# The Bowtie diagram: a simple tool for analysis and planning in anesthesia

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**Purpose of review**
The purpose is to show the advantages of a Bowtie diagram as a versatile tool for displaying and understanding the evolvement and management of critical incidents.

**Recent findings**
The Bowtie diagram has been used recently in anesthesia to depict critical incidents having been used in high-risk industries for several decades. This diagram displays the progression from latent factors to potential harm in five steps.

**Summary**
The Bowtie diagram combines the features of a fault tree and an event tree with the adverse event, known as the Top Event separating the two sections. The fault tree is similar in concept to a Swiss Cheese diagram and the event tree similar in concept to an emergency management algorithm. Preventive barriers and escalation measures are used to detect and trap abnormal states. If these fail, the event proceeds to a crisis, leading to the Top Event, a time for making decisions. A recovery state follows, which depicts an emergency state mandating immediate life or limb-saving management to recover from the crisis. Finally, in the aftermath state, a time for reflection and learning, ultimate outcomes are shown in the right-hand column.

**Video abstract**
The Bowtie Diagram. Designed and created by Yasmin Endlich, Martin D. Culwick and Stavros N. Prineas, http://links.lww.com/COAN/A68.

**Keywords**
Bowtie diagram, critical incident, Swiss Cheese diagram

## INTRODUCTION

Bowtie diagrams were first suggested in 1979 [1] and have been used in high-risk industries such as aviation [2] and accident probability analysis since then [3]. More recently, they have been applied to healthcare [4,5] and anesthesia [6,7]. The diagram comprises a combined fault tree [8,9], which is similar in concept to a Swiss Cheese diagram and an event tree [10,11], which are not commonly used in health but similar in concept to disaster response plans or emergency management pathways.

## FAULT TREE

Figure 1 shows a 'Swiss Cheese' diagram (adapted from James Reason) [12]. The equivalent of the Swiss Cheese slices is shown with yellow panels and each panel represents a barrier to the hazards moving from routine progress to a critical event. These are listed to the right of each slice. One shortcoming of the Swiss Cheese diagram is that it does not depict the opportunities to reduce harm after a critical incident has occurred. In this way, a Swiss Cheese diagram is essentially the same as a fault tree

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## KEY POINTS

- Bowtie diagrams have been used since 1979 for accident analysis and to improve safety in high-risk industries.
- Bowtie diagrams have been used since 2009 to improve patient safety.
- Bowtie diagram have been used at annual scientific meetings relating to anesthesia since 2011.
- Bowtie diagrams have been used and published in the anesthetic literature since 2016.
- Bowtie diagrams are a simple tool that can be used to map out the hazards, preventive measures, emergency management and learning from outcomes of a critical incident or a category of similar critical incidents.

(representing success or failure in *prevention* of the incident) and what follows the critical event is known as an event tree (representing success or failure in *recovery* from the incident).

## EVENT TREE

The section beyond a critical event is shown in Fig. 2 as an event tree and attempts at rescue are shown which indicate a deteriorating condition, wherein harm is not only occurring but compounding on itself. This condition requires immediate action to either prevent harm or to reduce the severity and duration of the harm. Using the Swiss Cheese diagram, conceptual slices are used to depict barriers to reduce harm by escalation measures in the rescue section to try to recover from the crisis. If recovery is not achieved, then the crisis progresses to the

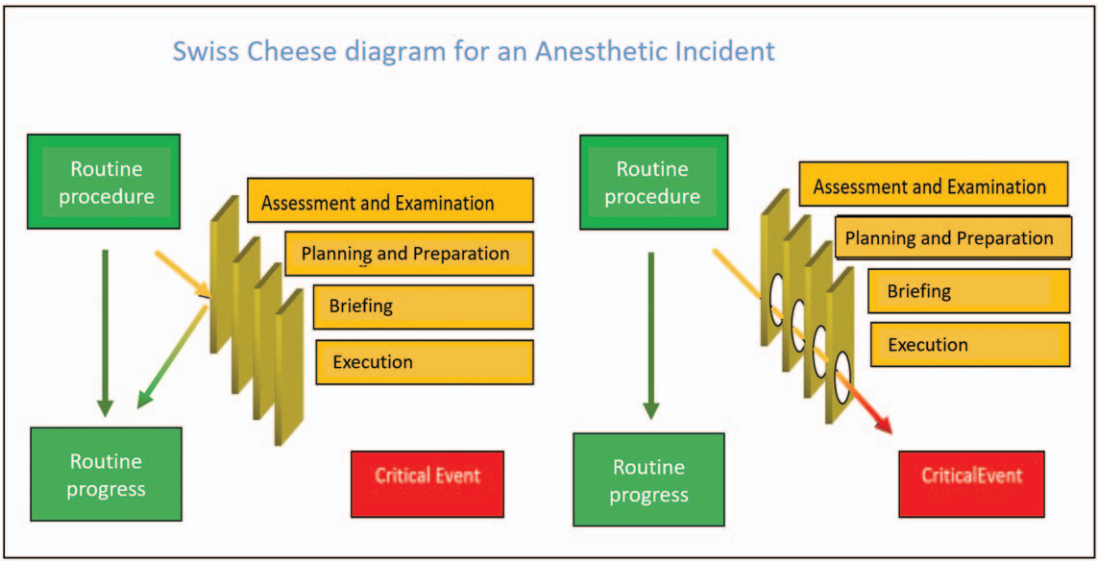


**FIGURE 1.** An adaption of a Swiss Cheese diagram for an anesthetic incident (Original).

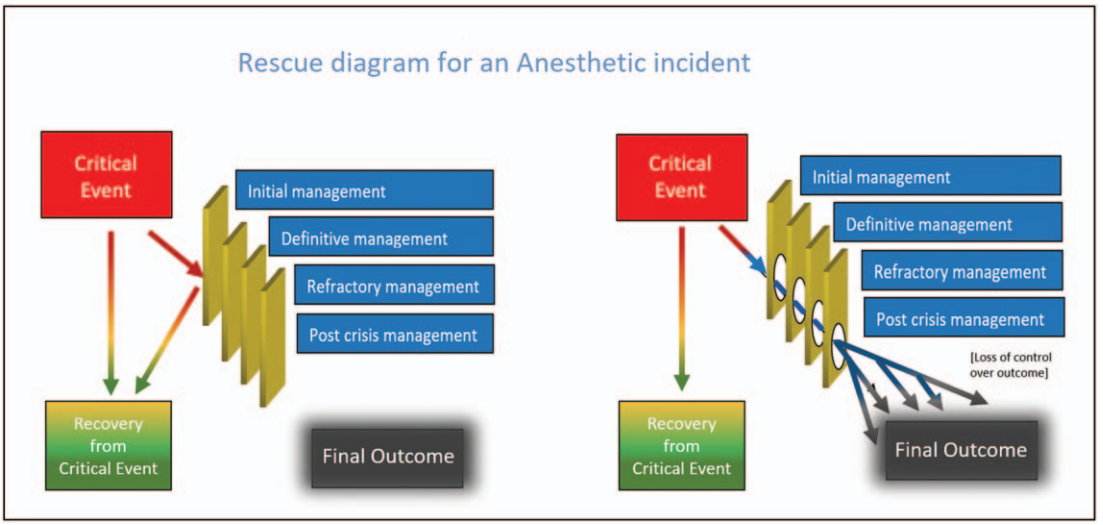


**FIGURE 2.** A rescue diagram for an anesthetic incident (Original).

outcome, which could be associated with harm. This might vary from no harm apparent, to death.

## SWISS CHEESE

The Swiss Cheese diagram has been a useful first step in understanding how adverse events might occur through a breakdown of 'defences-in-depth' [12]. In clinical practice, hazards can be defended against through a series of generic practical steps. For instance, identification of potential hazards by clinical assessment, examination and investigation. Then, planning and preparation in order to control these hazards, briefing the team and executing the plan with expertise and skill, using appropriate drugs and equipment; in the event of contingencies, moving to a plan B, C or D; and finally, should a critical event become inevitable, attempting to mitigate the harm that might occur. However, the model risks oversimplifying real-world phenomena.

Various methods, diagrams and adaptions of diagrams have been described recently in anesthetic circles in Australia. The authors had developed the diagrams in the years leading up to the following meetings where they were independently presented. These included the Australian Society of Anaesthetists (ASA) National Scientific Meeting (NSC) 2012 [13], Australian and New Zealand College of Anaesthetists (ANZCA) Annual Scientific Meeting (ASM) (Singapore 2014) and the New Zealand Society of Anaesthetists (NZSA) ASM (Dunedin 2013). The principles of the Bowtie diagram [6] and an example depicting hypertension during anesthesia were published in 2016 [7].

The Resilient Anaesthetist model [13] used the principles of a fault tree but stressed that prior to the critical event that there is still an opportunity to escalate attempts to avoid the incident and finally, immediately prior to the critical event and when it is inevitable, that there is still an opportunity for mitigating the outcome. It should be also noted that mitigation and immediate management of an event may be a continuous process, but once a certain point is passed, then it is not possible to turn back to a position prior to a critical event. However, it is possible to have no harm as a final outcome of the event. Once the management of the event is complete, it is possible to reach a new zone of stability, but it is not completely the same zone as prior to the event and there might be harm that is present but not detectable clinically at that point in time. The Vortex [13] is a similar analogy relating to the vortex of a plug hole in a sink or bath. Again, at the top of the vortex, there is a possibility of escaping the whirl of the vortex, but once entering the whirlpool at some point, there is no possibility of avoiding being sucked into the vortex created. These two approaches describe a process that includes features of both a fault tree and an event tree as a continuous process.

## BOWTIE ANALYSIS

A Bowtie diagram represents the fusion of both a fault tree and an event tree, with the Top Event as the 'knot' connecting the two. The concept appears to have been first presented in a lecture course at the University of Queensland in 1979 [1] and has been used in high-risk industries such as the airlines [2]. The Bowtie diagram concept has been applied to medication safety [5], followed by studies in other medical specialities [4] and has more recently been described for the assessment of incidents, crisis and emergency management in anesthesia [6,7,14▪].

Figure 3 shows a generalized Bowtie diagram, which is designed to map anesthetic incidents in a logical, sequential and complete manner. Each of the components has been slightly modified from previous articles, [6,14▪] to improve the match to existing anesthetic nomenclature. The first column on the left-hand lists the possible causal factors, which are called 'hazards' in Bowtie nomenclature. This has been renamed 'AVOID hazards', as there may or may not be latent factors (hazards) in one of the arbitrarily divided categories, patient factors, task factors, caregiver factors, system factors and other factors. These potential hazards have not yet progressed to the point wherein an adverse event might occur. Therefore, the anesthesiologist and patient find themselves in a well tolerated zone, with anesthesia still proceeding normally and without the various potential hazards necessarily leading to an unstable situation.

Any of these hazards have the potential to lead to a critical incident. The second section lists various methods or specific barriers devised to detect or trap abnormal states that may represent developing hazards; these are known as 'Preventive' Controls in conventional Bowtie nomenclature. The two columns on the left-hand side of the diagram consist of strategies to prevent the critical incident, which is named a 'Top Event' in a Bowtie diagram.

In traditional Bowtie diagrams, lines are drawn to show a one-to-one pathway from Hazards towards the Top Event. These are known as quantitative Bowtie diagrams [15]. However, the complexity of anesthetic emergencies makes a set of pathways difficult to depict without a large number of lines. Instead, we have used conceptual pathways with blocks to show the type of each barrier. Each block could subsequently be expanded to show the components either in a supporting document or a

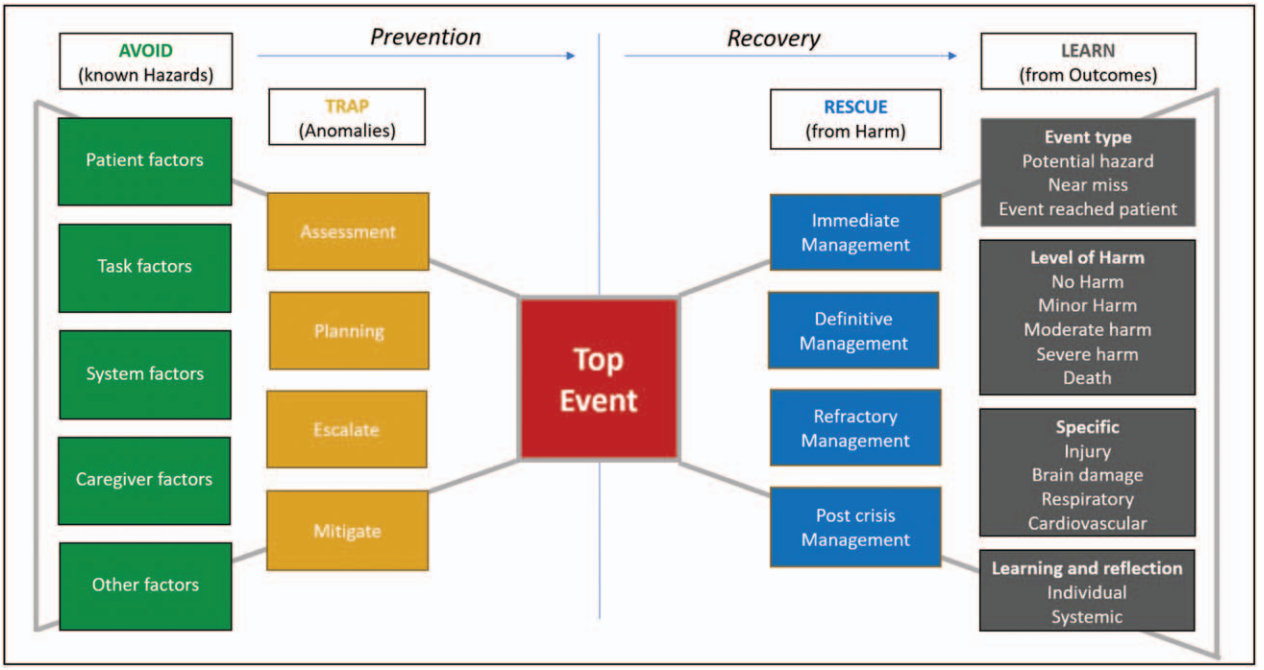


**FIGURE 3.** A generalized Bowtie diagram for use in anesthesia. See Conflicts of interest (Original).

hyperlink could be used in a web application. In this way, the progression of the hazards to a critical event are not intended to be a strict one to one pathway in this diagram, but each of the components in the second columns might be active in preventing any of the potential hazards progressing to a critical event. It is therefore a series of concepts of prevention rather than a fixed pathway [6,14▪] and these are known as qualitative Bowties [15]. It is possible to expand one of these concepts into a separate one to one quantitative Bowtie to explain one section in detail as a supporting diagram to the qualitative overview.

Should the barriers fail, a Top Event may occur, which represents a crisis. Management options designed to control the Top Event are listed on right side columns labelled Rescue Controls, tailgated by outcomes of the incident on the far right. Note that failure to manage the Top Event in the Rescue column might trigger other Top Events. For example, failure to manage a Top Event of 'anaphylaxis' promptly may lead to a Top Event of 'severe bronchospasm'; failure to manage bronchospasm may lead to a 'hypoxia' Top Event; failure to manage hypoxia may trigger 'cardiac arrest', and so on. Alternatively, anaphylaxis may lead to cardiac arrest through a 'severe hypotension' Top Event. Each of these Top Events would carry their own Bowtie. Death or irreversible brain injury arising from cardiac arrest are irreversible consequences, which are then depicted as the outcome in the aftermath.

The Bowtie diagram has been previously described as a tool, which depicts critical incidents in anesthesia and has gained significant popularity since the ANZCA ASM in 2011. It is regularly used to analyse cases reported to WebAIRS, a Web Based Anaesthetic Incident Reporting System (www.anztadc.net) used in Australia and New Zealand, and has recently been identified as an excellent mapping tool for the classification and management of unanticipated airway events [15]. Figure 4 is included (with permission) as an example [15]. This figure includes an earlier version of the nomenclature for each of the five columns, but the functionality of each column is identical. Following feedback from this publication, small changes regarding the nomenclature of each column and the addition of arrows to show the direction of flow should a critical event evolve have been added as shown in Fig. 3.

The Bowtie diagram may also be used as a risk assessment and management tool and will provide clear visualization and understanding of hazards, preventive factors, management and outcomes of critical events such as a pandemic. A practical and topical example of a Bowtie diagram is shown in Fig. 5 using the updated nomenclature. Although Corona Virus Disease 2019 (COVID-19) infections may resolve without hospital management, a significant number progress to other major complications such as cytokine storm, cardiac events, respiratory failure and the infection of healthcare workers. The Bowtie diagram can be expanded further by cascading into other Top Events and a new diagram created to prevent and manage each new scenario. These are shown as additional Top Events in red underneath the rescue column.

 

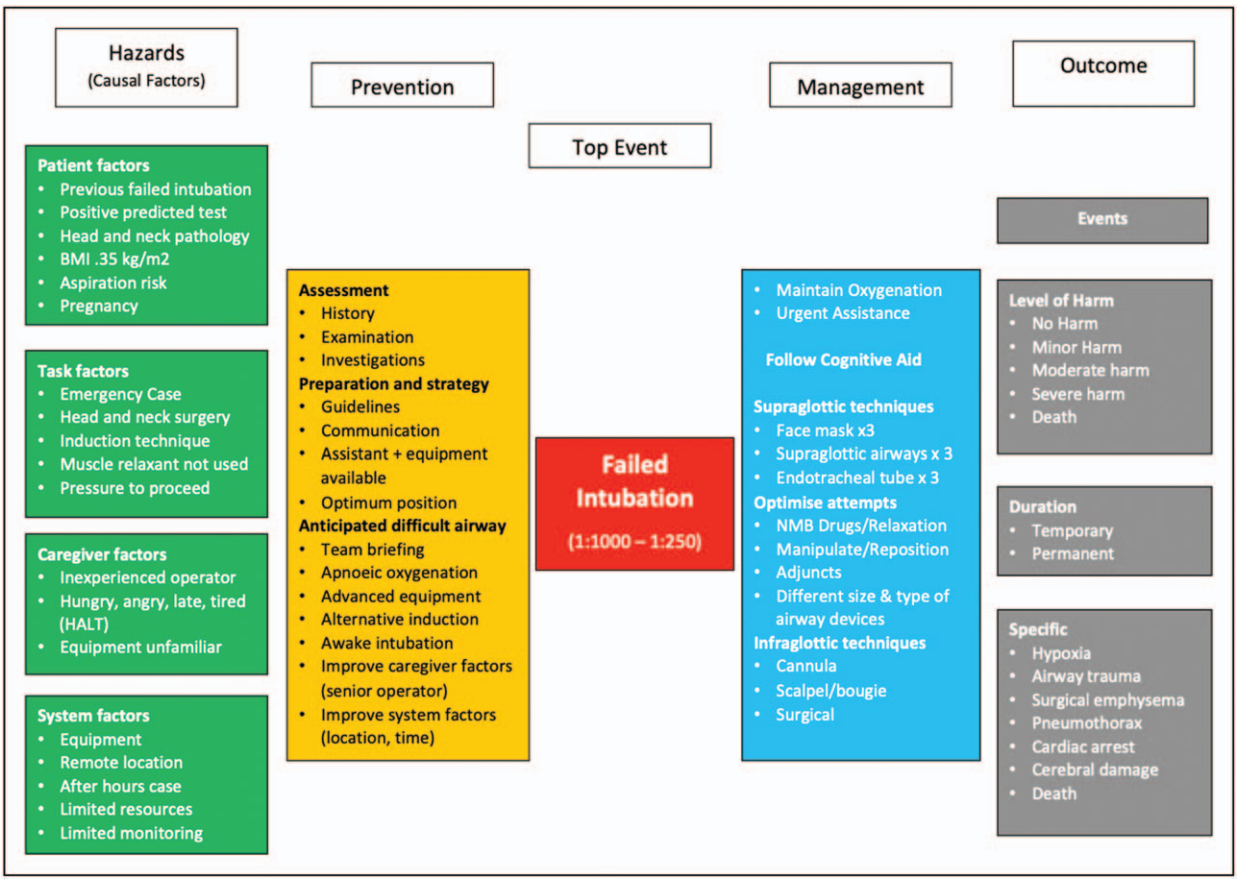


**FIGURE 4.** A Bowtie diagram depicting failed intubation [14▪]. See Conflicts of interest.

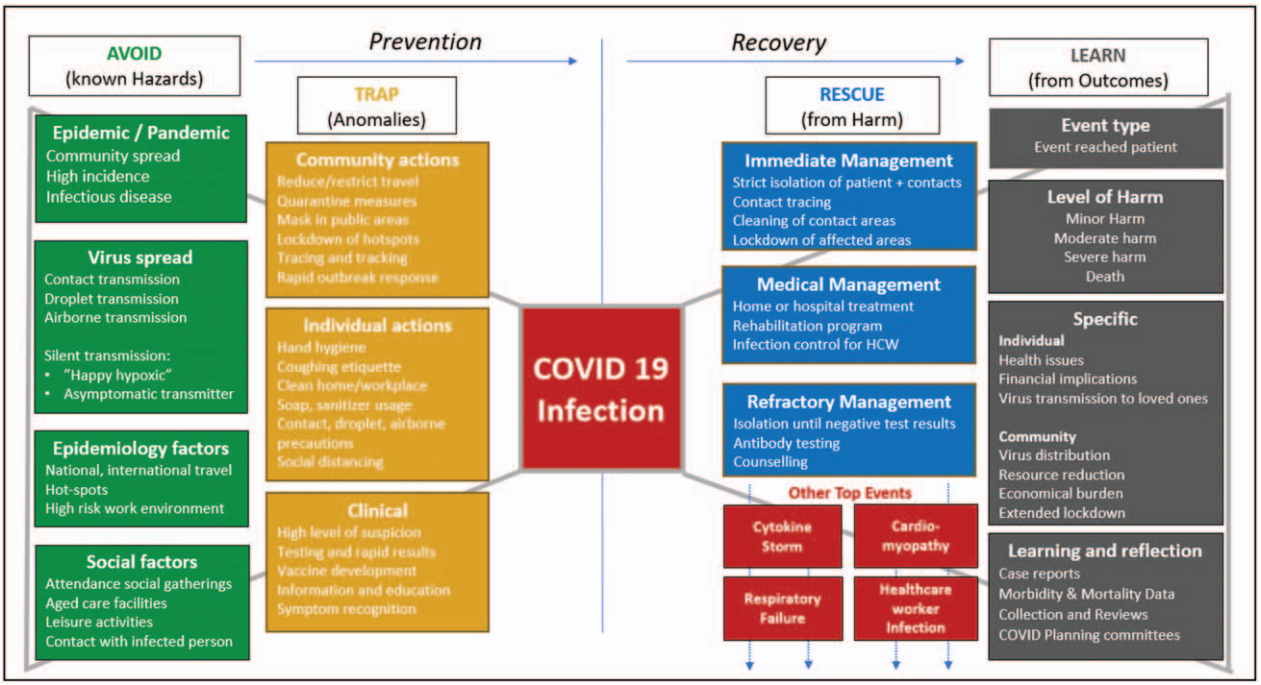


**FIGURE 5.** COVID-19 a topical example of risk analysis using a conceptual Bowtie diagram. See Conflicts of interest.

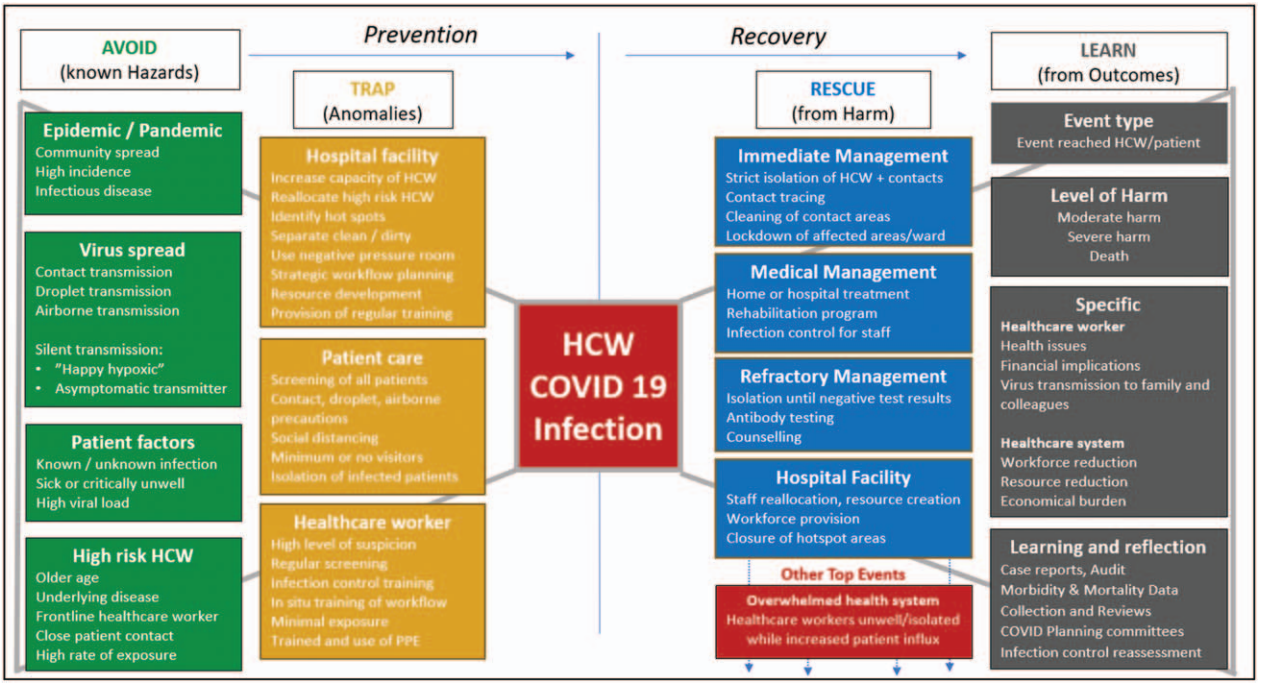


**FIGURE 6.** Bowtie diagram for COVID-19 infection in a healthcare worker. See Conflicts of interest.

Figure 6 shows an example of a cascading Top Event whereby a healthcare worker is infected with COVID-19. Additional diagrams can be created for additional Top Events as they are either observed or predicted as possibilities. In this way Bowtie diagrams can be used for both known events, for future events that might be predicted, even if they have yet to occur.

## RELEVANCE OF THE BOWTIE DIAGRAM IN ANESTHESIA

Bowtie diagrams relating to anesthesia have been published in both American [7] and Australian publications [6] since 2016. Recently, an article has been published using a set of Bowtie diagrams relating to airway management [15]. In the Bowtie diagram, the various hazards are listed in the left-hand column, which if not controlled by preventive barriers, escalation controls and mitigation in the next column, will progress to the Top Event, which is in the centre of the diagram. Although the items in the left-hand column indicate latent factors, at this point, the potential hazards are under control, and therefore, well tolerated if avoided at this point. Within the trap zone in the second column, some hazards might start to be expressed and the situation is potentially progressing to a Top Event if the barriers and controls fail. This section which includes the avoid hazards and trap anomalies columns is designed to prevent the Top Event occurring. If these interventions fail, the Top Event is reached, but there is still an opportunity to mitigate the harm by strategies to rescue the situation and to prevent further harm. This is in the recovery section after the Top Event. After this phase is complete, the outcome is depicted in the final column wherein the degree of harm might vary from no harm to death. This is also the zone in which there is reflection, learning from the event and designing strategies in each zone from prevention to recovery wherein the event might be either trapped or rescued.

## CONCLUSION

Bowtie diagrams have an advantage over existing methods to analyse and understand critical incidents as they combine possible causes and methods to prevent similar events in the future, with management strategies and learning from outcomes. In this way, all the aspects of a critical incident are combined into a single diagram, which can be used as an educational tool, as an analysis summary or a document to assist with safety and quality improvement.

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### Conflicts of interest

*Dr Martin Culwick has received an honorarium from Merke, Sharpe and Dohme to cover expenses to present at educational meetings. The presentations did not promote any commercial products and the topic was not related to this article. The last time meeting for which an honorarium was received was in October 2017.*

*Dr Yasmin Endlich and Dr Martin Culwick are members of ANZTADC.*

*Dr Yasmin Endlich is Director of Extended Global Medical Training, which is a not-for-profit organization that supports medical learning and teaching in low-income countries and rural Australia.*

*Dr Stavros Prineas is Chief Executive Officer of ErroMed Pty Ltd, a commercial human factor training consultancy based in Sydney, Australia. ErroMed has created some material, which is reproduced in the body of this article with ErroMed's free and open permission without condition or reservation of rights save attribution for its provenance. ErroMed has provided no funding or grants for my contribution to this paper, nor have I received any grants or sponsorships from any third party in this regard.*

*The diagrams shown in this review are examples only and are not a complete set of risk assessment and management recommendations for COVID 19, or for airway management.*

*We declare that there are no other conflicts of interest.*

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- ■■ of outstanding interest

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