleeding from the surface of the wound was avoided. The wound was then covered routinely with Granuflex® hydrocolloid dressing. The dressing was changed every 2–4 days, until the wound had healed completely (Fig. 1b).

Conservative treatment using Granuflex® hydrocolloid dressings

The sheets of Granuflex® covered the wound including a 2–3 cm margin of intact skin. Before being covered with the dressing, the wounds were disinfected, dried, and the margins of the healthy skin were degreased. The sizes of Granuflex® sheets used were 10 × 10 cm, 10 × 15 cm, or 20 × 20 cm; the dressing was cut with scissors in order to adjust it to the required size, shape and loca-

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Table 1  Structure of the group of patients

<table>
<thead>
<tr>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
<th>Group D</th>
<th>Group E</th>
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</thead>
<tbody>
<tr>
<td>(excision and grafting)</td>
<td>(mechanical dermabrasion)</td>
<td>(hydrocolloid dressings)</td>
<td>(enzymatic dressings)</td>
<td>(hydrofibre with Ag⁺)</td>
</tr>
<tr>
<td>Depth</td>
<td>TBSA</td>
<td>No.</td>
<td>Depth</td>
<td>TBSA</td>
</tr>
<tr>
<td>DDPT &lt; 10%</td>
<td>4</td>
<td>SPT/DDPT</td>
<td>10 – 20%</td>
<td>17</td>
</tr>
<tr>
<td>DDPT 10 – 20%</td>
<td>12</td>
<td>SPT/DDPT</td>
<td>10 – 20%</td>
<td>18</td>
</tr>
<tr>
<td>DDPT &gt; 20%</td>
<td>4</td>
<td>SPT/DDPT</td>
<td>DDPT/FT</td>
<td>25%</td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
<td>total</td>
<td>31</td>
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</tr>
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tion of the wound. No additional absorbing gauze layers were used on top of the Granuflex®. The dressing was sometimes attached with a bandage or Codofix® net. The dressing was changed every 2 – 4 days until the wound had completely healed (Fig. 2a–c).

**Conservative treatment using Iruxol Mono® enzymatic dressings**

The enzymatic ointment Iruxol Mono® was applied only to the burned surfaces, without covering the margin of intact skin. The wound was then covered with tulle gauze and fixed with a bandage or Codofix® net. Every 24 hours the dressing was changed, the wound was disinfected with 0.05% chlorhexidine solution; no iodic solutions were used so as not to disturb the enzymatic action of Iruxol Mono®. After superficial necrosis was completely demarcated, epithelialisation was carried out using the Granuflex® hydrocolloid dressing, according to the protocol described above.

**Conservative treatment using a hydrofibre dressing with ionic silver Aquacel Ag®**

The wound was covered with Aquacel Ag® including a 5 cm margin of healthy skin. The dressing was either left dry to absorb the exudate from the wound or gently misted with a sterile 0.9% saline solution to help it attach better to the wound bed. The dressing was then covered with tulle gauze and/or Codofix® net. After it had become dry and properly attached to the wound bed, the dressing was left on the surface of the wound and was not removed for a maximum period of 2 weeks. Routine control of the wound involved only changing the superficial layers of the tulle gauze above the Aquacel Ag®. The dressing was changed only when it no longer attached to the necrotic wound bed, or in certain cases when it absorbed too much exudate and tended to detach itself from the wound spontaneously. In all other cases re-epithelialisation took place from the bottom of the wound, and...
the edges of the shrinking dressing were simply cut off with sterile scissors. This procedure was carried out until the wound had healed completely (Fig. 3a–c).

Excluding patients from the study group
All patients in whom no distinct healing and re-epithelialisation of the burn wound was noticed until the 14th day of the treatment were excluded from the study group. In those patients tangential excision and/or skin grafting were performed.

The analysis of parameters
The following parameters were analysed during the study:
1. The total time of wound healing (days). Every wound free of necrotic tissue, in which the beginning of healing processes was noticed, was considered to be a demarcated wound. Every wound covered with the fresh epithelium, dry, clean and demanding nothing but cosmetic procedures was considered to be a healed wound.
2. The total duration of patients’ hospitalisation (days). The patients were usually discharged home after the above-described criteria of a healed wound were recognised.
3. The total number of dressing changes.
4. The mean pH value of the wound. The pH of the wound was measured at the time of every dressing change; the mean value of all measurements was subsequently analysed.
5. Wound swab results. Wound swabs were taken at the time of admission, and then every 7 days. The quantitative studies involved 3 types of wound swab results: a = sterile, b = single isolate, c = multiple isolates. The analysis also included the types of the organisms isolated from the wound cultures.
6. The appearance of the clinical signs of wound infection. The local signs of infection were purulent wound exudate, oedema, reddening, and the general signs were fever and increase of the WBC and CRP.
7. The late assessment of the scar according to the modified Vancouver Scar Scale (mVSS). The mVSS was assessed routinely after 6 months from the time of injury during a follow-up control in the outpatient clinic.

Results (Tables 2 and 3)

Results of the operative treatment (group A)
A total 25 patients underwent operative treatment. Four of them presented with DDPT burns covering up to 10% of TBSA, 17 of them presented with DDPT burns amounting to 10 to 20% of TBSA, and 4 of them had DDPT and mixed DDPT/FT burns over 20% of TBSA. The mean total time of wound healing for this group was 16 days (min. 14, max. 25 days). Partial graft rejection and the need to perform a re-grafting procedure were observed in 4 patients (16%), including 2 patients with DDPT of up to 10% of TBSA and 2 patients with DDPT over 20% of TBSA. The cause of graft rejection was infection of the wound in each these cases. Graft overgrowth was observed in 3 patients (12%), all of them with wounds less than 20% of TBSA. They were treated with silicone dressing and pressure garments. Melting wound-graft was found in 2 patients (8%), and it was treated conservatively. The mean total healing time for the donor-site wounds was 7 days (min. 6, max. 11 days). Complications in the healing of donor sites were noticed in 4 cases (infection – 2 cases, hypertrophic scarring – 2 cases). Mean pH of the wound in this group was 6.4. The mean total number of the dressing change procedures was 4 and mean mVSS was 4.

Results of the treatment using mechanical dermabrasion (group B)
Mechanical dermabrasion of the wound was performed in a total of 31 patients. 12 of them presented with mixed SPT/DDPT and DDPT burns covering less than 10% of TBSA, 15 presented with mixed SPT/DDPT and DDPT burns covering between 10 and 20% of TBSA and 4 presented with mixed SPT/DDPT and DDPT burns over 20% of TBSA. The mean total time of wound healing for this group
was 18 days (min. 12, max. 27 days). Wound infection was noticed in 3 patients (10%). Skin grafting for residual wounds without a chance for spontaneous epithelialisation was performed on the 12th day in 6 patients with DDPT wounds, 4 with wounds above 20% of TBSA and 2 below 20% of TBSA, which corresponds to 19% of the total of 31 patients in whom mechanical dermabrasion followed by conservative treatment was initially believed to be the method of choice. The extent of the grafted areas was 50% of the initial wound in 2 patients and 10–20% of the initial wound in the other 4 patients. In 5 grafted patients the wounds healed without complications by the 21st day post burn. In 1 patient with a DDPT wound of 25% of TBSA, grafting was complicated by infection and a re-grafting procedure was needed, which prolonged the total healing time to 27 days post burn. Nevertheless, the mean total time of wound healing for those patients in whom conservative treatment after dermabrasion was successful was 15 days (min. 12, max. 21 days). The mean pH of the wound in this group was 6.2. The mean total number of dressing changes was 6 and mean mVSS was 2.

Results of the conservative treatment using the Granuflex® hydrocolloid dressing (group C)

This group consisted of a total of 33 patients with mixed SPT/DDPT and DDPT burns: 15 of them with burns less than 10% of TBSA, and 18 with burns covering from 10 to 20% of TBSA. The mean total time of wound healing for this group was 19 days (min. 11, max. 22 days). Three patients were excluded from the group and underwent residual tangential necrectomy followed by skin grafting on the days 12–14 without complications. Wound infection was observed in 3 patients (9%). The mean pH of the wounds in this group was 6.2. The mean total number of dressing changes was 7 and mean mVSS was 4.

Results of the conservative treatment using the Iruxo Mono® enzymatic dressing (group D)

This group consisted of a total of 19 patients: 9 of them had mixed SPT/DDPT and DDPT burns of less than 10% of TBSA, 9 had mixed SPT/DDPT and DDPT burns ranging from 10 to 20% of TBSA and 1 had a mixed DDPT/FT burn covering 25% of TBSA. In the last patient, conservative treatment was carried out because the parents of the child did not consent to the operative treatment. Their consent was obtained only 14 days post burn, when the wound was not healing satisfactorily. The wound was then grafted and subsequently healed without complications. The mean total time of wound healing for this group was 22 days (min. 14; max. 23 days). Another 3 patients from this group with DDPT burns were excluded from conservative treatment and grafted on day 12–14 post burn. The overall rate of conversion in this group was 21% (4 patients). Wound infection was recorded in 4 patients (21%), all of them with burns of 10–20% of TBSA. The mean pH of the wound in this group was 6.4. The mean total number of dressing changes was 14 and mean mVSS was 5.

Results of the conservative treatment using a hydrofibre dressing with ionic silver Aquacel Ag® (group E)

This group consisted of 17 patients: 7 of them presented with mixed SPT/DDPT and DDPT burns of less than 10% of TBSA, 7 had mixed SPT/DDPT and DDPT burns of between 10 and 20% of TBSA and 3 had mixed SPT/DDPT burns over 20% of TBSA, with a maximum of 30% of TBSA. The mean total time of wound healing for this group was 17 days (min. 12; max. 21 days). 3 patients
(18%) had to be partially grafted on day 14; the grafted area was not more than 20% of the initial wound area in any of them. Wound infection was recorded in 1 patient (6%). The mean pH of the wound in this group was 6.2. The mean total number of dressing changes (i.e., total removal of the Aquacel Ag® from wound bed) was 3 and mean mVSS was 3.

Discussion

The proper local treatment of deep dermal partial-thickness paediatric scalds is still very controversial. Janzˇekowic was first to prove the necessity of an early operative treatment of necrotic burns [9]. Since then, early excision and grafting became the standard for the local treatment of those wounds which do not heal within 21 days, with a good final cosmetic and functional result. Excision and grafting of necrotic wounds is known to shorten the time of the treatment significantly, to decrease the number of early and late complications, the possibility of hypertrophic scarring, and in cases of life-threatening burns it was also reported to decrease mortality. Puchala [19] postulates that conservative treatment should be used to treat all non-complicated mixed SPT/DDPT wounds, but at the same time he strongly advises carrying out early excision and grafting for all DDPT and mixed DDPT/FT wounds on the 2nd – 5th day post burn. In cases of extensive wounds, he suggests carrying out total necrosis removal before day 7 post burn, with wound covering by a graft before day 21 post burn. Muller [17] postulates performing excision and grafting in cases with DDPT wounds, even if the wounds are less than 20% of TBSA, and refers to the possibility of complications with conservative treatment – which can include puritis, bad functional and cosmetic outcomes, and an increased risk of hypertrophic scarring. Yanaga [21] describes the technique of the treatment of tangential excision followed by covering of the wound with allografts of human keratinocytes cultured in vitro and banked in liquid nitrogen. The operative treatment of DDPT burns is also recommended by Engrav [4] and Gray [6], Peeters [18], Brans [1], Moerman [15], and others describe the management of DDPT burns using human cryopreserved and glycerol-preserved allograft skin.

Other authors have noted that, in contrast to FT burns, there is still a possibility of self-re-epithelialisation with DDPT burns. They point to the possibility of complications after invasive procedures, for example the increased loss of blood, the possibility of skin graft rejection, graft overgrowth of shallow excised wounds, melting wound-graft syndrome, infections of the donor site, etc. Wardrope and Smith [20] are among those authors who postulate that the extent of the DDPT wound must first be taken into consideration when deciding whether to treat the burn conservatively or operatively. They prefer conservative treatment for all non-extensive DDPT wounds, but they again point to the possibility of complications. Heimbach [7] noted that paediatric scalds are usually a mosaic of superficial and indeterminate dermal burns, and their accurate depth is difficult to assess during the first days post burn. Therefore he suggested using non-operative treatment for such wounds during the first 10 – 14 days, unless they are obviously deep, followed by excision of those areas which are unlikely to heal within a window of 3 weeks. Heimbach referred to the results presented by Desai [3], who compared the early operative treatment of paediatric scalds (first 3 days) versus late excision (after 2 weeks). Desai proved that early operation required considerably higher amounts of blood replacement without offering any clinical benefit. De Mey [2] also postulated using conservative treatment for most DDPT paediatric scalds, pointing to the difficulties in correctly assessing the burn wound depth during early stages and the threat of excising healthy tissue.

All methods of treatment of DDPT burns described in this paper have their own history and place in the management of thermal injuries, and many supporters among surgeons. The technique of mechanical dermabrason has been widely described for the treatment of burns. It was first described by Iverson and then popularised in the 1960s thanks to the work of Lorthioir [14] and his successors (Forster, Barkay, Gracia and others). Since then, many other surgeons have described different modifications of this technique for the so-called supported demarcation of necrotic tissue. Holmes [8] proposed performing late mechanical dermabrasion for DDPT wounds at 14 days post burn, followed either by conservative or operative treatment. Kaawach [11] covered dermabraded wounds with allografts of human keratinocytes cultured in vitro on the 14th day post burn. Floccard [5] used mechanical dermabrasion followed by conservative treatment, while Jonsson [10] always grafted the wounds after abrasion. In contrast, Krant [13] suggested that grafting the wounds after abrasion should not be recommended, as in this case the graft may only be considered as a temporary biological dressing.

The new generation of hydrocolloid dressings is believed to play an important role in the local treatment of burns [12]. Granuflex® is known to be a good representative of hydrocolloids, based on Winter’s theory of the moist treatment of wounds. The dressing has a number of properties that help to make wound healing faster, which include the fine absorption of wound exudate, maintenance of an accurate level of humidity in the wound as well as an optimal wound temperature, and control of the optimal wound pH (5.9 – 6.1), and which result in the increased migration of granulocytes, the increased activity of enzymes, while decreasing the risk of bacterial infection and activating neoangiogenesis. According to our findings, Granuflex® offered the combination of both sufficient wound debridement and good re-epithelialisation of the controversial deep dermal partial-thickness burn wounds.

Hydrofibre dressings with ionic silver are another interesting group of modern burn coverings. The role of silver and silver-related products in burn wound treatment has been strongly emphasised since many years [16]. The wide antimicrobial spectrum of ionic silver seems to prevent wound infection better than any other substance used in burn management. Silver nitrate and silver sulfadiazine, which were used to treat burns for many years, have since been reported to carry the risk of a pro-inflammatory action and to decrease healing. This has not occurred with dressings with ionic silver. Aquacel Ag®, which is a combination of a hydrofibre dressing and ionic silver, appears to be a very modern and promising type of dressing. It combines the above-described properties of hydrocolloids, including the increased capacity to absorb wound exudate, and the wide antimicrobial spectrum of silver ions. It has been especially designed to treat complicated wounds, and its role in the conservative treatment of DDPT burns seems to be important and needs to be investigated further.

In our single-centre study we did not manage to collect a sufficient number of patients which would have allowed us to present a proper statistical analysis of our results. Such an analysis will doubtless be performed after further investigations have been carried out. Nevertheless, preliminary results based on...
our clinical observations led us to the general conclusion that there is a relation between the TBSA of the DDPT burn and the choice of the method of wound treatment. In the material that was investigated, all patients with DDPT scalds of TBSA > 20% eventually required STASG for at least some parts of the wound. In our opinion the extent of the early (day 2 – 5) invasive procedure remains controversial, since some parts of paediatric scalds have the potential to self-epithelialise. However, in cases of extensive burns and with an increased risk of general complications, early operative treatment remains the method of choice for DDPT burns. For patients with burns < 20% of TBSA, the results of operative and conservative treatment were similar. Particularly good results with conservative treatment were noted in the group of patients with burns < 10% of TBSA. The sparing technique of mechanical dermabrasion followed by conservative wound epithelialisation seems to be a serious alternative to the operative treatment of DDPT paediatric scalds. The authors postulate that this technique covers the requirements developed for the ideal treatment of DDPT wounds: it provides early, safe and controlled necrotic demarcation and good wound re-epithelialisation under hydrocolloid dressings. Convincing results have also been recorded for patients treated only with hydrocolloids, both with Granuflex® and Aqualog AG®. In our opinion these modern dressings should be taken into consideration not only for the treatment of SPT burns, but also for some of the DDPT wounds. Enzymatic dressings, although safe and easy, did not provide wound healing within a convincing short period of time.

Conclusions

The method used for local treatment of DDPT paediatric scalds may depend on the extent of the burn. In our opinion the technique of mechanical dermabrasion followed by conservative wound epithelialisation using hydrocolloid dressings should be considered as the method of choice for DDPT burns of TBSA < 10%. For DDPT wounds of 10 – 20% TBSA the management decision should be based on the type of the wound; for most non-complicated mixed SPT/DDPT burns conservative treatment with or without mechanical dermabrasion should be sufficient; for isolated DDPT wounds conversion to STASG will depend on the progress of wound healing. Tangential necrectomy followed by STASG is the method of choice for DDPT burns of TBSA > 20%.

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