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Navigating the Challenges of Implementing New Fire Investigation Tools in Australia: The Fire Origin Matrix Method

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ABSTRACT

Fire investigation employs an interdisciplinary approach, integrating knowledge from fire science, chemistry, materials science, emergency management, and engineering, and applying it systematically through a forensic lens. In Australia, fire investigation spans both the public and private sectors, and pathways into the field are extremely varied. Although there are globally available guidelines for fire investigation, given the variation in initial and ongoing training and education of fire investigators, scene-to-scene variations, and the enduring changes in modern materials and building practices, the evolution and refinement of investigative methodology largely relies on the communication of tacit and experiential knowledge of the investigative cohort. This article provides a brief review of some fundamental fire investigation principles and discusses the introduction of the Fire Origin Matrix method of origin determination for fire investigation. We then highlight the challenges in the uptake and understanding of novel methods for fire investigation, discuss some of the barriers to advancing fire investigation, and provide some comments on the future of fire investigation in Australia.

1 | Introduction

The field of fire investigation is certainly distinctive, spanning the public and private sectors and encompassing the intricacies of the forensic science discipline of crime scene investigation (CSI), while being performed by individuals historically lacking formal education and training in scientific method-based investigation (Gorbett et al. 2015; Stauffer 2020). Despite their occupation requiring the employment of the scientific method, many fire investigators do not come from a scientific background, which Stauffer (2020) importantly observes is reflected in the literature where fire investigators have very limited publications. Anecdotal evidence indicates many fire investigators are primarily trained (at least initially) in fire suppression, engineering, or insurance/recovery-related roles. Carman (2013) claims that professionals in other forensic disciplines generally come from a more advanced scientific education than those in fire investigation. While possessing a scientific degree is not a guarantee for higher levels of success, it increases the likelihood of one utilizing critical and analytical approaches (Carman 2013).

Possibly due to the non-scientific background of many investigators, fire investigation worldwide lacks the multi case-based, research-driven, and science-oriented approaches needed to study traces as comprehensively as other arms of forensic science, if indeed it is to be classified as a forensic discipline. Fire investigation does rely on the detection, recognition, recovery, examination, and interpretation of traces to understand instances of fire with unknown causes and/or origins. Hence, it should be considered a "forensic science" in the true sense of the definition as provided by the Sydney Declaration (Roux et al. 2022). Furthermore, the field of fire investigation clearly encompasses the seven tenets of the common framework for forensic science, or at least aspects of them, whether or not these have been fully articulated in the literature to date. As such, fire investigation should therefore be subject to the same minimum requirements for training and education as other general or specialized areas of forensic science.

Considering the variation in entry pathways to become a fire investigator, and the reliance of the field on the acquisition of tacit knowledge to develop expertise, there exists a considerable challenge for fire investigators to make reliable determinations based on scientific methodology (Icove et al. 2012). This is especially the case in the investigation of complex scenes, such as post-flashover fire scenes, where apparent fire damage can make it difficult to accurately determine a fire's origin. The introduction of ventilation effects can further complicate these investigations, regardless of one's training, education, or experience. Ventilation changes the fire dynamics and can alter burn patterns, introducing the potential for an investigator to be misled. Historically, many fire investigators have not completely understood the impact of ventilation or applied the relevant principles to their investigations (Shanley et al. 1997; Carman 2013; Lentini 2019). This has largely been perpetuated by a lack of comprehensive research, limited education, and inadequate training. The publication of the National Fire Protection Association's (NFPA) 921 in 1992, and its subsequent editions, increased awareness of ventilation effects and provided clearer education on its impact on fire dynamics and damage. However, despite greater focus on ventilation effects in modern fire texts, they are commonly misunderstood or underestimated in fire investigations. These effects are also so varied in each different instance of fire that they are difficult (and unrealistic) to comprehensively model in training scenarios with demonstrative burns.

Ventilation-controlled fires commonly exhibit areas of greater damage proximate to the vent as opposed to the fire's origin. However, once a fire has burned for a longer duration post-flashover and imparted significant amounts of damage, a fire investigator's ability to easily distinguish damage at the origin and ventilation-associated damage is greatly affected. The traditional approach of moving from areas of least to most damage is unsuitable to apply in such a circumstance. The nature of ventilation-controlled fires can result in investigators incorrectly identifying areas with extensive damage as the fire's origin. NFPA 921 asserts that the correct identification of the fire's origin is integral for determining the correct cause.

One promising development in addressing this longstanding challenge is Cox's Fire Origin Matrix (FOM) analysis method, which was first published in 2013, and also included in the 2017 edition of the NFPA 921. This method is a structured thought process that can be applied to ventilation-controlled fires that have experienced post-flashover conditions. The matrix predicts damage based on ventilation and fire dynamics, providing a systematic approach to origin determination. The FOM aids in comparing origin hypotheses and enhances traditional investigative methods by emphasizing the importance of a thorough understanding of fire science. However, Cox's method is relatively new and requires further research and validation testing to assess its practicality in real-world scenarios and overall effectiveness in enhancing origin determinations. To understand the FOM methodology, this article will first cover the basic principles of fire investigation.

2 | Principles of Fire Investigation

Fire investigation is a broad forensic science discipline comprising many investigative and academic fields. The NFPA defines "fire investigation" as "the process of determining the origin, cause and development of a fire or explosion" in their publication, the NFPA 921 (NFPA 2017, 15). Fire investigation professionals must be well-versed in physics, chemistry, fire and fluid dynamics, data collection and analysis, and the scientific method (Lentini 2019).

At the core of a fire investigation is the identification of the fire's "origin" which, as defined by the NFPA (2017, 17), is the general location where the phenomenon began. Building on top of this, the "area of origin" denotes a specific structure, part of a structure, or a general geographic location within the fire scene that contains the "point of origin" (NFPA 2017, 14). The "point of origin" is the exact physical location where a heat source and a fuel first interacted, initiating the fire or explosion (NFPA 2017, 17). The particular location where the fire or explosion began (the origin) and the circumstances, conditions, or agencies that brought about or resulted in the incident (the cause) are both intricately linked and identified through expert analysis and interpretation of traces at the fire scene (NFPA 2017). The NFPA (2017) emphasizes that the most critical hypothesis in fire investigations pertains to identifying the fire's origin. Without elements of this crucial information, determining the cause becomes increasingly challenging. There is also the potential for an inaccurate identification of the origin further increasing the risk of erroneous cause determinations, whether that cause be accidental or incendiary (i.e., intentional) (Carman 2013; NFPA 2017). Evidently, the accuracy in determining the fire's origin serves as the cornerstone upon which the entire scientific foundation of fire investigation relies; however, there has not yet been a field-wide acceptance of the importance of traces in origin determinations, or at least not a change in the language formally used. Consideration of the Sydney Declaration's approach to fire investigation challenges the NFPA's assertion that the most critical hypothesis in fire investigations pertains to identifying the origin, and places the importance of the investigation back onto the interpretation of traces—whether these are indicative of the origin, or not. As a "remnant of the investigated activity," a trace must be questioned for its nature, location, meaning, and value in order to build a reconstruction of the matter at hand (Roux et al. 2022). The Declaration encourages us to "step back" and consider context, in order to be able to determine a sequence of events.

2.1 | Analysis of Fire Damage

Various terms are used to describe fire damage observed at a fire scene, including fire patterns, burn patterns, indicators, and geometric shapes (Gorbett et al. 2015). All of these can, and should, be classified under the banner of "traces," if the suggested approach in the Sydney Declaration is to be followed. Such traces serve an important role in tracing a fire back to its origin and ruling out areas that do not constitute its origin. There is a notable distinction between the damage imparted by the fire, known formally as fire effects, and the accumulation of fire effects that can be deciphered by an investigator, known as fire patterns (Gorbett et al. 2015). Both fire effects and patterns are essential fire scene 'data,' or traces. Fire effects, as defined by the NFPA (2017), are observable or measurable changes of a material as a result of fire exposure. Recognition of these by an investigator is the first step to then identify fire patterns. Examples of fire effects include charring, spalling, melting, clean burn, calcination, deformation, and soot deposition (Cox 2013; NFPA 2017).

Fire patterns are a collection of fire effects, seen as visible changes or identifiable shapes (NFPA 2017). Examples of fire patterns include lines of demarcation (a border between differing fire effects) and geometrical shapes like triangles, cones, and circles. In particular, V-patterns can be generated by a fire plume intersecting with a surface, as seen in Figure 1, and the base width increases with fire spread (NFPA 2017).

Other forms of fire pattern analysis include heat and flame vector analysis, greatest degree of damage, and area of lowest burn. Heat and flame vector analysis involves an investigator creating a diagram of the fire scene and then marking their interpretation of heat or flame spread direction with arrows based on the fire patterns they see (Lentini 2006; NFPA 2017). The general search pattern followed by a fire investigator goes from the area of least damage to the area of greatest damage (NFPA 2017). The most damaged area is often deemed as suggestive of the fire origin; however, the NFPA (2017) asserts that this should not be assumed, especially when considering

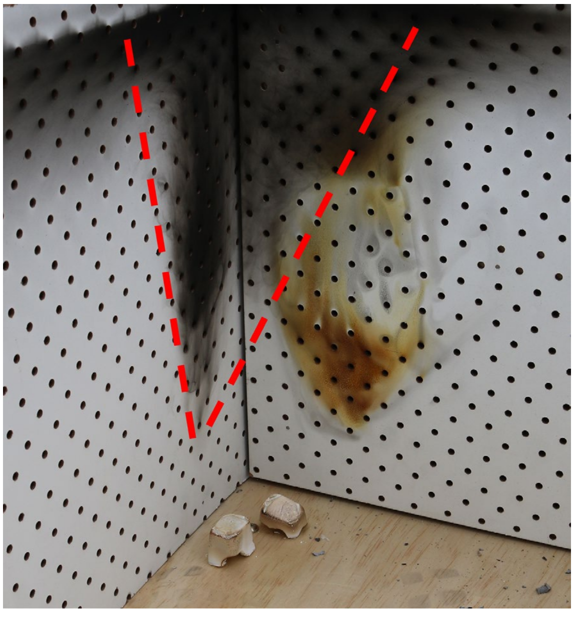

FIGURE 1 | Soot deposition observed in a V-pattern on the wall of a small demonstrative wooden compartment directly above a fuel package consisting of two firelighter cubes that were lit and burned for a short duration.

the impact of ventilation. The area of lowest burn is another consideration wherein there is evidence of burning on the floor and has been a widely discussed factor in literature due to the surrounding myth that it is indicative of ignitable liquids as a result of arson (Kirk and DeHaan 1983; Hine 2004; Gorbett et al. 2015). Low burning can be attributed to a number of factors such as the burning of ignitable liquids, furniture, ventilation paths, or drop down of burning materials, among others (Hine 2004; Gorbett et al. 2015; NFPA 2017).

The impact of a fire is characterized by fire damage assessment which comprises both fire effects and patterns. Cox (2013) lays out this process across four steps:

1. Document fire effects
2. Quantify fire effects (i.e., measurements or comparisons)
3. Document fire patterns
4. Label fire patterns

A fire investigator must collect all of these "traces" with active consideration of their properties and meaning. As the Sydney Declaration asserts, traces cannot just be collected blindly (Roux et al. 2022). The analysis of fire patterns involves determining how they were created and what significance they hold. The NFPA's Fire Protection Research Foundation released a white paper report entitled "Recommendations of The Research Advisory Council on Post-fire Analysis" in 2002. They identified fire pattern analysis as an essential area of research based on their significance to origin and cause determinations (NFPA 2002). In 2017, the American Association for the Advancement of Science (AAAS) released an in-depth review of the fire investigation discipline entitled "Forensic Science Assessments: A Quality and Gap Analysis. Report 1: Fire Investigation" that included many recommendations for the field (Almirall et al. 2017). In this review, they cautioned that while fire patterns provide important information and are often relied on by investigators to determine the origin, other factors must also be considered, such as knowledge of fire dynamics and eyewitness observations, to avoid erroneous origin and cause determinations due to over-reliance and tunnel vision. Roux et al. (2022) insist that reconstruction efforts consider a variety of traces, their context, and the potential altering effect of time.

2.2 | Flashover and the Role of Ventilation

Understanding the life of a fire, depicted in Figure 2, is crucial for both firefighters and fire investigators. The progression of a fire can be segmented into stages that are determined by the heat release rate (HRR): the incipient stage, growth stage, fully developed stage, and the decay stage (NFPA 2017). The HRR is described as the rate at which heat energy is produced by combustion and which determines the rate of fire growth (NFPA 2017). At the heart of this evolution is the phenomenon of flashover and a notable decrease in oxygen levels.

Flashover is a key fire investigation principle that signifies a rapid transition phase in the evolution of a compartment fire

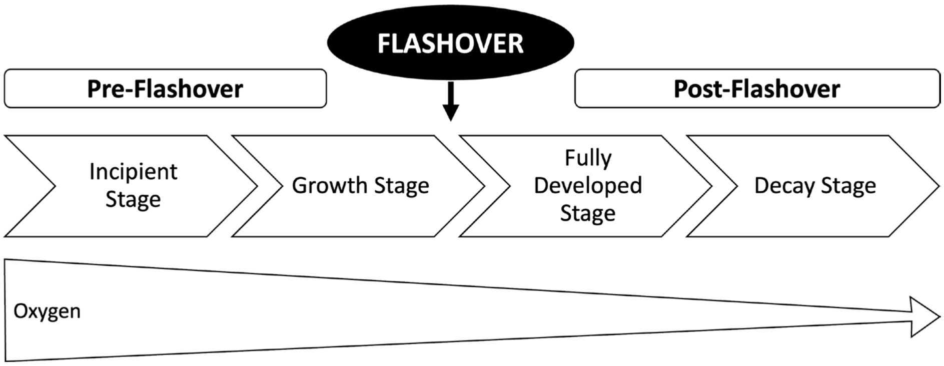

FIGURE 2 | The progression of a fire in respect to HRR and flashover. As depicted, oxygen depletes as the fire progresses.

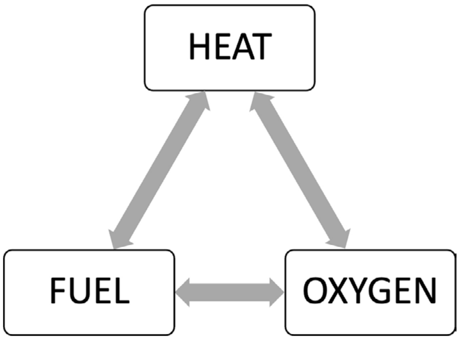

FIGURE 3 | The fire triangle consists of three elements that must exist simultaneously in a space for a fire to be sustained.

where all surfaces reach ignition temperature simultaneously, leading to a swift and extensive fire spread throughout the space resulting in full room involvement (NFPA 2017). In simpler terms, this is "when a fire in a room becomes a room on fire" (NFPA 2017, 48). Before this transition occurs, the fire is not yet fully developed and is smaller in both intensity and size, with flaming conditions concentrated in the general area of origin. A fire extinguished in this phase, known as pre-flashover, leaves behind minimal damage that is mostly limited to the area of origin, making it easier to determine the point of origin and the cause.

Should the fire not be extinguished at this stage, the heat energy generated during pre-flashover distributes throughout the whole compartment and reacts with the available oxygen, causing all solid and liquid fuels to produce sufficient gaseous fuel. Thus, the fire triangle, illustrated in Figure 3, is complete for most of the compartment (Cox 2013). This stage is when the whole compartment becomes involved, marking the onset of flashover. During flashover, the fire quickly consumes all the available oxygen in the compartment, giving rise to a ventilation-limited condition, which diminishes the fire (Ballou et al. 2012; Carman 2013). When the fire is extinguished at this stage, fire damage patterns can be observed in areas separate from the origin. The original fire patterns can be obscured, creating confusion in a fire investigator's interpretation of the fire's origin (Ballou et al. 2012).

When short-duration flashover occurs, the intensity of the fire is so strong that all surfaces in a compartment are noticeably damaged. This heightened level of damage, while making an origin determination more difficult, does not completely overshadow the more distinguishable fire damage present in the area of origin. This means that an origin determination is still very much possible, just not as easy. Long-duration flashover can result in other areas of the compartment mimicking the appearance of the origin of the fire, and interpretation can become even more complex, particularly if there are very combustible items consumed.

The post-flashover environment has significantly depleted oxygen levels and extremely high levels of heat energy that remain within the compartment and contribute to the pyrolysis of all solid and liquid fuels, filling the space with gaseous fuel that is either at or above its ignition temperature. These fuels cannot burn in an oxygen-void space and spread through the room via turbulence, traveling a distance from the fuel's origin until they encounter sufficient oxygen (Carman 2013). The missing element in the fire triangle at this point is oxygen, which can only be supplied to the compartment via ventilation points, such as a window or doorway. The fire triangle becomes complete again with the inflow of air through these vents mixing with the hot gaseous fuel. Because the compartment is now under-ventilated, flaming conditions will only exist in areas that are proximate to a ventilation point supplying fresh oxygen, irrespective of where the fire started (Cox 2013; Icove et al. 2004). This concept can be visualized in Figure 4. This ventilation-dependent fire behavior has been widely researched and observed in several experiments (Walton and Thomas 1995; Fleischmann 1994; Hu et al. 2005; Utiskul et al. 2005). Kawagoe (1958) was the first to introduce the concept of ventilation affecting the growth of a fire and explained that it was dependent on the size of the opening, which was later supported by Harmathy (1972a, 1972b), who then added that the shape and size of the compartment had an additional impact. Utiskul et al. (2005) and Hu et al. (2005) observed flames relocating from the fuel package's area towards the region of available oxygen, otherwise known as the ventilation point.

Ventilation effects drive the development of fire damage with more extreme fire conditions existing near the vent, giving rise to a higher potential for inaccurate determinations of origin and cause, especially if ventilation conditions are not well understood by the investigator (Carman 2008, 2013; Cox 2013). The intensity of post-flashover conditions will generate damage that masks and overshadows the initial damage, and as its duration

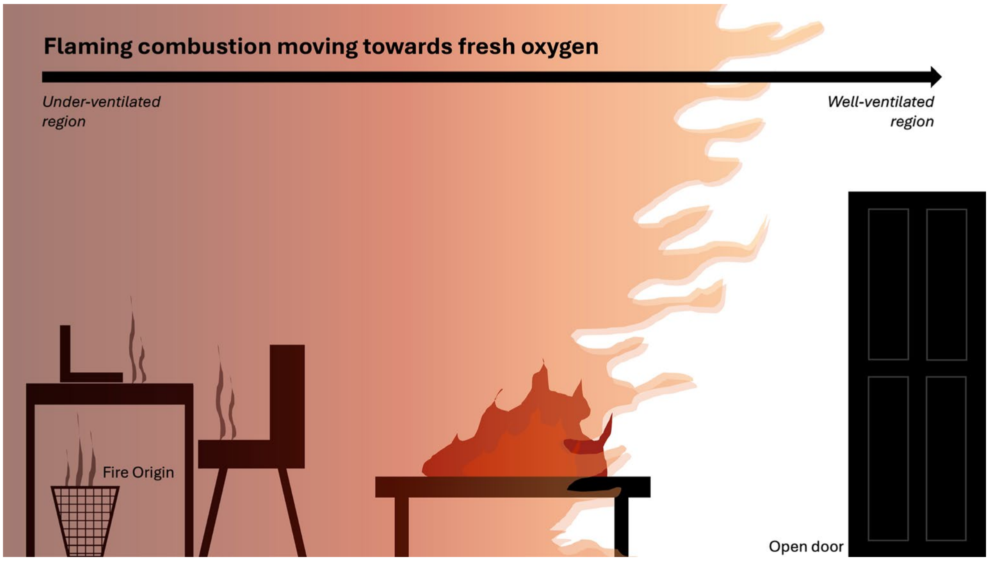

FIGURE 4 | Simplified demonstration of the migration of flaming combustion in a compartment fire, moving away from the origin and toward the ventilation point which provides fresh oxygen.

lengthens, the ventilation effects will become more dominant (Cox 2013).

3 | Navigating Ventilated Post-Flashover Fire Scenes

The damage imparted by a post-flashover fire is much more significant than a pre-flashover fire. It then becomes more difficult to determine the area of origin simply by interpreting fire patterns the longer the fire burns in a fully developed compartment (Almirall et al. 2017). It is therefore integral that fire investigators do not inappropriately use pre-flashover investigation techniques on post-flashover fires (Carman 2013). In pre-flashover fires, moving from areas of least damage to most damage will, in most cases, lead the investigator to the point of origin; however, in a post-flashover fire, this method is more likely to lead them away from it (Carman 2013). While the damage is extensive from a fully developed fire and investigators have much more difficulty interpreting the fire scene compared to a pre-flashover fire, the original fire damage patterns at the origin can persist and hence, guide an investigator towards a correct origin determination. Campaneli and Avato (2016) found through their experiments with small fuel packages that a fire pattern could survive post-flashover while cautioning that ventilation flow paths could produce similar fire patterns that should be carefully considered. Hopkins et al. (2007) affirmed through their experimentation that fire patterns, such as initial plume patterns, persist during post-flashover conditions and indicate to an investigator how the patterns evolved. Although initial plume patterns are more subtle, they are not destroyed and have been shown to reliably assist in area of origin determinations (Hopkins et al. 2007). These findings do not necessarily apply to all fire conditions, and the authors caveat that more research is required.

Given the circumstances, an investigator may start to search for remnants of an ignition source in an area where it will not be found and use a 'negative corpus' approach, for example, incorrectly concluding that a fire was intentionally set with a flammable liquid, for which there is no evidence of, because there is "no other explanation" (Ballou et al. 2012). The negative corpus method (NCM) often presents itself in the process of determining the ignition source of a fire by eliminating all known or suspected ignition sources found in or near the area of origin and claiming that such elimination is proof, despite having no physical evidence or supporting traces (Smith 2012).

Sound fire investigation should rely on tangible evidence and traces, rather than their absence. The NCM contradicts the principles of the scientific method, as it generates hypotheses that cannot be tested and may lead to erroneous conclusions regarding the ignition source. The NFPA (2017) recognizes that conclusions about the fire's cause can be drawn even when physical traces of the source's existence no longer remain, provided that other traces can be used to deduce the cause and origin. Negative corpus is deemed inappropriate and scientifically flawed, and the evolution of fire investigation standards reflects the gradual rejection of the NCM, as seen in its renouncement in the 2011 edition of NFPA 921. Unfortunately, in certain segments of the fire investigation community, the reliance on this improper and ethically questionable method persists, which further complicates the already challenging task of deciphering the complexities of fire and explosion scenes, particularly those marred by post-flashover conditions and ventilation factors (Smith 2012; Ballou et al. 2012).

It is integral that the correct origin is identified for the correct cause to be determined. In a post-flashover fire, however, this is the most challenging part of the fire investigation (Ballou et al. 2012). Published sources, like the NFPA 921 and Kirk's Fire Investigation, have historically contained contradicting and potentially misleading information on the basic concepts surrounding post-flashover fire conditions which exacerbates the difficulties faced when examining a post-flashover fire scene (Cox 2013). Additionally, most investigators will only witness live fire exercises with compartments that are not representative of those encountered in casework (e.g., with entire walls missing) in their flashover training. While beneficial for illustrative purposes, it provides a false impression of a post-flashover fire's behavior in a real-life scenario (Carman 2013). The logic that the most damage in a room is wherever the fire burned the longest generally does not apply to a ventilation-limited fire, which very few investigators have viewed from the inside of a compartment due to view-blocking walls (Carman 2013).

It is evident that ventilation has a major role in a fire's development, and Carman (2013) states that not understanding this role is a leading factor in incorrect origin determinations, which can have far-reaching implications, including the wrongful indictment of individuals in arson cases. Therefore, a fire investigator's opinion is not one without consequence. For this reason, ventilation effects must be carefully considered to ensure an accurate origin determination that considers ventilation-generated burn patterns (Carman 2008; Carman 2013). Kirk (1969) recognized in the core text "Fire Investigation" that a fire investigator may be distracted away from a point of origin by areas with significant ventilation. Such distraction has been evidenced well into the 21st century (Carman 2008; Heenan 2010; Tinsley and Gorbett 2012).

The combination of a post-flashover compartment fire with a ventilation point presents a real challenge for fire investigators. These factors typically result in two distinguishable areas of concentrated fire damage in a compartment with a doorway: the area of origin and the area surrounding the open door. The fire damage found in the area of origin, being the more subtle of the two, could easily be perceived by an investigator as secondary to the damage at the doorway or even overlooked. For a long-duration post-flashover fire, the generated damage at the vent will likely overshadow the damage imparted throughout the life of the fire in the rest of the compartment (Cox 2013). To discuss methods that may guide complex ventilated post-flashover fire origin determinations, a brief discussion of historical fire investigation approaches is required.

3.1 | Historical Approaches

While the collective understanding of ventilation effects on fire behavior and damage has evolved over the years, progress has been slower—compared to other forensic disciplines—in terms of the publication of research and the adoption of a more "scientific approach." In the early- to mid-20th-century, fire investigation relied heavily on anecdotal evidence and experience-based knowledge, with an emphasis on observational skills to perform an initial scene assessment. The general process involved investigators identifying the relevant traces (including burn patterns, residue deposits, and the condition of materials) and documenting their observations. Steadily, this skillset was then expanded to include more analytical skills, such as an understanding of fire dynamics (e.g., fire behavior, flashover, ventilation effects and heat transfer mechanisms), trace interpretation, and forensic analysis (e.g., ignitable liquid residue analysis). Basic principles of fire dynamics began to be more closely studied through the mid- to late-20th century, but the practical fire investigation techniques used in the field were noticeably lacking a scientific foundation and not developing with the same rigor as other forensic disciplines. Specific fire patterns and abnormal heat effects were commonly believed to indicate the presence of an ignitable liquid and treated as sufficient evidence of arson. Ventilation was known to influence a fire's behavior, but it was not clear the effect it had on fire patterns and its impact on making an origin determination.

The publication of the first edition of the NFPA 921 "Guide for Fire and Explosion Investigations" by the NFPA in 1992 marked a necessary and significant step towards more standardized and scientific practices within fire investigation. The NFPA 921 is recognized as best practice in the United States (U.S.) and is widely available and respected by fire professionals and legal professionals. It has even judicially been referred to as the "bible of arson forensic science" in Babick v Berghuis (2010) 620 F.3d 571 (6th Cir.). Lentini (2019) recounts how at its inception, the NFPA 921 was not entirely embraced by fire investigation professionals. However, as the value of a scientific approach to investigation became better understood, the guide was able to take its place as a key text in the fire community. Since its first edition was released in 1992 to its most recent eleventh release in 2024, the NFPA 921 has become a widely endorsed document. The NFPA 921 emphasizes an understanding of fire dynamics and the application of the scientific method. The International Association of Arson Investigation (IAAI) endorsed the adoption of the NFPA 921 in 2000 and now currently recognizes it as an authoritative guide, using it as a foundational document for their training and certification programs (IAAI 2013). The National Association of Fire Investigators (NAFI) states it is "the only Fire Investigator Certification based solely on the scientific principles of NFPA 921" (NAFI n.d.).

Unlike other forensic professionals, many fire investigators do not come from a scientific background, despite the scientific nature of their profession. In the same vein, there is an apparent lack of published fire investigation research in comparison to other forensic disciplines, especially in Australia. Lentini (2012) suggests that a failure of knowledge transfer has persisted between experienced investigators and newcomers to the profession, resulting in the passing on of misinformation and misconceptions rooted in outdated concepts and beliefs due to their limited additional training and lack of awareness of the flaws in their early training. Almirall et al. (2017) argue that there are insufficient testing requirements for fire investigators' education and proficiency and recommended further study on the effects of an investigator's background on their ability to determine a fire origin (Almirall et al. 2017). Tinsley and Gorbett (2012) discuss an additional consideration: the evolution of existing knowledge surrounding fire behavior and fire investigation has not been in tandem with the distribution of knowledge among investigators. Further, Carman has repeatedly stressed the low rates of correct quadrant of origin determinations in test exercises (Carman 2008, 2009).

A series of U.S. test burn exercises in the early 2000's highlight the concerningly low accuracy rate of fire investigators' origin determinations of post-flashover fires. These studies were preceded by years of attendees at the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF)'s advanced arson school beginning their course by reviewing a test fire scene and identifying a quadrant of origin (Lentini 2019). The unpublished accuracy rate was reported to be less than 10% (Lentini 2019, 41). The first critical exercise took place in 2005 in Las Vegas and was conducted by members from the ATF with the Nevada IAAI (Heenan 2010). Public and private fire investigator-students and non-investigators were involved in the origin determination of two burn cells that burned 3.5 min after flashover with an open doorway (Carman 2008, 2009). Out of 53 attendees at the seminar, only 3 participants chose the correct quadrant of origin per burn cell (Carman 2008, 2; 2009, 1). This is a success rate of 5.7%, and the results evidenced that students were most drawn to and easily influenced by the area of the compartment with more severe damage (Carman 2008, 2009, 2013). It is important to consider that the participants were asked to walk through and select a quadrant based on visual observations and did not have the chance to employ other traditional investigative methods such as collection of witness statements and movement of debris (Carman 2008). Another limitation of this study is that not all the participants' qualifications were known, and they were all at different levels of experience (Carman 2008). Without knowing the qualifications of all those involved, it would not be able to be guaranteed that the study participants were comparable. Some investigators may have had extensive training and experience, while others may have had very little, leading to variations in their abilities, methodologies, and decision-making processes. Such variation impacts the ability to accurately assess and interpret fire scenes and therefore produces a broader range in determination results. Therefore, the results may not accurately represent the typical practices and abilities of fire investigators, making it difficult to draw meaningful conclusions or make recommendations based on the study, especially given that some participating individuals were non-investigators. Aside from these limitations, the low success rate was importantly attributed to a lack of understanding of pre- and post-flashover fire behavior and damage (Carman 2008).

The Oklahoma City exercise in 2007 was conducted by ATF agents and involved three burn cells based on the Las Vegas study with 70 participating investigators (Heenan 2010). The results of this experiment saw a dramatic decrease in correct origin determinations from 84% to 69% to 25% as the fire was allowed to progress 30, 70, and 180-s post-flashover, respectively (Heenan 2010, slide 59). This confirmed that fire investigators were less likely to arrive at the correct quadrant of origin when the duration of a fire post-flashover was increased. Both studies revealed that the damage from a post-flashover, ventilation-controlled fire can be highly confusing to an investigator and that "lowest burn, deepest char" is not a reliable indicator of the origin (Carman 2008). Although somewhat concerning, these results are not a surprise given that training of fire investigators is primarily concentrated on pre-flashover behavior and its corresponding damage, alongside the limited education on ventilation-controlled fires.

Another key study, conducted by Tinsley and Gorbett in 2012, explored the ability of fire investigators to accurately make an origin determination for a post-flashover fire when provided with a scene diagram and photographs, and also surveyed demographics, particularly discussing the investigators' educational and professional backgrounds. The results of this study saw 73.8% of 586 investigators come to correct conclusions about the origin of a 60-s post-flashover fire (without measurable data), which is not too different from the Oklahoma City study's 70-s post-flashover results; however, the large difference in sample sizes (586 vs. 70) is important to consider and note (Tinsley and Gorbett 2012, 12). They concluded that the demographics of their subject pool demonstrated that those in the industry are primarily well-experienced and educated while coming from a wide variety of backgrounds (Tinsley and Gorbett 2012). Aside from Tinsley and Gorbett's survey on fire investigators' backgrounds, there is a limited number of existing publications that discuss education and training levels. Currently published studies do not necessarily imply a direct correlation between education and accuracy but consistently highlight the need for more research and improved training on post-flashover fire conditions.

Maynard et al. (2019) discussed Carman's publications and asserted that they were intended to illustrate the challenging nature of post-flashover fire pattern interpretation rather than test fire investigators and criticize them. They make a noteworthy comment that these studies were demonstrations, not scientific studies. Beyler et al. (2019) insist that Carman's works are valid and incentivize investigators to avoid making area of origin determinations based on visual observations alone. Carman (2008) discusses the implications of the 2005 and 2007 studies and suggests increased training and emphasis on ventilation-controlled fires in order to improve investigator performance.

The early editions of the NFPA 921 provided a foundational comprehension of fire dynamics but was still relatively general regarding the impact of ventilation. In 1997, the USFA Fire Pattern Test report was published by the United States Fire Administration (USFA) and the National Institute of Standards and Technology, Building and Fire Research Laboratory (NIST-BFRL) (Shanley et al. 1997). Their research committee performed integral research into fire patterns over 10 tests and the resulting data demonstrated their usefulness to fire investigations (Gorbett et al. 2015). Notably, some of their tests demonstrated the phenomenon of areas of intense burning remote from the fire's origin. The report warned that "without careful study and a full understanding of all the factors which influenced the progress and growth of the fire, [these patterns] could easily be interpreted to indicate incorrect or multiple origins" (Shanley et al. 1997, 56). Accordingly, the authors identified flashover and ventilation as misunderstood variables affecting fire pattern production. Subsequent increased emphasis on fire dynamics research in the 2000's has resulted in greater awareness of ventilation effects, but Lentini (2019) affirms that the enhanced understanding has only gradually disseminated among fire investigators over the past decade. Lentini (2019) also claims that this shift has resulted in an increase of undetermined fires, which, when coupled with the increasing complexity of fire scenes due to modern building materials and changes in construction methods, is no surprise given the impact of extensive fire exposure, potential fire suppression efforts, limited investigative resources, further advancements in fire science and more stringent investigative standards.

3.2 | A Novel Approach: The Fire Origin Matrix

In 2013, Andrew Cox, a Special Agent (SA) of the ATF and IAAI Certified Fire Investigator (CFI), published an article where he proposed a new methodology to employ in the interpretation of fire damage in a compartment with a ventilation point called the Fire Origin Matrix (Cox 2013). This method was then included in the 2017 edition of the NFPA 921.

The FOM involves a comparative analysis based on "the fundamentals of fire science and damage dynamics" (Cox 2013, 41). Using this method, the investigator divides the compartment into smaller sections, most commonly into quadrants, and then records traces such as fire patterns, structure damage, and potential ignition sources to lead them towards the origin. As interpreted by Gorbett et al. (2015), in this process, the investigator uses the location of any ventilation points as a "predictor," utilizing the expected airflow paths to explain the resulting damage.

Using the FOM method, an investigator maps out the damage in the fire scene and compares it to a matrix of expected fire damage to help them identify a potential area of origin. This cognitive process follows a sequence of moving from damage assessment to damage interpretation. The matrix, pictured in Figure 5, presents a range of possible origin hypotheses to consider. From this, the investigator compares the potential origins to all information gathered from the investigation to discern the validity of each hypothesis. Noticeably, in the long duration post-flashover scenarios, regardless of which quadrant the fire started in, the same level of fire damage is observed throughout all four quadrants. Additional data, such as witness statements, can aid them in eliminating particular quadrants, but the method is not dependent on this information. The FOM is quite flexible for an investigator to decide which matrix scenarios are more suitable or for them to work by process of elimination. What sets this method apart is that it provides a systematic approach to analyzing fire damage based on the premise that the damage that a fire produces can be somewhat predicted. Due to the matrix's ease of application, it can also be utilized by fire investigators with varying degrees of experience. An added benefit is that it is a form of documentation of the investigation and aids in communicating one's findings. The Fire Origin Matrix is not a replacement for traditional fire investigation methods, but it most definitely enhances them by providing a standardized and systematic analysis approach.

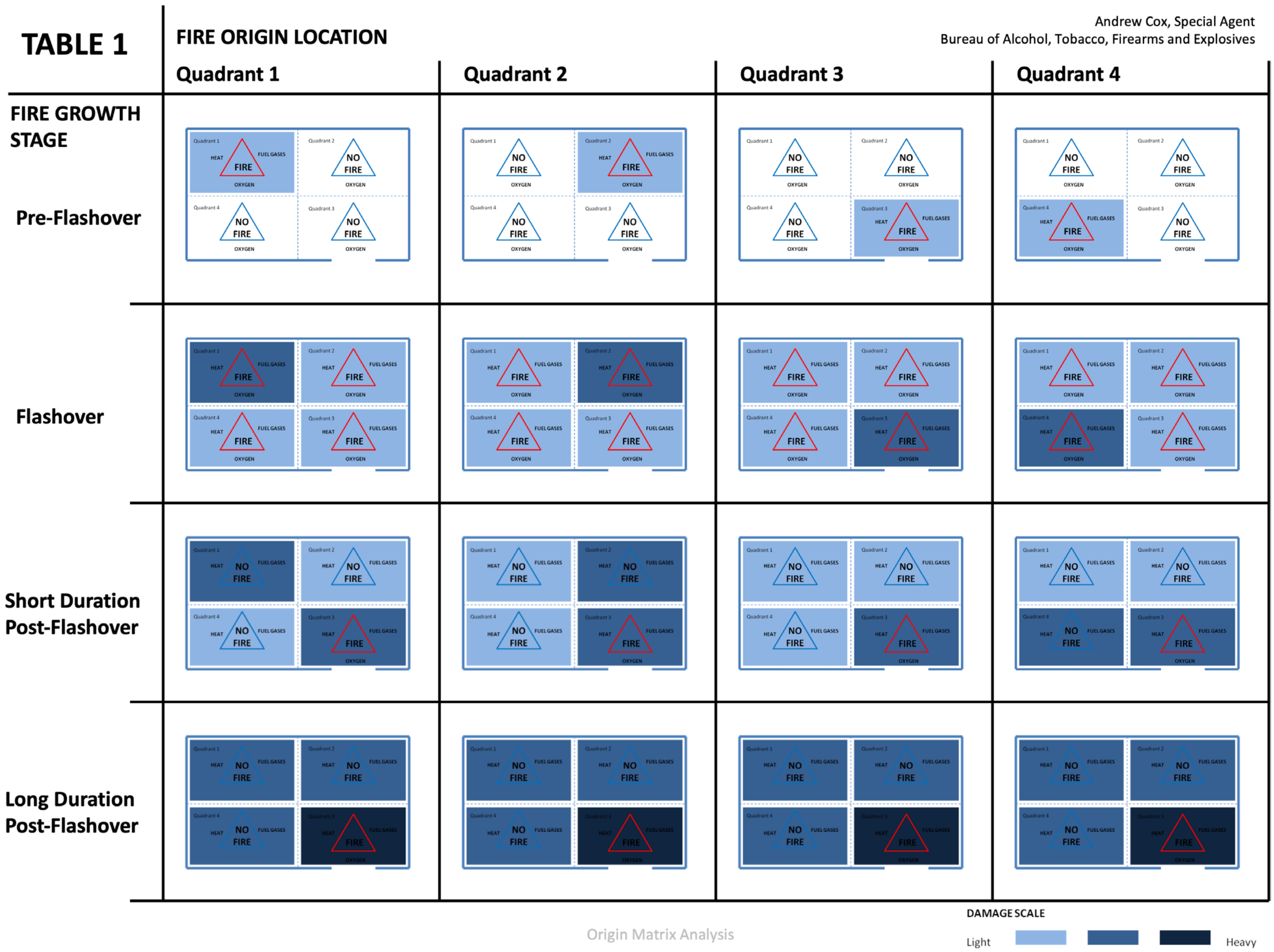

FIGURE 5 | Fire Origin Matrix analysis' possible outcomes by Cox (2013) demonstrating the layers of damage that accumulate as a fire progresses depending on which quadrant the fire originated. *Source:* Image reproduced with permission from Andrew Cox.

The FOM provides an improved process for interpreting fire behavior in a compartment but has yet to be incorporated in contemporary published studies. Lentini (2019, 41) provided commentary on Cox's method, elaborating that if the investigator decides that ventilation did indeed have a role in the creation of the observable fire patterns, then “the most likely conclusion to be reached” is that those patterns arose during the ventilation-controlled stage of the fire. Thus, it can then be induced which patterns were created as a result of ventilation effects, and which may indicate the area of origin. In line with the Sydney Declaration, the FOM combines the collection and interpretation of traces using scientific knowledge and logical reasoning whilst utilizing contextual information (e.g., the presence of a vent) to frame their interpretation.

Despite first being published in 2013, the adoption or recognition of the FOM in Australia has been slow. For such a valuable method to have been around for 10 years and still have such limited discussion and no recorded validation testing in the literature is a testament to the persisting lack of focus on addressing the misunderstanding of ventilation effects. It is possible that investigators are considering the FOM (or a very similar methodology learnt anecdotally) when they are undertaking their investigations; however, in Australia, it is not explicitly used or referred to in investigative reports. Awareness of the FOM in the U.S. is much more widespread, likely due to the higher prevalence and accessibility of training courses available through associations such as the IAAI that actively endorse the NFPA 921, in which the FOM is described. Interestingly, becoming certified with the IAAI requires a comprehensive working knowledge of the NFPA 921, and many Australian investigators hold this certification.

4 | Barriers in Advancing Fire Investigation in Australia

The prevalent challenges in fire investigation, including the apparent difficulty in interpreting fire damage and the perceivable misunderstanding of ventilation effects, highlight a broader issue in this field—the disparity between fire investigation and other forensic disciplines like crime scene investigation (CSI). Fire investigation (in a forensic capacity) anecdotally receives less funding for research compared to CSI, leading to slower development of new methods and technologies. It appears that innovation is not as heavily emphasized in fire investigation when compared to other arms of forensic science, resulting in slower adoption of cutting-edge technologies or improvement on existing methodologies/practices. Without this constant refinement, fire investigators may continue to rely on outdated knowledge and practices. Fire investigation findings and advancements are seemingly published and shared less frequently in scientific journals or at professional conferences compared to CSI. The dissemination of research findings is essential for the growth and development of any scientific discipline. However, fire investigation seems to suffer from a lower profile in academic and professional circles, possibly as a result of the vast range of “industries” that play into this field (insurance, forensic science, emergency services, law enforcement). As a result of the industry diversity involved in fire investigation, there are fewer opportunities for clear pathways for continuing education and professional development, leading to potential gaps in knowledge. This is likely due to the inability of one of these industries to provide relevant opportunities to professionals across all of these industries. The field of CSI seemingly has a higher profile in both the public eye and professional spaces, possibly due to media portrayals and general community needs. This higher visibility translates into greater public and governmental support, which may not be as strong for fire investigation.

Another barrier is the specific disparity between the U.S. and Australia in terms of research output and the adoption of standards and guidelines. The U.S. has a more substantial body of published literature and considers itself a global leader in fire investigation, likely due in part to being the home base of the IAAI and a large portion of its membership. In comparison, Australia has a significantly lesser contribution to the published literature sphere. Additionally, while the importance and application of the NFPA 921 is evident in the U.S., it is not held to the same level of authority in Australia, despite Australian investigators commonly undertaking or striving towards IAAI certifications. Its use varies between different jurisdictions, agencies, and individual investigators. Not having a widely accepted and integrated guideline in Australia such as the NFPA 921 can contribute to challenges in legal proceedings, impact communication among fire professionals, and affect levels of expertise and professionalism among fire investigators.

An Australian fire investigator can become certified via several associations. However, the most endorsed associations, being the NAFI and the IAAI, are based in the U.S. Additionally, the annual IAAI International Training Conference (ITC) is always held in the U.S., limiting the participation of investigators from other countries such as Australia due to high costs and lengthy travel. These certifications and training opportunities provide fire investigators with increased credibility and demonstrate their level of specialized training. However, it is not mandated across all fire agencies (in any country) that a fire investigator obtain these certifications. Notably, an Australian-based certification is not as prevalent or widely recognized, and instead, Australian fire investigators must seek to obtain such esteemed certifications from the U.S. The Australasian Fire and Emergency Services Authorities Council's (AFAC) Emergency Management Professionalization Scheme (EMPS) is one avenue from which Australian fire investigators can obtain certification from, but it does not seem to hold the same international recognition as one from the IAAI or NAFI.

As articulated in the Sydney Declaration, a fire investigator, as a professional in the forensic discipline, is expected to possess a “trained mind” and therefore be equipped with sufficient education, training, and experience (Roux et al. 2022). However, the shortcomings in Australian fire investigation qualifications and certifications are not conducive to such proficiency among the entire professional cohort. Also recommended in the Declaration is that forensic scientists be educated as scientists as opposed to just technicians (Roux et al. 2022). It is clear that the foundations of fire investigation education and training require an increased focus on the broader principles and methods of forensic science that importantly underpin the profession.

A more conceptual and fundamental barrier to the advancement of the field of fire investigation is the lack of application of an articulated forensic framework surrounding the discipline. Mostly referred to as "fire investigation" but operating under the auspices of a true forensic discipline, there is a point at which we need to better qualify the discipline as a forensic one, and begin utilizing more informative labels such as, "forensic fire investigation," and applying the same rigor as other more "typical" forensic disciplines. The concept of "traces" as presented in the Sydney Declaration is pivotal in transforming forensic science, emphasizing the importance of traces as remnants of past events (Roux et al. 2022). Using this approach shifts the focus from purely laboratory-based analysis to a more holistic view that considers the context in which the traces are found, a shift in thinking that is crucial to the field of forensic fire investigation. Fires often destroy or alter physical evidence, making it challenging to determine the origin and cause. However, traces such as burn patterns and chemical residues can provide critical information. The Sydney Declaration underscores the need to understand how these traces are generated, how they might be compromised over time, and what they reveal about the incident.

Through adopting a "trace-centric" approach, forensic fire investigators can better reconstruct the sequence of events leading to a fire. This involves not only identifying the presence of ignitable liquids or ignition sources, but also interpreting the spatial distribution and context of the traces to be able to describe a fire's progression. This emphasis on traces and context aligns with the fundamental principles of forensic fire investigation, where understanding the nuances of trace evidence can significantly impact the investigation's outcome and subsequent legal proceedings.

To effectively uptake useful investigative tools such as the FOM in Australia, we require a shift in the perception of "fire investigation," to "forensic fire investigation," and the application of a full forensic framework, not solely elements of it. For Australia, this would encompass improving the Australian certification and training offerings, and ensuring that all forensic fire education and training is based on current evidence from research. The FOM is just one example of a methodology that may be useful in Australian forensic fire investigations, however without more published research assessing this tool and clearer pathways for the communication of it through more local education and training, could Australian investigators be missing out on vital instruments to make more accurate origin and cause determinations?

5 | Conclusion

The persistent difficulties in fire investigation, particularly concerning the interpretation of fire damage, underscore a broader issue within the profession. Compared to the more established and high-profile field of crime scene investigation (CSI), fire investigation receives significantly less funding for research and training, fewer opportunities for professional development, a lower volume of research output, and slower adoption (or unclear pathways) for the implementation of new practices and technologies. In some countries, Australia being one, the entry pathways into fire investigation education at a tertiary level are limited to those who are already engaged in fire suppression services or crime scene investigation roles.

The Fire Origin Matrix enhances traditional fire investigation methods by providing a standardized and systematic approach towards the analysis of ventilation-controlled post-flashover fire damage. However, it is clear that further validation and recorded applications of this method in real-world scenarios would be extremely beneficial in refining the FOM and broadening its reach to fire investigators. An understanding of the role of ventilation and the ability to accurately interpret fire patterns within their context are absolutely crucial for reliable origin and cause determinations. Hence, the utilization of an investigative tool that is built upon these necessities would ultimately improve the accuracy, reliability, and overall proficiency of fire investigations.

To effectively use tools like the FOM, fire investigators must stay updated with revisions to the NFPA 921 (a costly resource) as well as remain engaged with conversations that take place within the fire investigation community. However, the NFPA 921 is an American document with a primarily American following. Many Australian fire investigators rely on Kirk's Fire Investigation, which lacks coverage of innovative methods like the FOM and is updated less frequently. This discrepancy underscores the need for continuing professional development activities for Australian fire investigators and potentially developing Australian-based qualifications in fire investigation that are across the newest methods and embrace ongoing learning.

Ultimately, the field of fire investigation encompasses the requisite tenets to be considered a discipline of "forensic science," as defined by the Sydney Declaration. As such, fire investigation requires the same scientific rigor and devotion to scientific advancement as seen in other more common arms of forensic science. Recognizing the unique variety in backgrounds, experience, and training of fire investigators, more effective means of certification and dissemination of novel and validated methods need to be explored, particularly for investigators in countries such as Australia, where organizations such as IAAI are not wholly interlaced in fire investigation culture. Advancement of fire investigation in Australia (at a comparable rate with other arms of forensic science) relies on increased resource allocation and funding, better standardization, accreditation, and certification, improved and more accessible education and training programs, layered with increased investment into research and development. To accomplish this, better collaboration between government agencies, universities, and industry stakeholders is paramount.

Author Contributions

Amy Aldrick: conceptualization (equal), data curation (equal), project administration (supporting), writing – original draft (lead), writing – review and editing (equal). **Mackenzie de la Hunty:** conceptualization (equal), data curation (equal), project administration (lead), resources (lead), supervision (lead), writing – original draft (supporting), writing – review and editing (equal).

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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