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Review

Fluid resuscitation in adults with severe burns at risk of secondary abdominal compartment syndrome—An evidence based systematic review☆

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ABSTRACT

Background: Secondary abdominal compartment syndrome (sACS) in adults with severe burns is commonly unsuspected, can be rapidly fatal and seriously compromises the reliability of urine output as an indicator of perfusion and resuscitation status. Current literature lacks an exhaustive, evidence-based review critically appraising all retrieved literature on which clinical decisions may be based.

Methods: The evidence on three inter-related concepts was evaluated: fluid-volume management and its contribution to sACS; the role of urinary bladder pressure monitoring; and awareness of the burns community to sACS. Literature published over the last ten years across the major databases was retrieved, and the search strategy was fully reported to reduce the retrieval bias ubiquitous in previous literature. Each article was individually appraised and classified into a framework of evidence, enabling the formulation of specific, graded recommendations.

Results: Current best evidence supports recommendations to reduce fluid-volume administered through use of colloids or hypertonic saline especially if the projected resuscitation volume surpasses a 'volume ceiling'. Continuous intra-vesical monitoring is recommended: to guide fluid resuscitation for early diagnosis of sACS; and as a guide to reliability of urine output as indicator of organ perfusion. A priming volume of 75 cm^3 or less is recommended.

Conclusion: Fluid resuscitation volume is causative to sACS, especially once a predetermined maxima is reached. Continuous intra-vesical pressure monitoring is a cheap, reliable, user-friendly monitoring method recommended in high-risk patients. Poor awareness among the burns community requires urgent dissemination of evidence based information.

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Contents

1. Background

1.1. *Description of the condition*

Secondary abdominal compartment syndrome (sACS) in severely burnt adults is a commonly under-recognized, under-treated and rapidly fatal condition [1,2]. Although first recognized by Wendt more than 100 years ago [3] only recently was it recognized to occur in burnt patients without abdominal trauma [2]. A consensus definition for ACS was finally formulated by Malbrain et al. as a sustained intra-abdominal pressure (IAP) $\geq$20 mmHg that is associated to new organ dysfunction or failure; secondary ACS was defined as pertaining to conditions not arising from the abdomino-pelvic region [5].

1.2. *Importance of the review*

sACS complicates fluid resuscitation and undermines the reliability of urinary monitoring as the gold standard guiding fluid resuscitation [2,6,7]. It causes urine output to become an inaccurate guide to fluid administration [8] prompting administration of more fluid-volume, itself implicated as a cause of sACS. The rapidly increasing intra-abdominal pressure reduces renal perfusion, decreasing urine output, prompting the unsuspecting surgeon to administer even more fluid. Recent studies have reported poor syndrome-awareness [9–11] which may lead to late diagnosis and dismal outcome. This rapidly mortal vicious spiral necessitated an evaluation of these inter-related issues together. IAH and secondary ACS in the severely burnt patient are a common phenomenon, with studies suggesting an IAH incidence of 36–70% and an ACS incidence of 1–20% [5,12–17]. This variation is at least in part due to the lack of a consensus definition until 2007 [5].

1.3. *Objectives*

The aim of this systematic review was to provide evidence-based recommendations on three key inter-related management issues in the initial fluid management of the severely burnt adult developing secondary ACS. These were: the effect of fluid-volume on the development of secondary ACS; the role of intra-vesical pressure monitoring in guiding fluid resuscitation compared with serial clinical examination; the state of awareness about secondary ACS in the burns community on the effects of secondary ACS on fluid resuscitation and monitoring.

1.3.1. *Management of fluid resuscitation volume in the severely burnt adult developing secondary abdominal compartment syndrome*

Current trends towards enthusiastic fluid resuscitation fluid-volumes may be implicated as a cause of IAH/ACS [2,6,7]. The evidence linking fluid-volume administered to IAH/ACS development, threshold volumes for IAH/ACS development, and recommendations on preventive strategies specific to burnt patients including Hypertonic Lactated Saline (HLS) and colloids were evaluated.

1.3.2. *The role of urinary bladder pressure monitoring in the severely burnt patient developing IAH and secondary ACS to guide fluid resuscitation compared with serial clinical examinations*

Undetected rising intra-abdominal pressure (IAP) rapidly compromises abdominal perfusion; compresses renal parenchyma thus making urine output an unreliable indicator of fluid requirement [8]. Recommendations on sensitivity of clinical exam versus intra-vesical monitoring, bladder priming volumes, and continuous monitoring were evaluated.

1.3.3. *The lack of awareness of IAH and ACS leading to late recognition of the syndrome*

Poor awareness of IAH/ACS and its effects on the fluid management of the severely burnt patient may contribute to late diagnosis and poor outcome. Yelon et al. [11], Ravishankar and Hunter [10] and Kimball et al. [9] specifically investigated awareness and management-readiness of the burnt patient developing IAH/ACS. Evidence on current awareness among the burns community was appraised.

2. Method

2.1. *Literature search*

An electronic search was performed across Pubmed; Cochrane Database of Systematic Reviews: ACP Journal Club, Database of Abstracts of Reviews of Effects; Cochrane Central Register of Controlled Trials; Cochrane Methodology Register; Allied and Complementary Medicine; British Nursing Index; CINAHL; EMBASE; Ovid-MEDLINE® In-Process & Other Non-Indexed Citations; The search-construct: 'Abdominal AND compartment AND syndrome AND burns AND ((Fluid AND resuscitation) OR (monitoring))' was used in Boolean Logic format. Although current best evidence would normally be accepted as studies published over the last five years, literature over the last ten years was evaluated, to include key papers and seminal research. Literature obtained by this method was back-referenced and hand-searched.

2.2. *Literature appraisal*

Literature was critically evaluated based on the Rees' [18] framework for quantitative research and the Public Health Resource Unit, England [19] framework for appraisal of qualitative research and systematic reviews and the AGREE (2001) framework [20] for guideline appraisal. Studies thus critically appraised were classified according to their robustness into the University of Oxford's Levels of Evidence by Phillips et al. [21]. This enabled graded recommendations based on the presence of consistent evidence at a particular level, to be formulated for future practice.

3. Study analysis and appraisal

3.1. *Management of resuscitation fluid-volume in the severely burnt adult developing secondary abdominal compartment syndrome*

O'Mara et al. [7] performed a two-armed RCT on severely burnt patients comparing the effects of fluid-volume (crystalloid and colloid) on intra-abdominal pressure (IAP) and reported a causal relationship. Less volume was required in the colloid arm of their study, resulting in a lower incidence of IAH/ACS enabling colloids to be recommended in this specific scenario. Clear inclusion/exclusion criteria, baseline demographic and clinical details increase applicability of their recommendations. Block randomization was suitable to this small trial, ensuring an equal distribution of confounding factors, mimising bias and increasing reproducibility. The reproducible methodological account provided (including a pilot study, flow of participants, dates defining recruitment and follow-up), and the sample size calculation (power of 80% at $p < 0.05$), increased the power to demonstrate an association between fluid-volume and IAP however, however a lack of blinding may have introduced observer bias. Linear regression-analysis was used to demonstrate the causal relationship of fluid-volume on IAH. An $R^2 = 0.621$ at $p < 0.0001$ indicated that approximately 62% of the increase in IAH was explained by the resuscitation volume administered (Table 1). This RCT with narrow confidence intervals placed at level 1b in Phillips et al.'s (2001) framework [21]. Their rigorous approach and valid conclusions suggest that the use of colloids in early resuscitation of severely burnt adult would lower the incidence of sACS.

Oda et al. [2] and Ivy et al. [6] also concluded that resuscitative fluid-volume was a cause of IAH/ACS, corroborating the findings of O'Mara et al. [7]. The rigorous approach is reflected by the meticulously reported inclusion/exclusion criteria, baseline clinical and demographic characteristics of the cohort of burns patients. Both studies appropriately used a cohort methodology to follow-up severely burnt patients undergoing resuscitation and monitor for sACS (the outcome). Use of the method validated by Iberti et al. [22] for intra-vesical IAP monitoring increased rigor lending more credibility to their findings which are summarized in Table 1.

Table 1 – Fluid resuscitation volume and IAH: a synthesis of main conclusions from Oda et al. [2] and Ivy et al. [6] and O'Mara et al. [7].

Study	Sample size	Fluid threshold to produce 'IAH'	R^2 (vol. fluid and IAP)	p-Value	Cut-off for IAH	Time to onset of IAH
O'Mara et al. [7]	31	475 ml/kg overall (350 ml/kg with crystalloid) (600 ml/kg with colloid)	0.351 crystalloid 0.657 colloid 0.621 overall	$p < 0.0001$	25 mmHg	60–80 h post-burn
Oda et al. [2]	48	300 ml/kg	0.7261	$p < 0.01$	30 mmHg	n/a
Ivy et al. [6]	10	250 ml/kg	0.121	Unreported	25 mmHg	48 h

Table 2 – Results from the International Conference of Experts on Intra-Abdominal Hypertension and ACS (Cheatham et al., 2007) [5], Appraisal after the AGREE framework (2001) [20].

Objectives: The development of practice guidelines on diagnosis management and prevention of IAH and ACS.
The clinical question is specifically described: The clinical question is explicitly described. 'EBM guidelines' by 'consensus group' to diagnose manage and prevent IAH and ACS.
Patients to whom the guideline is meant to apply are specifically described: The patient group to whom these guidelines refer and not specifically described.
Stakeholder involvement, guideline development included individuals from all the relevant professional groups: The consensus group included a multidisciplinary critical care specialist panel.
The patients' views and preferences have been sought: There is no mention of this is the text.
The target users of the guideline are clearly defined: This is not specifically mentioned in the text.
The guideline has been piloted among target users: This is not mentioned in the text.
Systematic methods were used to search for evidence: A systematic and reproducible literature search strategy is not reported in the text.
Criteria for selecting the evidence are clearly described: An extensive literature collection is presented to substantiate guidelines but the selection criteria are not reproduced. The recommendations are graded A to C based on ''quality of evidence according to study design, consistency of results and directness'' however the critical appraisal process is not reported.
The methods used for formulating the recommendations are clearly described: A clearly defined methodology is presented including a definitions blueprint to standardize definitions, refined in a world-level conference.
The health benefits, side-effects and risks have been considered in formulating the recommendations: The incidence and mortality of IAH and ACS have been reviewed.
The guideline has been externally reviewed by experts prior to its publication: An international expert panel formulated and reviewed the guidelines however they were not submitted to independent review.
A procedure for updating the guideline is provided: A section on direction of future research is present, and the guidelines are to be reviewed again at the next WACS international meeting.
The recommendations are specific and unambiguous: Clear and explicitly stated.
Different options for management of the condition are well presented: An assessment algorithm and management options are presented. The algorithm is however complex to master.
Key recommendations are easily identifiable: Key recommendations are summarized and identifiable.
Potential organizational barriers in applying the recommendations have been discussed: Has not been explicitly mentioned in the text.
The potential cost implications of applying the recommendations: This has not been considered.
The guideline presents key review criteria for monitoring and/or audit purposes: Not mentioned.

Both Oda et al. [2] and Ivy et al. [6] arrived to similar conclusions but the former's methodological and statistical strengths suggests their conclusions to be more valid. Ivy et al. [6] did not report their intended follow-up time. Instead they stated that 'if IAH resolved by 24 h, it is reasonable to discontinue IAP measurements' (p. 390). However Ball and Kirkpatrick [23] reported a case of post-operative ACS on post-burn day 3 ACS (refer to appendix 4). This would have been missed had Ivy et al.'s [6] recommendations been followed. Ivy et al. (2001) [6] also did not report their priming volumes, decreasing rigor (see Table 3). The two cohort studies' lack of blinding may have reduced validity through introduction of observer bias. Ivy et al. [6] reported a weaker R^2, perhaps since their small sample size would not be likely to satisfy the assumptions of ordinary least squares regression. Not reporting p-values [24] made it difficult to assess the significance of Ivy et al.'s (2000) analysis (Table 1). These two cohort studies addressing aetiology (level 2b in Phillips et al.'s (2001) framework) [21] provided further evidence of the causal role of fluid-volume in ACS development and in suggesting a volume threshold for development of IAH.

The main results of Ivy et al. [6], O'Mara et al. [7] and Oda et al. [2] are summarized in Table 1. It is evident from this table

Table 3 – Synthesis of recommendations on intra-vesical priming volume: comparing Fusco et al. [38] and Malbrain and Dereen [39].

	Study	
	Fusco et al. [38]	Malbrain and Dereen (2006) [39]
Method	Compared direct and indirect IAP measurements at different volumes in patients undergoing laparoscopy in 37 patients	Calculated absolute bias for each incremental volume minus IBP at zero volume over 30 measurement-sets in 13 patients
Effect on validity	Malbrain and Dereen (2006) [39] argued that in this study IAP was artificially adjusted to a specific value *after* bladder instillation, masking the increased IAP caused by the instilled volume, possibly affecting validity of the results	Iatrogenic raising of IAP avoided
Recommendation	Optimal volume of 50 ml priming volume recommended	25 ml, just enough to create a fluid column and remove air was recommended
Concluding effect of bladder priming volume on IAP	Increased priming volume raises IAP	Increased priming volume more than 75 ml raises IAP

that resuscitation fluid-volume is related to IAH. The studies also reported a threshold beyond which IAH developed. A possible future approach would be to compare this threshold to planned fluid-volume requirements obtained from consensus formulae. If this is exceeded then the colloid and HLS resuscitation strategies outlined below could be useful to prevent IAH/ACS development.

Cheatham et al. (2007) presented their study as ‘evidence based clinical practice guidelines’, but it was evident from the text that no reproducible search strategy or formal critical appraisal was attempted (level 5) [5]. Johnson et al.’s [8] tutorial-style article similarly lacked an attempt at critical appraisal. They are illustrating that expert opinion agrees with Oda et al. [2], Ivy et al. [6] and O’Mara et al. [7]. This would facilitate endorsement of the evidence in actual practice which is often hindered by reluctant clinicians adhering to ‘traditional’ consensus practice. Cheatham and co-workers [5] study was also invaluable in providing consensus definitions facilitating further research. A formal critical appraisal is provided in Table 2.

Oda et al. [2] recommended the beneficial effect of HLS in early resuscitation of severely burned patients in reducing the resuscitative fluid-load and therefore secondary ACS. A cohort of burns patients were administered HLS while controls were administered saline and followed forwards in time to determine an outcome (IAH). This methodology was consistent with a cohort study (level 2b) [21]. Cases and controls were matched by meticulously stated inclusion criteria increasing applicability. However case/control assignment was not randomized, introducing bias that may have reduced validity. Like Ivy et al. [6] follow-up was until only 24 h post-burn. The authors observed that IAH developed regardless of the solution used once fluid exceeded 350 ml/kg/24 h, emphasizing that HLS should be given early to keep the total volume administered below the IAH threshold. The authors cautioned against complications of administering HLS especially in elderly and dehydrated patients. Within this context it is surprising how the authors did not report data on measuring serum osmolality which may be a limitation to HLS use, as an outcome measure, although this was acknowledged in the ensuing correspondence. Consideration of HLS as resuscitation fluid may have helped the patient reviewed to avoid developing IAH/ACS, with strict monitoring of serum osmolality.

The studies considered above [2,6,7] strongly suggest that fluid-volume is implicated in the aetiology of sACS in the severely burnt patient. Although a critical appraisal of studies evaluating current trends in the use of resuscitation formulae is beyond the scope of this review, it is worth noting that the Parkland formula, based on the studies of Baxter [25–31] which uses crystalloid is the only one presented in several standard burn texts [32,33]. Furthermore, a recent study [34] reported a trend towards administration of fluids in excess of the Baxter formula. Considering HLS or colloid resuscitation to keep fluid requirement below an identified threshold may provide a strategy to pre-empt the development of sACS in the at risk severely burnt patient. No studies targeting the burns ‘inflammatory insult’ causing endothelial leak, third-space fluid loss and thus IAH/ACS have been conducted. This area of study may be a future avenue of management.

3.2. *The role of urinary bladder pressure monitoring in the severely burnt patient developing IAH and secondary ACS in guiding fluid resuscitation compared with serial clinical abdominal examinations*

Recent surveys [9] suggest that a significant proportion of burns practitioners use serial clinical examination to diagnose sACS in contrast to the low sensitivity of clinical examination in diagnosing ACS reported by Sugrue et al. [35] and Kirkpatrick et al. [36]. Both studies compared clinical impression and intra-vesical pressure measurement simultaneously for each patient, minimizing confounding factor influence. However, while Kirkpatrick et al. (2000) [36] used ‘expert panel’ serial examination Sugrue et al. (2002) [35] employed clinical impressions taken during ward rounds. This may have introduced observer bias, but reflected better actual clinical practice. A possible weakness with Kirkpatrick et al.’s (2000) [36] methodology was the selection of a low cut-off (10 mmHg) to diagnose IAP. In agitated patients intra-vesical pressure may rise above 10 mmHg when this would not have been clinically significant. Only Sugrue et al. (2002) [35] reported Kappa scores with confidence intervals enabling the reader to observe how much of the reported agreement was due to chance alone, increasing the study’s validity. Furthermore Sugrue et al. (2002) [35] appropriately used a Bland–Altman plot (Tukey mean-difference plot) to determine agreement between the two techniques. These studies’ methodology was comparable to a cohort study with good reference standards (level 2b) [15] however Sugrue et al.’s (2002) [35] statistical technique and methodological use of ‘ward round’ clinical impressions increased both its validity and applicability with respect to Kirkpatrick et al. (2000) [36]. Patient management in this instance was thus not evidence-based, and future patients would benefit from IAP monitoring.

Balogh et al.’s [1] prospective unblinded study concluded that continuous intra-vesical pressure monitoring had ‘excellent agreement with intermittent measurement’, and recommended its greater availability at lesser cost. Data collection was performed by three simultaneous measurements from each of 25 patients. Results from the two methodologies were analysed using the Bland–Altman technique, which appropriately uses differences in each split sample to measure agreement. This technique may be used to measure agreement over variable conditions mitigating for the non-reportage of inclusion/exclusion criteria. They also reported not finding any typical patterns of systematic bias, increasing validity. Some worrying factors in this otherwise exemplary study were the lack of blinding and sample-randomization which may have introduced bias. This exploratory cohort study, with validation based on split samples, thus placed level 2b [21]. Surprisingly, Cheatham et al. (2007) [5] recommended ‘intermittent intra-vesical pressure measurement for identifying ACS and guiding resuscitative therapy’, disregarding this study’s conclusions. Continuous intra-vesical pressure monitoring may lead to quicker faster and more accessible monitoring leading to an earlier diagnosis. Being quicker and easier to perform it would have been more likely to be used within a busy unit such as a burns unit.

Muangman et al. [37] proposed a novel 'Siriraj device' technique for IAP monitoring, recommending it as 'convenient, inexpensive and safe' (p. 338). Although they claimed that this technique was new, the description was very similar to that described by Sugrue et al. (2002) [33]. They collected data by comparing 'standard' intravesicular and 'Siriraj' IAP measurements from five non-randomized samples and used the Mann–Whitney test to measure whether the two sets of observations came from the same distribution. This does not necessarily indicate agreement. Therefore it appears that the statistical test used was inappropriate to the study's aims so the results need to be viewed with caution.

Fusco et al. [38] and Malbrain and Dereen [39] both debated the effect of an unstandardized priming volume on intravesical pressure as an indirect measurement of IAP. Differences were however observed in the methodology that could have affected the studies' validity.

Both prospective studies used a cohort methodology and used validated data collection methods increasing rigor. While Malbrain and Dereen [39] compared different priming volumes with each other Fusco et al. [38] compared direct IAP to intra-vesical pressures at different priming volumes (Table 3). Fusco's technique would have been ideal; however Malbrain and Dereen [39] argued that the former had introduced bias by adjusting IAP after introducing the priming volume, potentially masking the iatrogenic effect they were measuring. The Bland–Altman analysis used by Malbrain and Dereen [39] is more robust and appropriate to small sample size than the Pearson's correlation coefficient used by Fusco et al. [38] which does not necessarily measure agreement between two methods. It also assumes normal distribution, which unlikely in such a small sample. For these reasons, although both studies were regarded as cohort studies with good reference standard (level 2b) [20] Malbrain and Dereen's [39] study would be more valid. The importance of their article was illustrated by Ball and Kirkpatrick's (2006) editorial [23], which illustrates the dangers of non-standardized priming volumes, and the consequences of possible false positives, including decompression laparotomy.

Teplick and Hassan (2006) [40] argued that while different studies delved into evaluating accuracy and precision of IAP measurment using the intra-vesical route, the lower precision of bladder pressure measurement compared to other experimental techniques would be unlikely to affect diagnosis and subsequent management of ACS *in vivo*. To substantiate their argument, they evaluated how IAP monitoring using the intravesical approach altered pretest probability for diagnosing ACS. Using Bayes' theorem in a hypothetical scenario, they found that measuring IAP in itself substantially changed the pretest probability. The authors thus speculated that measuring IAP was probably more important than determining exactly the accuracy and precision of intra-vesical pressure monitoring in clinical decision-making. This expert opinion article was appraised at level 5 since the authors argued their point 'from first principles' [21] rather than basing their arguments on explicit critical appraisal.

Based on the available evidence, continuous intra-vesical monitoring, using a priming volume of less than 75 ml would be useful to guide early fluid resuscitation of a severely burnt patient rather than clinical examination alone.

3.3. Poor awareness and absence of burn unit guidelines on IAH/secondary ACS

3.3.1. Current recommendations for syndrome and fluid management in a severely burnt patient

There was consensus among Kimball et al. (2006) [9], Ravishankar and Hunter [10] and Yelon et al. (2002) [11] that IAH/ACS management in context of severely burnt adults developing IAH/ACS was poor. Yelon et al. [11] urgently recommended greater awareness among burn surgeons. Additionally Ravishankar and Hunter [10] recommended introduction of evidence-based practice guidelines to aid both intensivists and surgeons, while Kimball et al. [9] took a further step by recommending that anesthetists should be trained early and across the board for a lead role in fluid management of the severely burnt adult developing IAH/secondary ACS.

The above-mentioned surveys investigated intensivists and burn-surgeons reflecting actual practice where responsibility for the severely burnt adult developing ACS is shared. Additionally, Kimball et al. [9] investigated a spectrum of different intensivist training-backgrounds making their conclusions more applicable to the case discussed, where several intensivist sub-specialties were required to cross-cover.

All three studies [9–11] used a structured survey methodology to describe subjective awareness and practice among respondents. This was appropriate to the clearly reported descriptive aims (Table 4). The questionnaire used was reported in each case and did not contain leading questions, minimizing response bias, increasing rigor and credibility. An audit-research methodology approach was noted in each case. Although all three studies had similar conclusions, the robustness of Kimball et al.'s [9] methodology was illustrated by their pilot study (reducing possible distorting effects of questionnaires as data collection tools), the cross-section of intensivist sub-specialties, and their appreciation of the study's limitations. This increased the validity of their recommendations and applicability.

Membership bias may have been introduced by selection from specific Societies (Table 4), however the results would still be locally valid as all team-members were members of those societies. Ravishankar and Hunter's [10] inclusion/exclusion criteria tailored well to the local setting, increasing their recommendations' validity. However by excluding small hospitals they may have biased against burns teams with less experience, possibly underestimating the problem.

Each study used postal surveys for data collection. However only Kimball et al. [9] provided a call–recall system to increase respondent rates, reflecting a well-planned methodology. Considering the 'self-reporting' nature of the three studies' questionnaires, response-rates reported were relatively high, increasing validity. Ravishankar and Hunter [10] and Yelon et al. [11] analysed data through

Table 4 – Synthesis of recommendations from Kimball et al. [9], Ravishankar and Hunter [10] and Yelon et al. [11].

	Study		
	Kimball et al. [9]	Ravishankar and Hunter [10]	Yelon et al. [11]
Aims	To assess current understanding and clinical management of IAH and ACS among critical care physicians.	To explore the attitudes of intensivists in the UK to IAP measurement and ACS and to determine current practice.	To determine current opinion of burns surgeons regarding ACS in burns patients.
Sample	Society of Critical Care Medicine Members. Possible introduction of membership bias. No randomization.	Sample obtained from Directory of Operating Theaters. Hospitals with <4000 operations/yr excluded. Possible bias against smaller hospitals. No randomization.	American Burns Association members. No randomization, possible selection bias.
Survey method	Self-reporting postal questionnaire.	Self-reporting postal questionnaire.	Self-reporting postal questionnaire.
Conclusions	Most intensivists were 'unaware of current approaches to ACS management'.	1. Most intensivists were aware of ACS but never measured IAP. 2. Intensivists considered [monitoring] a 'waste of time (. . .) intensivists remain skeptical about the utility of IAP monitoring' (p. 764).	ACS is Acknowledged by burns surgeons but only a few would treat aggressively.
Recommendations	1. 'Significant variation across (. . .) training exists in the management of IAH/ACS. . .future research and education are necessary' (p. 2346). 2. Intensivists play a 'central role (.) for the diagnosis and management of IAH/ACS [and] in establishing guidelines' (p. 2346).	1. Produce clinical practice guidelines to help clinicians in management.	Common definition of ACS needed. Increased awareness among burns surgeons.

summary statistics (percentages). This was appropriate to their descriptive aims and facilitated the visualization of their statement of findings. However a lack of inferential statistics would make generalization difficult. Kimball et al. [9] assumed (without testing for ex: Bartlett's test) homogeneity of within-group variances. If sufficient heteroscedasticity would be present, the probability of a type-one error when using the Kruskal–Wallis technique (as in this study) would be increased, affecting the validity of the results. These articles were in keeping with an audit-research methodology and were consequently placed at level 2c [21].

Kimball et al. [9] provided useful 'across the board' insight into the extent of lack of awareness. Their study also highlighted that shared management may lead to delayed decision-taking. Their recommendation for lead role anesthetists is relevant to the case studied, where the diagnosis was made late, and the decision for celiotomy was made by a colleague outside the burns team. Yelon et al. [11] corroborated the recommendations of the previous two studies in the United States. Ivatury and Sugerman's (2000) [41] editorial also comments on the lack of awareness about ACS. This article was relevant in emphasizing the dangers of untreated ACS in the burns patient. However the lack of a literature search strategy, critical appraisal or formal analysis relegated this article to level 5 within Phillips et al.'s (2001) framework [21]

Johnson et al. [8] state that even with timely diagnosis and surgical treatment, the syndrome carries a mortality of 43–73% thus any delay caused by ignorance is unacceptable, and these recommendations should be implemented urgently. The above level 2c [20] evidence makes a strong case for inclusion of IAH/ACS into current burns course texts. These are currently devoid of any reference to IAH/ACS (Table 5).

3.4. *Specific recommendations for practice*

A set of specific recommendations is being proposed in Table 6, based on the appraised evidence to inform future practice. The lack of standard definitions used for IAH and ACS hindered comparison of different studies. Cheatham et al.'s

Table 5 – Reference to IAH and ACS as possible complications of fluid resuscitation in severe burns in current burns course texts.

Burns course	Institution	Reference to IAH and ACS	Emphasis on
ABLS™ Advanced Burns Life Support Course [32]	American Burns Association	Nil	Enthusiastic fluid resuscitation
EMSB™-Emergency Management of Severe Burns [33]	Australia & New Zealand Burns Association	Nil	Enthusiastic fluid resuscitation
EMSB-UK ™ [34]	British Burns Association	Nil	Enthusiastic fluid resuscitation

Table 6 – Specific recommendations for future practice based on the identified evidence.

1 Consider colloid based resuscitation and HLS with strict monitoring of serum osmolality when projected fluid requirement is likely to exceed threshold for development of IAH and secondary ACS. Volume of resuscitation fluid is implicated in the development of IAH and secondary IAH. Management of fluid resuscitation-volume in a severely burnt adult at risk of developing secondary abdominal compartment syndrome would benefit from considering whether the estimated crystalloid requirement (from the Parkland formula) would be likely to exceed the threshold above which IAH and secondary ACS become likely. Switching to a colloid-based formula or using HLS with strict monitoring of serum osmolalities would be beneficial. Supporting evidence: one study at level 1b; two studies at level 2b; two studies at level 5 (Grade B).
2 Continuous intra-vesical monitoring is recommended to guide fluid resuscitation; for early diagnosis of IAH and secondary ACS; as a guide to reliability of urine output as indicator of organ perfusion. Clinical examination alone is not sufficiently sensitive in diagnosing elevated IAP (level 2c evidence). Use of intra-vesical pressure monitoring is recommended to help in early diagnosis and management of IAH and secondary ACS. Continuous intra-vesical pressure monitoring has been validated to be in agreement with intermittent intra-vesical pressure monitoring (level 2b evidence) yet may be simpler, cheaper, less cumbersome, and is thus recommended. Supporting evidence: one study at level 2B; two studies at level 2C; one study at level5 (Grade B).
3 Use of a priming volume of less than 75 cm^3 is recommended for intra-vesical pressure monitoring as a guide to IAP. Supporting evidence; two studies at level 2b; one study at level 5 (Grade B).
4 Urgently disseminate awareness; introduce secondary ACS and their role in fluid resuscitation in burns course literature; train intensivists across the board to take the lead role in clinical management; introduce clinical practice guidelines. Current best evidence was unanimous in pointing out poor awareness of management of secondary ACS and recommended training intensivists across the board to take a lead role in the management of this lethal condition, and setting up clear clinical practice guidelines for clinicians. Current best evidence strongly argued for dissemination of awareness about IAH and secondary ACS to the widest target audience possible. Including ACS in burns course texts is one feasible way of achieving this. Supporting evidence: three studies at level 2c; one at level 5 (Grade B).

(2007) [5] consensus definitions have addressed this problem and will thus be of benefit to standardize future studies addressing this issue. Future use of statistical analyses and tests must be more appropriate and robust to the small sample sizes typically encountered in order to increase the validity of the results. Future studies could benefit from a multi-center setup, to increase sample size and from inclusion of medical statisticians as part of a triple-blind RCT. Finally, a novel area of approach would be to target the increased capillary leakage caused by the massive inflammatory reaction precipitated by a major burns insult.

4. Discussion

Current best evidence suggests sACS in the severely burnt adult is a common, rapidly fatal and poorly managed syndrome. Such a situation should raise concern among the burns community. Rather than accept current literature at face-value, our contribution aimed to provide an in-depth critical analysis of the robustness of the literature such that each recommendation is underscored by objectively graded evidence. Rigorously applying a hierarchy of evidence model allows an 'explicit and judicious application of current best evidence' [42] from which future patients may benefit.

In the face of a syndrome with such a high mortality [8] the studies by Oda et al. [2], Ivy et al. [6] and O'Mara et al. [7] suggest a strategy for prevention. Despite differing definitions used for IAH and ACS these studies provide Grade B evidence supports the causal role of excessive fluid administration in IAH and ACS (Table 1). Severely burnt adults should have their estimated early fluid requirements compared to the threshold above which IAH and secondary ACS would be expected [4–6]. When this threshold is exceeded the burns expert may consider specific prevention strategies, including the early use of Hypertonic Lactated Saline or Colloid resuscitation [2,6,7]. The consensus definition adopted by the International Conference of Experts on Intra-abdominal Hypertension and Abdominal Compartment Syndrome [5] paves the way for improved comparability of future studies.

Current best evidence suggests that continuous bladder pressure monitoring using a priming volume of less than 75 cm^3 is a simple cheap and validated monitoring method that should be strongly advocated in 'at risk' patients (Grade B). Performance of monitoring may in itself raise the diagnostic value of clinical examination [38,39], which on its own is an inadequate diagnostic method. Inadequate renal perfusion pressure and renal filtration gradient has been associated by many authors to IAH-induced renal failure [43–45]. It would follow that increased fluid administration would cause increased intra-abdominal pressure, hence further reduction in renal blood flow and renal perfusion pressure. In this scenario urine output may become an inadequate/confounding indicator of fluid requirement. Continuous bladder pressure monitoring could therefore also serve as a guide to the reliability of urine output as indicator of fluid requirement.

The contrast between the rapid mortality of sACS, its commonness in the severely burnt and the poor awareness of the syndrome among the burns community on either side of the Atlantic [9–11] urgently suggests a scope for a strategy to disseminate information among burns teams (Grade B). Several techniques have been suggested to decrease the elevated intra-abdominal pressure both conservative and surgical (catheter drainage and laparotomy), elegantly integrated into a management algorithm by Cheatham and co-workers [5]. A paper by Hobson et al. [46] has also countered previous notions that laparotomy in a severely burnt patient universally resulted in death. Although an in-depth appraisal of treatment success rates is beyond the scope of this review, we maintain that the best approach is prevention in the first instance. The development of local burn unit guidelines, specific reference to the syndrome in current Burns Course texts and training anesthesiologists to take on a leadership role in the multidisciplinary burns team may help to reduce its incidence and impact on the management of our severely burnt patients.

Conflict of interest statement

Pertaining to all authors listed on this paper, there are no financial and personal relationships and no conflict of interest.

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