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Literature Review

Stabilization of Teeth After Exposure to High Temperature Conditions for Forensic Identification: A Scoping Review

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KEYWORDS

Forensic dentistry, forensic identification, high temperatures, incineration, stabilization

ABSTRACT

Introduction: Teeth are used as a primary method of forensic identification due to their robust nature. Although resistant to various environmental destruction, prolonged exposure to extreme temperatures may alter the tissue, rendering it fragile and prone to fragmentation. This poses a challenge for forensic odontologists in postmortem identification, as postmortem dental analysis often requires teeth to be intact for further investigation beyond the crime scene. This article aims to examine and discuss methods of teeth stabilization following exposure to high temperatures, focusing on materials selection and key properties for selecting the optimum stabilizing agents to preserve/reinforce the heat-affected teeth.
Review: The literature review was performed using PubMed and ScienceDirect in accordance with the PRISMA workflow, including only full papers and original research and/or case reports. Various natural and synthetic solutions were effective for teeth stabilization, with spraying as the most effective method for maximum surface coverage. Aside from ease of use, material availability, rapid curing time, and non-volatility, the long-term durability and chemical stability are crucial factors in selecting the appropriate stabilizing agent to store heat-affected teeth for archiving.
Conclusion: In conjunction with proper teeth stabilization methods, forensic odontologists must also consider proper storage of evidence, planning a safe route from the crime scene to the mortuary, and evidence storage time for possible future analysis to ensure the best evidence preservation.

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INTRODUCTION

Fire is one of the most common causes of death in the world.[1] According to disaster reports from the Indonesian National Police (POLRI), fires were the most frequently occurring type of disaster within the period of January to October 2024, accounting for 38.82% of 2408 incidents.[2] Fire incidents could be caused by airline crashes, automobile accidents, bombings, house fires, murder, cremation of the victim's body for disposal, or suicide.[1,3]

Due to the destructive nature of fire, fire-related cases are particularly challenging for forensic investigations, including the process of victim identification.[4] The extensive destruction of soft tissues and even skeletal tissues makes conventional and visual methods of identification impossible, especially when the body is partially or completely carbonized. DNA and fingerprints might also be significantly challenging to obtain. When this happens, forensic odontology plays a key role since dental data is one of the primary identifiers used for forensic identification.[5,6] Even the first scientific text on forensic odontology was due to Dr. Oscar Amoedo's personal account on the 1897 fire disaster at the annual charity bazaar in Paris, where he attempted to identify the charred bodies through comparison of dental records.[7] Teeth can withstand various extreme conditions, such as extreme temperatures or acidic conditions. This is because teeth are the most robust component of the human body, which are protected by a layer of enamel, as well as thick layers of soft tissues such as the lips and cheeks. The inherent biological stability of human teeth makes them the perfect instrument to provide a record of physiological and pathological conditions of the individual's dentition.[3]

Identification of unknown deceased individuals is achieved through the process of forensic identification. This is achieved by comparing postmortem and antemortem data.[8] Successful identification through dental data comparison is not only achieved through adequate amounts of antemortem data, but also through the quality and maintenance of the postmortem data. In this case, it is the state of the postmortem teeth themselves.[9,10] Although teeth are resistant to extreme environmental conditions, prolonged exposure to high temperatures could render them fragile and even fragmented. The crown of the tooth is likely to shatter because the pressure inside the enamel and dentine matrix of the tooth will increase as moisture evaporates during high-temperature conditions. On the other hand, because the roots of the tooth have less moisture and are usually embedded inside the bone, this provides extra protection and increases survivability in extreme conditions.[10] In contrast with permanent dentition, deciduous dentition tends to be more fragile. Hence, they are at even greater risk of fragmentation even before visibly looking charred.[3]

If the burnt teeth do not survive the recovery and transportation process to the mortuary, postmortem dental profile that includes age, sex, ancestry, and socio-economic background cannot be established, and dental radiographs might also be impossible to obtain for further analysis. The evidence handling process at the crime scene and transportation of evidence from the crime scene to the mortuary might also cause damage to the fragile teeth, increasing the risk for evidence destruction and inability to conduct a proper post-mortem and ante-mortem data comparison. As such, evidence management and preservation of burned dental evidence remain a significant concern in forensic odontology.[3,9–11]

There have been recommendations for handling fire-related dental evidence, including the use of stabilizing agents to physically strengthen fragile teeth so that they can withstand the vibrations and impact of handling in the crime scene and transportation.[3] The use of cyanoacrylate glue has been mentioned in various literature and remains one of the most reliable and preferred methods of stabilization.[5,11,12] However, concerns for its flowability and rapid setting should be noted, as it could also cause unwanted problems, such as when it flows between the jaws and sets, which will make separation of the jaws and eventual examination even more difficult than it previously was.[5] Using tubes of cyanoacrylate glue is also not effective for larger areas that need stabilization.[9] Other synthetic stabilizing agents have also been described previously to stabilize teeth and bone, especially using the spraying method instead of droplets or brushing, as described by Mincer et al.[9,12,13] However, volatility becomes an issue as the vapors emitted after spraying will potentially compromise the crime scene, especially when testing for accelerants is required during the investigation.[14] A pilot study by Topoleski and Christensen tested the use of a non-volatile gelatin-based stabilizing agent for incinerated skeletal remains, which were then tested by Berketa et al on charred dental specimens. Both experiments were successful, but both articles noted that temperature might affect setting time and that it may contaminate the sample with non-human DNA due to the nature of gelatin being created from bovine or pig connective tissues.[14,15]

Currently, there is no standardized protocol or agreement among experts regarding the approach to preserving human remains after incineration, including the human dentition. The purpose of this review is to examine and discuss methods of teeth stabilization following exposure to high temperatures for forensic identification purposes, focusing on material selection and the key properties for selecting the optimum stabilizing agent to physically reinforce the heat-affected teeth.

REVIEW

This scoping review is conducted in accordance with the PRISMA method for scoping reviews. The literature search included the electronic databases PubMed and ScienceDirect. Only comprehensive original research and/or case report articles written in English that focus on the methods description of incinerated teeth stabilization were considered. Thus, any type of literature review and non-English articles are excluded from this study, as well as articles using non-dental samples. There were also no time constraints for the published literature to be included in the study. The Boolean search included the keywords of "forensic dentistry OR forensic odontology", "heat OR fire OR incineration", and "stabilise OR stabilisation OR stabilisation".

The research question was formulated using the PICO guidelines, which are P = incinerated dental structure, I = stabilization agents, C = different methods of stabilization, and O = efficacy of the stabilization process. Further topics to focus on in this article include materials selection and key properties for selecting the optimum stabilizing agents to reinforce and preserve the heat-affected teeth.

The search in the online databases yielded a total of 44 articles. 36 records were then excluded due to being duplicates and not related to the topic of interest. 2 articles were excluded because they did not include dental samples, but instead utilized bones. Another article was then excluded for being a review that did not discuss original research nor case report. After thorough analysis and evaluation, there were 5 articles included in this literature review, ranging from the year 1990 to 2021, which

included 4 experimental studies and 1 case report. One of the experimental studies also included an additional qualitative study using questionnaires with a limited sample size. The details for the PRISMA methodology are presented in Figure 1.

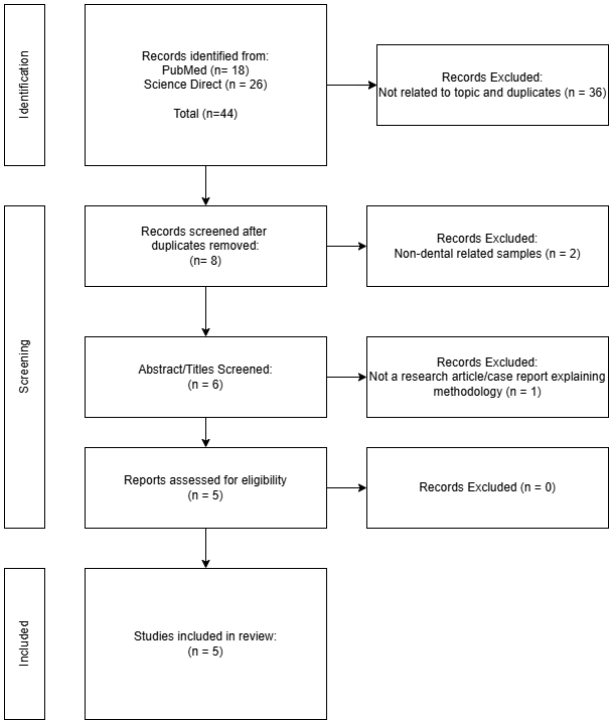

Figure 1. PRISMA-SR chart for this literature review.

Table 1. The summary of the existing literature is included in the literature review.

Author & Year	Title	Sample	Methods Of Stabilization		Results
			Materials used	Application Method	
Mincer HH, Berryman HE, Murray GA, Dickens RL. (1990)	Methods for physical stabilization of ashed teeth in incinerated remains.	Human dentition	Cyanoacrylate (Superglue®)	Drop	All materials adequately increased physical stability. All incinerated teeth that have been treated with each stabilizing agent withstood the vibration test, as well as other insults such as tapping the teeth with a pencil or scratching with fingernail. According to the authors, the most advantageous stabilizing agents are the acrylic spray paint and the cyanoacrylate adhesive. If the setting time is not of concern, the PVA mixture can be considered.
			Acrylic Spray (Krylon®, clear No.1303)	Spray. Applied 3 coats with 3 minutes drying time between coats.	
			Hair spray (Style Superhold®, unscented)	Applied 3 coats with 3 minutes drying time between coats	
			Spray varnish (Illinois Bronze®, clear satin)	Applied 3 coats with 3 minutes drying time between coats	
			Finger nail polish (Hard as Nails®, clear)	Brush	
			Epoxy Cement	Brush	
			Epoxy Cement in acetone (1:1 ratio)	Brush	
			Household Cement (Duco®)	Brush	
			Household cement in acetone (1:1 ratio)	Brush	
			PVA polymer (Union Carbide®) ~5% in acetone	Brush	

			PVA polymer (Union Carbide®) ~1% in acetone Acrylic resin (Coe®, orthodontic self-cure clear resin)	Brush Brush	
Griffiths CJ, Bellamy GD (1993)	Protection and radiography of heat affected teeth	Human dentition	Loctite (Cyanoacrylate adhesive)	Unspecified, most probably dropped on the specimen	Stabilization of teeth structures using cyanoacrylate adhesives proves to be successful, enabling forensic odontologists to transport the dental tissues safely to the mortuary for radiological examination
Berketa J, James H, Langlois N, Richards L, Pigou P. (2015)	Use of a non-volatile agent to stabilize severely incinerated dental remains.	Sheep mandible with teeth (anterior)	Plain flour in water solution (White Wings, North Ryde, Australia) with a 1:2 ratio ClagTM paste diluted in a water solution (Bostik, Melbourne, Australia) with a 1:1 ratio	Spray for 15 seconds, wait until setting for 20 minutes. Spray for 15 seconds, wait until setting for 20 minutes.	Treatment of the samples with the ClagTM/water mixture and flour/water mixture improved the stability of incinerated dental remains. Both mixtures are non-volatile and did not impair radiographical assessment of the samples. However, the flour/water mixture caused a visible white cast on the samples.
Berketa J, Fauzi A, James H, Lake A, Langlois N. (2015)	The utilization of a commercial gloss spray in stabilization of incinerated dental structures	Sheep mandibles with teeth (anterior)	Dulux® Spraypack™ clear gloss enamel (composition: 10% Butoxy Ethanol, <10% Butanol, and 30-60 %)	Spray for 30 seconds at a distance of 25 cm, wait until it sets for 20 minutes. Nozzle spray was kept at factory settings.	Application of the stabilizing agents improved the stability of the burned sheep mandibles without causing any visible opaque layer on the surface of the samples. Samples were also able to be assessed radiographically. However, the volatility of the spray is of concern for forensic investigations.
Berketa J, Higgins D. (2021)	The use of gelling agents to preserve burnt teeth within the dental alveoli for dental human identification - a study utilising sheep mandibles.	Sheep mandibles with teeth (anterior)	Agar (2 g: 100 ml water) Gelatin (5 gr : 100 ml) solution	Each solution was placed inside a fine-nozzled hand pump spray, then sprayed for approximately 15 seconds. Each solution was placed inside a fine nozzled hand pump spray, then sprayed for approximately 15 seconds.	Gelatin solution proved to be a good stabilizing agent for burnt teeth within the jaw with no hindrance for radiographic dental examination, especially for low temperature environments (<31°C). Meanwhile, wheatpaste has an advantage in low humidity environments (above 31°C).

The result of all the articles included in the literature review showed that various stabilizing agents showed the ability to increase the physical stability of incinerated teeth. Each of them passed some kind of vibration test in order to mimic the disturbance that might happen during transportation, especially on rougher roads.[14] Mincer et al included vibration tests with a dental vibrator, as well as tapping them with significant force with a pencil, and scratching manually with fingernails.[12] Berketa et al also used the dental vibrator set at maximum setting as a vibration test method.[9,14,16] It is important to note that Mincer et al's study only reported qualitative data, meaning that there were no specific statistical data

regarding the vibration test, whereas the newer studies by Berketa et al included statistical test results comparing the teeth conditions before and after treatment using stabilizing agents after being subjected to vibration.[9,12,14,16] Only the case report article by Griffiths and Bellamy did not apply a vibration test since they already described that the incinerated teeth successfully survived the journey from the crime scene to the mortuary after attempts at stabilization. Additionally, they also described protecting the fragmented evidence with shock-absorbent materials such as wrapping foam bands around the skull and using bubble plastic and insulation tape.[11] Their study heavily suggested that it is recommended to take further precautions to avoid further damage to the already fragile burnt remains.[14]

Two studies (older than the year 2000) used human dentition as samples, while three newer articles used sheep mandibles for the experiments. For human dentition, Mincer et al's experiment embedded the dental roots in dental investment material, which was then subjected to incineration in a dental laboratory porcelain furnace.[12] Griffiths and Bellamy described three of their endeavors in stabilizing human jaw and dentition during real fire cases.[11] Berketa et al used sheep mandibles with their anterior teeth still intact for three separate experiments with different stabilizing agents. They noted that sheep teeth were smaller and thinner compared to human teeth, and that the condition of sheep teeth may be varied due to the differences in age, health, or sex of each sheep.[9,14,16]

Among the experimental studies, Mincer et al included a qualitative study aimed to identify which materials forensic experts use to stabilize charred teeth. The sample in the study was 154 board-certified and active forensic practitioners (81 forensic odontologists and 73 forensic anthropologists), but only 34 responses were acquired regarding the materials used to stabilize incinerated teeth. The top two materials used are cyanoacrylate glue (Superglue) and Polyvinyl acetate glue.[12]

Based on the literature review, the authors attempted to classify the stabilizing agents into two categories, which are divided based on volatility and their composition. The classification chart synthesized from the literature is presented in Figure 2. Volatility describes how liquid evaporates and vaporizes into gas. This characteristic is of importance when choosing stabilizing agents for incinerated teeth, since volatile gas elements (such as ethanol, methyl methacrylate, and toluene in cyanoacrylate adhesives) could potentially contaminate the scene and compromise testing for accelerants when needed, for example, in arson cases.[13,14] A pilot study by Berketa et al[14] discovered that sprayed agents may drift up to 55 cm away from the specimen in an enclosed environment. The vapors could also be further spread out with wind, further increasing the area of contamination.[14]

Regarding its composition, stabilization agents could be divided into natural materials or synthetic materials. This classification also applies to materials used to treat archaeological skeletal specimens.[17] Synthetic materials usually encompass polymer-based materials or originate from the petrochemical industry, such as acrylic sprays. On the other hand, stabilizing agents made from natural ingredients are usually plant or animal-based and do not contain volatile components. According to the literature, stabilizing agent solutions have been created using agar (seaweed), gelatin (hydrolyzed collagen sourced from animal connective tissues, usually pigs or cows), and flour.[16]

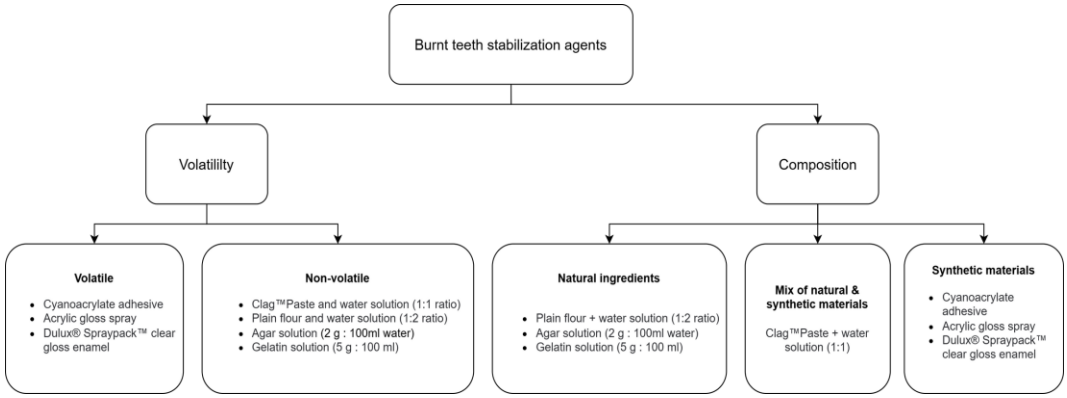

Figure 2. Classification of stabilization agents for incinerated teeth, which are based on the materials' volatility and composition.

Method of application

According to the study by Mincer et al[12], there were three main material application methods, which are sprayed, brushed, and dropped (droplet from a tube or squeeze bottle). They concluded that acrylic spray paint and cyanoacrylate glue are the most effective and efficient, especially acrylic spray paint, which is easier to apply in situ.[12] Ideally, a stabilizing agent for incinerated teeth must be able to be applied directly in the location of the incident, which is why portability and ease of use directly in the scene are key aspects to consider.[16] Furthermore, spraying allows a larger surface area coverage in a short amount of time compared to droplets from a tube, as long as the application is done at a proper distance so that the material is sprayed as a fine mist instead of a heavy spray.[9,12] On the other hand, there is also a risk of airborne contamination in an enclosed environment since sprayed liquid may drift up to 55 cm away from the intended target, and the vapors could also be further spread out with the wind. Thus, non-volatile stabilizing agents are preferred and should be further explored in future studies.[14]

Even though cyanoacrylate adhesives are shown to be effective for smaller areas, it is not recommended to spray cyanoacrylate solutions, as it is a health hazard due to the possibility of the invisible micro droplets of cured cyanoacrylate being trapped between eyelids and could cause abrasive damage to the operator and surrounding persons.[14,16] Siegert et al noted in their study that polyurethane squeeze bottles are practical to use for field application as opposed to using immersion or brushing techniques for stabilization of burned skeletal remains.[13] Hence, droplets from squeeze bottles might be preferred for specific cases, such as when the stabilizing agents are hazardous and cannot be transformed into a liquid solution for spraying purposes, or when the surface area of stabilization is minimal.

Visual observation (radiographical and surface appearance)

Griffiths and Bellamy encouraged using non-radiopaque materials for forensic odontologists to obtain good quality dental radiographs for further post mortem examination, such as for age estimation and dental comparison.[11] Dental age estimation methods often require radiographs to observe tooth development, dental pulp chamber changes, root length, and other variables. Methods of age estimation that use radiographs include the Schour and Massler atlas, Ubelaker Atlas, The London Atlas, Camierere's method, Demirjian's method, Thevissen, and many more.[7,18] Dental radiographs

are sometimes available in both ante mortem and post mortem records, enabling forensic odontologists to compare the dental anatomy, restorations, and endodontic treatment on the ante mortem and post mortem data.[19] The newer studies took before and after treatment radiographic photographs to ensure the radiopacity of the tested materials. They also filled some of the teeth with restorative materials to imitate the conditions of the human dentition. None of them impaired the results of the radiological assessment.[9,14,16]

Aside from the radiopacity, surface opacity of the stabilizing agents on the surface of the treated teeth was also an important aspect to note, as it will impair visibility for observation. As an example in Berketa et al's experiment, a flour mixture creates an opaque white-ish layer on incinerated samples compared to using a mixture of Clag™Paste and water, as well as commercial enamel gloss spray, which resulted in a transparent layer.[14]

Accessibility and preparation of materials

There is also an issue with acquiring the materials and preparing the solution of these stabilizing agents. Although commercially available products are more accessible, convenient, and excel in their ease of use, forensic practitioners have less control over the concentration of each element in the solution. Thus, their versatility decreases, limiting them to only be used in the field in situ. This applies to many of the materials mentioned, such as cyanoacrylate glue, Dulux© Spraypack™ enamel gloss spray, and other acrylic-type spray. Furthermore, some commercial materials might not be easily acquired outside of certain countries, such as the Clag™Paste that might not be available in many countries outside Australia. This means that the forensic odontologists must find similar materials that are equally effective to mimic the same results.[14] On the other hand, solutions that need to be manually prepared, such as the agar and gelatin solution, as well as the synthetic-based agents (such as the Acryloid™ B-72, Acrysol™ WS-24, Rhoplex™ B-60A, and Butvar® B-98), enable the practitioner to control the ratio and concentration. As an example, 10% concentration of Acryloid™ B-72 solution can be used for recovery in the crime scene, where the 50% concentration can be used during the analysis process for reconstruction purposes.[9,13]

Stabilizing agents made from natural ingredients such as flour mixture, agar, and gelatin also have their own quirks regarding the preparation. The practitioner must consider the application time after creating the solution. This is because the mixture might block the spray nozzle due to the cooling and setting, which will then inhibit the stabilizing process altogether. Agar will not dissolve until it reaches a temperature of 90°C, meaning that it will be difficult to create the agar-based stabilizing solution without a heat source at the scene. On the other hand, gelatin-based solution did not set and block the nozzle if immediately sprayed, but it will not fully set in a hot environment.[15,16]

Setting time

The setting time and the characteristics of how the stabilizing agents are set are also interesting to consider. Synthetic materials usually have a faster setting/curing time, making them more ideal for forensic evidence preservation.[9,15] The most used stabilizing agent, which is cyanoacrylate adhesives, is a double-edged sword in terms of this aspect. Because of its fast-setting time, cyanoacrylate adhesives have become a favorite choice among forensic odontologists. However, its flowability and rapid setting could also cause unwanted problems to arise, such as when it flows between the jaws and sets, which will make separation of the

jaws and eventual examination even more difficult.[5] Synthetic materials such as the Dulux© Spraypack™ enamel gloss spray have an acceptable setting time (15 minutes) and can be resprayed after 30 minutes if needed. However, this spray poses a potential problem due to its volatility.[9] Although tested on skeletal remains, Acrysol™ WS-24 and Rhoplex™ B-60A pass the criteria of being non-volatile with promising archival quality, but suffer from a slower setting time that could be disadvantageous for forensic investigations.[13]

As discussed previously, stabilizing agents made from agar and gelatin solutions are heavily affected by temperature, wind, and humidity, thus making their efficacy reliant on the environmental conditions.[14,15] Gelatin-based solution did not set inside the container nor block the nozzle if immediately sprayed at a temperature of 23-31°C, which makes it more practical than agar solution because agar needs to be at a temperature of 90°C to fully dissolve. However, gelatin melts with the increase of temperature, making agar and wheatpaste solutions more reliable in hotter environments.[15,16] Therefore, forensic practitioners must be certain whether or not the stabilizing agent has set on the surface of the burned sample before attempting to transport it elsewhere.[14]

Archival qualities

Long term storage—or in other words, archival properties—after application of the stabilizing material must also be considered, including color change of the specimen, shrinkage, cracking, flaking, warping, and the continued effectiveness of the stabilizing agent itself after a long period of time.[13,15] Topoleski suggested the use of food grade gelatin to preserve skeletal remains for at least 8 months, though unable to confirm any potential changes afterwards.[15] Berketa et al described no visual changes in the treated incinerated sheep dentition after one year of being treated with both flour-water mixture and ClagPaste-water mixture.[14] Despite the results, the long-term properties and their effect on the incinerated tissues are still questionable and should still be explored, since the stabilized samples might be relevant in the upcoming years when the case needs to be revisited again.[13]

Other Considerations and Limitations

At the end of the day, the true purpose of stabilizing incinerated teeth is to preserve dental evidence as much as possible to later be utilized for forensic identification. However, forensic odontologists must also consider not only odontology-related analysis, but also other aspects. Gelatin-based stabilizing agents may contaminate the burned dentition samples with non-human DNA due to the nature of gelatin being created from bovine or pig connective tissues. This could potentially disrupt DNA analysis attempts on the incinerated samples.[14,15] Besides DNA analysis, isotope analysis could still be performed on calcined samples, but synthetic stabilizing agents (especially polymers) could potentially impair isotope analysis because it adds additional carbon atoms to the sample, which will then produce inaccurate carbon dating on the samples if needed.[13]

As of this date, there are only very limited studies regarding stabilizing agents of burnt teeth, making this review article itself limited in terms of evidence gathering and discussion. In addition to that, three of the studies were done within the same country. Environmental conditions in other countries, especially with different climates, as well as accessibility to certain products, whether it be commercial or naturally sourced, might differ considerably in each region. As such, material

selection should also consider environmental factors and product availability, as mentioned previously in this article. [9,14,16] Furthermore, most of the experiments are done using only teeth and animal models (sheep mandibles). Only one literature used human jaws and teeth, but that is because it was a case report that describes the stabilizing method in a real fire-related case.[11] Albeit difficult to achieve due to ethical reasons, future studies could benefit from using human heads, or at least jaws with teeth still embedded.[16]

CONCLUSION

Stabilization of incinerated teeth is an imperative procedure in fire-related cases to ensure proper handling of burnt dental evidence, and thus promotes a conducive forensic identification process. If no postmortem dental data remains, then there is nothing to be compared to the antemortem data. This is also true for damaged or compromised postmortem dental data. However, at the same time, there are a few aspects to consider for a stabilizing agent to be an 'ideal' reinforcement method for incinerated teeth.

To balance the 'ideal' and the 'practical', the stabilizing agents criteria should be as followed: easy to apply, readily available in the market and/or easy to DIY, chemically stable, non-toxic and preferably non-volatile, portable and/or possible to be DIY-ed in the crime scene, radiolucent after application so that the postmortem dentition can be assessed using radiographic techniques. Cyanoacrylate glue seems to be the favorite and is still mentioned frequently due to its availability and rapid setting time. Stabilizing agents using spray could also be considered to increase surface area coverage and ensure efficient evidence handling time. However, when choosing to use sprays, the practitioner must consider the type of stabilizing agent used (e.g., whether it is volatile or not) and still strictly adhere to crime scene investigation protocols specific to the case at hand. Although proper selection of stabilizing agents and method of application is important, forensic odontologists must also consider other factors related to evidence handling, such as evidence storage time, proper containment and storage of evidence, as well as planning a safe route from the crime scene to the mortuary to ensure the best evidence preservation for forensic analysis.

Future prospective research regarding this topic would be to explore locally accessible commercial products for stabilization agents for burnt teeth, be it potential stabilizing agents made from synthetic or natural materials. Instead of limiting the search for materials from a dental perspective, future research could also explore stabilizing agents experimented on bones and archaeological samples, as they also share some similar qualities with burnt dentition, like being fragile and easily fragmented when not handled properly. Furthermore, experiments using human heads instead of animal models could be beneficial, but at the same time, difficult due to ethical reasons.

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