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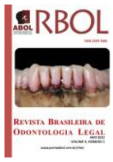

Forensic dentistry

EFFECTS OF INCINERATION TO DIFFERENT DENTAL MATERIALS USED IN PROSTHODONTICS: A SYSTEMATIC LITERATURE REVIEW.

Efeitos da incineração em diferentes materiais odontológicos usados em prótese dentária – revisão sistemática de literatura.

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ABSTRACT

Comprehensive data for the detectable changes occurring when various prosthodontic devices are exposed to elevated temperatures is still poorly recorded. The present study aimed to revisit the scientific literature in order to systematically review and assess experimental studies that analyze the effects of high temperature on different materials used in prosthodontics. A systematic literature review was structured according to PRISMA. Four primary electronic databases and one source of grey literature were searched. Only academic and peer-reviewed original experimental studies and proceedings of scientific conferences were included. The risk of bias was assessed using formulated questions by the authors adapted from the strategy proposed by Onofre et al. 2014. The search resulted in 1526 scientific articles, from which met the eligibility criteria. Out of the eligible studies, 60% exhibited a medium risk of bias, which demonstrates a positive characteristic of the present study. Results showed that the detectable changes due to extreme heat observed in the included studies were dependent on the type of prosthodontic device exposed and the type of material used in its fabrication. The data gathered from this study could aid further in the analysis and identification when dealing with incinerated remains.

KEYWORDS

Forensic dentistry; High temperature; Dental prosthesis; Dental implants.

INTRODUCTION

A disaster is defined as an event that originates from either a natural or man-made incident resulting in the occurrence of several injuries, structural damages and mortality[1]. Such events may be accompanied most often by the presence of fire, which remains to be one of the major causes of injury and death throughout the world and can result in severely burnt remains making identification very difficult [2]. Incidents of fire may be owed to electrical malfunctions or flammable materials present on the scene, which increases the severity of injuries and the number of mortalities. It has been found that the maximum temperature caused by petroleum combustion in burning vehicles can reach more than 1000 ºC[3,4] while natural firestorms can reach temperatures up to 2000 ºC[5,6]. In comparison, human cremation chambers may reach a maximum temperature that ranges from 950-1000 ºC[7,8].

The classification of bodily injury caused by burning was well described by Norrlander[9] into five categories: (A) superficial burns, (B) destroyed epidermis areas, (C) destruction of the epidermis, dermis, and necrotic areas in the underlying tissues, (D) total destruction of the skin and deep tissue, and (E) burned remains. With the 3rd, 4th and 5th category, it already demonstrates very extensive and widespread destruction of tissues which makes conventional methods of identification, such as the use of fingerprint and visual recognition, impossible to be utilized[10]. It is very important to be able to establish the identification of burned remains as it satisfies the social, criminal, marriage, monetary and emotional aspects of certain disaster incidents. For this reason, forensic odontology plays a vital role and is considered to be a well-established and reliable method in human identification of burnt human remains through dental means[11]. In some reports, this technique has still been the method of choice owing to 43-89% of positive identification[12].

The human teeth function as a relevant tool in forensics because it is one of the hardest and the most indestructible component of the human body[13]. This is possible due to the teeth' structural components, which makes them withstand harsh environments and therefore can be even salvaged for examination in decomposing or burned remains. However, when teeth are exposed to temperatures above 1000 ºC, it loses their organic components resulting to a higher tendency of shrinkage and fracture to happen[14,15]. This is where restorations and dental prosthetic materials come into play in supplementing the human identification process by dental means. In recent years, there has been a marked increase in the usage of restorative materials in dental treatments[16]. Based on a study, it showed that in some countries, half of the adult population has been wearing some type of prosthetic dental restoration[17], which increases the likelihood that these dental appliances will be present during post-mortem examinations. A number of studies show that when different restorative and prosthetic materials, such as amalgam[10,18-20], composite[10,18], glass ionomer[20], dentures made from a combination of a metal framework and acrylic base[21], implants[14,22-25] and orthodontic brackets[26] were exposed to elevated temperatures, they undergo several macroscopic changes depending on what temperature range these specimens were exposed to. The changes and behavior of these materials and dental structures including the color change[10, 20, 21], restoration removal[10,18], or breakdown of the natural teeth[10,20] can help in establishing the temperature from which these specific restorations and structures were exposed to during identification of the incinerated remains[27].

In addition, the advancement of dental technology has also introduced the utilization of several materials used in fabricating dental prostheses. Dental prostheses such as, implants, dentures or crowns, are commonly made with materials like cobalt-chromium, zirconia and pure titanium, which can have a melting point of 1330 ºC, 1650 ºC, 1850 ºC, respectively[22,28]. These results to the improved survivability of such materials from thermal insult than the human teeth leading to additional evidence to be used for identification. However, experimental studies on the detectable changes in prosthodontic materials due to exposure to high temperatures are still insufficient and lacking. For this reason, this study aimed to revisit the scientific literature to systematically review and assess experimental studies that analyze the effects of high temperature on different materials used in prosthodontics.

MATERIALS AND METHODS

A. Protocol

This present systematic literature review was performed following the guidelines and checklist provided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses PRISMA[29] (www.prisma-statement.org).

B. Study Design and Eligibility Criteria

A systematic literature review was designed in order to focus on answering the question: What are the detectable changes in prosthodontic materials when experimentally exposed to high temperature? The research question was based on the PICO strategy for Systematic Exploratory Review, wherein 'P' stands for population (prosthodontic materials); 'I' stands for intervention (exposure to high temperature); 'C' stands for comparison (non-exposed prosthodontic materials); 'O' stands for the outcome (detectable changes of the materials).

Inclusion Criteria: Included academic and peer-reviewed original experimental studies only regarding the effects of elevated temperature in different materials used in prosthodontics. Unpublished scientific products circulated in diverse channels of communications such as proceedings of scientific conferences, within the topic of interest. No restrictions of language, time and status of publication was applied.

Exclusion Criteria: books; book chapters; systematic literature reviews; letters to the editor and/or editorials; non-experimental studies.

C. Information Sources

A systematic review was performed in May 2021. The search for scientific articles regarding the field of interest was conducted using the following electronic databases: PubMed, ScienceDirect, Scopus, and Web of Science. In order to reduce any selection bias and to allow searching for unpublished scientific articles, the "Grey Literature" was verified through OpenGrey.

D. Search Strategy

The searching of scientific papers was established with a standard strategy using Medical Subject Headings (MeSH) such as, "effects," "incineration"," dental", "high temperature"," dental Crown"," dental prosthesis" and "dental implants" combined with the Boolean operators "AND" and "OR" - Table 1. The search and the subsequent processes were led by a forensic odontologist, familiar with the topic of interest, supervised by two other professionals in the field.

E. Search Selection

The selection process was performed in four steps. The first consisted of the identification of studies after bibliographic search. The studies were then imported through the research information system (RIS) into EndNote X9.3.3 software for Windows in order to remove the duplicates. Subsequently, manual removal of duplicates was performed to double-check the remaining articles using the same software. The second phase consisted of excluding studies based on title reading. In case of doubt regarding the eligibility of the study by title, exclusions were avoided at this phase. To be able to further screen the articles, the third phase established study exclusion based on the abstract reading. Lastly, in the fourth phase, exclusion was performed based on eligibility criteria after full-text reading.

F. Data Extraction of Included Articles

The initial data extracted from the included articles were the 1) authorship/year of publication; 2) study's country of origin; 3) type of experimental study; 4) specific prosthodontic appliance used; 5) brand and material from which the prosthodontic appliance was fabricated;6) the heating machine utilized; 7) the temperature interval and 8) temperature range from which the prosthodontic materials were exposed to; 9) time of exposure; and 10) the type of cooling implemented after exposure of the specimens to heat.

The data extracted from the studies were qualitatively compared and analyzed through the compilation of the most pertinent findings across the studies. These included information regarding the a) type of prosthodontic appliance used; b) whether the dental prostheses were separately exposed or in combination with other *ex-vivo* anatomic structures (tooth, bone, or ribs); c) the variations in temperature ranges; d) time and manner of exposure; e) the type of cooling employed after heating of the prosthodontic appliance and lastly g) the outcomes of each study.

Furthermore, extracted variables/ data such as the number of implants and crowns for each specific brand/manufacturer in each article were also utilized for the quantitative analysis by calculating the absolute (n) and relative frequencies (%) for each data collection. Absolute frequency (n), was defined as the number of occurrences of a value/phenomenon in a given set of data while relative frequency, expressed in percentage, was defined as the absolute frequency expressed as the proportion of the total frequency multiplied by 100.

Table 1. Electronic databases and applied search strategy.

Database	Search strategy	Total
PubMed http://www.ncbi.nlm.nih.gov/ Pubmed	((“high temperature” OR “cremation” OR “incineration”) AND ((“dental”)AND (“implants” OR “crowns” OR “prosthesis”)))	675
	((“high temperature” OR “cremation” OR “incineration”) AND ((“dental”)AND (“implants” OR “crowns” OR “dentures”)))	497
	((“cremation”) AND ((“dental”) AND (“implants” OR “crowns” OR “dentures”))	15
	((“incineration”) AND ((“dental”) AND (“implants” OR “crowns” OR “dentures”))	16
ScienceDirect http://www.sciencedirect.com	((“incineration”) AND ((“dental”) AND (“implants” OR “crowns” OR “prosthesis” OR “restorations”)))	210
Scopus https://www.scopus.com	((“incineration”) AND ((“dental”) AND (“implants” OR “crowns” OR “prosthesis” OR “restorations”)))	70
Web of Science http://apps.webofknowledge.com	((“incineration”) AND ((“dental”) AND (“implants” OR “crowns” OR “prosthesis”)))	4
	((“incineration”) AND (“dental implants” OR “dental crowns” OR “dental dentures”))	39
OpenGray http://www.opengrey.eu	((“incineration”) AND ((“dental”) AND (“implants” OR “crowns” OR “prosthesis”)))	0
Total		**1526**

The results of the analysis and comparison were visually represented and summarized in a tabular form to demonstrate patterns and relationships on the methods and outcomes of the included articles.

G. Risk of Bias of Eligible Studies

The individual risk of bias concerning the procedural qualities of each eligible study was assessed using formulated questions by the authors adapted from the strategy proposed by Onofre et al.[30] in 2014. The following questions were used: 1) Are the ethical aspects mentioned? 2) Is the study design described? 3) Is there a rationale for sample size calculation? 4) Were the prosthodontic specimens new? 5) Were the prosthodontic specimens with similar dimensions/type? 6) Were the prosthodontic specimens manufactured from the same company? 7) Was temperature control described? 8) Was time interval between temperatures described? 9) Were macro- or microscopic analyses reported? 10) Were visual, photographic or radiographic analyses reported? Two authors independently read and assessed the studies following PRISMA guidelines[29].

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Each of the studies was categorized depending on the percentage of positive answers to each of the questions. A high risk of bias was registered when a study answered positively up to 49%; moderate risk of bias ranged between 50% and 69% of positive answers; and low risk of bias was found when positive answers were above 70%.

RESULTS

A. Study Selection

The initial search resulted in 1526 scientific articles distributed in five electronic databases, including the gray literature. There were 998 studies that remained after the removal of the duplicates. A total of 993 papers were subsequently excluded by screening, which resulted in five full articles eligible for full-text reading. The excluded papers did not meet the inclusion criteria due to different reasons as described in figure 1. There were five additional studies, added by the expert after full-text reading, which were not identified during the initial searching phase using the databases, although they have satisfied the inclusion criteria and were later added for the systematic review. Finally, ten qualified scientific articles were included for the final line-up of papers that were analyzed and evaluated for this systematic review.

B. Characteristics of eligible studies

The extracted data from the included studies were summarized in table 2. Based on the analysis performed on the articles in this systematic review, it exhibited that the year of publication of the literature were in between 2002 and 2020. All of the articles were experimental studies in which they investigated the effects of high temperature on different prosthodontic appliances fabricated from various materials and brands/manufacturers. The experimental studies originated from a variety of locations with most of the papers emanating from Australia (n=4) [14, 22-24] and India (n=4) [16, 19, 31, 32], while one paper each originated from Brazil (n=1)[25] and Italy (n=1)[21]. All of the studies may have included at least one type of dental prosthetic restoration which was either an implant, crown or dentures that were exposed to elevated temperatures. Among the ten eligible studies, five experimentations conducted in Australia and Brazil investigated the effects of elevated temperatures on dental implants. Four scientific articles from Australia, focusing on implants alone, were systematically done and were performed by the same authors. The first two studies[22,23] published in 2010 and 2011 respectively, were executed by utilizing in-vitro exposure of the dental implants. Subsequently, the other two articles[14,24] from 2011 and 2014, exposed dental implants that were integrated into jaw bones. The sole Brazilian study[25] included integration of the dental implants in a pig's sectioned ribs before heat exposure.

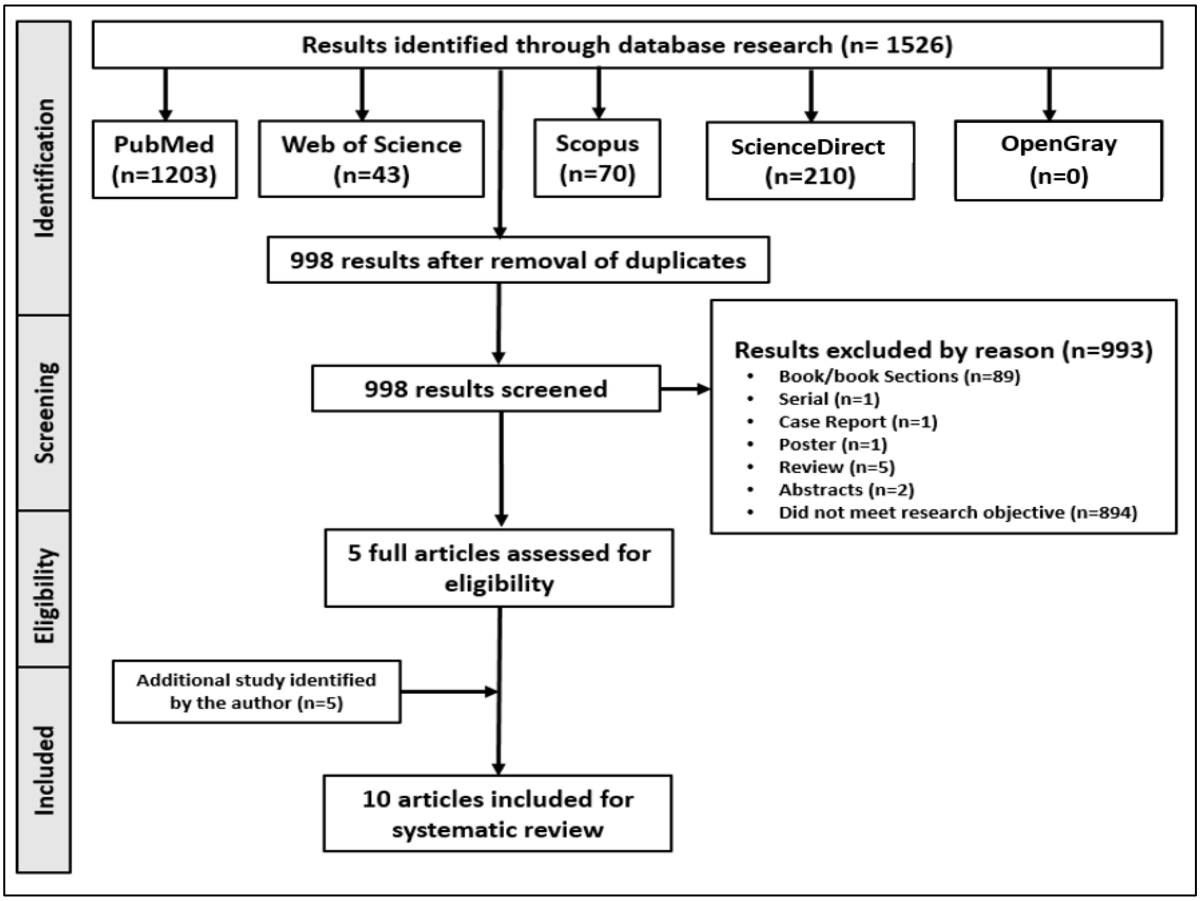

Figure 1: Flowchart depicting the steps of the present systematic literature review and quantification of studies from literature search to selection criteria of included scientific articles adapted from PRISMA[29].

Table 2: Summary of main descriptive characteristics of eligible studies.

Author/Year	Country	Experimental Study	Dental Prosthetic Material	Specific Type and Brand	Heating Machine	Temperature Rise	Temperature Range	Time of Exposure	Type of Cooling
Berketa et al. [22](2010)	Australia	In vitro	Implants	• Straumann™ Standard Plus 3.3 x 8 mm implant, with no healing cap nor abutment [β] • Straumann™ Standard Plus 3.3 x 8 mm with abutment [β]	INFI-TROL™ kiln	N/A	Heated to 1125ºC	5-min at 1125 ºC	Type 1
Berketa et al. [23](2011)	Australia	In Vitro	Implants	• Straumann™ Standard Plus 3.3 X 8 mm (Pure Titanium) [β] • Nobel-Biocare™ Branemark Mk III Groovy 15 X 5 mm (Pure Titanium)[Σ] • Nobel-Biocare™ All-in-one™ 13 X 3 mm (Pure Titanium)[Σ] • 3i Biomet Certain 4 X 8.5 mm(Alloy)[Ω]	INFI-TROL™ kiln	N/A	Heated to 1125ºC	N/A	Type 1
Berketa et. al [24](2011)	Australia	Non-Osseointigrated in sheep mandible	Implants	• Straumann™ Regular 3.3 x 10mm [β] • Nobel Biocare Replace Select™4.3 x 8mm[Σ] • Ankylos plus 3.5 x 17mm[Δ] • Zimmer™ 3.7 x 13 mm [Ω] • Neoss™ 3.5 x 9mm[¥]	Animal Cremation Chamber* (gas fired Pathological Incinerator)	N/A	Heated to 780ºC	2.5 hours	Type 1
Berketa et al. [14](2014)	Australia	Osseointigrated in Human Maxilla/ Mandible	Implants	• Gold Alloy Hybrid(CALCITEK)[Φ] • Titanium Alloy Hybrid(CALCITEK)[Φ]	Human Cremation Chamber*	N/A	Heated to 1050ºC	N/A	Type 2
Bonetti et. al. [25](2020)	Brazil	Non-Osseointigrated in sectioned pig ribs	Implants	• Pure Titanium, Cylindrical,3.5 mm × 15 mm*	EDG 10P-S oven	N/A	200ºC, 400ºC and 600ºC	30 min/temperature	N/A
Merlati et al. [21](2002)	Italy	Teeth(Unrestored/ Restored), Crowns,	Crowns	• Fixed Prosthetic Crown or Bridge made of polycarbonate, acrylic or composite material (FC-PAC)*	Laboratory Furnace*	30 ºC/min	200–1100ºC	6.6min (RT-200°C) to 36.6min (RT-1100°C)	Type 1

Author/Year	Country	Experimental Study	Dental Prosthetic Material	Specific Type and Brand	Heating Machine	Temperature Rise	Temperature Range	Time of Exposure	Type of Cooling
		Bridges, Dentures		• Fixed Prosthetic Crown or Bridge made in metal alloy covered with aesthetic resinous material (FC-MAR)* • Fixed Prosthetic Crown or Bridge made in metal-feldspathic (FC-PFM)*					
			Dentures	• Removable Partial Denture (base metal alloy framework and acrylic resin denture base)					
Lokhasudhan and Ajitha[32](2017)	India	In Vitro	Crowns	• Lithium disilicate (Emax)[α] • Zirconia (BruxZir)[θ] • Indirect composite resin (Adoro)[α]	Laboratory Furnace*	N/A	400 ºC and 1100 ºC	5,15,30 min (400 ºC) 15 min (1100 ºC)	N/A
Patidar et al. [16](2010)	India	Teeth(Unrestored/ Restored), Crowns on teeth	Crowns	• Nickel-Chromium(NiCr) Metal Crown[π] • Metal-Ceramic Crown(PFM)[Φ]	Laboratory Furnace*	N/A	400ºC and 1100ºC	5,15,30 min (400 ºC) 15 min (1100 ºC)	N/A
Khirtika and Ramesh[31] (2017)	India	Endodontically treated teeth restored with crowns	Crowns	• All ceramic (zirconia) crowns* • Metal ceramic crowns*	Laboratory Furnace*	30 ºC/min	400ºC, 800ºC, and 1200ºC	5 min(400ºC), 5 min (800ºC),and 15 min(1200ºC)	N/A
Pol et al. [19](2015)	India	Teeth(Unrestored/ Restored), Crowns on teeth	Crowns	• All Ceramic (Ceramco II)[□]	Laboratory Furnace*	30 ºC/min	200ºC, 400ºC, 600ºC, 800ºC and 1000ºC	15 min/ temperature	Type 1

* Brand not specified; β- Straumann Dental Implant System (Straumann's factory, Villeret, Switzerland); ∑- Nobel Biocare Implant System(Nobel Biocare Company, United States, Sweden and Japan); Ω- Zimmer Biomet Dental Certain Implant System (Zimmer Biomet Holdings Inc., United States); ∆- Ankylos C/X Implant System (Dentsply Sirona, Germany) ; ¥- Neoss Implant System (Neoss, Sweden) Ψ- Calcitek Implant System (Calcitek Inc., Sulzer Medica, Carlsbad, CA, USA); α- Emax/Adoro (Ivoclar-Vivadent, Schaan, Liechtenstein); θ-BruxZir (Glidwell laboratories, USA); π- Ruby max white metal soft type, (Ruby Dental Products, Osaka, Japan); ф- Ceramic powder-Ceramco 3 (Dentsply USA) /Metal-Max bond (Ruby Dental Products, Osaka, Japan); □- Ceramco II (Dentsply International Inc., New York, United States); Types of cooling: Type 1, removed from heating device and cooled in air to room temperature (RT); Type 2, left overnight to cool down.

Concerning the relative frequency (table 3) of which brand and manufacturer of implant specimens were used in the five studies, it showed that most were manufactured by Straumann Dental Implant System followed by Zimmer Biomet Dental Certain Implant System with 33.33% and 22.22% of occurrence, respectively.

Table 3: Relative and absolute frequencies of implant brand/manufacturer

Implant brand/manufacturer	Articles using Specific Brand	Absolute Frequency (n)	Relative Frequency (%)
Straumann Dental Implant System (Straumann's factory, Villeret, Switzerland);	Berketa et al. [22](2010) Berketa et al. [23](2011) Berketa et. al [24](2011)	3	33.33%
Nobel Biocare Implant System (Nobel Biocare Company, United States, Sweden and Japan)	Berketa et al. [23](2011)	1	11.11%
Zimmer Biomet Dental Certain Implant System (Zimmer Biomet Holdings Inc., United States)	Berketa et al. [23](2011) Berketa et. al [24](2011)	2	22.22%
Ankylos C/X Implant System (Denstply Sirona, Germany)	Berketa et. al [24](2011)	1	11.11%
Neoss Implant System (Neoss, Sweden)	Berketa et. al [24](2011)	1	11.11%
Calcitek Implant System (Calcitek Inc., Sulzer Medica, Carlsbad, CA, USA)	Berketa et al. [14](2014)	1	11.11%
TOTAL FREQUENCY	**9**		

**Quantitative analysis of the frequency only utilized the extracted data regarding the specific manufacturer of the implants identified in the eligible studies regardless of other variables such as the type and the brand. One study[25] was not included in the analysis because the brand and manufacturer of the implant were not mentioned.*

In the case of dental crowns, most of the articles were performed from India[16,19,31,32] with one study emerging from Italy[21]. Among the five studies, four[16,19,21,31] of which were performed exposure of dental crowns which were cemented/attached to a natural tooth, while only one study[32] utilized in-vitro exposure. Results from the quantitative analysis (table 4) demonstrated the utilization of various brands of dental crowns that were exposed to high temperatures. The data from this analysis were based on studies where specific brands were mentioned.

Table 4: Relative and absolute frequencies of crown brand/manufacturer.

Crown brand/manufacturer	Articles using Specific Brand	Absolute Frequency (n)	Relative Frequency (%)
Emax (Ivoclar-Vivadent, Schaan, Liechtenstein)	Lokhasudhan and Ajitha[32](2017)	1	17%
Adoro(Ivoclar-Vivadent, Schaan, Liechtenstein	Lokhasudhan and Ajitha[32](2017)	1	17%
BruxZir (Glidewell laboratories, USA)	Lokhasudhan and Ajitha[32](2017)	1	17%
Ruby max white metal soft type, (Ruby Dental Products, Osaka, Japan)	Patidar et al. [16](2010)	1	17%
Ceramco 3 (Dentsply USA) /Metal-Max bond (Ruby Dental Products, Osaka, Japan)	Patidar et al. [16](2010)	1	17%
Ceramco II (Dentsply International Inc., New York, United States)	Pol et al.[19] (2017)	1	17%
TOTAL FREQUENCY	**6**		

The inclusion of the effects of heat on dentures was conducted only by a single study[21], which made use of a removable partial denture composed of a combination of an acrylic denture base and a metal framework.

Most of the heat exposure was done using a laboratory furnace except for one study that used a human cremation chamber. Amongst the included studies, five[14,21-24] of which performed constant exposure of the prosthodontic restorations to a temperature with maximum heat in between 780ºC- 1125ºC, while the remaining articles[16,19,25,31,32] utilized incremental increase in temperature from 200ºC, 400ºC, 600ºC, 800ºC, 1000ºC, 1100ºC and 1200ºC with varying exposure times.

After heating, the manner of cooling of the specimens was also analyzed. It demonstrated that, majority of the publications[19,21-24] immediately removed the specimens from the heating device and cooled them in the air to room temperature (Type 1). In contrast, only one article[14] performed cooling by leaving the specimens to cool down overnight (Type 2). Lastly, for the remaining articles the authors did not mention any cooling regime after the exposure.

C. Individual outcomes of the studies

The summary of outcomes from the eligible studies demonstrating the varying changes of dental prosthetic materials after exposure to elevated temperatures was listed in table 5.

C.1 Dental implants

After exposure of implant restorations to extreme heat, overall, it demonstrated minimal detectable changes in its physical properties with great survivability to thermal insults whatever material was used in the implant's fabrication. Studies[14,24] integrating implants in bone structures mostly conducted long exposure of the specimens to elevated temperatures above 600 ºC, resulting in the bone becoming fragile and unstable. The fragility of the bone surrounding the implants caused detachment and separation of the implants except in one study[25] in which they remained attached. The absence of detachment was because of the lower temperature used in the exposure of the specimens.

The survivability of implants compared to bone was higher because of the implant's structural and physical components. However, the presence of sagging/melting of the metal[14] was seen but was not associated with the implants themselves but rather with the restoration attached on the implants, which was made from a different material with a lower melting point. With in-vitro studies, it demonstrated that there was a slight increase in the implant's dimensions due to the formation of an external crust, approximately 0.01mm thick[23], subsequently from the oxidation process underwent by the metal upon incineration. The oxidation process also contributed to the obvious change in the surface color of the implants, but the specific color produced was not consistent with the type of material that the implants were made of. Lastly, results from incineration also demonstrated that serial numbers inscribed on the implants were preserved most often when an abutment/ healing cap was attached and can be a tool to be used for identification purposes.

C.2 Dental crowns

The dental crown specimens used in the included studies involved those which were fabricated from several materials, which include all metal[16], all ceramic[19,21,31,32] or a combination of both[16,21,31]. There was increased resistance and survivability from extreme thermal insult with slight changes in morphology in materials involving porcelain[16,19,21,31], zirconia[31,32], lithium disilicate[32] and the metal component[16,21,31] in combined materials. In contrast, materials such as composites or were resinous in nature demonstrated total disappearance when exposed to temperatures ranging from 400ºC to 600 ºC[21,32]. Furthermore, the metal component in combined materials underwent a change in color upon exposure to high temperature resulting from the oxidation process. Lastly, with crowns specimens cemented on teeth, results showed that the prosthetic crowns were displaced due to the disintegration of the natural teeth caused by extreme heat, which was where the restorations were attached[16,19,31].

C.3 Dentures

Only one study[21] performed exposure of denture to extreme heat, which involved a dental prosthesis made from a combination of metal for the framework and resinous material for the artificial teeth and gums. Results from the study demonstrated that the metal framework survived the incineration wherein the dimensions were unaltered and only presented a change in color typically because of the oxidation process. However, regarding the artificial teeth and gums, since resinous materials have lower melting points, they went undetectable when exposed at a temperature of 600ºC, similarly in crowns made from the same material.

III.D. Risk of Bias of Eligible Studies

The majority of the included studies[14,19,21,23,25,31] presented the medium risk of bias indicating a percentage of answers with "yes" to the formulated questions ranging between 50% to 69%. While two studies each were categorized for low[16,22] and high[24,32] risk of bias - Table 6.

DISCUSSION

Identification by dental means has played a vital role as a reliable and well-established method in dealing with incinerated human remains[13]. While facial recognition and fingerprint analysis may deem difficult to use during this situation, great importance has been given in the employment of the knowledge on teeth, in particular its anatomy and morphology, in the identification process. Although to some degree, dental remains may survive and retain some of its anatomical properties after incineration; they may however undergo morphological alterations and can be extremely fragile especially in prolonged exposure to high temperature[33]. In such circumstances, dental treatments present on an individual may provide additional information, which is useful in the comparative and reconciliation phase of identification.

Abundant studies have been conducted on the analysis of the effects of elevated temperature on both intact teeth and with those treated with restorative materials such as amalgam, glass ionomer, and composite resins[10,16,18-21,32,34]. Most of the evident alterations, based on the studies, can be attributed to the color of the restorative material, which will differ depending on the time of exposure, the intensity of the heat, and the microscopic changes seen in scanning electron microscopic (SEM) analysis.

However, data on the detectable changes in prosthodontic materials namely, crowns, implants and dentures, when experimentally exposed to high temperature especially with the recent materials used in fabrication is still inadequate. Prosthodontic devices have higher survivability against thermal insult compared to restorative material owing to their physical properties and having extremely high melting points that could assist in identification of severely incinerated victims[13].

Table 6: Risk of bias assessed using formulated questions by the authors adapted from the strategy proposed by Onofre et al.[30] in 2014.

Authorship, year	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	%-YES	Risk of Bias
Berketa et al. [22](2010)	-	-	-	√	√	√	√	√	√	√	70	Low
Berketa et al. [23](2011)	-	-	-	√	-	-	√	√	√	√	50	Medium
Berketa et. al [24](2011)	-	-	-	√	-	-	-	√	√	√	40	High
Berketa et al. [14](2014)	√	-	-	-	√	√	√	-	√	√	60	Medium
Bonetti et. al. [25](2020)	-	-	-	*N/A*	√	*N/A*	√	-	√	√	50	Medium
Merlati et al. [21](2002)	-	√	-	-	-	-	√	√	√	√	50	Medium
Lokhasudhan and Ajitha[32](2017)	-	√	-	*N/A*	-	-	√	√	-	-	33	High
Patidar et al.[16](2010)	-	-	-	√	√	√	√	√	√	√	70	Low
Khirtika and Ramesh[31](2017)	-	-	-	-	√	-	√	√	√	√	50	Medium
Pol et al.[19](2015)	-	-	-	-	√	√	√	√	√	√	60	Medium

√: yes; -: no; N/A: not applicable Q1) Are the ethical aspects mentioned? Q2) Is the study design described? Q3) Is there rationale for sample size calculation? Q4) Were the prosthodontic specimens new? Q5) Were the prosthodontic specimens with similar dimensions/type? Q6) Were the prosthodontic specimens manufactured from the same company? Q7) Was temperature control described? Q8) Was the time interval between temperatures described? Q9) Were macro- or microscopic analyses reported? Q10) Were visual, photographic or radiographic analyses reported?

The present study aimed to review and assess the literature regarding scientific articles conducting experimentation on the effects of elevated temperature on different prosthodontic devices.

The results from the review demonstrate that like teeth and restorative materials, prosthodontic devices also undergo detectable changes which correlate significantly with the exposure to different temperatures at various durations. Overall, the observed changes are mostly influenced by the type of device exposed, whether it is a crown, implant or denture and the physiochemical properties of the materials used to fabricate each prosthodontic device. The factors abovementioned coincide with Merlati et al.[21] and Reesu et al.'s[13] observations that these elements greatly contributed to the capacity of the materials to be recognized and identified even after exposure to intense heat.

Although almost all of the eligible studies performed a laboratory-based heating regimen as seen in table 4, data from each study has been interpreted with caution due to several factors not considered like those present in tangible situations. These real-life circumstances, as mentioned in the articles written by Sandholzer[35], Reesu et al.[13], Merlati et al.[21], and Gonzales-Colmenares et al.[26], include the presence of soft (i.e. lips, cheeks and tongue) and hard tissue (i.e. alveolar bone) surrounding the dental components and the devices which functions as protection and provide insulation during exposure to fire but can also alter the color of the incinerated dental structures[7,21,36]. In addition, elements such as the duration of heat exposure, the manner of fire development, the rate of temperature increase, and the substance used to extinguish the fire[21] are also not considered in the included studies and could affect the condition of the incinerated remains. Herewith, to be able to replicate the actual circumstances during fire exposure, Bohnert et al.[37] and Muller et al.[38] suggest that in the experimental studies the exposure to constant temperature may be comparable to sudden thermal shock, which was applied by five eligible studies[14,21-24], whilst incremental exposure as performed by the other half[16,19,25,31,32], can be similar to the slow increase in temperature due to the presence of protective structures. Regarding the cooling procedure, the studies only performed air cooling either until the heated specimens reached room temperature (type1) or overnight cooling (type 2). In contrast with real-life situations, fire extinguishers are most often used to cool the incinerated remains and are dependent on the specific type of fire namely: Type A- ordinary combustibles such as wood, cloth and paper in which water based substances are used; Type B-flammable liquids such as oils and grease where carbon dioxide, dry chemical and foam water are used; Type C- involving fire caused by live electrical equipment and can be extinguished with dry chemicals and carbon dioxide; lastly, type D- combustible metals like magnesium, potassium and sodium which can be extinguished by heat absorbing medium such as dry powders[39,40]. These in vivo and ex vivo circumstances may have an effect on the macroscopic alterations in heated prosthodontic devices observed between exposure to heat using a laboratory-based regimen compared to actual fire conditions.

The eligible studies were performed using formulated questionnaires by the authors to assess the risk of bias in each study. The adapted approach for the construction of the questions was based on the proposed strategy of Onofre et al.[30] in 2014. The rationale for this approach is used in this study because according to Tran et al.[41] in 2021, it showed that in 51% of in-vitro studies, risk assessment questions were formulated by their own authors and were mostly established on the strategy utilized by Onofre et al[30]. Most of the included studies (n=6) in this systematic review demonstrated medium risk of bias, which exhibits a positive characteristic of the present study. However, regarding in-vitro/laboratory-based experiments, authors of future studies are still encouraged to follow standardized protocols for conducting and reporting data, including consideration of ethical aspects, detailed description of the study design, and demonstrating rationale for sample size calculation.

The advancement of dental technology has introduced numerous types of restorative treatment options in replacing missing teeth in particular dental endosseous implants, which has been growing in usage exponentially and increases the likelihood to be present in post-mortem dental examination[13]. A study by Al-Wahadni et al.[42] from surveying 2001 dentists revealed that in implant system selection practices, practitioners tend to largely base their selection on implant-abutment connections as well as the available scientific evidence for the of the implant system. In ten-year retrospective studies[43-45], it exhibited that Straumann implants have a very high long-term survival rate, low incidence of pathological reaction during osseointegration, and showed low failure rate which implies to the increased usage of this system by dental practitioners. These correlates to the result of the review demonstrating multiple frequency of Straumann specimens being used in the experimental studies due to the increasing likelihood of finding this type of implant in incinerated remains. In the included studies, two main methodologies were performed including in-vitro and ex-vivo exposure through integration to bony structures. Great emphasis must be given to the results of studies that integrated dental implants to bone because it can be comparable to actual circumstances in incinerated remains. In osseointegrated implants, the area most susceptible to increase exposure to heat would be the coronal part where the healing cap or the final restoration would be attached.

Although implants are generally resistant to thermal insults due to their physical properties[14,22-25], several challenges might be encountered when it is utilized as a tool for identification. Firstly, the recognition of the engraved unique serial numbers, specifically in included studies[23,24] that exposed Straumann implants, might impose some difficulty in visualization especially when the implants are osseointegrated. In the in-vitro experimentation performed by Berketa et al.[23,24], it was observed that the batch numbers can still be visualized particularly when a healing cap or abutment is attached over the implant as it serves as a protection from the formation of oxidation layer. However, in actual cases of incinerated remains, the coronal area that is not surrounded by bone is exposed to more heat and may result in melting and fusing of the restoration/abutment to the implant. These findings were observed, likewise, in a study using osseointegrated implants with superstructures wherein the increased oxidation created a welding effect between the implant and the attached component that made the implant cap impossible to remove[14]. This makes the access for the visualization of the serial number very difficult. Second, the formation of an oxidation layer, initially described by Pilling and Bedworth[46], on the implant's surface resulting from the reaction of the metal to elevated temperatures may also affect the identification process. The layer produced on the implant's surface consists of a fragile crust resulting to the change in the implant's surface color. In the first study of Berketa et al.[23], it was mentioned that pure titanium implants produced a distinctive gold crust on the surface that did not occur on alloy type implants. In contrast, the succeeding study[24] demonstrated that this specific crust color was not produced even if it was from the same manufacturer and was fabricated from the same metal. Similarly, in a study that exposed pure titanium implants from a different manufacturer, it was observed that the implant's color changed to grey, which implies that the gold crust layer was not a consistent indicator with implants that are titanium in origin. These inconsistencies suggest that the color of the oxidation layer should not be used for identification of the specific metal or alloy used in the fabrication of the implant. Instead, utilization of scanning electron microscopy and elemental analysis should be the best option in this situation[22]. In addition, the location in the jaw, presence and type of abutment/restoration and distinctive features (i.e., tapered/straight, thread pattern etc.) of the implant, which was employed by Berketa et.al[14] in 2014, can also be used as a strategy when dealing with implants during post-mortem dental examination.

The second prosthodontic device of interest reviewed in this study was the effects of heat exposure on different types of dental crowns. In general, there was increased survivability in crowns made of porcelain[16,19,21,31], zirconia[31,32], lithium disilicate[32] and full metal crown or the metal component in crowns with combined materials[16,21,31] than with composite or those which were resinous in origin[21,32]. In crowns with porcelain components, Pol et al.[19], Khirtika et al.[31], Patidar et al.[16], and Merlati et al.[21] observed similar outcomes even though the crowns were from different manufacturers and exposed to either incremental increase or constant temperatures. There were no significant changes happened on the crowns not until the temperature reached 1000 ºC where the loss of glaze, splintering, and morphological changes occurred. Unlike porcelain, crowns made from zirconia[31,32] that were exposed in incremental increase in temperature, only presented with very slight morphological change, even when exposed to temperatures exceeding 1000 ºC. The metal crowns[16], particularly nickel-chromium, and the metal component of crowns with fused materials[21] exhibited change in surface color, similar to implants [14,22-24], because of the oxidation process occurring when metal is exposed to high temperature.

The resistance to the thermal insult of materials fabricated from components such as porcelain, zirconia, lithium di-silicate and nickel-chromium is mainly caused by their innate physical properties specifically having a very high melting point, 850–1100 ºC[47], 1170-2680 ºC[48], 1032 ºC[49], and 1400 ºC[50] respectively. These temperatures are relatively higher than actual fire conditions like burning vehicles, which can reach more than 1000 ºC[3,4] or human cremation chambers with maximum temperatures from 950-1000 ºC[7,8] therefore giving rise to the above-mentioned materials' increase survivability. However, during forensic investigations, incinerated remains including charred teeth become very unstable and fragile[13]. This becomes a significant problem because dental crowns are supported by natural tooth structures that may not survive very high temperature unlike the aforementioned materials. Based on this systematic review, displacement of the crowns takes place between 600 to 800 ºC due to the fracture and disintegration of enamel, which is the structure where the prostheses are cemented. These findings were comparable from the studies of Merlati et al. in 2002[21] and 2004[18] intact restored and un-restored teeth were exposed to elevated temperatures. The fragility of the teeth supporting the devices increases the probability of it being lost or detached during forensic work. Thereby, it is very significant that proper technique in stabilization should be employed during retrieval and examination of incinerated remains to prevent losing valuable dental evidence like crowns and implants during identification.

The last prosthodontic appliance of interest is the observation of the effects of elevated temperatures in a denture. In the current study, only one scientific article experimented on exposure of denture to heat, which involved a removable partial prosthesis made from base metal alloy for the framework and acrylic resin for the artificial teeth and denture base[21]. Based on the results of the included study, it showed that at 400 ºC the denture base and artificial teeth made from polymethyl methacrylate (PMMA) were completely burnt and charred. In contrast, the metal framework, even 1100 ºC, only demonstrated change in color due to oxidation process that increases with elevation of temperature. In addition, there were no alterations observed and the structural morphology of the framework was well preserved. In dentistry, cobalt-chromium based alloys which contain mainly cobalt, chromium and trace materials, have been commonly used in the fabrication of the metallic framework in removable dentures[51]. Crooks[52] described that this alloy is known for its satisfactory resistance to tarnish and corrosion, and are high strength and heat-resistant (melting point: 1330 ºC[53]), which explains the excellent survival capability of the material against thermal insult as seen in the results of the study by Merlati et al.[21]. As opposed to polymethyl methacrylate (PMMA), which has a melting point of 120 but was observed by Merlati et al[21] to only show softening of the material at 200 ºC. Even though the acrylic base is more susceptible to damage in thermal insults, informations from the denture design, coverage of edentulous areas, type of material used, and manufacturer of the prosthesis can still be utilized in order to supplement the data used in comparative dental analysis. However, great caution is advised in the interpretation of the results from this experimental study because the outcome presented might be dissimilar and cannot represent other materials, although similar in type but different in composition and processing method.

The outcomes observed from the ten eligible studies demonstrated that detectable changes in dental crowns, implants and dentures could be correlated to the temperature from which they are exposed to. However, data are only limited to the materials that were included in the study as well as exposure to heat was only done in a controlled environment which might be different to actual conditions considering fire dynamics. The present study suggests that in further experimentations there should be inclusion of more materials available in the market for the fabrication of different prosthodontic device to be able to create enough data to support the findings during post-mortem dental examination. Furthermore, increased documentation, through visual aid, regarding the detectable changes should be presented for enhancement of the comparison.

FINAL CONSIDERATIONS

Forensic dentists employ several techniques in the retrieval, analysis, and identification of incinerated remains during post-mortem examination. With the increasing usage of several restorations and prosthodontic devices as treatment options, information regarding their properties, type of material used in fabrication, location in the mouth and detectable changes due to effects of elevated temperature can aid in dealing with burned remains.

The present study encourages experimentation of more types of materials not only limited to prosthodontic devices, but also covering all dental materials used in all aspects of dentistry as treatment inside the mouth. Furthermore, experimental studies must be supplemented by optimal documentation of the outcomes through good quality images and accurate, complete, and detailed worded interpretation of the photographs in order increase the understanding and appreciation of the study. Finally, in reference to the findings of this research, future laboratory-based studies on effects of incineration to different dental materials must take into consideration tangible simulation of fire dynamics and conditions, although in a controlled environment, in order to increase the ecological validity of the result.

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RESUMO

Dados abrangentes sobre as mudanças detectáveis que ocorrem quando vários dispositivos protéticos são expostos a temperaturas elevadas ainda são pouco registrados. O presente estudo teve como objetivo revisitar a literatura científica a fim de revisar e avaliar sistematicamente estudos experimentais que analisam os efeitos da alta temperatura em diferentes materiais utilizados em prótese. Uma revisão sistemática da literatura foi estruturada de acordo com PRISMA. Quatro bases de dados foram pesquisadas e uma fonte de literatura cinzenta (grey literature) foi selecionada. Apenas estudos acadêmicos de revisão, experimentais, originais e revisados por pares e anais de conferências científicas foram incluídos. O risco de viés foi avaliado por meio de questões formuladas pelos autores e adaptadas usando a estratégia proposta por Onofre et al. (2014). A busca resultou em 1526 artigos científicos, dos quais atenderam aos critérios de elegibilidade. Dos estudos elegíveis, 60% apresentaram risco médio de viés, o que demonstra uma característica positiva do presente estudo. Os resultados mostraram que as alterações detectáveis devido ao calor extremo observadas nos estudos incluídos foram dependentes do tipo de dispositivo protético exposto e do tipo de material utilizado em sua fabricação. Os dados coletados neste estudo podem auxiliar ainda mais na análise e identificação quando se trata de restos incinerados.

PALAVRAS-CHAVE

Odontologia legal; Altas temperaturas; Prótese dentária; Implantes dentários.

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