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Air-fluidized therapy in the treatment of severe burns: A retrospective study from a burn intensive care unit in Austria

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ABSTRACT

Introduction: Air-fluidized therapy (AFT) has long been used in the treatment of severe burns. In patients with extensive burns involving the posterior trunk, we aim to keep affected posterior areas dry and to postpone their treatment, initially applying available split-thickness skin grafts in functionally more important regions. We retrospectively assessed the impact of AFT on the survival of patients treated in the burn intensive care unit (ICU) of the Medical University of Vienna, Austria, between 2003 and 2016.
Methods: This retrospective single-center study included patients aged ≥18 years with burned total body surface area (TBSA) ≥20% and IIb–III° thermal injuries on the posterior trunk who received AFT. Survival rates were compared with those predicted by the abbreviated burn severity index (ABSI). Demographic, clinical, and surgical data were analyzed.
Results: Seventy-five of 110 patients with posterior trunk burns received AFT. Their survival rate exceeded that predicted by the ABSI score (mean ABSI, 10.0 ± 2.0; 73.3% (95% CI: 62-83%) survival rate vs. 20-40% predicted; $p < 0.0001$); no such difference was observed in the non-AFT group (mean, 8.8 ± 1.9; 65.7% (95% CI: 48-81%) survival rate vs. 50-70% predicted). Patients receiving AFT had significantly greater TBSA (median, 50% (35–60) vs. 30% (25–45) and longer ICU stays (median, 63 (36–92) vs. 18 (9–52) days; both $p < 0.0001$). Fifty-one (68.0%) patients in the AFT group and 26 (74.3%) patients in the non-AFT group underwent posterior trunk surgery ($p = 0.66$) a median of 16 (10–26) and 5 (2.5–9.5) days, respectively, after admission ($p < 0.0001$).
Conclusions: Patients receiving AFT had significantly better survival than predicted by ABSI score in contrast to patients not receiving AFT although burn injuries in this group were more severe (greater TBSA, higher ABSI). As intensive care was similar in these groups aside from AFT, the better survival could be attributed to this additional therapy.

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1. Introduction

The posterior trunk is a special area in the treatment of severe burns largely because of its considerable body surface area which directly influences prognosis in terms of survival and outcome [1]. In the supine position, the posterior trunk bears a major portion of the body weight; take rates of skin grafts are often poor in this region because of shear stress and pressure, and surgical procedures might be complicated by necessary changes from the supine to the prone position when the use of split-thickness skin grafts (STSGs) is undertaken [2,3].

The air-fluidized bed was developed in 1968 and soon thereafter used in the treatment of burn patients. Compressed air induces a vertical airflow which suspends up to 150 μm small ceramic beads contained within a polyester sheet, resulting in interface pressures in air-fluidized therapy (AFT) that are much lower than those on other support surfaces [4]. Advantages of AFT are rapid drying of burn wounds, faster epithelialization of superficial burns, shorter periods of wound preparation for STSG donor sites, less rejection of replanted STSGs due to pressure, and easy adjustment of bed temperature to help maintain core body temperature in patients with extensive burns [2,5–11].

To address the above-mentioned problems in patients with extensive burns involving the posterior trunk, AFT has been used in our burn intensive care unit (ICU) for many years. Our concept is to keep the affected posterior areas dry to impede bacterial or fungal infection and to aim for postponed surgical– or, when possible, conservative– treatment of the back using available STSGs for other, functionally more important, burned body regions [12].

Although AFT has been used successfully in the treatment of burn patients since the late 1960s, to our knowledge no large study investigating AFT and its impact on survival has been conducted in recent decades. In this study, we retrospectively assessed the impact of AFT as an additional therapy on the survival rates of patients with extensive burns treated in our burn ICU; survival rates of our patients were compared to the survival rates predicted by the ABSI score [13]. We further observed that the skin of the posterior trunk shows great regenerative potential due to its anatomical properties as long as the overlying eschar is kept dry; therefore, the timing and number of posterior trunk surgical procedures in patients receiving and not receiving AFT were also evaluated.

2. Methods

2.1. Study design, patients, and data collection

This retrospective single-center study included patients admitted to the burn ICU of the Division of Plastic and Reconstructive Surgery, Medical University of Vienna/Vienna General Hospital, Austria, between January 2003 and December 2016. Inclusion criteria were age ≥ 18 years, burned total body surface area (TBSA) ≥ 20%, and presence of deep partial- to full-thickness (IIb–III°) thermal injuries on the posterior trunk. Data from patients who survived < 7 days after admission to the burn ICU were excluded from the analysis as well as patients with burns involving less than one third of the posterior trunk area. All patients meeting the inclusion criteria were identified using medical records and the electronic hospital database. Demographic and clinical data (age, sex, TBSA, abbreviated burn severity index [ABSI] score, inhalation trauma, type of thermal injury, use of AFT, results of blood culture testing, presence of hypernatremia [sodium levels > 145 mmol/L], days spent in the ICU, mortality rate), as well as surgical data (timing, number, and type of surgical procedures performed on the posterior trunk), were extracted from the electronic hospital database and from medical records, respectively. Survival rates of patients with and without AFT treatment (ArjoHuntleigh; Getinge Group, Malmö, Sweden) were assessed and compared to those predicted by the ABSI score (Table 1) [13]. Decisions to use AFT were made based upon the availability of air-fluidized beds and upon the clinical assessments of plastic surgeons on duty at the time of patient admission.

The study was approved by the local ethics committee review board (no. 1733/2015) and was carried out in compliance with the Declaration of Helsinki.

2.2. Statistical analysis

Descriptive statistics were used to summarize patient characteristics and surgical data. Frequency tables were used to summarize categorical variables. Means ± standard deviations for normally distributed data and medians and interquartile ranges in case of non-normal distributed data were used to describe continuous variables. Continuous variables were compared using Student's *t* test or the Mann–Whitney *U* test, and categorical variables were compared using Fisher's exact test or the Chi-squared test. Survival rates were

Table 1 – Abbreviated Burn Severity Index.

Characteristic	Score	Characteristic	Score
Sex		TBSA burned (%)	
male	0	1– 10	1
female	1	11– 20	2
Age		21– 30	3
0– 20	1	31– 40	4
21– 40	2	41– 50	5
41– 60	3	51– 60	6
61– 80	4	61– 70	7
81– 100	5	71– 80	8
Inhalation injury	1	81– 90	9
III° burn	1	91– 100	10

ABSI Score	Probability of Survival
2– 3	≥99%
4– 5	98%
6– 7	80– 90%
8– 9	50– 70%
10– 11	20– 40%
12– 13	≤10%

TBSA, total body surface area; ABSI, abbreviated burn severity index.

By adding the number of points of each corresponding variable, an estimate of patients' survival probability can be obtained using the ABSI score.

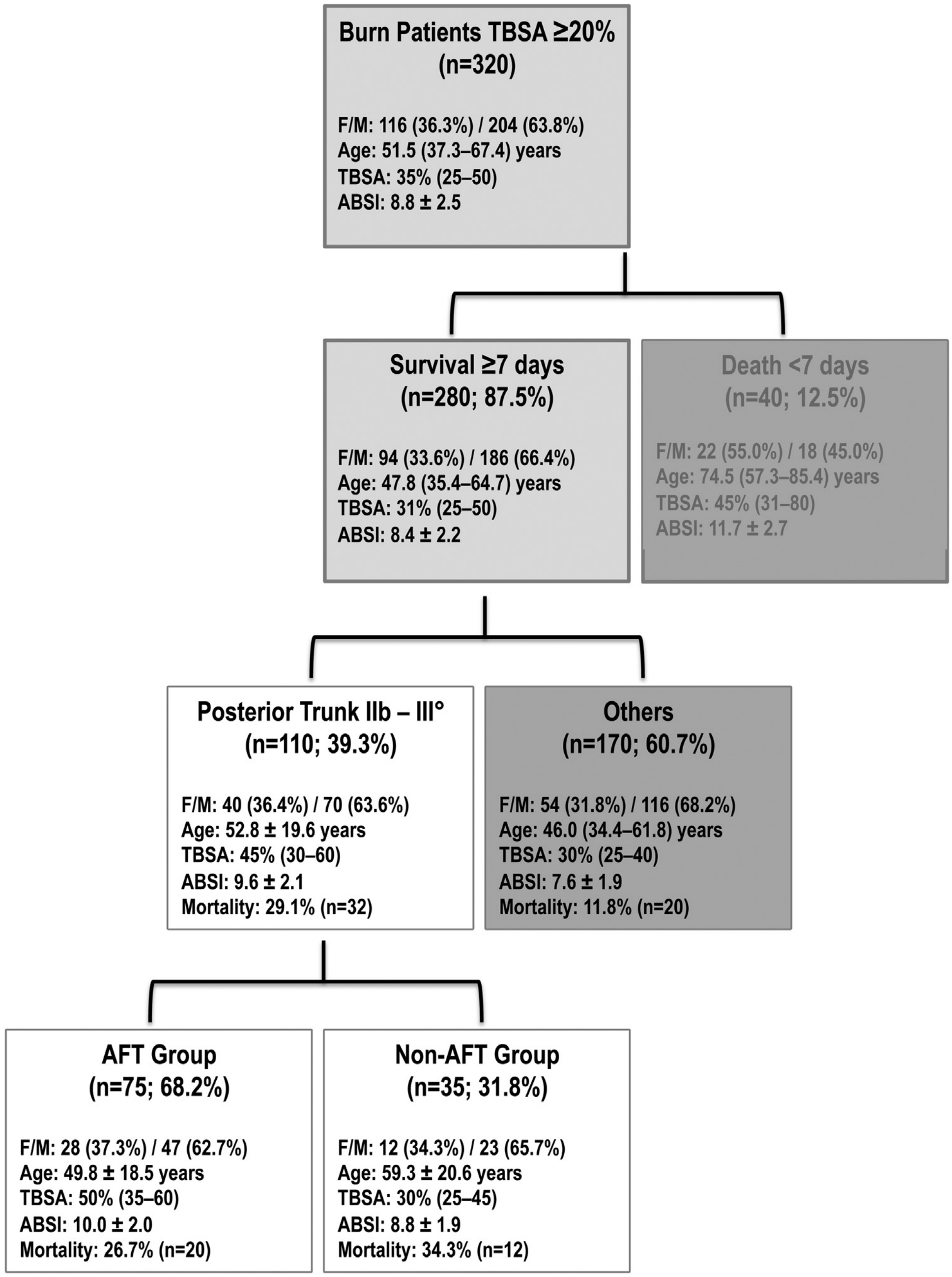

Fig. 1 – Characteristics of patients in the study population.
Results are presented as mean ± standard deviation and median (1st– 3rd quartile), respectively.
TBSA, total body surface area (affected by thermal injury); F/M, female/male; ABSI, abbreviated burn severity index; AFT, air-fluidized therapy.

compared with those predicted by the ABSI score [13] by using a one sample binomial test based on exact methods. 95% confidence intervals for the survival rates were computed by using Pearson-Clopper confidence intervals. All tests were done two-sided, and p-values < 0.05 were considered to be significant. StatXact (2013), Version 10.0.0, Cytel software cooperation (Cambridge, MA, USA) and GraphPad Prism7 (GraphPad Software, La Jolla, CA, USA) were used for all statistical analyses.

3. RESULTS

The study population comprised 110 patients, with thermal injuries on the posterior trunk ($n = 110$), 75 (68.2%) of whom received AFT and 35 (31.8%) of whom were patients managed with conventional pressure-reducing mattresses (Fig. 1). Patients in the AFT group were significantly younger than those in the non-AFT group (mean, 49.8 ± 18.5 vs. 59.3 ± 20.6

Table 2 – Demographical and surgical data of patients with thermal injuries involving the posterior trunk.

Characteristic	Posterior trunk IIb– III°	AFT group	Non-AFT group	p– values
n	110	75	35	
%	100	68.2	31.8	
Female %	36.4	37.3	34.3	0.83
Age	52.8 ± 19.6	49.8 ± 18.5	59.3 ± 20.6	0.0231*
Type of thermal injury				0.61
Combustion	73 (66.4%)	50 (66.7%)	23 (65.7%)	
Scald	17 (15.5%)	11 (14.7%)	6 (17.1%)	
Explosion	13 (11.8%)	10 (13.3%)	3 (8.6%)	
Electrical burn	6 (5.5%)	4 (5.3%)	2 (5.7%)	
Others	1 (0.9%)	0 (0%)	1 (2.9%)	
TBSA%	45 (30–60)	50 (35–60)	30 (25–45)	<0.0001*
ABSI score	9.6 ± 2.1	10.0 ± 2.0	8.8 ± 1.9	0.0028*
Inhalation injury	38 (34.5%)	27 (36.0%)	11 (31.4%)	0.67
Positive blood cultures	61 (55.5%)	47 (62.7%)	14 (40.0%)	0.0388*
Hypernatremia	86 (78.2%)	64 (85.3%)	22 (62.9%)	0.0125*
Surgical data (posterior trunk)				
Patients undergoing surgery	77 (70.0%)	51 (68.0%)	26 (74.3%)	0.66
Days until surgery	11.5 (5.0–21.8)	16.0 (10.0–26.0)	5.0 (2.5–9.5)	<0.0001*
Number of surgical procedures	1.1 ± 0.9	1.1 ± 1.0	1.0 ± 0.8	0.66
STSG or keratinocytes	71/77 (92.2%)	47/51 (92.2%)	24/26 (92.3%)	>0.99
LOS (days)	46 (20–85)	63 (36–92)	18 (9–52)	<0.0001*
Mortality	32 (29.1%)	20 (26.7%)	12 (34.3%)	0.50

AFT, air-fluidized therapy; TBSA, total body surface area (affected by thermal injury); ABSI, abbreviated burn severity index; STSG, split thickness skin graft; LOS, length of stay.

Data are given in absolute numbers and percentages, median (1^{st}– 3^{rd} quartiles) and mean ± standard deviation, respectively. Hypernatremia was defined as serum sodium levels > 145 mmol/L measured at some point during ICU stay.

* Significant results.

years; p = 0.0231); they had significantly greater TBSAs (median, 50% (35–60) vs. 30% (25–45); $p <$ 0.0001), higher ABSI scores (mean, 10.0 ± 2.0 vs. 8.8 ± 1.9; p = 0.0028), and longer ICU stays (median, 63 (36–92) vs. 18 (9–52) days; $p <$ 0.0001).

Patients receiving AFT had significantly higher survival rates than predicted by the ABSI score (73.3% (95% CI: 62-83%) vs. 20–40% predicted, p < 0.0001), whereas the survival rate of patients in the non-AFT group (65.7% (95% CI: 48-81%)) was not higher than predicted (ABSI score: 50–70% predicted).

Surgical procedures were performed on the posterior trunk in 51 (68.0%) patients in the AFT group and 26 (74.3%) patients in the non-AFT group (p = 0.66). The timing of posterior trunk surgery differed between the AFT and non-AFT group (median, 16 (10–26) vs. 5 (2.5–9.5) days after ICU admission; $p <$ 0.0001). No significant difference was detected in the number of patients undergoing surgery on the posterior trunk or in the total number of operations needed. Details are shown in Table 2.

Systemic infection and hypernatremia occurred more often in the AFT group than in the non-AFT group (62.7% vs. 40.0% positive blood cultures, p = 0.0388; 85.3% vs. 62.9% with sodium levels >145mmol/L, p = 0.0125).

No significant difference in sex, type of thermal injury, presence of inhalation injury, or mortality rate was detected between groups (Table 2).

A patient treated in an air-fluidized bed can be seen in Fig. 2. An example of burn wounds treated by means of AFT is shown in Fig. 3.

4. Discussion

The aim of this study was to determine whether AFT has a potentially beneficial impact on the outcome of patients with severe burns involving the posterior trunk. Our results show a significantly better survival rate in patients receiving AFT than predicted by the ABSI score (73.3% vs. 20– 40% predicted by ABSI) in contrast to those patients who did not receive AFT as additional therapy (65.7% survival rate vs. 50–70% predicted by ABSI). Patients treated with AFT suffered from more severe thermal injuries with significantly higher ABSI scores and significantly greater TBSA. Given that intensive care was similar in the two study groups with the use of air-fluidized beds being the only major difference, the significantly better survival rate in the AFT group, compared to predicted survival rates by the ABSI score,might be attributed to the additional use of this therapy.

The ABSI score, which we used as a reference value for mortality, was described by Tobiasen et al. [13] in 1982. Although the need to modify the ABSI score due to changes in demographics and dramatic advances in medical care in recent decades might be presumed, studies based on 3000 patients suggest that it remains a useful and accurate means of mortality prediction in burn patients even more than 30 years after its development [14].

Contrary to the widely accepted early necrectomy approach in burn surgery [15,16] a possible explanation for the better

Fig. 2 – Patient treated in an air-fluidized bed (burn ICU, Medical University of Vienna/Vienna General Hospital, Austria).

outcome in the AFT group is that we pursue in part a “late necrectomy” treatment strategy for patients with extensive burns involving the posterior trunk. Whereas the median time to surgery for burn wounds on the posterior trunk was 5 days in patients managed using pressure-reducing mattresses, necrectomy of the back was performed a median of 16 days after admission in patients managed with AFT. In our opinion, this concept has various advantages: it allows clinicians to focus on early necrectomy in aesthetically and functionally important regions while patients are managed in air-fluidized beds, and it increases the healing time for STSG and donor sites while keeping the eschar on the posterior trunk dry thereby avoiding the creation of additional large wound areas.

Possible concerns about an increased infection rate due to late necrectomy and retention of the eschar on the posterior trunk can be addressed as follows. First, late necrectomy is not necessarily a disadvantage under certain circumstances, as shown by Herndon et al. [17] Patients with second- and third-degree burn injuries were assigned to early excision with skin grafting or a conservative wound-management protocol with antimicrobial dressing and debridement no earlier than 21 days after burn. In patients aged $>$ 30 years and in those with inhalation injuries, no difference in the mortality rate could be detected between the two groups. Secondly, the bactericidal properties of AFT were described shortly after the invention of the air-fluidized bed. Cultures of silicone microspheres from air-fluidized beds have been proven to be sterile after 24 hours; the suggested mechanism is that the sequestration of bacteria into clumps of fluid microspheres prevents their survival by promoting their desiccation by airflow [18,19]. Given that more than 80% of burn wounds are affected by bacterial colonization within the first week [20] and that mortality is associated with infection in up to 75% of severely burned patients [21], the bactericidal feature of AFT is highly beneficial in this vulnerable patient population. Currently, wound infection with often multidrug-resistant *Pseudomonas aeruginosa* [22,23] or *Acinetobacter baumannii* [24] is a complication encountered commonly in burn units. As these bacteria require a moist environment for colonization [24,25], the properties of the air-fluidized bed can prevent local colonization and subsequent infection with them. However, in our study population, the rate of *systemic* infection was significantly higher in the AFT group (62.7%) than in the non-AFT group (40.0%). This difference could be explained by the significantly longer median ICU stay (63 vs. 18 days) in the AFT group which was mainly attributable to the significantly larger burn wounds (median 50% vs. 30%). Although AFT was apparently more likely to be used in serious cases, mortality did not differ between groups.

Another aim of this study was to evaluate differences in surgical procedures in patients treated with and without additional AFT. The mean number of surgical procedures for the treatment of the posterior trunk and the percentage of patients who underwent autologous skin grafting did not differ significantly between groups. However, we observed in numerous cases that conservative treatment with AFT led to full regeneration of IIb-III° burns on the posterior trunk (Fig. 3).

Although AFT is largely considered to be useful and safe, some disadvantages of this therapy have been reported. One of the most frequently described issues is dehydration of the patient with potential subsequent hypernatremia and disorientation [2,6]. In a population of patients with pressure sores, a dehydration rate of about 3–4% was reported [26]. In another study, healthy volunteers showed a mean weight loss of 1524 mL/m^2 over 24 hours in an air-fluidized bed at 36 °C [27]. However, some of these studies were conducted more than 30 years ago, and the management of critically ill patients has improved dramatically since that time. Advanced hemodynamic monitoring using trans-cardiopulmonary thermodilution and pulse contour analysis (PiCCO; Pulsion Medical Systems, Feldkirchen, Germany) is routinely applied for every severely burned patient admitted to our burn ICU enabling the continuous measurement of parameters reflecting cardiac output, pulmonary edema, and volume responsiveness. In addition, we measure patients’ sodium levels at least four times a day. These measurements allow us to detect hypernatremia, dehydration, and pulmonary edema at an early stage and to respond immediately. However, in our study population, 85.3% of patients in the AFT group and 62.9% of patients in the non-AFT group presented with hypernatremia. In most patients, elevated sodium levels only occurred within the first five days of admission. Nonetheless, no severe adverse events caused by hypernatremia were recorded.

Fig. 3 – Patient presenting with 73% burned total body surface area, including burn wounds on the posterior trunk.
Upper: On the day of admission, air-fluidized therapy was immediately started.
Middle: Detachment of the dried eschar after 17 days of air-fluidized therapy.
Lower: After 31 days of air-fluidized therapy, the back showed complete re-epithelialization; surgery for the treatment of burns on the posterior trunk was not necessary.

Another frequently described issue is the need for more aggressive pulmonary hygiene in patients receiving AFT [5], as lack of mobility might lead to atelectasis. As severely burned patients usually undergo tracheotomy in our burn ICU, we do not consider airway hygiene or atelectasis – which can be successfully prevented by using ventilator settings with positive end expiratory pressure [28] – to be a major problem associated with the use of AFT. In contrast to reports of and concern about pulmonary complications, some reports have shown a survival benefit of AFT in patients with inhalation injury [4]. In our study, the mortality rate was not significantly higher in patients receiving conventional therapy than in those receiving AFT but slightly differed in the subgroup of patients with inhalation injury. In our patient population, 36.0% of patients in the AFT group and 31.4% of patients in the non-AFT group suffered from inhalation injury; mortality rates were 29.6% and 63.6%, respectively ($p = 0.07$), suggesting that AFT confers a survival benefit in patients with inhalation injury.

This study has some limitations, the most obvious of which are the retrospective design and the lack of matched-pair analysis. Although AFT tended to be used in more severe burn cases, survival rates did not differ between the AFT and non-AFT groups. Moreover, conducting a prospective case-control study over a similarly long time period would be challenging, both from an organizational point of view and from an ethical perspective. Given the number of patients from this highly selective group that we were able to include in this study, we believe that the results are still conclusive and valid. Another limitation we could not avoid due to the retrospective design of the study was the assessment of the exact area of the posterior trunk affected by thermal injury which might be useful additional information. At least one third of the posterior trunk was affected in all patients, and injuries between the two groups are indeed comparable which is further corroborated by the fact that surgical data, aside from the timing of posterior trunk surgery, between the AFT and non-AFT group, do not differ.

5. Conclusions

In conclusion, we could show that patients receiving AFT as an additional tool in the treatment of severe burns including the posterior trunk had a significant survival benefit when compared to survival rates predicted by the ABSI score, whereas the non-AFT group did not exceed predicted survival rates. AFT permits the prioritization of necrectomy and STSG application in aesthetically and functionally important regions while the posterior eschar is kept dry and STSG donor sites are allowed to heal. Our results indicate that AFT remains a highly beneficial additional tool in the treatment of patients with extensive burn wounds including deep dermal and full-thickness burns on the posterior trunk, even 50 years after the development of this therapeutical approach.

Conflicts of Interest and Source of Funding

No fundings from any sources have been received for this work. The authors declare no conflicts of interest.

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