Swift Kate (Orcid ID: 0000-0003-0760-2496)

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TITLE PAGE

Caravan explosions: a case series of burns patients at the Royal Brisbane and Women's Hospital

Authors' full names and qualifications:

Dr Kate Swift, MBBS, MTrauma [1,2]

Dr Elizabeth Vujcich, MBBS, FRACS [1,2]

Teresa Matthews, AO [2]

Professor Michael C. Reade DPhil, FCICM [1,3,4]

Authors' affiliations:

1. The University of Queensland Faculty of Medicine
2. Division of General Surgery and Burns, Royal Brisbane and Women's Hospital, Brisbane, Australia
3. Department of Intensive Care Medicine, Royal Brisbane and Women's Hospital, Brisbane, Australia
4. Australian Defence Force Joint Health Command

Corresponding author:

Name: Kate Swift

Postal address: 11 San Remo Blvd, Bundall QLD 4217

Email: kate_swift@live.com.au

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ABSTRACT

Background: Caravan explosions due to gas cylinder explosions or gas leaks are responsible for a small but significantly injured group of burns patients. Those involved in explosions are sometimes assumed to be at risk of primary blast wave injury, however the likelihood of such injuries is unclear. The aim of this research was to seek evidence of primary blast injury in groups defined by clinicians as having sustained burns in explosive and non-explosive events.

Methods: This is a single centre case series of patients with caravan-related burns from 2009 to 2019, identified using the burns data registry at the Royal Brisbane and Women's Hospital. Patients were divided into two groups based on mechanism of injury, with injuries sustained from either a gas bottle explosion (Group 1) or from gas ignition (Group 2).

Results: Twenty-one patients were identified over the 10-year period. The explosion group suffered more extensive burns, with a median % total body surface area of 31% (23.5-43.5) and 9.5% (5-20) in Group 1 and Group 2, respectively ($p=0.01$). There was a numerically longer median hospital and ICU length of stay in Group 1. In multivariable analysis, there were no statistically significant predictors of ICU or hospital length of stay. None of the patients appeared to have suffered any of the expected effects of primary blast wave injury.

Conclusion: Gas bottle explosions in caravans uncommonly if ever result in a blast wave of sufficient energy to cause primary blast injury.

Key words: Trauma, General Surgery, Burns, Blast wave injuries, Caravan explosions, BLEVEs

MAIN TEXT

INTRODUCTION

Caravanning is a common Australian pastime, with over 600,000 registered recreational vehicles and a $20.46 billion annual contribution to the Australian economy.[1] Gas cylinder storage is an essential component of caravan design, with Australian standards specifying that liquefied petroleum gas (LPG) bottles are stored with adequate and permanent ventilation, proper clearance from gas burners, and must be stored outside of living areas with no access from inside of the caravan.[2] Despite these safety regulations, a small number of caravan fires and explosions are reported annually, usually attributed to gas cylinder explosions or gas leaks. Patients who survive to receive medical care typically have substantial burns. Those involved in explosions are sometimes assumed to be at risk of the consequences of a "primary" blast wave injury, such as that which follows military explosions. However, the likelihood of such injuries is unclear. This question is important as incorrect assumptions potentially distract clinicians from more relevant priorities.

Explosions in a caravan might cause a primary blast injury due to the theoretical combined effects of an 'enhanced' blast accentuated in a closed environment. An enhanced blast is one in which the duration of the overpressure is more prolonged than in conventional blast. One example is a boiling liquid-expanding vapour explosion (BLEVE), which occurs when gases stored as liquids under pressure at temperatures above their boiling points are released, mimicking a thermobaric weapon.[3] For example, a BLEVE may occur when an LPG cylinder is heated and explodes within the confined environment of a caravan. For this to occur, the pressure within the tank would have to increase rapidly and to a large degree to overcome the pressure release valve, which is a mandatory fitting in Australia. How often this occurs in practice is unknown.

Patients suffering blast wave trauma present with a range of possible injuries including acute respiratory distress syndrome, pneumothorax, haemothorax, tympanic membrane perforation, and gastrointestinal perforation.[4] In comparison, a gas leak that mixes with air and meets an ignition source creates a gas leak conflagration, rather than a blast. The energy of the explosive wave created by this ignition is much lower, and should not create any substantial pathophysiological primary blast wave effect. Surviving patients would be expected to present primarily with burn injury, including inhalational burns. Higher energy explosions can propel debris into the patient, causing penetrating (or "secondary") blast trauma. The blast wind created by either high or low energy explosions or conflagrations can propel the patient into their surroundings, or cause structural collapse, both of which result in blunt (or “tertiary) blast trauma. Penetrating and blunt trauma after blast is usually apparent from the clinical situation and will not be discussed further.

Correctly anticipating whether patients in caravan ‘explosions’ are likely to suffer the consequences of primary blast trauma is important for clinicians, who need to direct their attention to the most likely pathology. No large case series of such patients has previously been described. Queensland, Australia, has a particularly large number of caravan users, with the highest number of registered caravans in Australia.[6] Accordingly, we analysed ten years’ data from the Queensland statewide adult burns service’s data registry in an attempt to better guide clinical practice.

METHODS

This was a single centre case series using serially recorded data from the burns data registry at the Royal Brisbane and Women’s Hospital (RBWH), a comprehensive database of every burns patient managed by the RBWH. The Professor Pegg Adult Burns Unit at RBWH is a major referral centre servicing Queensland, Northern New South Wales, the Northern Territory and the Pacific Islands.

An initial database search was performed spanning January 2009 to December 2019 using the search term “caravan”, and then cases were individually reviewed for inclusion. Any patient managed at RBWH for a burn injury following a caravan gas bottle explosion or gas ignition within a caravan was included. All other caravan-related burns, such as scald burns, electrical burns, friction burns, or contact burns not related to gas explosion or ignition, were excluded from this study. There were no other exclusion criteria. Patients were then divided into two prospectively defined groups based on mechanism of injury, where injuries were sustained from either a gas bottle explosion (Group 1) or from gas ignition (Group 2). Allocation to Group 1 was based on the description of a gas bottle or cannister explosion, and allocation to Group 2 was based on evidence of a gas leak, fumes, ignition source, gas stove explosion, or no clear identification of the gas bottle as the source of explosion. These two groups were then compared to determine if there was a difference in injury pattern and severity to suggest any evidence of primary blast injury in Group 1.

Data collected included patient demographics, date of injury, mechanism of injury, % total body surface area (TBSA), ICU and hospital length of stay, mortality, and other associated injuries such as pneumothorax, inhalational lung injury and traumatic brain injury. Data is reported as a number (percentage) for categorical data, and mean ($\pm$ SD) or median (IQR) for continuous data according to normal or non-normal distribution, as appropriate. Between-group comparisons were made with chi-squared tests, Student t tests or Mann-Whitney U tests, as appropriate. Multivariable linear regression was used to identify predictors of ICU and hospital length of stay. Analyses were performed using State version 16.0 (StataCorp, College Station, Texas, USA). This research study was deemed low risk, and ethical approval was received from the Royal Brisbane and Women's Hospital Human Research and Ethics Committee (HREC).

RESULTS

We identified 29 patients over the specified time period with the term "caravan" in their recorded mechanism of injury. Eight of these patients were excluded on the basis of detailed analysis of their mechanism of injury. The remaining 21 patients were divided into two groups as outlined above. This is demonstrated in flowchart in Figure 1.

Demographics and length of stay:

The 21 patients analysed had a mean age of 48.8 years (± 18.8), with an age range of 18 to 78 years. Most patients (66.7%) were male. There was no significant difference in demographic features between the two subgroups. The explosion group had a numerically longer ICU length of stay compared to the ignition group (median 7.5 (IQR 2.5-15.5) days vs. 0 (0-1) days respectively) that did not reach statistical significance (difference in medians -5 days (95% CI -15 – 0 days); p=0.12) and also a longer hospital length of stay (median 30 (17-47) days vs. 10(3-23) days respectively) that similarly failed to reach statistical significance (difference in medians -16.5 days (95% CI -36 – 2 days); p=0.06). There were no statistically significant predictors of ICU or hospital length of stay on multivariable analysis. The explosion group suffered more extensive burns, with a median %TBSA of 31% (23.5-43.5) and 9.5% (5-20) in the gas bottle explosion and gas ignition groups, respectively (difference in medians -0.2% (95% CI -0.3 – -0.1 %); p=0.01). Injury Severity Score was also higher in the explosion group (difference in medians -11 (95% CI -20 – -1); p=0.04). Demographic data is summarised in Table 1.

Mortality:

Each group had one death. In the gas explosion group, a patient with 19% TBSA burns died on day 5 of ICU admission due to intracranial injuries. In the gas ignition group, a patient with a self-inflicted 99% TBSA burn died shortly after arrival to hospital. This patient's injury was deemed unsurvivable and so he was not resuscitated or investigated for other injuries, therefore their details have been included in the initial demographic data (N, age, sex, mortality, %TBSA and lengths of stay) and then excluded from calculations regarding blast wave injuries as he was not investigated for these injuries upon arrival to hospital.

Blast-related injuries:

Group 1 had a numerically higher incidence of inhalational lung injury (50% compared to 33.33%) and a higher incidence of airway burns (50% compared to 25%). One patient in this group had a traumatic brain injury. One patient in Group 2 had a clinically significant pneumothorax requiring an intercostal catheter. There were no documented cases of tympanic membrane perforation or gastrointestinal perforation in either group. These data are displayed in Figure 2.

DISCUSSION

In this 10-year case series of patients in a large burns centre who had suffered injury from "explosions" from gas bottles in caravans, none had clear evidence of primary blast injury. A high proportion had respiratory injuries attributable to inhalational burns, but the proportion of patients with respiratory effects was not statistically higher in patients exposed to gas bottle "explosions" than it was in patients burned in gas ignition conflagrations.

The most significant difference between the two study groups was the severity of the burn sustained. The greater severity of burns in the gas bottle explosion group, measured as %TBSA, is better explained by a deflagration of the fuel-air mixture causing more extensive burns rather than a qualitatively different injury pattern from a blast. Another notable difference is that patients in Group 1 had numerically longer hospital and ICU lengths of stay. It is possible that the lack of statistical significance in differences in other observed characteristics between the two study groups was due to inadequate sample size rather than a true absence of differences in the populations from which they were drawn. However, even if greater sample sizes were to result in statistically significant between-group differences in such outcomes, it is likely that this would be explained by the confounding effect of the size of the burns rather than an independent effect of blast, as burn size correlates with physiological impact and larger burns require more surgical procedures and intensive rehabilitation, along with increased risk of complications such as kidney injury and pneumonia.

None of these patients appeared to have suffered any of the expected effects of blast. However, the incidence of blast lung was difficult to ascertain, given that it might be clinically indistinguishable from other causes of ARDS. The incidence of haemopneumothorax and head injury were too small to draw conclusions, and there were no cases of more rare complications such as gastrointestinal perforation. Tympanic membrane perforation is the commonest effect of high-explosive blast in an enclosed environment, with incidence of approximately 30% in patients surviving primary blast wave injuries.[5] That none of our patients had this readily identifiable feature suggests that they had not been exposed to this type of high energy blast wave. This represents level IV evidence (case series and poor quality cohort and case-control studies) in the hierarchy defined by the Oxford Centre for Evidence-based Medicine.[7]

The RBWH burns database is very comprehensive, recording a high level of detail for every burns patient managed by the RBWH (with the exception of non-consenting patients on an opt-out basis). Our search is likely to have been effective at identifying every patient over the study period with a caravan-related burn who survived to hospital. However, this study includes only a small number of patients due to the relative infrequency of this injury pattern and small total number of cases. This makes the statistical analyses of limited relevance, however we have reported our p-values for completeness. Another limitation of this dataset is that it only captures patients who have survived to hospital. It is theoretically possible that accidents causing primary blast trauma might have occurred with patients dying pre-hospital, either due to their burns or due to blast-wave injuries. This theoretical limitation does not diminish the importance of our findings for hospital clinicians, as our aim was to guide treatment priorities for patients who survive to hospital admission.

Another consideration is the division of patients into the blast versus ignition groups for the purpose of comparison, based on the descript of their mechanism of injury in the burns data registry. This mechanism is recorded at time of presentation and often relies on second-hand descriptions of the injury mechanism from the patient, bystanders, or emergency services. Therefore, some of the injuries do not clearly specify if the gas bottle was leaking, or destroyed during the explosion. For the purpose of this research gas stove explosions were deemed to have less explosive force than a gas cylinder explosion and were therefore included in the ignition group.

Finally, it is important to note the distinction between domestic and industrial LPG gas cannisters. Domestic LPG bottles such as those used in caravans are designed with a pressure release valve, which allows the gas cylinder to vent excessive pressure and prevent explosion. Some industrial propane bottles and other LPG containers do not have this safety fitting and therefore are more likely to cause a BLEVE, and subsequently may cause blast wave injuries. However, these are less likely to be involved in a fire than domestic gas cylinders, making them less likely to explode, and also less likely to have bystanders at risk of injury in the event of an explosion. Our study would not have identified such patients due to our search terms, however in our experience this mechanism of injury is very uncommon.

CONCLUSIONS

To our knowledge, this is the first published case series reporting caravan gas bottle explosions. This dataset demonstrates that domestic explosions (such as gas bottle explosions) causing a primary blast wave injury are likely to be very uncommon, even in the confined environment of a caravan. Whilst it is essential that clinicians identify and manage traumatic injuries as guided by their clinical acumen, they should not be distracted looking for rare blast-related injuries based on mechanism of injury alone.

Nonetheless, from a public health perspective, our study highlights the danger of LPG gas bottles in caravans, and the necessity for education and regulation of their safe storage and maintenance. The patients in this series are a small but significantly injured group which demonstrate the high morbidity of gas-related burns in caravans.

ACKNOWLEDGEMENTS

The study was conceived by M.C.R.. Data was collated by T.M., and then data interpretation and statistical analysis were performed by K.S and M.C.R. The manuscript was written and edited by K.S., M.R., M.C.R. and E.V.

DISCLOSURE STATEMENT

The authors declare no conflicts of interest. Ethical approval was obtained and no financial support was received for this study.

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FIGURE LEGENDS

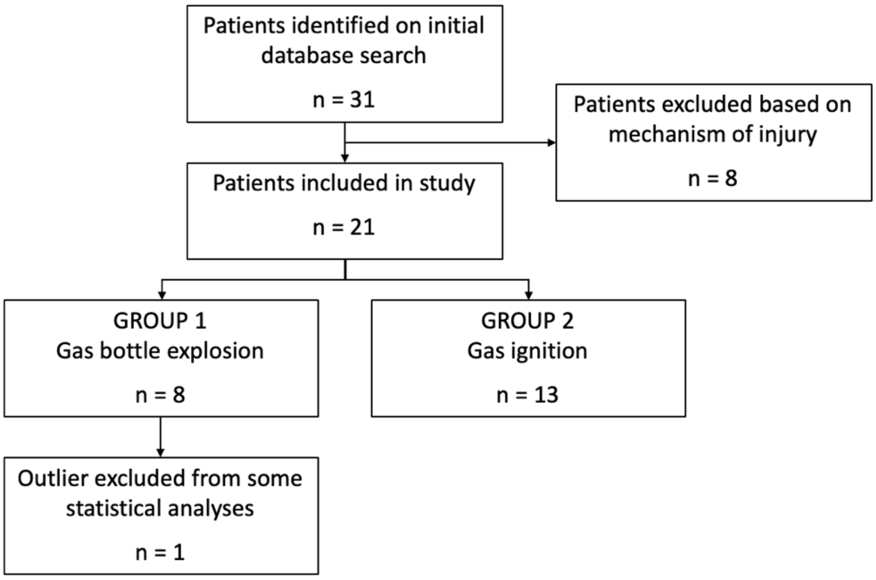
Table 1: Demographic data

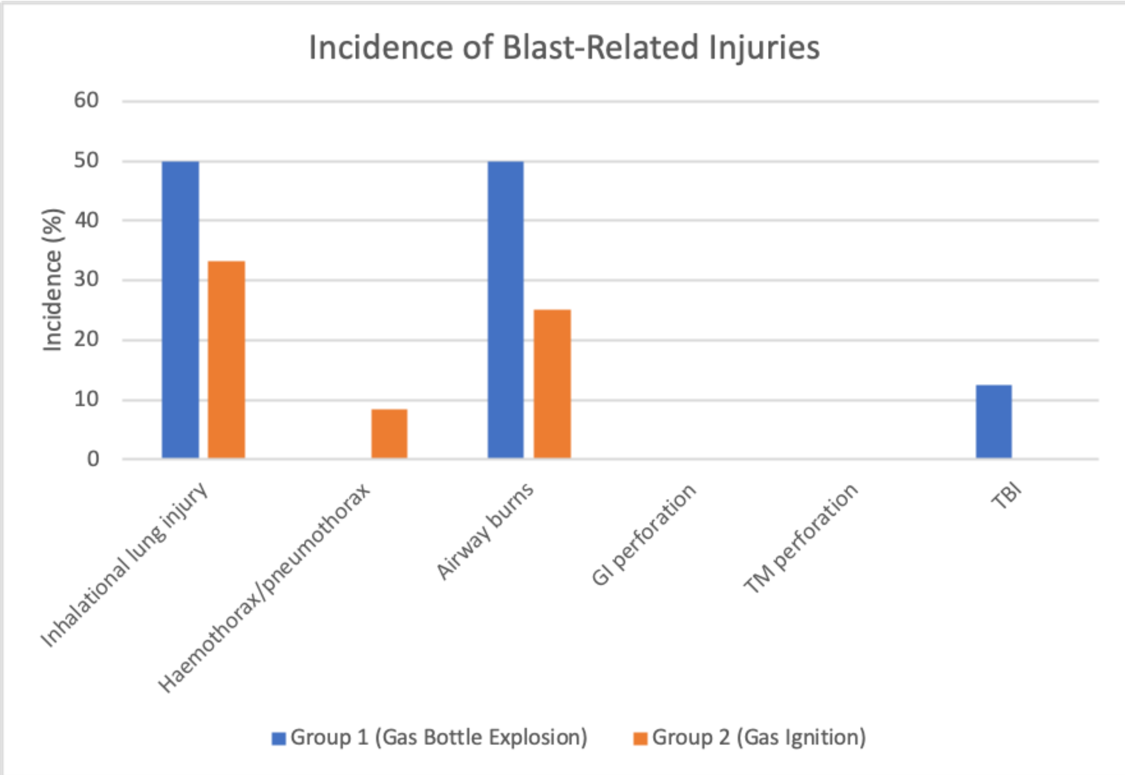
Figure 1: Study inclusion criteria

Figure 2: Incidence of blast-related injuries

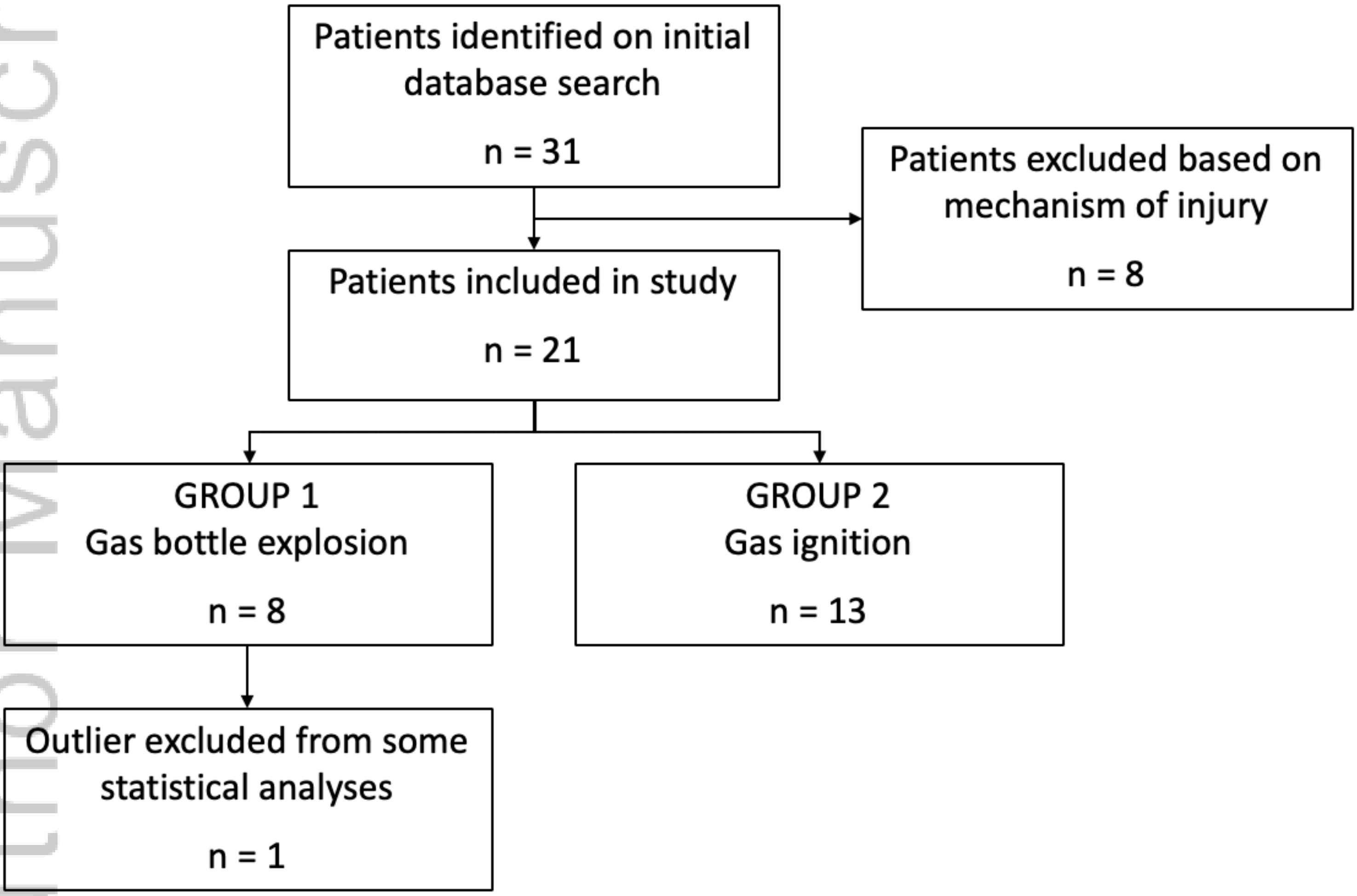
	Group 1 Gas bottle explosion	**Group 2** Gas ignition	Total
N	8	13	21
Mean age (years)	57.1 (±18.3)	43.6 (±17.2)	48.8 (±18.8)

Male	6 (75%)	8 (61.5%)	14 (66.7%)
Median injury severity (ISS)	18 (12.5-27)	5 (1-13)	9 (1-22)
Mortality	1 (12.5%)	1 (7.7%)	2 (9.5%)
Median %TBSA	31 (23.3-43.5)	9.5 (5-20)	20 (7-30)
Median hospital LOS (days)	30 (17-47)	10 (3-23)	20 (3-39)
Median ICU LOS (days)	7.5 (2.5-15.5)	0 (0-1)	1 (0-9)





Incidence of Blast-Related Injuries
Incidence (%)
60
50
40
30
20
10
0
Inhalational lung injury
Haemothorax/pneumothorax
Airway burns
GI perforation
TM perforation
TBI
Group 1 (Gas Bottle Explosion)
Group 2 (Gas Ignition)



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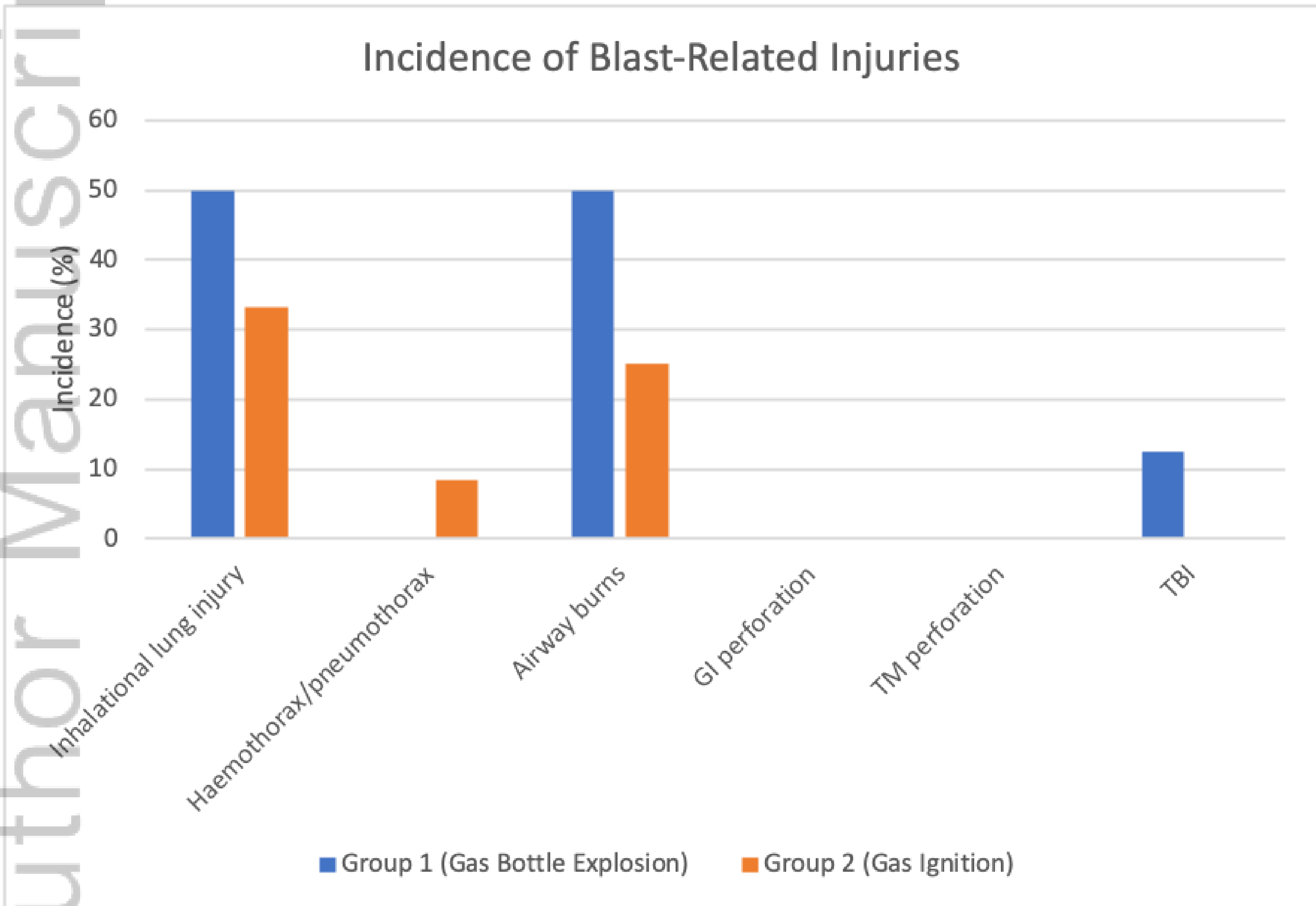

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	Group 1 Gas bottle explosion	Group 2 Gas ignition	Total
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Male	6 (75%)	8 (61.5%)	14 (66.7%)
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