ISSN 2219-6749

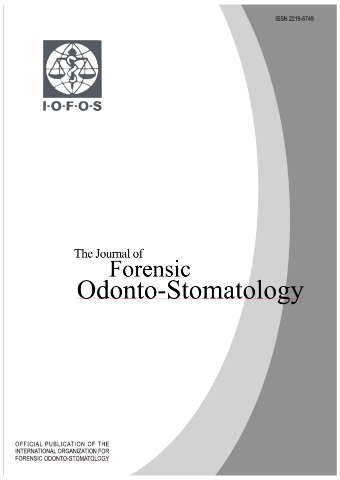
I-O-F-O-S

The Journal of Forensic Odonto-Stomatology

Volume 40, n. 3 - Dec 2022

OFFICIAL PUBLICATION OF THE
INTERNATIONAL ORGANIZATION FOR
FORENSIC ODONTO-STOMATOLOGY

JFOS
ISSN: 2219-6749



THE JOURNAL OF FORENSIC ODONTO-STOMATOLOGY

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The Journal of Forensic Odonto-Stomatology

Vol 40 n. 3 Dec 2022

CONTENTS

A systematic review and meta-analysis of oral and maxillofacial trauma

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The authors declare that they have no conflict of interest.

KEYWORDS

Trauma;
Oro-maxillofacial;
Injuries;
Accidents;
Epidemiology

J Forensic Odontostomatol
2022. Dec;(40): 3-2:21
ISSN :2219-6749

ABSTRACT

Objective of work: The aim of this study was to determine the most frequent injuries and their relationship with gender, age and aetiology.

Materials and Methods: An Epidemiologic Systematic Review was carried out, in the databases PUBMED and Scopus, between 2010-2020. We used Joanna Briggs Institute Checklist to access the Risk of Bias and Grading of recommendations, assessment, development, and the evaluations (GRADE) method was applied to assess the quality of the evidence of the 78 included articles.

Results and Conclusions: Out of the 78 articles included, 14 were classified as moderate-risk bias and 58 as low risk. Only 20.5% had a prospective design and the male/female ratio ranged from 0.299 to 11.83. The majority of the studies described fractures (67) and only 26 reported dental injuries. The studies were distributed into five regions of countries: Asia, Africa, Latin America, Europe and Muslin regions.

The results showed that road traffic accidents (55.37%) were the most frequent type of trauma, followed by assault (17.56%) and falls (10.21%). Fractures were the most prevalent injuries (84.3%). It was possible to establish an association between road traffic accidents and Asian countries. Assaults were more frequent in Africa, predominantly males, whilst falls increased with age, amongst women, in European countries. Fractures were usually observed in Muslin regions.

INTRODUCTION

Trauma is defined as an unexpected event beyond the victim's control, resulting in the presence of a traumatic injury. There are several types of trauma, the most common being those caused by physical injuries, constituting one of the greatest health concerns worldwide.[1-23] In the event of a traumatic situation, this can culminate in either the full recovery of the injury, or the presence of a temporary disorder or a sequel.[23, 24]

These lesions can occur in any part of the body, and in this case, the focus will be on oral maxillofacial region. By oral maxillofacial injuries it is understood any lesion that includes the region of the oral cavity, the teeth, the tongue, the mucous membranes, the mandible, the maxilla, the zygomatic bones, the vessels, the nerves, the temporo-mandibular joint and the soft tissues that form the face. At the dental level, injuries can be divided into periodontal tissue injuries such as: concussion, subluxation, extrusion, lateral dislocation, intrusion, and

avulsion; lesions of the tooth itself: incomplete enamel fracture, uncomplicated coronary fracture, complicated coronary fracture, coronal-radicular fracture, root fracture and finally bone fracture, i.e., fracture of the alveolar process. This division follows the classification proposed by Andreasen.[25,26]
Oral-maxillofacial trauma represents between 7.4 to 8.7% of medical emergencies.[27-29] Their causes differ from country to country, depending on culture, socio-economic status, and environmental factors, [3, 4, 5, 12, 31-54] the main causes being road accidents, falls and violence.
The treatment of these traumas is quite challenging, involving not only the aesthetic aspect but also the function of the injured structures, always taking into consideration the psychological damage.[3, 6-8, 11, 33, 37, 42- 45, 55-62]
To establish the significance and the applicability of the Disabilities Tables for oral-maxillofacial evaluation in civil and labour laws, an evaluation of the prevalence of the type of oral maxillofacial trauma and the aetiology of the injuries are required. Understanding the epidemiology of oral and maxillofacial trauma is essential to shape public health policy and create more adjustable evaluation tables for disabilities. Therefore, the aim of this study was to investigate the epidemiological characteristics of oral maxillofacial trauma, namely to analyse the following features:

- Probabilities of attaining each type of oral and maxillofacial trauma by aetiology.
- Descriptive statistics on age and gender distribution within the different types of trauma.
- Association between oral and maxillofacial trauma type, sequelae, aetiology, age, and gender.

MATERIAL AND METHODS

Protocol and registration
In carrying out this systematic review, the guidelines of the PRISMA recommendations (Preferred Reporting Items for Systematic Reviews and Meta-analyses), version 2020 were followed, rules usually chosen in the performance of systematic reviews and meta-analyses. The protocol was registered in the PROSPERO database (International Prospective Register of Systematic Review), in 2021 (CRD42021251364).

Information sources and search strategy
In this study, the following databases were searched: PubMed/MEDLINE and SCOPUS between the years 2010 and 2020 with Mandarin language restriction. This study included individuals aged 21 years or older who had trauma in the oral maxillofacial region. The age of 21 was chosen because at that time we reach the completion of growth and we are considered adults.
Moreover, no restriction regarding the type of study (retrospective or prospective) was considered. Letters to the editor and studies on individuals that had injuries caused by military service were excluded.
The Medical Subject Headings (MeSH) terms selected for the purposes of this research included 'oral maxillofacial', 'trauma', 'accident' and 'injuries', and included all possible combinations.
Subsequently, we used the PICO framework, which stands for P (Patient Population), I (Intervention or Exposure, in case of observational studies), C (Comparison) and O (Outcomes). In this systematic review, the PICO approach involved Population (adults with oral maxillofacial injuries), Exposure (aetiology of oral maxillofacial trauma), Comparison (different countries with different emergency services) and Outcome (association between aetiology, age, gender and type of trauma).

Eligibility criteria
The following eligibility criteria were implemented for the acquisition of research studies that were directly related to the aim of this investigation: studies needed to be available as full text articles and not merely in the form of an abstract. Moreover, they needed to use a retrospective or prospective design that focused on adult aged 21 years or older and on civilian-type injuries. In addition, studies were included provided that injuries were diagnosed as a result of patients' complaints, and verified clinically, radiographically and during treatment.
The articles were then analyzed through their titles and abstracts, carried out by three evaluators, who independently applied the exclusion and inclusion criteria. Disagreements were discussed among evaluators until a consensus was reached. Finally, the studies were selected after full text assessment. As a result, an Excel form was developed for this purpose and filled out for each study. Cohen's Kappa index [63] was used to verify the agreement of the two main reviewers in the selection of included studies and thus reduce the

risk of losing an admissible study and the possibility of bias (Cohen's Kappa index of 1).
Data extraction was performed using a standardized form that included information on: 1) Study number; 2) Article; 3) Year of publication; 4) Type of Study; 5) Country; 6) Group Countries; 7) Risk of Bias; 8) n (sample size); 9) Male(No.); 10) Female (No.); 11) Proportion of male gender; 12) Male/female ratio; 13) Average age; 14) Standard deviation; 15) Aetiology of trauma; 16) Total injuries; 17) Average number of injuries per patient; 18) Number of patients with fractures; 19) Number of patients with soft tissue injuries; 20) Number of patients with dental lesions. (Table 1)

Table 1. Articles included in this systematic review and the results from the analyzed studies

Article	Type of study	Country	n	Male	Mean age	SD	A	F	RTA	W	S	O	Total Injuries	P/F	P/STI	P/DI
Richard et al [73], 2013	P	UK	64	56			28	18	0	0		18		32	32	6
Shreya et al, [63] 2015	P	Australia	111	98			0	0	0	0	0	0	159	111		
Daniel et al, [30] 2015	R	Germany	409	323	42,7	21,1	185	103	55	20	29	17	775	409		20
Marcus et al, [9] 2015	R	Brasil	47	21	72,4	8,33	5	5	22	0	0	15				
Sahand et al, [3] 2015	R	Iran	221	169	26,9	12	27	25	157	5	0	7	384	221	146	
Benjamin et al,[7] 2015	R	Germany	1305	784	14,7	15,7	87	456	81	22	175	484	2319	1287	355	1287
Razia et al, [39] 2017	R	India	136	104			44	12	59	0	11	10				
Tiwary et al,[74] 2017	P	India	84	57	33,6	14,55	19	6	47	3	9	0		84		
Amare et al, [32] 2017	R	Ethiopia	326	261	29,12	8,62	247	0	70	0	0	9		164	162	
Sahand et al,[4] 2017	R	Iran	502	403	28,8	13,56	36	56	405	0	0	5		502		
Omri et al, [33] 2017	R	Israel	1091	853	36,7	24,8	122	495	428	0	0	46		1091		
Felix et al, [34] 2017	R	Venezuela	334	284			70	23	118	0	3	120	522	334		
Alessandro et al[64], 2017	R	Italy	112	79	41		0	0	0	112	0	0		112		
Seyed et al, [8] 2018	R	Iran	330	291	27,2	6,5	0	0	330	0	0	0		330		228
Mohammed et al,[12] 2019	R	Saudi Arabia	270	241	24,29	11,89	18	43	171	8	22	8	476	270		
Farzin et al [11], 2019	R	Iran	293	231			54	47	160	0	11	21	474	293		
Joab et al,[1] 2018	R	Brasil	332	276	32,9	15,11	38	18	213	7	21	35		319	226	

Dur et al [75], 2018	P	Pakistan	42	36			1	4	34	0	3	0	58	42		
Maher et al,[36] 2019	R	Malaysia	473	389	30,6	18,35	17	27	393	7	6	23		473		
Maximilian et al,[37] 2019	R	Germany	573	441	41,8	19,9	165	137	18	22	45	186	921	573		
Brucoli et al, [76] 2019	R	Europa	1334	599	79,3	6,5	55	1054	105	30	28	62	1717			
Ziyad et al, [10] 2019	R	Saudi Arabia	295	262			0	0	295	0	0	0		295	21	
Safal et al, [38] 2020	R	Nepal	528	425			49	63	226	0	15	25		182	196	
Liu et al,[6] 2020	R	China	829	624	36,1		72	256	379	0	73	49	1486	829		
Fouad et al, [27] 2020	R	Saudi Arabia	166	140	30,69	14,65	26	24	87	8	14	7		166		
Patiguli et al,[2] 2020	R	China	2492	1981			0	383	1042	45	0	1022	3597		826	
Vivek et al, [5] 2020	R	India	64	53			9	12	31	12	0	0		64		8
Sergio et al, [77] 2012	R	Brasil	923	735			0	0	923	0	0	0	1151	471	452	242
Miika et al, [78] 2018	R	Finland	161	110			36	82	28	0	10	5		161		
Muhammad et al,[13] 2019	P	Europa	326	225			0	0	268	0	0	58	442			
Chee et al, [14] 2017	R	Malaysia	618	529	31		73	78	406	0	18	43		193	458	148
Sebastian et al,[79] 2019	R	Germany	62196	44274	42,7	20,5	0	0	52195	0	0	100 01		12613		
Satshkumar et al,[54] 2018	P	India	300	273			9	12	279	0	0	0		432		
Yu et al,[18] 2020	R	Japan	130	88	28	17,2	0	0	130	0	0	0		74	143	103
Mats et al, [80] 2020	P	Norway	1543	1126	39,2	18,9	0	0	1543	0	0	0	753	1420		123
Scmuel et al,[81] 2020	P	Israel	4829	1112			0	0	4632	0	0	197	12064		115	2462
Scmuel et al,[46] 2016	R	Israel	8444	6157			0	3881	4563	0	0	0				
Olojede et al,[41] 2016	P	Nigeria	33	25	28,2	7,4	33	0	0	0	0	0		26	33	3
Utsad et al, [58] 2020	R	India	1110	823	25,95	9,35	0	0	1110	0	0	0		586	1110	661

Karuna et al,[48] 2018	R	India	104	82			29	9	51	0	7	8		104		
Adeola et al, [82] 2015	P	Nigeria	259	206	32,21	16,588	29	22	204	0	0	4		177	82	
Max et al, [83] 2015	R	Germany	67	55			9	25	27	0	0	6	287	67		
Lokesh et al,[40] 2019	R	India	1278	1053			158	91	1029	0	0	0		1278		
Arabion et al,[43] 2014	R	Iran	768	660	26,6	12,6	40	88	520	0	10	110	1118	730	104	57
Fouzia et al,[44] 2019	R	Pakistan	148	130	30,76	12,74	4	10	127	3	2	2		148		
Paolo et al, [16] 2015	P	Europa	1309	1207	32,3	14	1309	0	0	0	0	0	1485	1309		
Cavalcanti et al,[56] 2010	R	Brasil	186	166	33,2	13,1	38	15	74	0	1	58		169	185	14
Phillipo et al,[45] 2011	P	Tanzania	154	112	28,32	16,48	25	22	88	0	4	15	154	54		
Meire et al, [28] 2014	R	Brasil	772	521			140	0	0	0	0	0	2772			
Elitsa et al, [65] 2012	R	Bulgaria	276	216			98	40	56	6	14	2	285			
Mohammed et al,[57] 2018	R	Libya	187	161			32	19	109	0	1	26	326	187		
Kiran et al, [17] 2013	R	India	6872	4912	32,7		128	608	5936	0	64	136	12503			
Ashish et al,[47] 2018	R	India	1850	1228	29	17,2	489	199	781	0	326	34	1465	1850		
Rishi et al, [66] 2013	R	India	740	600			42	120	532	0	21	35	1054	740		82
Pranav et al,[59] 2012	R	India	1000	853	37,4		538	37	404	0	11	10		180	840	225
Umar et al, [50] 2010	R	Pakistan	340	254	25,85	16,45	14	101	154	0	8	63	387	340		
George et al,[84] 2012	R	Greece	727	618	34,3	16,5	191	100	369	23	22	22	1142	727		
Kumar et al,[51] 2015	R	India	2731	2370			315	260	2086	16	54	0		2052	172	555
La Salete et al,[85] 2014	P	Portugal	209	181	45		6	0	145	35	0	23	546	209		
Parveen et al,[19] 2014	R	India	787	646			105	89	582	3	0	7		667	39	81
Loutroukis et al,[86] 2020	R	Switzerland	201	139	33,67	12,76	86	25	7	8	11	64		148	73	53

Mabrouk et al,[87] 2014	R	Egypt	215	183	25,7256	9,168	88	17	88	0	0	22		215		
Majambo et al,[52] 2013	P	Rwanda	182	126			27	32	83	0	10	30		172	181	67
Sergio et al,[20] 2016	R	Brasil	1179	769			136	362	136	5	17	73	1213	118	760	39
Thanvir et al,[29] 2017	R	India	136	117	32,58	11,15	4	31	92	0	4	5		136	136	
Obitade et al, [53] 2013	R	Nigeria	34	22	21,4	6,26	34	0	0	0	0	0		14	18	2
Stella et al,[21] 2015	P	Nigeria	70	56	30,11	14,97	8	9	49	0	0	4	128	42	52	
Cláudio et al,[88] 2011	R	Brasil	521	412			130	67	222	40	19	43	615	521		
Nathalie et al, [89] 2014	R	France	364	300	34	0,9	143	73	89	14	45	0		364		
Leeza et al,[90] 2015	R	Nepal	279	214			23	74	137	0	20	25	376	147	229	38
George et al,[91] 2015	R	Greece	9616	7532			1744	1633	5272	319	337	311	15484	9616		
Zahoor et al,[92] 2010	R	Pakistan	2112	1533			142	231	1202	0	0	537		941	904	267
Ilky et al,[22] 2017	R	Brasil	244	224	31,16	15,17	32	19	155	0	0	38		218	26	
Vibha et al,[67] 2012	R	India	1038	931			4	22	100 8	0	0	4		1670		
Mohanavalli et al,[93] 2016	R	India	267	199	35	11,8	18	48	197	0	4	0		179	18	70
Udeabor et al,[61] 2014	R	Nigeria	86	65			6	0	40	0	0	40	135			
Weihsin et al,[94] 2014	R	India	4437	3730			1041	786	2347	126	54	83	3867	4437		
Mohammad et al,[60] 2011	P	Iran	2450	1887			404	202	858	113	126	747		895	2206	127

R - Retrospective and **P** - Prospective; **SD** - Standart deviation ; **A** - Assault, **F** – Falls, **RTA** - Road traffic accidents, **W** – Work, **S** – Sports, **O** – Others; **P/F** - Patients with fracture, **P/SFI** - Patients with soft tissues injuries, **P/DI** - Patients with dental injuries

Quality of the studies

To access the risk of bias in all identified and collected full text articles included in this study we used Joanna Briggs Institute Checklist for Prevalence Studies (Joanna Briggs Institute. JBI Critical Appraisal Tools for use in JBI Systematic Reviews. Checklist for Prevalence Studies, 2017) (Table 2)[64]. For the qualification of potentially included studies, an independent analysis of the studies was performed by the two main reviewers, with the aim of detecting similarities and differences between them and thus avoiding a selection bias. Each item was scored in "yes", "unclear", "no", or "not applicable" and then each study was classified into three categories:

(a) low risk of bias, if studies reached more than 70% scores of "yes",

(b) moderate risk of bias, if "yes" scores were between 50% and 69%, and

(c) high risk of bias, if "yes" scores were below 49%.

Moreover, GRADE (Grading of Recommendations, Assessment, Development, and Evaluation) method was applied to assess the quality of the evidence, i.e. the cumulative evidence of the included articles. (Table 2)
The value of weighted kappa statistic between author agreements was 100%. After confirming the quality of each study, 2 authors independently extracted the data to the pre-specified data extraction sheet in Microsoft Excel, 2022 version 16.64. Nevertheless, it was not possible to perform a cumulative analysis as the outcome of variables was not homogeneous across the selected studies.

Table 2. GRADE method applied to all articles to assess the quality of the evidence and risk of bias

Article	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Risk of bias	GRADE
Richard et al, 2013	yes	yes	no	yes	yes	yes	yes	unclear	unclear	moderate	low
Shreya et al, 2015	yes	yes	yes	yes	yes	unclear	unclear	yes	yes	low	moderate
Daniel et al, 2015	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Marcus et al, 2015	yes	yes	yes	yes	yes	unclear	unclear	yes	yes	low	low
Sahand et al, 2015	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Benjamin et al, 2015	yes	yes	yes	yes	yes	unclear	unclear	yes	yes	low	moderate
Razia et al, 2017	yes	yes	yes	yes	yes	yes	yes	unclear	unclear	low	moderate
Tiwary et al, 2017	yes	yes	no	yes	yes	yes	yes	yes	yes	low	moderate
Amare et al, 2017	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Sahand et al, 2017	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Omri et al, 2017	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Felix et al, 2017	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Alessandro et al, 2017	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Seyed et al, 2018	yes	yes	yes	yes	yes	yes	yes	yes	no	low	low
Mohammed et al, 2019	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Farzin et al, 2019	yes	yes	yes	yes	yes	unclear	unclear	unclear	yes	moderate	low
Joab et al, 2018	yes	yes	yes	yes	yes	unclear	yes	yes	no	low	moderate
Dur et al, 2018	yes	yes	no	yes	yes	yes	yes	unclear	no	moderate	low
Maher et al, 2019	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Maximilian et al, 2019	yes	yes	yes	yes	yes	unclear	unclear	yes	yes	low	moderate
Brucoli et al, 2019	yes	yes	yes	yes	yes	yes	yes	yes	unclear	low	moderate
Ziyad et al, 2019	yes	unclear	yes	yes	yes	unclear	yes	yes	yes	low	low
Safal et al, 2020	unclear	unclear	yes	no	unclear	unclear	unclear	yes	yes	high	very low
Liu et al, 2020	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Fouad et al, 2020	yes	yes	yes	yes	no	yes	unclear	unclear	yes	moderate	low
Patiguli et al, 2020	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Vivek et al, 2020	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	low
Sergio et al, 2012	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate

Miika et al, 2018	yes	yes	yes	yes	yes	yes	yes	yes	unclear	low	moderate
Muhammad et al, 2019	yes	yes	yes	yes	unclear	yes	unclear	unclear	unclear	moderate	low
Chee et al, 2017	yes	yes	yes	yes	yes	unclear	unclear	unclear	yes	moderate	low
Sebastian et al, 2019	yes	yes	yes	yes	unclear	yes	no	yes	yes	low	moderate
Satshkumar et al, 2018	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Yu et al, 2020	yes	yes	yes	yes	yes	yes	yes	yes	unclear	low	low
Mats et al, 2020	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Scmuel et al, 2020	yes	yes	yes	yes	yes	yes	unclear	yes	yes	low	moderate
Scmuel et al, 2016	yes	unclear	yes	no	yes	yes	unclear	yes	yes	moderate	low
Olojede et al, 2016	yes	unclear	no	yes	no	unclear	unclear	yes	unclear	high	Very low
Utsad et al, 2020	yes	yes	yes	yes	yes	unclear	unclear	yes	yes	low	moderate
Karuna et al, 2018	yes	yes	yes	yes	yes	unclear	unclear	unclear	yes	moderate	low
Adeola et al, 2015	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Max et al, 2015	yes	yes	no	yes	yes	yes	yes	yes	yes	low	low
Lokesh et al, 2019	yes	yes	yes	yes	yes	yes	yes	unclear	unclear	low	moderate
Arabion et al, 2014	yes	yes	yes	yes	yes	yes	yes	unclear	yes	low	moderate
Fouzia et al, 2019	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Paolo et al, 2015	yes	yes	yes	yes	yes	yes	unclear	unclear	yes	low	moderate
Cavalcanti et al, 2010	yes	yes	yes	yes	yes	unclear	unclear	yes	yes	low	moderate
Phillipo et al, 2011	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	Moderate
Meire et al, 2014	yes	yes	yes	no	yes	unclear	unclear	yes	yes	moderate	low
Elitsa et al, 2012	yes	unclear	yes	yes	yes	unclear	unclear	unclear	unclear	high	Very low
Mohammed et al, 2018	yes	yes	yes	yes	yes	yes	yes	unclear	yes	low	moderate
Kiran et al, 2013	yes	yes	yes	yes	yes	yes	yes	unclear	yes	low	moderate
Ashish et al, 2018	yes	yes	yes	yes	yes	unclear	unclear	unclear	unclear	moderate	low
Rishi et al, 2013	yes	unclear	yes	no	unclear	unclear	no	no	no	high	very low
Pranav et al, 2012	yes	yes	yes	yes	yes	unclear	unclear	unclear	yes	moderate	low
Umar et al, 2010	yes	yes	yes	yes	yes	yes	yes	unclear	yes	low	moderate
George et al, 2012	yes	yes	yes	yes	yes	unclear	unclear	yes	unclear	moderate	low
Kumar et al, 2015	yes	yes	yes	yes	yes	yes	yes	unclear	unclear	low	moderate
La Salete et al, 2014	yes	yes	yes	yes	yes	yes	yes	unclear	unclear	low	moderate
Parveen et al, 2014	yes	yes	yes	yes	yes	unclear	unclear	unclear	yes	moderate	low
Triantafillos et al, 2020	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Mabrouk et al, 2014	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Majambo et al, 2013	yes	yes	yes	yes	yes	yes	yes	unclear	yes	low	moderate

Sergio et al, 2016	yes	yes	yes	yes	yes	yes	yes	unclear	yes	low	moderate
Thanvir et al, 2017	yes	unclear	yes	yes	yes	unclear	unclear	unclear	unclear	high	low
Obitade et al, 2013	yes	yes	yes	yes	yes	yes	yes	unclear	yes	low	moderate
Stella et al, 2015	yes	yes	no	yes	yes	yes	yes	unclear	yes	low	moderate
Cláudio et al, 2011	yes	yes	yes	yes	yes	unclear	unclear	unclear	unclear	moderate	low
Nathalie et al, 2014	yes	yes	yes	yes	yes	yes	yes	yes	unclear	low	moderate
Leeza et al, 2015	yes	yes	yes	yes	yes	unclear	yes	unclear	yes	low	moderate
George et al, 2015	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Zahoor et al, 2010	yes	unclear	yes	yes	yes	unclear	unclear	unclear	unclear	high	low
Ilky et al, 2017	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate
Vibha et al, 2012	yes	yes	yes	yes	yes	yes	yes	unclear	unclear	low	moderate
Mohanavalli et al, 2016	yes	yes	yes	yes	yes	yes	yes	yes	unclear	low	moderate
Udeabor et al, 2014	yes	yes	no	yes	yes	unclear	yes	yes	yes	low	moderate
Weihsin et al, 2014	yes	yes	yes	yes	yes	yes	yes	unclear	yes	low	moderate
Mohammad et al, 2011	yes	yes	yes	yes	yes	yes	yes	yes	yes	low	moderate

Q1. Was the sample frame appropriate to address the target population?
Q2. Were study participants recruited in an appropriate way?
Q3. Was the sample size adequate?
Q4. Were the study subjects and setting described in detail?
Q5. Was data analysis conducted with sufficient coverage of the identified sample?
Q6. Were valid methods used for the identification of the condition?
Q7. Was the condition measured in a standard, reliable way for all participants?
Q8. Was there appropriate statistical analysis?
Q9. Was the response rate adequate, and if not, was the low response rate managed appropriately?

RESULTS

Study selection

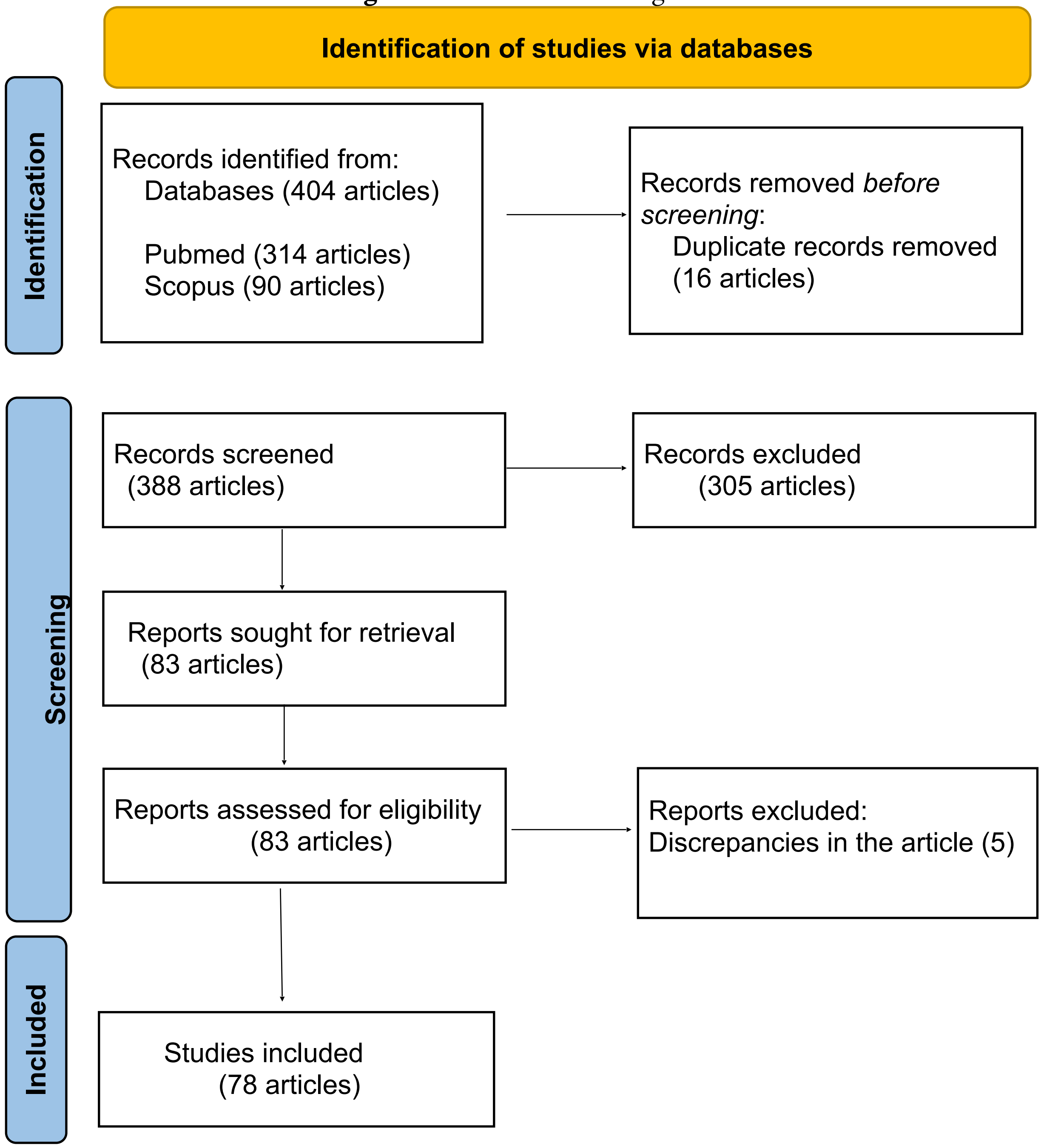
The review search process yielded 404 articles. Of these, 16 were duplicated on the databases and were excluded. Therefore, 388 articles were screened by titles and abstracts evaluation and only 83 articles were included according to the eligibility criteria. The final number of studies included was 78. The remaining 5 studies were excluded due to discrepancies in the results available in the article. Figure 1 shows the flow diagram with all phases of the review process.
The main results from the analysed studies are described in Table 1, including the number of the study, name of the article, year of publication, study type, country, risk of bias, N (number of patients), number of males and females, male proportion, male/female ratio, mean age, standard deviation of mean age, aetiology, total injuries, average of injuries per patient, number of patients with fractures, number of patients with injuries in the soft tissues and number of patients with dental injuries.

Study characteristics

A total of 78 articles published between 2010 and 2020 that fulfilled the inclusion criteria were included in the review. Out of 78 studies selected, 58 were classified as low risk bias and 14 were classified as moderate-risk bias (Table2).
The majority of the studies were retrospective, and only 20.5% had a prospective design. The male/female ratio was discrepant and ranged from 0.299 to 11.83. Dental injuries were reported in 26 studies, fractures were described in 67 and only 31 articles presented information on soft tissue injury.
The distribution according to the region of countries was as follows: nine studies from Latin America, twenty-one from Europe, twenty-four from Asia, nine from Africa and fourteen from Muslin countries. Israel was included in the European group because of similar social lifestyle.

Eight of the 78 articles were not included in the aetiological meta-analysis as they did not contain the necessary information [21,29,39,48,65-68].
In terms of statistical analysis, the I^2 statistic from Higgins and Thompson was applied to assess the degree of inconsistency across studies in the meta-analysis, i.e. to measure the impact of the heterogeneity of the studies on the conclusions of the meta-analysis. Once the heterogeneity was greater than 50% (measures Q and I^2), it was not possible to apply a fixed effects model. Hence, we cannot consider that all studies come from the same population and, therefore, there is no homogeneity among them. Thus, the overall failure estimate and the weight assigned to each study were determined through the random effects model, for the estimation of a proportion and the construction of 95% confidence intervals using the DerSimonian-Laird method. A sensitivity analysis was also carried out, due to the high heterogeneity, through a meta-regression that included the predictors: risk of bias, mean age, ratio between the number of male and female individuals and the region. For statistical treatment, the R software was used, applying the package Meta.

Figure 1. PRISMA Flow Diagram



Figures 2-4 show the aetiologies for each study eligible for the meta-analysis, as well as the combined estimated prevalence. The analysis was based on a random effects model for each aetiology separately, in spite of the multivariate (multinomial) nature of the data. The multivariate approach was not considered here, since the data does not allow the evaluation of some important multivariate statistics, such as Cochran's Q statistic. This occurs because for the calculation of this statistic it is required to invert matrices that, in the database under analysis, are not invertible. The main cause of trauma was road traffic accidents with a prevalence of 55.37 % (95% confidence interval - CI, 43.80% - 66.94%), followed by assault with 17.56% (95% CI, 15.39% - 19.73%) and falls with 10.21% (95% CI, 9.78% - 10.64%). The observed heterogeneity was quite within all aetiologies, even when stratified by world region.

By performing a meta-regression, it was possible to establish an association between some predictors. Assaults were more frequent in males and Africa (p-value <0.001). Falls increased with age and usually occurred in women and in the European and Muslin countries (p-value <0.001). The frequency of road traffic accidents was higher in Asia (p-value between 0.01 and 0.05) and lower in Europe. For sports events, an association between Europe and Latin America and young ages had been established (p-value <0.001).

As for the meta-analysis of injuries, 3 studies [55,66,69] were not taken into account, since in the last two the number of injuries was higher than the sample size. Figures 5, 6 and 7 showed the estimated prevalence of the type of injuries. Fractures were the most frequent type of injury with a prevalence of 84.30% (95% CI, 82.99 - 85.61%). These injuries were often observed in the Muslin regions.

Regarding the soft tissues injuries, the estimated prevalence was 52.11% (95% CI, 32.79% - 71.44%), although no association had been established between the predictors.

The frequency of dental injuries was 25.41% (95% CI, 8.60% - 42.23%). A statistical association had been made between these injuries, young ages and Europe and Asia (p-value <0.001).

DISCUSSION

The main aetiology differed from country to country, being influenced by culture, social environment and laws. The results regarding the road traffic accidents being the most frequent cause of trauma corroborated the literature.[15, 56, 70-74] This finding can be explained by the lack of safety measures or negligence in complying with them, the poor quality of the roads and aggressive driving.[15, 56, 71-74] This aetiology being more frequent in Asia and less in Europe had been verified by many studies,[15, 70-72] which established that in recent years this tended to decrease in Europe due to strict road laws.

In this study, assault and falls were also considered as the main cause of maxillofacial trauma.[15, 70-73] Assault was more usual [71, 74] in the European and Latin America countries, while the falls were more frequent in Europe.[72,74]

The systematic reviews of Al Qahtani et al.[71,72] and Boffano et al.[15] showed that falls were more frequent in elderly people and Chrcanovic [74] revealed that females were more likely to fall. These studies were in agreement with the obtained results.

As we can see, the remaining aetiologies were less frequent,[15, 71-74] however sport had a higher incidence in young people in Europe and Latin America.[15, 74]

Despite the fact of the male/female ratio between the studies being quite discrepant, we can observe a higher number of males, which is corroborated by several authors.[70-74]

As for the type of injury, the prevalence of fractures was significant,[71-74] although few systematic reviews addressed the different types of injuries.

Our study had some limitations, one of them was the high heterogeneity, which can be explained by the different sample sizes and the fact that the majority of the studies were observational, which made the data obtained through the analysis of processes distinct, as each hospital was different and the quality of the information contained in each report can differ.

CONCLUSIONS

Based on the results of our review, it was concluded that road traffic accidents were the main aetiology of oral maxillofacial trauma and special attention should be given to Asia, which presented the highest prevalence. Assault was also a main cause of trauma, being more frequent in males, while falls were more evident in European countries, amongst females and with ageing.

Regarding the type of trauma, fractures were the main type, and dental injuries were frequently seen in young people and Europa/Asia.

Figure 2. Articles included in this systematic review showing aetiology of road traffic accidents

Study	Events	Total	Proportion	95%-CI	Weight
Burnham Richard et al,2013	0	64	0.00	[0.00; 0.06]	1.4%
Schneider Daniel et al,2015	55	409	0.13	[0.10; 0.17]	1.4%
Carvalho Filho Marcus et al,2015	22	47	0.47	[0.32; 0.62]	1.4%
Samieirad Sahand et al,2015	157	221	0.71	[0.65; 0.77]	1.4%
Mahmoodi Benjamin et al,2015	81	1305	0.06	[0.05; 0.08]	1.4%
Sultana Razia et al,2017	59	136	0.43	[0.35; 0.52]	1.4%
Dr.Tiwary et al,2017	47	84	0.56	[0.45; 0.67]	1.4%
Teshome Amare et al,2017	70	326	0.21	[0.17; 0.26]	1.4%
Samieirad Sahand et al,2017	405	502	0.81	[0.77; 0.84]	1.4%
Emodi Omri et al,2017	428	1091	0.39	[0.36; 0.42]	1.4%
Rojas Felix et al,2017	118	334	0.35	[0.30; 0.41]	1.4%
Mosaddad Seyed et al,2018	330	330	1.00	[0.99; 1.00]	1.4%
Al-Bokhamseen Mohammed et al,2019	171	270	0.63	[0.57; 0.69]	1.4%
Sarkarat Farzin et al,2019	160	293	0.55	[0.49; 0.60]	1.4%
Ramos Joab et al,2018	213	332	0.64	[0.59; 0.69]	1.4%
Lashari Dur et al,2018	34	42	0.81	[0.66; 0.91]	1.4%
Abosadegh Maher et al,2019	393	473	0.83	[0.79; 0.86]	1.4%
Goedecke Maximilian et al,2019	18	573	0.03	[0.02; 0.05]	1.4%
Brucoli M. et al,2019	105	1334	0.08	[0.06; 0.09]	1.4%
AlHammad Ziyad et al,2019	295	295	1.00	[0.99; 1.00]	1.4%
Dong Liu et al,2020	379	829	0.46	[0.42; 0.49]	1.4%
Alharbi Fouad et al,2020	87	166	0.52	[0.45; 0.60]	1.4%
Wusiman Patiguli et al,2020	1042	2492	0.42	[0.40; 0.44]	1.4%
B. Vivek et al,2020	31	64	0.48	[0.36; 0.61]	1.4%
Júnior Sergio et al,2012	923	923	1.00	[1.00; 1.00]	1.4%
Toivari Miika et al,2018	28	161	0.17	[0.12; 0.24]	1.4%
Ruslin Muhammad et al,2019	268	326	0.82	[0.78; 0.86]	1.4%
Lee Chee et al,2017	406	618	0.66	[0.62; 0.69]	1.4%
Pietza Sebastian et al,2019	52195	62196	0.84	[0.84; 0.84]	1.4%
Patil Satshkumar et al,2018	279	300	0.93	[0.89; 0.96]	1.4%
Hirobe Yu et al,2020	130	130	1.00	[0.97; 1.00]	1.4%
Doving Mats et al,2020	1543	1543	1.00	[1.00; 1.00]	1.4%
Einy Scmuel et al,2020	4632	4829	0.96	[0.95; 0.96]	1.4%
Einy Scmuel et al,2016	4563	8444	0.54	[0.53; 0.55]	1.4%
ACO Olojede et al,2016	0	33	0.00	[0.00; 0.11]	1.4%
Gurung Utsad et al,2020	1110	1110	1.00	[1.00; 1.00]	1.4%
Jindwani Karuna et al,2018	51	104	0.49	[0.39; 0.59]	1.4%
Olusanya Adeola et al,2015	204	259	0.79	[0.73; 0.84]	1.4%
Scheyerer Max et al,2015	27	67	0.40	[0.28; 0.53]	1.4%
Chandra Lokesh et al,2019	1029	1278	0.81	[0.78; 0.83]	1.4%
Arabion HR et aal,2014	520	768	0.68	[0.64; 0.71]	1.4%
Aslam Fouzia et al,2019	127	148	0.86	[0.79; 0.91]	1.4%
Boffano Paolo et al,2015	0	1309	0.00	[0.00; 0.00]	1.4%
Cavalcanti A. et al,2010	74	186	0.40	[0.33; 0.47]	1.4%
Chalya Phillipo et al,2011	88	154	0.57	[0.49; 0.65]	1.4%
Elarabi Mohammed et al,2018	109	187	0.58	[0.51; 0.65]	1.4%
Gadre Kiran et al,2013	5936	6872	0.86	[0.86; 0.87]	1.4%
Kapoor Pranav et al,2012	404	1000	0.40	[0.37; 0.44]	1.4%
Khitab Umar et al,2010	154	340	0.45	[0.40; 0.51]	1.4%
Kostakis George et al,2012	369	727	0.51	[0.47; 0.54]	1.4%
Kumar GB et al,2015	2086	2731	0.76	[0.75; 0.78]	1.4%
Alves La Salete et al,2014	145	209	0.69	[0.63; 0.76]	1.4%
Lone Parveen et al,2014	582	787	0.74	[0.71; 0.77]	1.4%
Loutroukis Triantafillos et al,2020	7	201	0.03	[0.01; 0.07]	1.4%
Mabrouk Amr et al,2014	88	215	0.41	[0.34; 0.48]	1.4%
MH Majambo et al,2013	83	182	0.46	[0.38; 0.53]	1.4%
Niazi Thanvir et al,2017	92	136	0.68	[0.59; 0.75]	1.4%
Obimakinde Obitade et al,2013	0	34	0.00	[0.00; 0.10]	1.4%
Ogunmuyiwa Stella et al,2015	49	70	0.70	[0.58; 0.80]	1.4%
Pereira Cláudio et al,2011	222	521	0.43	[0.38; 0.47]	1.4%
Pham-Dang Nathalie et al,2014	89	364	0.24	[0.20; 0.29]	1.4%
Pradhan Leeza et al,2015	137	279	0.49	[0.43; 0.55]	1.4%
Rallis George et al,2015	5272	9616	0.55	[0.54; 0.56]	1.4%
Rana Zahoor et al,2010	1202	2112	0.57	[0.55; 0.59]	1.4%
Silva e Farias Ilky et al,2017	155	244	0.64	[0.57; 0.70]	1.4%
Singh Vibha et al,2012	1008	1038	0.97	[0.96; 0.98]	1.4%
Singaram Mohanavalli et al,2016	197	267	0.74	[0.68; 0.79]	1.4%
Udeabor S.E et al,2014	40	86	0.47	[0.36; 0.58]	1.4%
Weihsin Hu et al,2014	2347	4437	0.53	[0.51; 0.54]	1.4%
Zandi Mohammad et al,2011	858	2450	0.35	[0.33; 0.37]	1.4%
Random effects model		**132003**	**0.55**	**[0.44; 0.67]**	**100.0%**

Heterogeneity: $I^2 = 100\%$, $\tau^2 = 0.2430$, $p = 0$

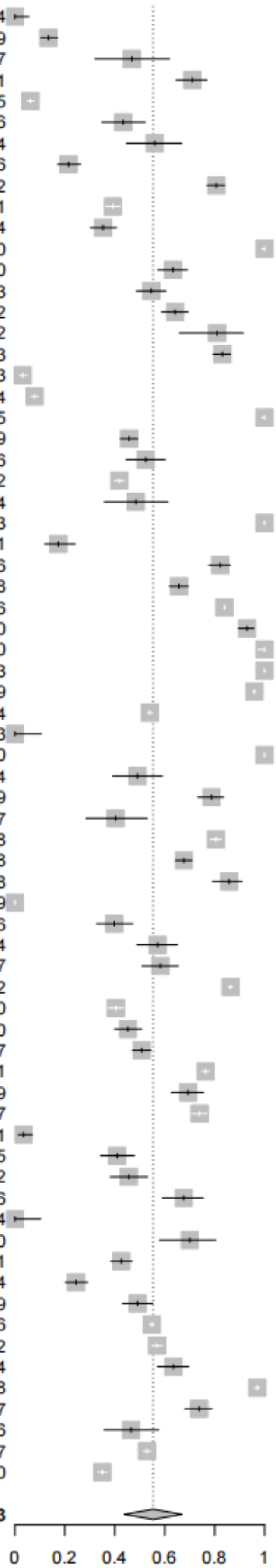


Figure 3. Articles included in this systematic review showing the aetiology assault

Study	Events	Total	Proportion	95%−CI	Weight
Burnham Richard et al,2013	28	64	0.44	[0.31; 0.57]	1.0%
Schneider Daniel et al,2015	185	409	0.45	[0.40; 0.50]	1.4%
Carvalho Filho Marcus et al,2015	5	47	0.11	[0.04; 0.23]	1.2%
Samieirad Sahand et al,2015	27	221	0.12	[0.08; 0.17]	1.4%
Mahmoodi Benjamin et al,2015	87	1305	0.07	[0.05; 0.08]	1.5%
Sultana Razia et al,2017	44	136	0.32	[0.25; 0.41]	1.3%
Dr.Tiwary et al,2017	19	84	0.23	[0.14; 0.33]	1.2%
Teshome Amare et al,2017	247	326	0.76	[0.71; 0.80]	1.4%
Samieirad Sahand et al,2017	36	502	0.07	[0.05; 0.10]	1.5%
Emodi Omri et al,2017	122	1091	0.11	[0.09; 0.13]	1.5%
Rojas Felix et al,2017	70	334	0.21	[0.17; 0.26]	1.4%
Mosaddad Seyed et al,2018	0	330	0.00	[0.00; 0.01]	1.5%
Al−Bokhamseen Mohammed et al,2019	18	270	0.07	[0.04; 0.10]	1.5%
Sarkarat Farzin et al,2019	54	293	0.18	[0.14; 0.23]	1.4%
Ramos Joab et al,2018	38	332	0.11	[0.08; 0.15]	1.5%
Lashari Dur et al,2018	1	42	0.02	[0.00; 0.13]	1.4%
Abosadegh Maher et al,2019	17	473	0.04	[0.02; 0.06]	1.5%
Goedecke Maximilian et al,2019	165	573	0.29	[0.25; 0.33]	1.4%
Brucoli M. et al,2019	55	1334	0.04	[0.03; 0.05]	1.5%
AlHammad Ziyad et al,2019	0	295	0.00	[0.00; 0.01]	1.5%
Dong Liu et al,2020	72	829	0.09	[0.07; 0.11]	1.5%
Alharbi Fouad et al,2020	26	166	0.16	[0.10; 0.22]	1.4%
Wusiman Patiguli et al,2020	0	2492	0.00	[0.00; 0.00]	1.5%
B. Vivek et al,2020	9	64	0.14	[0.07; 0.25]	1.2%
Júnior Sergio et al,2012	0	923	0.00	[0.00; 0.00]	1.5%
Toivari Miika et al,2018	36	161	0.22	[0.16; 0.30]	1.3%
Ruslin Muhammad et al,2019	0	326	0.00	[0.00; 0.01]	1.5%
Lee Chee et al,2017	73	618	0.12	[0.09; 0.15]	1.5%
Pietza Sebastian et al,2019	0	62196	0.00	[0.00; 0.00]	1.5%
Patil Satshkumar et al,2018	9	300	0.03	[0.01; 0.06]	1.5%
Hirobe Yu et al,2020	0	130	0.00	[0.00; 0.03]	1.5%
Doving Mats et al,2020	0	1543	0.00	[0.00; 0.00]	1.5%
Einy Scmuel et al,2020	0	4829	0.00	[0.00; 0.00]	1.5%
Einy Scmuel et al,2016	0	8444	0.00	[0.00; 0.00]	1.5%
ACO Olojede et al,2016	33	33	1.00	[0.89; 1.00]	1.4%
Gurung Utsad et al,2020	0	1110	0.00	[0.00; 0.00]	1.5%
Jindwani Karuna et al,2018	29	104	0.28	[0.20; 0.38]	1.2%
Olusanya Adeola et al,2015	29	259	0.11	[0.08; 0.16]	1.4%
Scheyerer Max et al,2015	9	67	0.13	[0.06; 0.24]	1.2%
Chandra Lokesh et al,2019	158	1278	0.12	[0.11; 0.14]	1.5%
Arabion HR et aal,2014	40	768	0.05	[0.04; 0.07]	1.5%
Aslam Fouzia et al,2019	4	148	0.03	[0.01; 0.07]	1.5%
Boffano Paolo et al,2015	1309	1309	1.00	[1.00; 1.00]	1.5%
Cavalcanti A. et al,2010	38	186	0.20	[0.15; 0.27]	1.4%
Chalya Phillipo et al,2011	25	154	0.16	[0.11; 0.23]	1.4%
Elarabi Mohammed et al,2018	32	187	0.17	[0.12; 0.23]	1.4%
Gadre Kiran et al,2013	128	6872	0.02	[0.02; 0.02]	1.5%
Kapoor Pranav et al,2012	538	1000	0.54	[0.51; 0.57]	1.5%
Khitab Umar et al,2010	14	340	0.04	[0.02; 0.07]	1.5%
Kostakis George et al,2012	191	727	0.26	[0.23; 0.30]	1.5%
Kumar GB et al,2015	315	2731	0.12	[0.10; 0.13]	1.5%
Alves La Salete et al,2014	6	209	0.03	[0.01; 0.06]	1.5%
Lone Parveen et al,2014	105	787	0.13	[0.11; 0.16]	1.5%
Loutroukis Triantafillos et al,2020	86	201	0.43	[0.36; 0.50]	1.3%
Mabrouk Amr et al,2014	88	215	0.41	[0.34; 0.48]	1.3%
MH Majambo et al,2013	27	182	0.15	[0.10; 0.21]	1.4%
Niazi Thanvir et al,2017	4	136	0.03	[0.01; 0.07]	1.5%
Obimakinde Obitade et al,2013	34	34	1.00	[0.90; 1.00]	1.4%
Ogunmuyiwa Stella et al,2015	8	70	0.11	[0.05; 0.21]	1.3%
Pereira Cláudio et al,2011	130	521	0.25	[0.21; 0.29]	1.4%
Pham−Dang Nathalie et al,2014	143	364	0.39	[0.34; 0.45]	1.4%
Pradhan Leeza et al,2015	23	279	0.08	[0.05; 0.12]	1.5%
Rallis George et al,2015	1744	9616	0.18	[0.17; 0.19]	1.5%
Rana Zahoor et al,2010	142	2112	0.07	[0.06; 0.08]	1.5%
Silva e Farias Ilky et al,2017	32	244	0.13	[0.09; 0.18]	1.4%
Singh Vibha et al,2012	4	1038	0.00	[0.00; 0.01]	1.5%
Singaram Mohanavalli et al,2016	18	267	0.07	[0.04; 0.10]	1.5%
Udeabor S.E et al,2014	6	86	0.07	[0.03; 0.15]	1.4%
Weihsin Hu et al,2014	1041	4437	0.23	[0.22; 0.25]	1.5%
Zandi Mohammad et al,2011	404	2450	0.16	[0.15; 0.18]	1.5%
Random effects model		**132003**	**0.18**	**[0.15; 0.20]**	**100.0%**

Heterogeneity: $I^2 = 100\%$, $\tau^2 = 0.0081$, $p = 0$

Figure 4. Articles included in this systematic review showing the aetiology falls

Study	Events	Total	Proportion	95%-CI	Weight
Burnham Richard et al,2013	18	64	0.28	[0.18; 0.41]	0.1%
Schneider Daniel et al,2015	103	409	0.25	[0.21; 0.30]	0.8%
Carvalho Filho Marcus et al,2015	5	47	0.11	[0.04; 0.23]	0.2%
Samieirad Sahand et al,2015	25	221	0.11	[0.07; 0.16]	0.8%
Mahmoodi Benjamin et al,2015	456	1305	0.35	[0.32; 0.38]	1.4%
Sultana Razia et al,2017	12	136	0.09	[0.05; 0.15]	0.6%
Dr.Tiwary et al,2017	6	84	0.07	[0.03; 0.15]	0.5%
Teshome Amare et al,2017	0	326	0.00	[0.00; 0.01]	2.7%
Samieirad Sahand et al,2017	56	502	0.11	[0.09; 0.14]	1.3%
Emodi Omri et al,2017	495	1091	0.45	[0.42; 0.48]	1.2%
Rojas Felix et al,2017	23	334	0.07	[0.04; 0.10]	1.3%
Mosaddad Seyed et al,2018	0	330	0.00	[0.00; 0.01]	2.7%
Al−Bokhamseen Mohammed et al,2019	43	270	0.16	[0.12; 0.21]	0.7%
Sarkarat Farzin et al,2019	47	293	0.16	[0.12; 0.21]	0.8%
Ramos Joab et al,2018	18	332	0.05	[0.03; 0.08]	1.5%
Lashari Dur et al,2018	4	42	0.10	[0.03; 0.23]	0.2%
Abosadegh Maher et al,2019	27	473	0.06	[0.04; 0.08]	1.7%
Goedecke Maximilian et al,2019	137	573	0.24	[0.20; 0.28]	1.0%
Brucoli M. et al,2019	1054	1334	0.79	[0.77; 0.81]	1.6%
AlHammad Ziyad et al,2019	0	295	0.00	[0.00; 0.01]	2.7%
Dong Liu et al,2020	256	829	0.31	[0.28; 0.34]	1.1%
Alharbi Fouad et al,2020	24	166	0.14	[0.09; 0.21]	0.5%
Wusiman Patiguli et al,2020	383	2492	0.15	[0.14; 0.17]	2.1%
B. Vivek et al,2020	12	64	0.19	[0.10; 0.30]	0.2%
Júnior Sergio et al,2012	0	923	0.00	[0.00; 0.00]	2.8%
Toivari Miika et al,2018	82	161	0.51	[0.43; 0.59]	0.3%
Ruslin Muhammad et al,2019	0	326	0.00	[0.00; 0.01]	2.7%
Lee Chee et al,2017	78	618	0.13	[0.10; 0.16]	1.4%
Pietza Sebastian et al,2019	0	62196	0.00	[0.00; 0.00]	2.8%
Patil Satshkumar et al,2018	12	300	0.04	[0.02; 0.07]	1.6%
Hirobe Yu et al,2020	0	130	0.00	[0.00; 0.03]	2.4%
Doving Mats et al,2020	0	1543	0.00	[0.00; 0.00]	2.8%
Einy Scmuel et al,2020	0	4829	0.00	[0.00; 0.00]	2.8%
Einy Scmuel et al,2016	3881	8444	0.46	[0.45; 0.47]	2.4%
ACO Olojede et al,2016	0	33	0.00	[0.00; 0.11]	0.8%
Gurung Utsad et al,2020	0	1110	0.00	[0.00; 0.00]	2.8%
Jindwani Karuna et al,2018	9	104	0.09	[0.04; 0.16]	0.5%
Olusanya Adeola et al,2015	22	259	0.08	[0.05; 0.13]	1.0%
Scheyerer Max et al,2015	25	67	0.37	[0.26; 0.50]	0.1%
Chandra Lokesh et al,2019	91	1278	0.07	[0.06; 0.09]	2.2%
Arabion HR et aal,2014	88	768	0.11	[0.09; 0.14]	1.6%
Aslam Fouzia et al,2019	10	148	0.07	[0.03; 0.12]	0.8%
Boffano Paolo et al,2015	0	1309	0.00	[0.00; 0.00]	2.8%
Cavalcanti A. et al,2010	15	186	0.08	[0.05; 0.13]	0.9%
Chalya Phillipo et al,2011	22	154	0.14	[0.09; 0.21]	0.5%
Elarabi Mohammed et al,2018	19	187	0.10	[0.06; 0.15]	0.7%
Gadre Kiran et al,2013	608	6872	0.09	[0.08; 0.10]	2.6%
Kapoor Pranav et al,2012	37	1000	0.04	[0.03; 0.05]	2.3%
Khitab Umar et al,2010	101	340	0.30	[0.25; 0.35]	0.6%
Kostakis George et al,2012	100	727	0.14	[0.11; 0.16]	1.4%
Kumar GB et al,2015	260	2731	0.10	[0.08; 0.11]	2.4%
Alves La Salete et al,2014	0	209	0.00	[0.00; 0.02]	2.6%
Lone Parveen et al,2014	89	787	0.11	[0.09; 0.14]	1.6%
Loutroukis Triantafillos et al,2020	25	201	0.12	[0.08; 0.18]	0.7%
Mabrouk Amr et al,2014	17	215	0.08	[0.05; 0.12]	1.0%
MH Majambo et al,2013	32	182	0.18	[0.12; 0.24]	0.5%
Niazi Thanvir et al,2017	31	136	0.23	[0.16; 0.31]	0.3%
Obimakinde Obitade et al,2013	0	34	0.00	[0.00; 0.10]	0.8%
Ogunmuyiwa Stella et al,2015	9	70	0.13	[0.06; 0.23]	0.3%
Pereira Cláudio et al,2011	67	521	0.13	[0.10; 0.16]	1.3%
Pham−Dang Nathalie et al,2014	73	364	0.20	[0.16; 0.25]	0.8%
Pradhan Leeza et al,2015	74	279	0.27	[0.21; 0.32]	0.6%
Rallis George et al,2015	1633	9616	0.17	[0.16; 0.18]	2.6%
Rana Zahoor et al,2010	231	2112	0.11	[0.10; 0.12]	2.2%
Silva e Farias Ilky et al,2017	19	244	0.08	[0.05; 0.12]	1.0%
Singh Vibha et al,2012	22	1038	0.02	[0.01; 0.03]	2.5%
Singaram Mohanavalli et al,2016	48	267	0.18	[0.14; 0.23]	0.7%
Udeabor S.E et al,2014	0	86	0.00	[0.00; 0.04]	2.0%
Weihsin Hu et al,2014	786	4437	0.18	[0.17; 0.19]	2.3%
Zandi Mohammad et al,2011	202	2450	0.08	[0.07; 0.09]	2.4%
Random effects model		**132003**	**0.10**	**[0.10; 0.11]**	**100.0%**

Heterogeneity: $I^2 = 100\%$, $\tau^2 = 0.0002$, $p = 0$

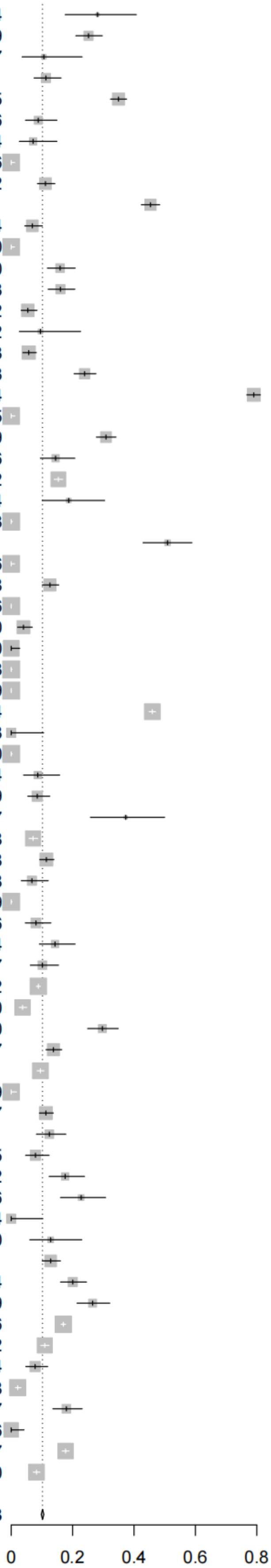


Figure 5. Articles included in this systematic review showing the proportion of fractures

Study	Events	Total	Proportion	95%−CI	Weight
Burnham Richard et al,2013	32	64	0.50	[0.37; 0.63]	0.7%
Verma Shreya et al,2015	111	111	1.00	[0.97; 1.00]	1.7%
Schneider Daniel et al,2015	409	409	1.00	[0.99; 1.00]	1.7%
Carvalho Filho Marcus et al,2015	.	47			0.0%
Samieirad Sahand et al,2015	221	221	1.00	[0.98; 1.00]	1.7%
Mahmoodi Benjamin et al,2015	1287	1305	0.99	[0.98; 0.99]	1.7%
Sultana Razia et al,2017	.	136			0.0%
Dr.Tiwary et al,2017	84	84	1.00	[0.96; 1.00]	1.7%
Teshome Amare et al,2017	164	326	0.50	[0.45; 0.56]	1.3%
Samieirad Sahand et al,2017	502	502	1.00	[0.99; 1.00]	1.7%
Emodi Omri et al,2017	1091	1091	1.00	[1.00; 1.00]	1.7%
Rojas Felix et al,2017	334	334	1.00	[0.99; 1.00]	1.7%
Mosaddad Seyed et al,2018	330	330	1.00	[0.99; 1.00]	1.7%
Al−Bokhamseen Mohammed et al,2019	270	270	1.00	[0.99; 1.00]	1.7%
Sarkarat Farzin et al,2019	293	293	1.00	[0.99; 1.00]	1.7%
Ramos Joab et al,2018	319	332	0.96	[0.93; 0.98]	1.7%
Lashari Dur et al,2018	42	42	1.00	[0.92; 1.00]	1.6%
Abosadegh Maher et al,2019	473	473	1.00	[0.99; 1.00]	1.7%
Goedecke Maximilian et al,2019	573	573	1.00	[0.99; 1.00]	1.7%
Brucoli M. et al,2019	.	1334			0.0%
AlHammad Ziyad et al,2019	295	295	1.00	[0.99; 1.00]	1.7%
Dhungel Safal et al,2020	182	528	0.34	[0.30; 0.39]	1.5%
Dong Liu et al,2020	829	829	1.00	[1.00; 1.00]	1.7%
Alharbi Fouad et al,2020	166	166	1.00	[0.98; 1.00]	1.7%
Wusiman Patiguli et al,2020	.	2492			0.0%
B. Vivek et al,2020	64	64	1.00	[0.94; 1.00]	1.7%
Júnior Sergio et al,2012	471	923	0.51	[0.48; 0.54]	1.6%
Toivari Miika et al,2018	161	161	1.00	[0.98; 1.00]	1.7%
Ruslin Muhammad et al,2019	.	326			0.0%
Lee Chee et al,2017	193	618	0.31	[0.28; 0.35]	1.5%
Pietza Sebastian et al,2019	12613	62196	0.20	[0.20; 0.21]	1.7%
Hirobe Yu et al,2020	74	130	0.57	[0.48; 0.66]	1.0%
Doving Mats et al,2020	1420	1543	0.92	[0.91; 0.93]	1.7%
Einy Scmuel et al,2020	.	4829			0.0%
Einy Scmuel et al,2016	.	8444			0.0%
ACO Olojede et al,2016	26	33	0.79	[0.61; 0.91]	0.6%
Gurung Utsad et al,2020	586	1110	0.53	[0.50; 0.56]	1.6%
Jindwani Karuna et al,2018	104	104	1.00	[0.97; 1.00]	1.7%
Olusanya Adeola et al,2015	177	259	0.68	[0.62; 0.74]	1.3%
Scheyerer Max et al,2015	67	67	1.00	[0.95; 1.00]	1.7%
Chandra Lokesh et al,2019	1278	1278	1.00	[1.00; 1.00]	1.7%
Arabion HR et aal,2014	730	768	0.95	[0.93; 0.96]	1.7%
Aslam Fouzia et al,2019	148	148	1.00	[0.98; 1.00]	1.7%
Boffano Paolo et al,2015	1309	1309	1.00	[1.00; 1.00]	1.7%
Cavalcanti A. et al,2010	169	186	0.91	[0.86; 0.95]	1.5%
Chalya Phillipo et al,2011	54	154	0.35	[0.28; 0.43]	1.1%
Ferreira Meire et al,2014	.	772			0.0%
Deliverska Elitsa et al,2012	.	276			0.0%
Elarabi Mohammed et al,2018	187	187	1.00	[0.98; 1.00]	1.7%
Gadre Kiran et al,2013	.	6872			0.0%
Gupta Ashish et al,2018	1850	1850	1.00	[1.00; 1.00]	1.7%
Bali Rishi,2013	740	740	1.00	[1.00; 1.00]	1.7%
Kapoor Pranav et al,2012	180	1000	0.18	[0.16; 0.21]	1.6%
Khitab Umar et al,2010	340	340	1.00	[0.99; 1.00]	1.7%
Kostakis George et al,2012	727	727	1.00	[0.99; 1.00]	1.7%
Kumar GB et al,2015	2052	2731	0.75	[0.73; 0.77]	1.7%
Alves La Salete et al,2014	209	209	1.00	[0.98; 1.00]	1.7%
Lone Parveen et al,2014	667	787	0.85	[0.82; 0.87]	1.6%
Loutroukis Triantafillos et al,2020	148	201	0.74	[0.67; 0.80]	1.3%
Mabrouk Amr et al,2014	215	215	1.00	[0.98; 1.00]	1.7%
MH Majambo et al,2013	172	182	0.95	[0.90; 0.97]	1.6%
Miguens−Jr Sergio et al,2016	118	1179	0.10	[0.08; 0.12]	1.7%
Niazi Thanvir et al,2017	136	136	1.00	[0.97; 1.00]	1.7%
Obimakinde Obitade et al,2013	14	34	0.41	[0.25; 0.59]	0.5%
Ogunmuyiwa Stella et al,2015	42	70	0.60	[0.48; 0.72]	0.7%
Pereira Cláudio et al,2011	521	521	1.00	[0.99; 1.00]	1.7%
Pham−Dang Nathalie et al,2014	364	364	1.00	[0.99; 1.00]	1.7%
Pradhan Leeza et al,2015	147	279	0.53	[0.47; 0.59]	1.3%
Rallis George et al,2015	9616	9616	1.00	[1.00; 1.00]	1.7%
Rana Zahoor et al,2010	941	2112	0.45	[0.42; 0.47]	1.7%
Silva e Farias Ilky et al,2017	218	244	0.89	[0.85; 0.93]	1.5%
Singaram Mohanavalli et al,2016	179	267	0.67	[0.61; 0.73]	1.3%
Udeabor S.E et al,2014	.	86			0.0%
Weihsin Hu et al,2014	4437	4437	1.00	[1.00; 1.00]	1.7%
Zandi Mohammad et al,2011	895	2450	0.37	[0.35; 0.38]	1.7%
Random effects model		**136121**	**0.84**	**[0.83; 0.86]**	**100.0%**

Heterogeneity: $I^2 = 100\%$, $\tau^2 = 0.0026$, $p = 0$

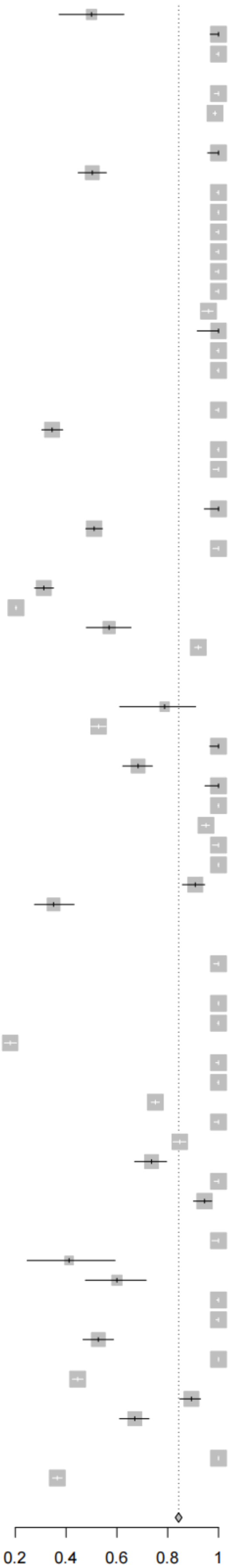


Figure 6. Articles included in this systematic review showing the proportion of soft tissue injuries

Study	Events	Total	Proportion	95%−CI	Weight
Burnham Richard et al,2013	32	64	0.50	[0.37; 0.63]	3.3%
Verma Shreya et al,2015	.	111			0.0%
Schneider Daniel et al,2015	.	409			0.0%
Carvalho Filho Marcus et al,2015	.	47			0.0%
Samieirad Sahand et al,2015	146	221	0.66	[0.59; 0.72]	3.3%
Mahmoodi Benjamin et al,2015	355	1305	0.27	[0.25; 0.30]	3.3%
Sultana Razia et al,2017	.	136			0.0%
Dr.Tiwary et al,2017	.	84			0.0%
Teshome Amare et al,2017	162	326	0.50	[0.44; 0.55]	3.3%
Samieirad Sahand et al,2017	.	502			0.0%
Emodi Omri et al,2017	.	1091			0.0%
Rojas Felix et al,2017	.	334			0.0%
Mosaddad Seyed et al,2018	.	330			0.0%
Al−Bokhamseen Mohammed et al,2019	.	270			0.0%
Sarkarat Farzin et al,2019	.	293			0.0%
Ramos Joab et al,2018	226	332	0.68	[0.63; 0.73]	3.3%
Lashari Dur et al,2018	.	42			0.0%
Abosadegh Maher et al,2019	.	473			0.0%
Goedecke Maximilian et al,2019	.	573			0.0%
Brucoli M. et al,2019	.	1334			0.0%
AlHammad Ziyad et al,2019	21	295	0.07	[0.04; 0.11]	3.3%
Dhungel Safal et al,2020	196	528	0.37	[0.33; 0.41]	3.3%
Dong Liu et al,2020	.	829			0.0%
Alharbi Fouad et al,2020	.	166			0.0%
Wusiman Patiguli et al,2020	826	2492	0.33	[0.31; 0.35]	3.3%
B. Vivek et al,2020	.	64			0.0%
Júnior Sergio et al,2012	452	923	0.49	[0.46; 0.52]	3.3%
Toivari Miika et al,2018	.	161			0.0%
Ruslin Muhammad et al,2019	.	326			0.0%
Lee Chee et al,2017	458	618	0.74	[0.70; 0.78]	3.3%
Pietza Sebastian et al,2019	.	62196			0.0%
Patil Satshkumar et al,2018	.	300			0.0%
Doving Mats et al,2020	.	1543			0.0%
Einy Scmuel et al,2020	115	4829	0.02	[0.02; 0.03]	3.3%
Einy Scmuel et al,2016	.	8444			0.0%
ACO Olojede et al,2016	33	33	1.00	[0.89; 1.00]	3.3%
Gurung Utsad et al,2020	1110	1110	1.00	[1.00; 1.00]	3.3%
Jindwani Karuna et al,2018	.	104			0.0%
Olusanya Adeola et al,2015	82	259	0.32	[0.26; 0.38]	3.3%
Scheyerer Max et al,2015	.	67			0.0%
Chandra Lokesh et al,2019	.	1278			0.0%
Arabion HR et aal,2014	104	768	0.14	[0.11; 0.16]	3.3%
Aslam Fouzia et al,2019	.	148			0.0%
Boffano Paolo et al,2015	.	1309			0.0%
Cavalcanti A. et al,2010	185	186	0.99	[0.97; 1.00]	3.3%
Chalya Phillipo et al,2011	.	154			0.0%
Ferreira Meire et al,2014	.	772			0.0%
Deliverska Elitsa et al,2012	.	276			0.0%
Elarabi Mohammed et al,2018	.	187			0.0%
Gadre Kiran et al,2013	.	6872			0.0%
Gupta Ashish et al,2018	.	1850			0.0%
Bali Rishi,2013	.	740			0.0%
Kapoor Pranav et al,2012	840	1000	0.84	[0.82; 0.86]	3.3%
Khitab Umar et al,2010	.	340			0.0%
Kostakis George et al,2012	.	727			0.0%
Kumar GB et al,2015	172	2731	0.06	[0.05; 0.07]	3.3%
Alves La Salete et al,2014	.	209			0.0%
Lone Parveen et al,2014	39	787	0.05	[0.04; 0.07]	3.3%
Loutroukis Triantafillos et al,2020	73	201	0.36	[0.30; 0.43]	3.3%
Mabrouk Amr et al,2014	.	215			0.0%
MH Majambo et al,2013	181	182	0.99	[0.97; 1.00]	3.3%
Miguens−Jr Sergio et al,2016	760	1179	0.64	[0.62; 0.67]	3.3%
Niazi Thanvir et al,2017	136	136	1.00	[0.97; 1.00]	3.3%
Obimakinde Obitade et al,2013	18	34	0.53	[0.35; 0.70]	3.3%
Ogunmuyiwa Stella et al,2015	52	70	0.74	[0.62; 0.84]	3.3%
Pereira Cláudio et al,2011	.	521			0.0%
Pham−Dang Nathalie et al,2014	.	364			0.0%
Pradhan Leeza et al,2015	229	279	0.82	[0.77; 0.86]	3.3%
Rallis George et al,2015	.	9616			0.0%
Rana Zahoor et al,2010	904	2112	0.43	[0.41; 0.45]	3.3%
Silva e Farias Ilky et al,2017	26	244	0.11	[0.07; 0.15]	3.3%
Singaram Mohanavalli et al,2016	18	267	0.07	[0.04; 0.10]	3.3%
Udeabor S.E et al,2014	.	86			0.0%
Weihsin Hu et al,2014	.	4437			0.0%
Zandi Mohammad et al,2011	2206	2450	0.90	[0.89; 0.91]	3.3%
Random effects model		**136291**	**0.52**	**[0.33; 0.71]**	**100.0%**

Heterogeneity: $I^2 = 100\%$, $\tau^2 = 0.2910$, $p = 0$

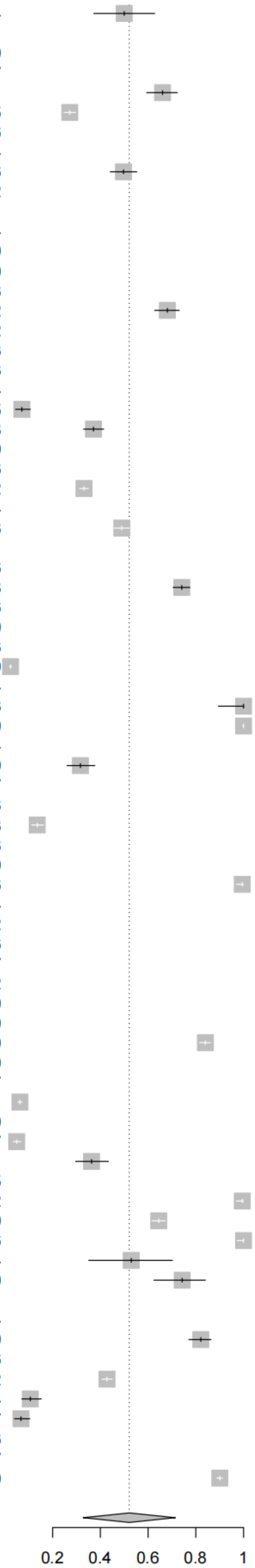
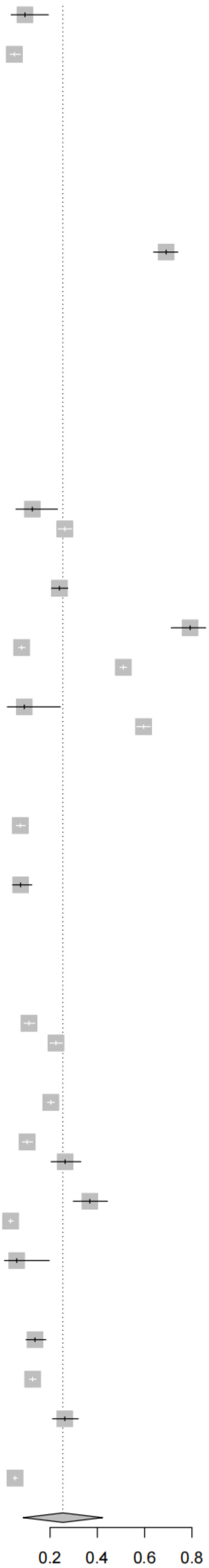


Figure 7. Articles included in this systematic review showing proportion of dental injuries

Study	Events	Total	Proportion	95%-CI	Weight
Burnham Richard et al,2013	6	64	0.09	[0.04; 0.19]	3.8%
Verma Shreya et al,2015	.	111			0.0%
Schneider Daniel et al,2015	20	409	0.05	[0.03; 0.07]	3.9%
Carvalho Filho Marcus et al,2015	.	47			0.0%
Samieirad Sahand et al,2015	.	221			0.0%
Mahmoodi Benjamin et al,2015	1287	1305	0.99	[0.98; 0.99]	3.9%
Sultana Razia et al,2017	.	136			0.0%
Dr.Tiwary et al,2017	.	84			0.0%
Teshome Amare et al,2017	.	326			0.0%
Samieirad Sahand et al,2017	.	502			0.0%
Emodi Omri et al,2017	.	1091			0.0%
Rojas Felix et al,2017	.	334			0.0%
Mosaddad Seyed et al,2018	228	330	0.69	[0.64; 0.74]	3.8%
Al−Bokhamseen Mohammed et al,2019	.	270			0.0%
Sarkarat Farzin et al,2019	.	293			0.0%
Ramos Joab et al,2018	.	332			0.0%
Lashari Dur et al,2018	.	42			0.0%
Abosadegh Maher et al,2019	.	473			0.0%
Goedecke Maximilian et al,2019	.	573			0.0%
Brucoli M. et al,2019	.	1334			0.0%
AlHammad Ziyad et al,2019	.	295			0.0%
Dhungel Safal et al,2020	.	528			0.0%
Dong Liu et al,2020	.	829			0.0%
Alharbi Fouad et al,2020	.	166			0.0%
Wusiman Patiguli et al,2020	.	2492			0.0%
B. Vivek et al,2020	8	64	0.12	[0.06; 0.23]	3.8%
Júnior Sergio et al,2012	242	923	0.26	[0.23; 0.29]	3.9%
Toivari Miika et al,2018	.	161			0.0%
Ruslin Muhammad et al,2019	.	326			0.0%
Lee Chee et al,2017	148	618	0.24	[0.21; 0.28]	3.9%
Pietza Sebastian et al,2019	.	62196			0.0%
Hirobe Yu et al,2020	103	130	0.79	[0.71; 0.86]	3.8%
Doving Mats et al,2020	123	1543	0.08	[0.07; 0.09]	3.9%
Einy Scmuel et al,2020	2462	4829	0.51	[0.50; 0.52]	3.9%
Einy Scmuel et al,2016	.	8444			0.0%
ACO Olojede et al,2016	3	33	0.09	[0.02; 0.24]	3.8%
Gurung Utsad et al,2020	661	1110	0.60	[0.57; 0.62]	3.9%
Jindwani Karuna et al,2018	.	104			0.0%
Olusanya Adeola et al,2015	.	259			0.0%
Scheyerer Max et al,2015	.	67			0.0%
Chandra Lokesh et al,2019	.	1278			0.0%
Arabion HR et aal,2014	57	768	0.07	[0.06; 0.10]	3.9%
Aslam Fouzia et al,2019	.	148			0.0%
Boffano Paolo et al,2015	.	1309			0.0%
Cavalcanti A. et al,2010	14	186	0.08	[0.04; 0.12]	3.8%
Chalya Phillipo et al,2011	.	154			0.0%
Ferreira Meire et al,2014	.	772			0.0%
Deliverska Elitsa et al,2012	.	276			0.0%
Elarabi Mohammed et al,2018	.	187			0.0%
Gadre Kiran et al,2013	.	6872			0.0%
Gupta Ashish et al,2018	.	1850			0.0%
Bali Rishi,2013	82	740	0.11	[0.09; 0.14]	3.9%
Kapoor Pranav et al,2012	225	1000	0.22	[0.20; 0.25]	3.9%
Khitab Umar et al,2010	.	340			0.0%
Kostakis George et al,2012	.	727			0.0%
Kumar GB et al,2015	555	2731	0.20	[0.19; 0.22]	3.9%
Alves La Salete et al,2014	.	209			0.0%
Lone Parveen et al,2014	81	787	0.10	[0.08; 0.13]	3.9%
Loutroukis Triantafillos et al,2020	53	201	0.26	[0.20; 0.33]	3.8%
Mabrouk Amr et al,2014	.	215			0.0%
MH Majambo et al,2013	67	182	0.37	[0.30; 0.44]	3.8%
Miguens−Jr Sergio et al,2016	39	1179	0.03	[0.02; 0.04]	3.9%
Niazi Thanvir et al,2017	.	136			0.0%
Obimakinde Obitade et al,2013	2	34	0.06	[0.01; 0.20]	3.8%
Ogunmuyiwa Stella et al,2015	.	70			0.0%
Pereira Cláudio et al,2011	.	521			0.0%
Pham−Dang Nathalie et al,2014	.	364			0.0%
Pradhan Leeza et al,2015	38	279	0.14	[0.10; 0.18]	3.8%
Rallis George et al,2015	.	9616			0.0%
Rana Zahoor et al,2010	267	2112	0.13	[0.11; 0.14]	3.9%
Silva e Farias Ilky et al,2017	.	244			0.0%
Singaram Mohanavalli et al,2016	70	267	0.26	[0.21; 0.32]	3.8%
Udeabor S.E et al,2014	.	86			0.0%
Weihsin Hu et al,2014	.	4437			0.0%
Zandi Mohammad et al,2011	127	2450	0.05	[0.04; 0.06]	3.9%
Random effects model		**136121**	**0.25**	**[0.09; 0.42]**	**100.0%**

Heterogeneity: $I^2 = 100\%$, $\tau^2 = 0.1908$, $p = 0$



ACKNOWLEDGEMENT

This research was supported by the Centro de Estatística e Aplicações da Universidade de Lisboa, CEAUL, FCT – Fundação para a Ciência e a Tecnologia, Grant Project reference UIDB/00006/2020

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Testing the maturation and the radiographic visibility of the root pulp of mandibular third molars for predicting 21 years. A digital panoramic radiographic study in emerging adults of south Indian origin

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The authors declare that they have no conflict of interest.

KEYWORDS

Forensic Odontology; Dental age estimation; 21 years; Third molar maturity index; Radiographic visibility of the root pulp

J Forensic Odontostomatol 2022. Dec;(40): 3-22:33
ISSN :2219-6749

ABSTRACT

Prediction of the attainment of legal age thresholds, especially in children and young adults, is a common task in medico-legal practice. In many countries, 21 years has medico-legal importance. In the present study, we assessed and compared the accuracy of the third molar maturity index (I3M) and the stages of radiographic visibility of the root pulp (RPV) in predicting the age threshold of 21 years. A sample of 910 digital panoramic radiographs (455 males and 455 females) of adolescents and young adults aged between 16 and 30 of south Indian origin were evaluated. The authors examined the performance of different I3M cut-off values and RPV stages. I3M cut-off value of 0.02 has resulted in better discrimination with an accuracy of 76.92% and 80.44%, specificity of 48.28% and 56.16% in males and females, a sensitivity of 100%, and post-test probability of 65.9% in both sexes. The accuracy and sensitivity of RPV stage 2 were 84.76% and 84.55%, 78.17%, and 78.97% in males and females, while the specificity and post-test probability were 100% in both sexes.

In conclusion, the I3M method resulted in a more significant percentage of false positives and cannot be used to state the attainment of 21 years. However, the presence of RPV stage 2 could say that the subject had already attained the age of 21 years. Further studies are warranted to address the usefulness of these methods.

INTRODUCTION

Assessment of the biological age of a living subject is a common practice in medico-legal, civil and social issues.[1] It becomes challenging for forensic experts when authorities want scientific proof of whether the examined subject is under or over the cut-off age of medico-legal importance. In India, as in many countries, it is required to provide proof of being under or over the legally defined age limits, especially for children who were part of criminal and medico-legal investigations. The applicable age limits in India for various legal issues range between 14 and 21 years of age (Table 1).[2] Lately, there has been increasing concern in India about raising the legal age of marriage for girls from 18 to 21 years.[3, 4] This highlights the need for age estimation methods to predict the legal age threshold of 21 years.

Choosing the parameters suitable for predicting the legal age of interest is essential in age estimation practice. According to the literature, teeth and their maturation are more reliable for age assessment than skeletal parameters due to lower variability in the former than in the latter.[5] In addition, the calcification rate of the teeth is more controlled by genetic than environmental factors.[6] Since the development of the third molar extends into the early twenties, it has a unique advantage over other teeth and has become a subject of interest in forensic age assessments. The third molar maturity index (I3M) method, introduced by Cameriere et al. (2008)[7] for predicting the legal age of 18 years, has gained much popularity in forensic age estimation.[8] Several authors have applied the I3M method to predict other legal age thresholds, such as 14[9, 10,] and 16 years.[11]

Olze et al. [12] recognized the importance of an alternative dental method that can be applied to the third molars after root completion. Therefore, they introduced a stage classification that examined the radiographic visibility of the third molars' root pulp (RPV) for age estimation purposes. They concluded that this method could help predict 18 and 21 years of age. Researchers tested this method in other populations to predict 18 years,[13, 14], 21 years[15, 16,] and both 18 and 21 years together.[17- 19] In 2021, Pyata et al.[20] compared the accuracy of four dental age estimation methods to predict the legal age threshold of 18 years and concluded that radiographic visibility of root pulp in lower third molars is not a reliable tool due to the more significant percentage of third molars with incomplete mineralization in younger age groups. Alternatively, SB Balla et al.[21] and Suvarna et al.[22] studied this stage classification in mandibular first and second molars and proved its usefulness in estimating 18 years of age.

To the best of our knowledge, no study was available in the scientific literature to predict the legal age threshold of 21 years in emerging adults of south Indian origin. Therefore, in the present investigation, we aim to predict the attainment of the legal age threshold of 21 years using Cameriere's third molar maturity index (I3M). We also intend to study the radiographic visibility of the root pulp of the mandibular third molars. Additionally, we want to determine the accuracy of both methods.

Table 1. Legal area, legally relevant age limits, and legal issues in India

<table>
<tr><th>Legal area</th><th>Age limit (In years)</th><th>Legal issue (s)</th></tr>
<tr><td>Article 24 of Indian constitution</td><td>14 years</td><td>A child below 14 years shall not be employed to work in any factory or mine or engaged in other hazardous employment (Child labour)</td></tr>
<tr><td>Article 24 of Indian constitution</td><td>16- 18 years</td><td>Addresses children in conflict with law and children in need of care and protection.</td></tr>
<tr><td>Article 24 of Indian constitution</td><td>16 years</td><td>Sexual intercourse with a woman even with her consent is rape, if she was below 16 years of age</td></tr>
<tr><td>Article 24 of Indian constitution</td><td rowspan="3">18 years</td><td>Age of majority</td></tr>
<tr><td>Article 24 of Indian constitution</td><td>A person who is below 18 years of age is a minor</td></tr>
<tr><td>Article 24 of Indian constitution</td><td>Applicability of Criminal law, Capacity for actions and processes</td></tr>
<tr><td>Article 24 of Indian constitution</td><td>21 years</td><td>The legal age for marriage for a male</td></tr>
</table>

I.P.C; Indian Penal Code

MATERIAL AND METHODS

Sample

We evaluated digital panoramic radiographs of 910 adolescents and young adults (455 males and 455 females) of south Indian origin, ranging from 16 to 30 years (Table 2). Radiographs of the subjects who attended the private dental clinics that were pre-treatment in nature were collected retrospectively. Patient details such as the age, sex, date of birth, and date of exposure, i.e., the date on which the radiograph was taken, were recorded separately in an excel file. Each radiograph is assigned an identification code that matches the patient's details. It allows a blinded approach, i.e., the examiner is unaware of the patient information to avoid bias during the analysis. Radiographs were retrieved as digitalized images from the database and then stored in digital format (JPEG). The examiners use ImageJ computer software (version 1.48, National Institute of Health, USA) to perform an analysis of the radiographs. It allows them to use "magnify" and "ruler" tools for measurements. Radiographs showing the presence of at least one mandibular third molar with no evident bone pathology will be included. Radiographs of unknown age, sex, those with missing lower third molars on both sides were excluded. Radiographs that were of poor quality or distorted were also excluded.

Methodology

Third molar maturity (I3M) index

The I3M index of each mandibular third molar was studied using the method of Cameriere et al.[7] I3M is evaluated as the sum of the distances between the inner sides of the two open apices (X+Y) divided by the tooth length (Z) (Figure 1). A score of "0" is allocated when the development of the third molar is complete.

Radiographic visibility of the root pulp

The prediction of the legal age threshold of 21 years was also determined using the Olze et al. stages of RPV[12], which include stages 0 to 3. Stage "0" includes mandibular third molars with root canals visible to the apex. In contrast, stage "3" has mandibular third molars, with the lumen of two root canals virtually invisible in total length (Figure 2).

All the measurements, i.e., I3M measurements and RPV stage allocation, were performed by a single examiner (SBB), an experienced forensic odontologist. Later, SBB and the fourth author analyzed 100 randomly selected OPGs 6 weeks after the first analysis.

Table 2. Distribution of the total sample according to sex and age, numbers in parenthesis represent samples with open apices of the left third mandibular molars

Age group	Males	Females	Total
16- 16.99	40 (40.8)	40 (35.1)	80
17- 17.99	40 (32.7)	40 (30.7)	80
18- 18.99	40 (15.3)	40 (15.8)	80
19- 19.99	40 (8.2)	40 (17.5)	80
20- 20.99	43 (3.1)	43 (0.9)	86
21- 21.99	37 (0)	36 (0.9)	73
22- 22.99	40 (0)	40 (0)	80
23- 23.99	25 (0)	25 (0)	50
24- 24.99	25 (0)	26 (0)	51
25- 25.99	25 (0)	25 (0)	50
26- 26.99	25 (0)	25 (0)	50
27- 27.99	25 (0)	25 (0)	50
28- 28.99	25 (0)	25 (0)	50
29- 29.99	25 (0)	25 (0)	50
Total	455	455	910

Figure 1. Measurements of third molar maturity index. I3M is evaluated as the sum of the distances between the inner sides of the two open apices (X+Y) divided by tooth length (Z)

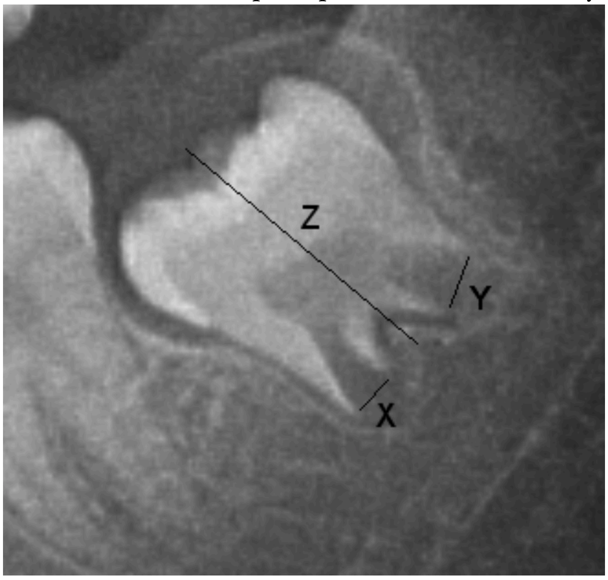
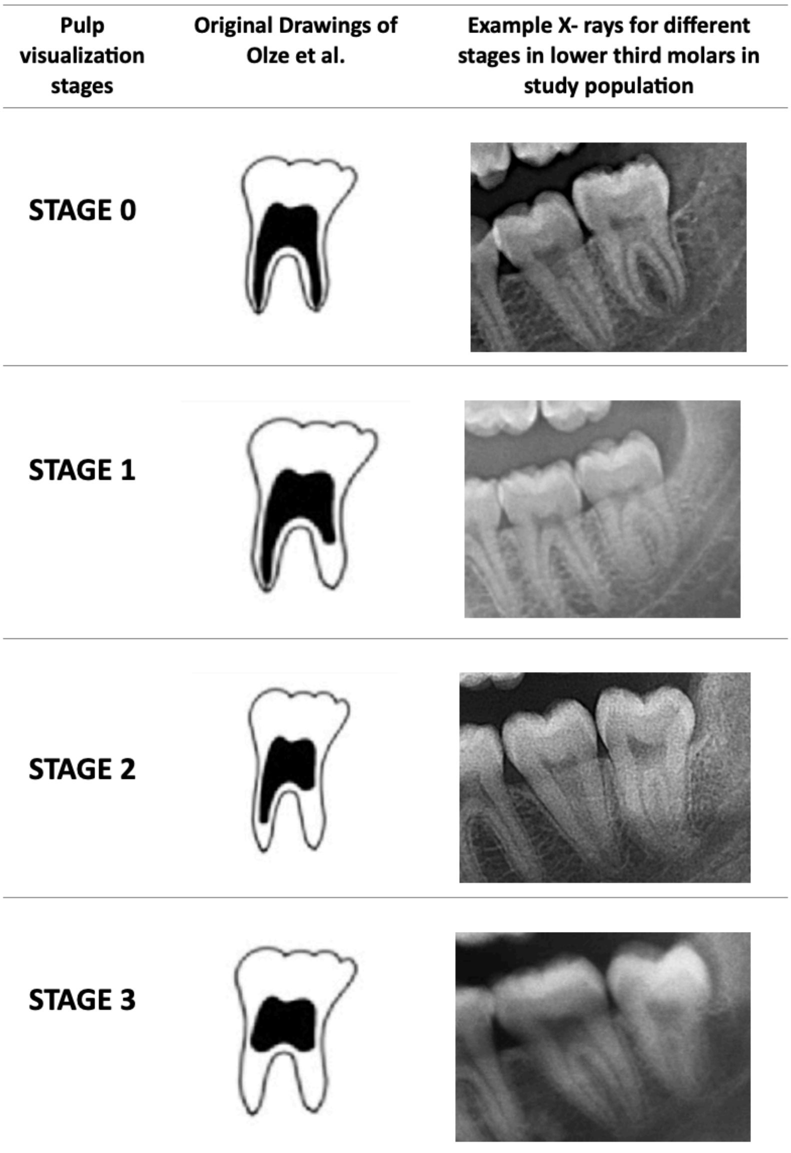


Figure 2. Images of the stages of radiographic visibility of the root pulp in mandibular third molars



Statistical analysis

Data analysis was performed using SPSS statistics v.20.0 for windows (IBM; Armonk; New York, USA). The significance level for the analysis was set at 5%. Intra- and inter-examiner agreement for both methods were calculated using the intra-class correlation coefficient (ICC) method. Four different widely used precision estimates were calculated: the technical error of measurement (TEM), the relative technical error of measurement (rTEM), and the coefficient of reliability (R) to study intra- and inter-examiner precision.

Descriptive statistics were performed. To test the performance of specific cut-off values of I3M and RPV stage, the results were summarized in a table consisting of 2x2 contingency tables. The details of the diagnostic performance indicators from a single 2x2 contingency table were determined and displayed in Table 3.

The post-test probability (p) of being 21 years of age or older can help to discriminate between those individuals who are 21 and over and those under 21. According to Bayes theorem, the post-test probability may be written as:

$$p = \frac{Se \times p0}{Se \times p0 + \left(1 - Sp\right) \times (1 - p0)}$$

where p is post-test probability and p_0 is the probability that the subject in question is ≥ 21 years, given that they are aged between 16 and 30 years, representing the target population. Probability p_0 was calculated as the proportion of subjects between 21 and 30 years of age who live in Andhra Pradesh and Telangana and those between 16 and 30 years, which was evaluated from data from the same web source. This value (po) was considered to be 0.50 for both males and females according to the demographic data from the 2011 census (http://www.censusindia.gov.in/2011census/C- series/C-13.html).

Table 3. Diagnostic performance indicators used in the comparative analysis

True positive	The number of participants who have I3M< 0.02 who are 21 years and older (OR) the number of participants who have RPV stage 2 or higher who are 21 years and older.
False positive	The number of participants who have I3M< 0.02 who are younger than 21 years (OR) the number of participants who have RPV stage 2 or higher who are younger than 21 years.
True negative	The number of participants who have I3M≥ 0.02 who are younger than 21 years (OR) the number of participants who have RPV stage 1 or lower who are younger than 21 years.
False negative	The number of participants who have I3M≥ 0.02 who are 21 years and older (OR) the number of participants who have RPV stage 1 or lower who are 21 years and older.
Accuracy	Proportion of correctly identified participants
Sensitivity	The proportion of the participants 21 years and older who had I3M or the RPV stage < cut-off
Specificity	The proportion of the participants younger than 21 years who had I3M or the RPV stage ≥ cut-off
Positive predictive value (PPV)	Tests that look at out of the positive tests of how many were truly positive and correctly classified
Negative predictive value (NPV)	Tests that look at out of the negative tests of how many were truly negative and correctly classified
Likelihood Ratio of the positive test (LR+)	The probability that an individual 21 and older selected positive for the tested age 21years (true positive) divided by the probability that an individual younger than 21 selected positive for the tested age 21 years (false positive).
Likelihood Ratio of the negative test (LR-)	The probability that an individual 21 and older selected negative for the tested age 21years (false negative) divided by the probability that an individual younger than 21 selected negative for the tested age 21years (true negative).

RESULTS

The intra- and inter-examiner agreements of I3M between the same examiner and two different examiners were 0. 961 (95% CI; 0.907 to 0.983) and 0.929 (95% CI 0.831 to 0.971), indicating good to excellent agreement between them. For the RPV stages, the results of intra-examiner reliability for the same examiner were 0.841 (95% CI 0.767 to 0.899), while the inter-examiner reliability were 0.801 (95% CI 0.744 to 0.968), indicating good agreement. The results of TEM, rTEM, and R values are presented in table 4. The coefficient of reliability (R) values was greater than 95% for I3M measurements for both intra- and inter-examiner agreements.

Table 5 and Figure 3 show the statistical description of the relationship between RPV stages and chronological age in both sexes. Table 6 displays the results of 2x2 contingency tables indicating the discrimination between the subjects aged <21 years and ≥ 21 years by using different I3M cut-off values (0.02 to 0.07). Table 7 displays the results of 2x2 contingency tables for RPV stage 2 for both males and females. Tables 8 and 9 show the quantities derived for different I3M cut-off values in males and females, respectively. Finally, table 10 shows the test results (RPV stage 2) for the discrimination of the subjects.

Table 4. TEM, rTEM and R tests for intra- and inter-examiner agreements

	TEM	rTEM	R
Intra-examiner			
Third molar maturity index	0.07	16.3	0.989
Root Pulp Visibility stages	0.31	25.72	0.950
Inter-examiner			
Third molar maturity index	0.054	12.1	0.972
Root Pulp Visibility stages	0.632	53.63	0.901

TEM, technical error of measurement; rTEM, relative technical error of measurement; R, coefficient of reliability

Table 5. Descriptive statistics of different stages of radiographic visibility of the root pulp in mandibular third molars according to age

Stage	Male					Female				
	Age (in years)					Age (in years)				
	n	Mean	SD	Min	Max	n	Mean	SD	Min	Max
0	22	18.25	0.74	17.33	20.26	20	19.14	1.90	17.41	22.92
1	142	20.72	1.51	18.39	25.81	124	20.85	1.65	18.13	25.66
2	158	25.24	2.20	21.21	29.86	147	24.96	2.09	21.03	29.67
3	39	28.58	0.83	26.31	29.81	52	28.48	1.11	25.68	29.88

SD, Standard deviation; Min, Minimum; Max, Maximum

Figure 3. Boxplot of relationship between chronological age and stages of radiographic visibility of the root pulp in mandibular third molars, according to males and females

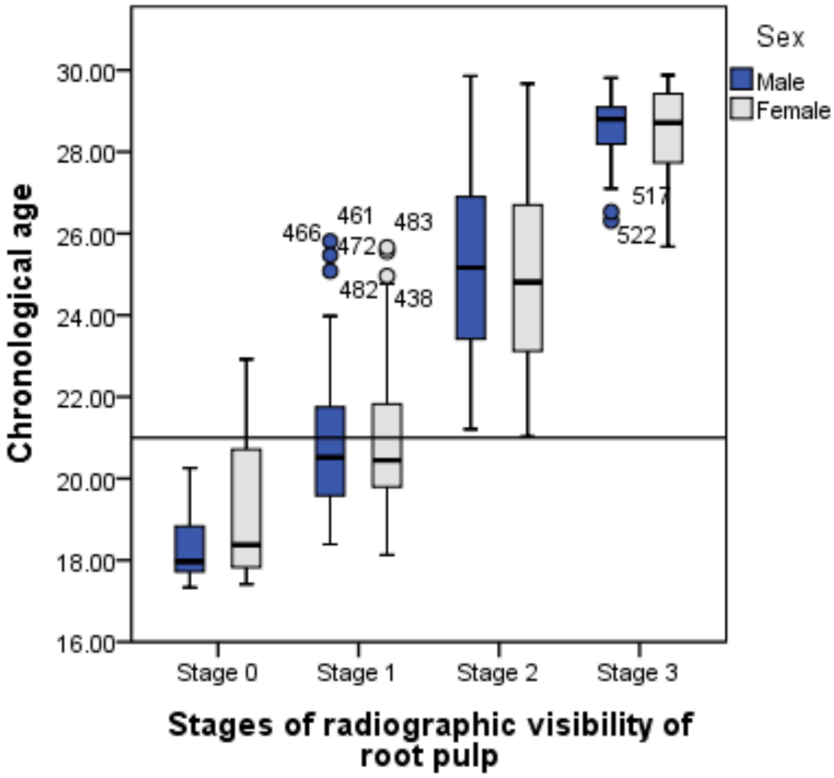


Table 6. Contingency data describing discrimination performance of the test for different cut-off values of third molar maturity index (I3M) in males and females

Males				Females			
Test	Age		Total	Test	Age		Total
	≥ 21 years	<21 years			≥ 21 years	<21 years	
I3M< 0.02	252TP	105FP	357	I3M< 0.02	252TP	89FP	341
I3M ≥ 0.02	0FN	98TN	98	I3M ≥ 0.02	0FN	114TN	114
I3M< 0.03	252TP	106FP	358	I3M< 0.03	252TP	90FP	342
I3M ≥ 0.03	0FN	97TN	97	I3M ≥ 0.03	0FN	113TN	113
I3M< 0.04	252TP	109FP	361	I3M< 0.04	252TP	90FP	342
I3M ≥ 0.04	0FN	94TN	94	I3M ≥ 0.04	0FN	113TN	113
I3M< 0.05	252TP	111FP	363	I3M< 0.05	252TP	94FP	346
I3M ≥ 0.05	0FN	92TN	92	I3M ≥ 0.05	0FN	109TN	109
I3M< 0.06	252TP	112FP	364	I3M< 0.06	252TP	98FP	350
I3M ≥ 0.06	0FN	91TN	91	I3M ≥ 0.06	0FN	105TN	105
I3M< 0.07	252TP	114FP	366	I3M< 0.07	252TP	103FP	355
I3M ≥ 0.07	0FN	89TN	89	I3M ≥ 0.07	0FN	100TN	100

TP, True positive; FP False positive; TN, True negative; FN, False negative

Table 7. Contingency data describing discrimination performance of the test for stage 2 of radiographic visibility of root pulp of mandibular third molars in males and females

Males				Females			
Test	Age		Total	Test	Age		Total
	≥21 years	<21 years			≥21 years	<21 years	
Stages <2	55 FN	109 TN	164	Stages <2	53 FN	91 TN	144
Stages ≥2	197 TP	0 FP	197	Stages ≥2	199 TP	0 FP	199

TP, True positive; FP False positive; TN, True negative; FN, False negative

Table 8. The quantities derived from 2x2 contingency tables of the test (predicting 21 years) in south Indian males when different cut-off values were used.

Quantities	0.02	0.03	0.04	0.05	0.06	0.07
Accuracy	76.92 (72.7- 80.7)	76.7 (72.5- 80.5)	76.04 (71.8- 79.9)	75.6 (71.3- 79.4)	75.3 (71.1- 79.2)	74.95 (70.7- 78.8)
Sensitivity	100 (98.5- 100)	100 (98.5- 100)	100 (98.5- 100)	100 (98.5- 100)	100 (98.5- 100)	100 (98.5- 100)
Specificity	48.28 (41.2- 55.3)	47.78 (40.7- 54.8)	46.31 (41.2- 55.3)	45.32 (38.3- 52.4)	44.83 (37.8- 51.9)	43.84 (36.9- 50.9)
PPV	70.59 (67.7- 73.2)	70.39 (67.5- 73.1)	69.81 (67.1- 72.4)	69.42 (66.7- 72.1)	69.23 (66.5- 71.8)	68.85 (66.1- 71.4)
NPV	100	100	100	100	100	100
LR+	1.93 (1.69- 2.21)	1.92 (1.68- 2.18)	1.86 (1.64- 2.12)	1.83 (1.61- 2.07)	1.81 (1.60- 2.05)	1.78 (1.58- 2.01)
LR-	0.00	0.00	0.00	0.00	0.00	0.00
PTP	65.9 (62.8- 68.8)	65.8 (62.7- 68.6)	65 (62.1- 67.9)	64.7 (61.7- 67.4)	64.4 (61.5- 67.2)	64 (61.2- 66.8)

Table 9. The quantities derived from 2 x 2 contingency tables of the test (predicting 21 years) in south Indian females when different cut-off values were used.

Quantities	0.02	0.03	0.04	0.05	0.06	0.07
Accuracy	80.44 (76.4- 83.9)	80.22 (76.2- 83.7)	80.22 (76.2- 83.7)	79.34 (75.3- 82.9)	78.46 (74.4- 82.1)	77.36 (73.2- 81.1)
Sensitivity	100 (98.5- 100)	100 (98.5- 100)	100 (98.5- 100)	100 (98.5- 100)	100 (98.5- 100)	100 (98.5- 100)
Specificity	56.16 (49.1- 63.1)	55.67 (48.5- 62.6)	55.67 (48.5- 62.6)	53.69 (46.5- 60.7)	51.72 (44.6- 58.7)	49.26 (42.1- 56.3)
PPV	73.9 (70.7- 76.7)	73.6 (70.5- 76.5)	73.6 (70.5- 76.5)	72.83 (69.8- 75.6)	72 (69.1- 74.7)	70.9 (68.1- 73.7)
NPV	100	100	100	100	100	100
LR+	2.28 (1.95- 2.67)	2.26 (1.93- 2.63)	2.26 (1.93- 2.63)	2.16 (1.86- 2.5)	2.07 (1.8- 2.39)	1.97 (1.72- 2.26)
LR-	0.00	0.00	0.00	0.00	0.00	0.00
PTP	69.5 (66.1- 72.8)	69.3 (65.9- 72.5)	69.3 (65.9- 72.5)	68.4 (65- 71.4)	67.4 (64.3- 70.5)	66.3 (63.2- 69.3)

Table 10. The quantities derived from 2x2 contingency tables of the test (predicting 21 years) in south Indian sample when different stages of radiographic visibility of root pulp of mandibular third molars in males and females

Quantities	RPV Stage 2	
	Males	Females
Accuracy	84.76 (80.6- 88.3)	84.55 (80.2- 88.2)
Sensitivity	78.17 (72.5- 83.1)	78.97 (73.4- 83.8)
Specificity	100 (96.6- 100)	100 (96- 100)
PPV	100	100
NPV	66.46 (61.1- 71.4)	63.19 (57.4- 68.5)
LR+	0.00	0.00
LR-	0.22 (0.17- 0.28)	0.21 (0.17- 0.27)
PTP	100	100

DISCUSSION

According to the age group of medico-legal interest, discriminating against subjects, especially children and young adults, is a common practice in forensic age assessments. Literature indicates evidence of extensive research to predict the attainment of various legal age thresholds, i.e., 12, 14, 15, 16, and 18 years.[7- 11, 23- 25] In addition to these, 21 years has medico-legal importance. According to article 33 of the Turkish Penal code, the legal age of adulthood is 21 years for individuals with hearing impairments.[17, 25] In German criminal courts, if the offender is below 21 years of age, he/she might receive a milder punishment by applying a special juvenile law.[12] According to the Indian marriage law, the legally permissible age of marriage is 21 years for males and 21 years is under consideration for females.[3, 4] Owing to the rise in child marriages, it is essential to determine whether he/she is 21 years old to assess the individual's right to marriage age. It is equally important and relevant to find a methodology to determine whether an individual has attained 21 years of age or not.

In India, forensic dentists receive requests for the assessment of the legal age of 21 years for civil purposes. The authors in this manuscript dealt with civil cases where the youth from the southern states of India, especially Telangana, sought age certificates. The government of Telangana announced multiple schemes, such as the "TS Nirudyoga Bruthi Scheme" and "Bangaru Thalli" scheme. The former provides financial assistance to the unemployed youth, and the latter provides incentives for achieving certain milestones for the female child until she reaches the age of 21.[26, 27]

Much research has been performed on third molar maturation and its application in forensic age assessments. According to the literature, the development of third molars extends into the early twenties. However, to date, no research was available in the literature testing the applicability of I3M for the prediction of 21 years. To the best of our knowledge, this is the first study to test the usefulness of I3M for the legal age threshold of 21 years. We also tried the radiographic visibility of root pulp by Olze et al.,[12], which is applicable after the completed formation of the mandibular third molars.

Third molar maturity index (I3M)

Our results showed that the mineralization of the mandibular third molars finished at 21 years in males and 22 years in females. We observed that very few female subjects (0.9%) 21 years and above had mandibular third molars with their root apices still open. These findings indicate that the maturation of the mandibular third molars was faster in males than in females, which is in line with the literature. No subjects have shown developing third molars beyond 23 years of age in the studied population.

From a forensic and legal point of view, discrimination performance of the test should show better specificity or fewer subjects who were below 21 years to be wrongly classified as 21 years or older. Considering this, we tested various I3M cut-off values ranging between 0.02 and 0.07. Our study results showed that for I3M< 0.02, the accuracy, sensitivity, specificity, and post-test probability values were 76.92 and 80.44, 100 and 100, 48.28 and 56.16, and 65.9 and 65.9 in both males and females, respectively. However, we did not observe any improvement in the discrimination performance of the test, especially specificity, with the increase in the I3M cut-off value from 0.02 to 0.07. The lower specificity values reflected the presence of a higher percentage of subjects younger than 21 years with fully matured mandibular third molars. Approximately 30% of males and 26% of females younger than 21 had fully developed mandibular third molars. These findings indicate a chance to wrongly identify one in four subjects younger than 21 as above 21.

On the other hand, the likelihood ratios, i.e., the alternative diagnostic measures to discriminate subjects around the legal age threshold, were evaluated.[28] These values are helpful to interpret how many times more or less likely subjects of 21 years or older are to be selected as 21 years and above than individuals below 21 years. Higher LR+ values and lower LR- values mean a good prediction of the probability of the individuals being 21 years and above. Our findings showed poorer LR- values (values close to or equal to 0) for all I3M cut-off values, indicating the probability of correctly identifying individuals aged 21 years or older.

One of the drawbacks of the I3M method for predicting the attainment of 21 years is the inclusion of subjects 23 years and older. It resulted in better sensitivity values as the older subjects whose root apices have closed affect mean measured value of I3M, thereby the performances of the discrimination test.[29]

Radiographic visibility of the root pulp

Our study findings showed almost perfect repeatability and substantial reproducibility. However, these findings are similar to the previous studies.[13-16] Since the scoring/staging method is a subjective perception of the regressive changes, examiners with experience in forensic age assessments preferred to perform evaluations. Our results further highlighted the need for the training of the examiners and calibration.

According to our study findings, stage 0 could be used as an age marker since all the males were younger than 21 years of age; for females, the results were not as discriminatory as for males since 20% of females marked stage 3 were older than 21. Stage 2 did not account for better discriminatory capacity; 61.3% of males and 60% of females were younger than 21. On the other hand, stages 2 and 3 proved valuable markers since all the males and females in these respective stages (2 and 3) were older than 21. These findings were similar to Olze et al. [12], which stated that stages 2 and 3 safely indicate age over 21 years. In addition, our results were partly identical to that of Pérez-Mongiovi et al. [15], in which they reported that stage 2 was not a helpful marker to indicate age over 21 years since it resulted in approximately 15% errors. According to them, stage 3 has better discriminatory capacity in both sexes. In another study by Guo et al. [18] in the Northern Chinese sample, subjects found to be in stages 2 and 3 were at least 21 years of age and older.

There are many ways to report a medical age assessment in medico-legal practice. They include presenting the most probable age, the minimum age, or the probability of the person being below or above the age of medico-legal importance.[30] The concept of minimum age is easy to understand, conservative, and should be applied when one needs the highest standard of proof.[31] It gives the benefit of the doubt to younger people. The minimum age concept shows that stages 2 and 3 have provided strong evidence to indicate the age over 21. Stage 2 indicated a minimum age of 21.21 years and 21.03 years, while stage 3 indicated 26.31 years and 25.68 years in both males and females, respectively. The sensitivity and specificity values for RPV stage 2 were better. The accuracy, sensitivity, and specificity for stage 2 were 84.76 and 84.55, 78.17 and 78.97, and 100 and 100 in both males and females, respectively.

The post-test probability was 100% for both sexes, i.e., the grading of stage 2 indicated the possibility for the subject to be over 21 was 100%.

One drawback of the radiographic visibility of the root pulp is its limited application to the fully developed third molars. It is rare to see fully formed mandibular third molars with closed roots under the age of 18 years.[12] We did not apply this method in a 100% sample of both sexes of 16 years age group, 80% males and 77.5% females in 17 years, 37.5% males and 45% females in 18 years; and 20% males and 50% females in 19 years age group. Timme et al. [19], in their study, have applied this method in only 36-46% of radiographs of the total sample. In another study by Guo et al.,[18], approximately 20% of the radiographs could not be evaluated due to fused roots, narrowed furcation, missing third molars, and insufficient quality. In the present study, we excluded the radiographs falling under the above-mentioned criteria, which resulted in a non-balanced distribution of the sample, especially in the younger age groups. It is a significant concern for this method. Therefore, we recommend using a larger sample size to predict legal age thresholds of 18 and 21 years, especially in the younger age groups.

CONCLUSIONS

To the best of our knowledge, this is the first study to investigate the use of the I3M method to predict the legal age threshold of 21 years in emerging adults of south Indian origin. Based on our results, the following observations were made;

1. I3M cut-off values ranging from 0.02 to 0.07 resulted in a more significant percentage of false positives. Subjects who were 21 years and older were correctly identified. However, there is a chance of wrongly identifying one in four subjects younger than 21 as above 21.
2. When the minimum age concept was applied, RPV stages 2 and 3 provided substantial evidence to indicate an age above 21. In addition, stage 2 resulted in better sensitivity values than stage 3.

To conclude, the I3M method cannot state the attainment of the legal age of 21 years, owing to a greater percentage of false positives. However, RPV stage 2 can say that a subject is over 21 years old in both sexes.

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Awareness and perception of an Indian dental professional in context to the process and their role in disaster victim identification as a taskmaster

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The authors declare that they have no conflict of interest.

KEYWORDS

Disaster victim identification, Forensic Odontology, India

J Forensic Odontostomatol 2022. Dec;(40): 3-34:44 ISSN :2219-6749

ABSTRACT

Forensic odontology is a young area in India. However, it has been used as an integral component in a various medicolegal cases in India. However, the involvement of a dentist in mass disasters still needs to be well recognized. The role of the dentists in any unforeseen circumstances is to contribute as an adjunct hand in Disaster Victim Identification (DVI) which is in an emergent stage in India. This study aimed to assess an Indian dental professional's knowledge and awareness of their role in DVI. A pre-tested, self-administered anonymous questionnaire consisting of 6 open-ended and 14 close-ended questions was mailed to the participants. A total of 441 responses were recorded. The study indicated adequate knowledge and awareness among dental practitioners. Conversely, only a handful of people had first-hand autopsy experience. Thus, to supplement the skills needed to work at ground zero, it is recommended to develop hands-on training programs for dentists in each state of India. Also, creating a pool of experts in each state of India can strengthen the task force.

INTRODUCTION

What hope is there for the living if we no longer treat the dead with dignity? [1] The most devastating outcome of the disaster is the loss of human lives, which mandates human identification.[2] Human Identification is a herculean task involving inter-agency and intra-agency coordination. Depending on the type of disaster, the protocol may vary, as each country has a variable capacity and disaster management plan to combat disasters depending upon the scale and type of disaster.[3] Of the various key personnel involved in the disaster, dentists are the most underestimated, whose knowledge and skills implicated during an operation can be game-changing.[4]

Teeth, being one of the hardest structures of the body, can resist a wide range of taphonomic changes and retain their integrity. Teeth, like bones, take a longer time to perish; they are often the only evidence to be found in mass graves. The postmortem (PM) analysis of teeth can reveal a lot of information that can help in reconstructing the past, identification of the victim given that there is some antemortem (AM) data present, the dental profiling of the remains, and much more. The result of dental profiling is only sometimes conclusive, but with support from other anthropological parameters, it can help identify or exclude.[5]

Various studies around the globe have stressed the inclusion of forensic odontology at the graduation level itself. Quite similar is the case with India, where formal forensic odontology (FO) training still needs to be improved. Only a handful of universities offer Master of Science (M.Sc) course in the subject and other reputed institution provides them.[6] Certificate courses, fellowships, and Post Graduate Diploma in the subject, but the biggest irony is none of the courses are recognized by the Dental Council of India (DCI). As long as there is a deficiency of proper guidelines and setup for propagating the knowledge of the subject, this lacuna will continue. Including forensic odontology as a part of a dental subject will enhance knowledge about the field early in the career. Also, highlight the significant contribution of a forensic dentist in human identification during Disaster Victim Identification (DVI) operation.[7] Thus, this research paper assesses the knowledge and awareness of Indian dental professionals in context to their role in DVI in India.

MATERIAL AND METHODS

Study setting

The study was performed at the National Forensic Sciences University, Gandhinagar, with additional support from Google Forms.

Sample Collection

A digital survey form was designed using Google Forms (Google Inc.). It consisted of 6 open-ended questions and 14 closed-ended questions. The open-ended questions were designed to document the basic information of the participants. The closed-ended questions assessed knowledge about the various components of the disaster. The participants' consent was obtained through Google Forms itself. The survey form was sent to 873 general dentists and dental students in their 3rd and 4th years through emails. The students of the 1st and 2nd academic years were excluded due to their lack of clinical exposure, and only dentists working in India were considered for the study.

RESULTS

A total of 441 responses were recorded, prior closing the form from dentists all over India.

In the first section, the demographic details of the participants were recorded. The study comprised a mixed group of dentists and students from various backgrounds, of whom 63.9% were associated with academic institutions, 28.1% with private practice, and 7.9% with hospitals.

Among them, 50.8% of the participants had experience spanning less than 3 years, 13.4% had the experience of 4-6 years and 35.8% had experience spanning more than 6 years. Of all the participants, 12.5% had an association with the mortuary/forensic medicine department, of which 7.5% had less than 3 years of association, and 4.5% had more than 3 years of association. 88% had no experience working in the mortuary or forensic medicine department. The study showed that only 3% had worked with the DVI team, and 87% did not have first-hand experience with human identification (Table 1).

Table 1. Demographic details of the participants enrolled in the study

	Categories	Total N (%)	Group		Chi-square	p-value
			Dentist N	Student N		
Years of experience in dentistry	0-3 years	224 (50.8)	90 (55.9)	134 (47.9)	5.904	0.05
	4-6 years	59 (13.4)	25 (15.5)	34 (12.1)		
	More than 6 years	158 (35.8)	46 (28.6)	112 (40)		
Association with the forensic medicine department or the autopsy center	No	386 (87.5)	151 (93.8)	235 (83.9)	9.104	**0.003**
	Yes	55 (12.5)	10 (6.2)	45 (16.1)		
Years of experience working with forensic medicine department or autopsy center	0-3 years	33 (7.5)	11 (6.8)	22 (7.9)	4.453	0.108
	More than 3 years	20 (4.5)	3 (1.9)	17 (6.1)		
	No experience	388 (88)	147(91.3)	241(86.1)		
Have you worked for the DVI team apart from that of India?	No	427 (96.8)	153 (95)	274 (97.9)	2.656	0.103
	Yes	14 (3.2)	8 (5)	6 (2.1)		

The second section assessed the knowledge about the disaster. The participants chose natural (89.3%), manmade (78.9%), techno-industrial (60.5%), and 18.6% others as different types of disasters (Table 2). Out of these, other categories showed significant p- value (p=0.006). The third section assessed the events categorized as DVI. The participants chose earthquake (78.2%), flood (70.1%), murder (23.4%), air crash (71.2%), bushfire (58.7%), death due to infectious diseases (21.1%) and, 18.1% others as the various events categorized as DVI for human identification. Among the multiple variables, earthquakes, floods, murder, air crashes, and others showed significant p values (Table 3).

Table 2. Distribution of response for the types of disaster

Types of disaster	Categories	Total N (%)	Group		Chi-square	p-value
			Dentist N (%)	Student N (%)		
Natural	No	47 (10.7)	23 (14.3)	24 (8.6)	3.506	0.061
	Yes	394 (89.3)	138 (85.7)	256 (91.4)		
Manmade	No	93 (21.1)	42 (26.1)	51 (18.2)	3.807	0.051
	Yes	348 (78.9)	119 (73.9)	229 (81.8)		
Techno Industrial	No	174 (39.5)	69 (42.9)	105 (37.5)	1.228	0.268
	Yes	267 (60.5)	92 (57.1)	175 (62.5)		
Others	No	358 (81.4)	121(75.6)	237 (84.6)	7.675	**0.006**
	Yes	82 (18.6)	39 (24.4)	43 (15.4)		

Table 3. Distribution of events categorized as DVI by the participants

Types of disaster	Categories	Total N (%)	Group		Chi-square	p- value
			Dentist N (%)	Student N (%)		
Earthquake	No	96 (21.8)	46 (28.6)	50 (17.9)	6.891	**0.009**
	Yes	345 (78.2)	115 (71.4)	230 (82.1)		
Flood	No	132 (29.9)	62 (38.5)	70 (25)	8.895	**0.003**
	Yes	309 (70.1)	99 (61.5)	210 (75)		
Murder	No	338 (76.6)	113 (70.2)	225 (80.4)	5.907	**0.015**
	Yes	103 (23.4)	48 (29.8)	55 (19.6)		
Air crashes	No	127 (28.8)	57 (35.4)	70 (25)	5.396	**0.02**
	Yes	314 (71.2)	104 (64.6)	210 (75)		
Bushfire	No	182 (41.3)	74 (46)	108 (38.6)	2.304	0.129
	Yes	259 (58.7)	87 (54)	172 (61.4)		
Death due to infectious diseases	No	348 (78.9)	122 (75.8)	226 (80.7)	1.498	0.221
	Yes	93 (21.1)	39 (24.2)	54 (19.3)		
Others	No	361 (81.9)	121 (75.2)	240 (85.7)	7.675	**0.006**
	Yes	80 (18.1)	40 (24.8)	40 (14.3)		

The fourth section assessed the knowledge about the human identification process. The different phases of the DVI process were identified as AM (69.6%), PM (85.7%), reconciliation (34.5%), debriefing (19.5%), and 12% as others (p=0.006) (Table 4).
The fifth section accessed the colour of the Interpol forms. The dentists chose yellow, (61.5%) white (16.8%), pink (12%), and blue (9.8%) as the colour of the AM Interpol forms. Similarly, the dentists chose yellow (20.9%), white (21.5%), pink (44.2%), and blue (13.4%) as the colour of the PM Interpol forms (Table 5).

Table 4. Events categorized as DVI for human identification

Knowledge of various phases of DVI	Categories	N (%)	Group		Chi-square	p- value
			Dentist N (%)	Student N (%)		
Antemortem	No	134 (30.4)	56 (34.8)	78 (27.9)	2.318	0.128
	Yes	307 (69.6)	105 (65.2)	202 (72.1)		
Postmortem	No	63 (14.3)	29 (18)	34 (12.1)	2.876	0.09
	Yes	378 (85.7)	132 (82)	246 (87.9)		
Reconciliation	No	289 (65.5)	99 (61.5)	190 (67.9)	1.834	0.176
	Yes	152 (34.5)	62 (38.5)	90 (32.1)		
Debriefing	No	355 (80.5)	128 (79.5)	227 (81.1)	0.16	0.689
	Yes	86 (19.5)	33 (20.5)	53 (18.9)		
Others	No	388 (88)	134 (83.2)	254 (90.7)	7.675	**0.006**
	Yes	53 (12)	27 (16.8)	26 (9.3)		

Table 5. Assessment of colour of Interpol forms

Color of the Interpol forms	Categories	N (%)	Group		Chi-square	p-value
			Dentist N (%)	Student N (%)		
Colour of AM forms	Yellow	271 (61.5)	96 (59.6)	175 (62.5)	3.657	0.301
	White	74 (16.8)	32 (19.9)	42 (15)		
	Pink	53 (12)	15 (9.3)	38 (13.6)		
	Blue	43 (9.8)	18 (11.2)	25 (8.9)		
Colour of PM forms	Yellow	92 (20.9)	38 (23.6)	54 (19.3)	3.077	0.38
	White	95 (21.5)	39 (24.2)	56 (20)		
	Pink	195 (44.2)	64 (39.8)	131 (46.8)		
	Blue	59 (13.4)	20 (12.4)	39 (13.9)		

The sixth section assessed the knowledge of AM phase. The dentists chose photographs (76.6%), dental cast (73.2 %), dental records (81%) radiographs (71.7%) and 15.5% as potential AM data (Table 6).

The seventh section assessed the dental professional's perception of AM data collection during DVI operations. The participants responded as police (5.4%), family members (20.9%), AM data collection team members (17.9%), national society (1.4%) and, forensic dentists (54.4%) as a potential candidates for antemortem data collection (Table 7).

Table 6. Assessment of potential antemortem data

Types of AM data	Categories	N (%)	Group		Chi-square	p-value
			Dentist N (%)	Student N (%)		
Photograph	No	103 (23.4)	48 (29.8)	55 (19.6)	5.907	**0.015**
	Yes	338 (76.6)	113 (70.2)	225 (80.4)		
Dental cast	No	118 (26.8)	52 (32.3)	66 (23.6)	3.972	**0.046**
	Yes	323 (73.2)	109 (67.7)	214 (76.4)		
Dental Records	No	84 (19)	38 (23.6)	46 (16.4)	3.412	0.065
	Yes	357 (81)	123 (76.4)	234 (83.6)		
Radiograph	No	125 (28.3)	56 (34.8)	69 (24.6)	5.175	**0.023**
	Yes	316 (71.7)	105(65.2)	211 (75.4)		
Others	No	372 (84.5)	129 (80.6)	243 (86.8)	7.675	**0.006**
	Yes	68 (15.5)	31 (19.4)	37 (13.2)		

Table 7. Assessment of potential candidate for antemortem data collection

Categories	N (%)	Group		Chi-square	p-value
		Dentist N (%)	Student N (%)		
The police	24 (5.4)	6 (3.7)	18 (6.4)	1,589	0,811
Family	92 (20.9)	33 (20.5)	59 (21.1)		
Antemortem data collection team member	79 (17.9)	30 (18.6)	49 (17.5)		
National society	6 (1.4)	2 (1.2)	4 (1.4)		
Forensic dentist	240 (54.4)	90 (55.9)	150 (53.6)		

The eighth section assessed the idea of the postmortem phase. The participants responded with 1 dentist (20.2 %), 2 dentists (57 %), 3 dentists (15.6%) and 4 dentists (6.8%) as the minimum no of dentists required for postmortem, dental examination (Table 8).

The ninth set of questions assessed the perception of various instruments needed for PM dental examination. The participants choose scalpel (57.6%), mouth mirror (77.1%), tweezer (69 6%), explorer (71.2%), probe (66.4%), jaw openers (78.8%), and others (20.4%) as the dental instruments that can be used for PM dental examination (Table 9).

The tenth section assessed the perception of the primary identifier. The participants chose fingerprints (88%), teeth (91.4%), DNA (89.1%), clothes (57.1%), tattoos (59%), the implant (68.9%), and others (21.8%) as the tools that can be used in human identification (Table 10).

The eleventh section assessed the perception of traits of teeth that can be used in identification. The participants chose shape of teeth (78.2%), crowns (71%),restorations (67.8%), midline diastema (55.6%), retainers (50.8%), caries (40.1%), and others (19%) as traits of teeth that

can be used in identification (Table 11).
The twelfth section assessed the perception of one point of agreement in human identification. Here, 17.9% strongly agreed, 29.5% agreed, 29.3% had a neutral response and 19.7% disagreed. In comparison, 3.6% strongly disagreed with the statement that one point of agreement is enough to identify a person during the reconciliation phase (Table 12).

The thirteen questions assessed the perception of likelihood of Post Traumatic Disorder (PTD) in individuals with first-hand experience in the management of the dead. Here, 12.5% strongly agreed, 26.8% agreed, 37.9% were neutral, 18.6% disagreed, 4.3% strongly disagreed with the statement of likelihood of PTD in forensic dentist after first-hand experience in DVI operations (Table 13).

Table 8. Assessment of minimum number of dentists required for postmortem dental examination

Minimum number of dentists	N (%)	Group		Chi-square	p- value
		Dentist N (%)	Student N (%)		
1	89 (20.2)	29 (18)	60 (21.4)	1.352	0.717
2	253 (57.4)	98 (60.9)	155 (55.4)		
3	69 (15.6)	24 (14.9)	45 (16.1)		
4	30 (6.8)	10 (6.2)	20 (7.1)		

Table 9. Perception of instruments needed for postmortem dental examination

Types of instruments	Categories	N (%)	Group		Chi-square	p-value
			Dentist N (%)	Student N (%)		
Scalpel	No	187 (42.4)	84 (52.2)	103 (36.8)	9.911	**0.002**
	Yes	254 (57.6)	77 (47.8)	177 (63.2)		
Mouth mirror	No	101 (22.9)	43 (26.7)	58 (20.7)	2.08	**0.149**
	Yes	340 (77.1)	118 (73.3)	222 (79.3)		
Tweezer	No	134 (30.4)	50 (31.1)	84 (30)	0.054	**0.816**
	Yes	307 (69.6)	111 (68.9)	196 (70)		
Explorer	No	127 (28.8)	47 (29.2)	80 (28.6)	0.019	**0.89**
	Yes	314 (71.2)	114 (70.8)	200 (71.4)		
Probe	No	148 (33.6)	61 (37.9)	87 (31.2)	2.056	**0.152**
	Yes	292 (33.6)	100 (62.1)	192 (68.8)		
Jaw opener	No	97 (22)	36 (22.4)	61 (21.8)	0.02	**0.888**
	Yes	344 (78)	125 (77.6)	219 (78.2)		
Others	No	351 (79.6)	126 (78.3)	225 (80.4)	7.675	**0.006**
	Yes	90 (20.4)	35 (21.7)	55 (19.6)		

Table 10. Distribution of answers for primary identifier

	Categories	N (%)	Group		Chi-square	p-value
			Dentist N (%)	Student N (%)		
Fingerprints	No	53 (12)	26 (16.1)	27 (9.6)	4.092	**0.043**
	Yes	388 (88)	135 (83.9)	253 (90.4)		
Teeth	No	38 (8.6)	21 (13)	17 (6.1)	6.31	**0.012**
	Yes	403 (91.4)	140 (87)	263 (93.9)		
DNA	No	48 (10.9)	23 (14.3)	25 (8.9)	3.025	0.082
	Yes	393 (89.1)	138 (85.7)	255 (91.1)		
Clothes	No	189 (42.9)	86 (53.4)	103 (36.8)	11.544	**0.001**
	Yes	252 (57.1)	75 (46.6)	177 (63.2)		
Tattoo	No	181 (41)	77 (47.8)	104 (37.1)	4.821	**0.028**
	Yes	260 (59)	84 (52.2)	176 (62.9)		
Implant	No	137 (31.1)	59 (36.6)	78 (27.9)	3.687	0.055
	Yes	304 (68.9)	102 (63.4)	202 (72.1)		
Others	No	345 (78.2)	126 (78.3)	219 (78.2)	7.675	**0.006**
	Yes	96 (21.8)	35 (21.7)	61 (21.8)		

Table 11. Perception of traits of teeth that can be used in identification

Traits for identification	Categories	N (%)	Group		Chi- square	p- value
			Dentist N (%)	Student N (%)		
Restoration	No	142 (32.2)	58 (36)	84 (30)	1.7	0.192
	Yes	299 (67.8)	103 (64)	196 (70)		
Midline diastema	No	196 (44.4)	74 (46)	122 (43.6)	0.237	0.627
	Yes	245 (55.6)	87 (54)	158 (56.4)		
Crowns	No	128 (29)	57 (35.4)	71 (25.4)	5.008	**0.025**
	Yes	313 (71)	104 (64.6)	209 (74.6)		
Retainers	No	217 (49.2)	88 (54.7)	129 (46.1)	3.016	0.082
	Yes	224 (50.8)	73 (45.3)	151 (53.9)		
Shape	No	96 (21.8)	43 (26.7)	53 (18.9)	3.633	0.057
	Yes	345 (78.2)	118 (73.3)	227 (81.1)		
Caries	No	264 (59.9)	99 (61.5)	165 (58.9)	0.279	0.597
	Yes	177 (40.1)	62 (38.5)	115 (41.1)		
Others	No	357 (81)	125 (77.6)	232 (82.9)	7.675	**0.006**
	Yes	84 (19)	36 (22.4)	48 (17.1)		

Table 12. Perception of one point of agreement in human identification during reconciliation phase

Categories	N (%)	Group		Chi- square	p- value
		Dentist N (%)	Student N (%)		
Strongly agree	79 (17.9)	28 (17.4)	51 (18.2)	7.821	0.098
Agree	130 (29.5)	50 (31.1)	80 (28.6)		
Neutral	129 (29.3)	56 (34.8)	73 (26.1)		
Disagree	87 (19.7)	22 (13.7)	65 (23.2)		
Strongly disagree	16 (3.6)	5 (3.1)	11 (3.9)		

Table 13. Distribution of perception of Post Traumatic Disorder (PTD)

Categories	N (%)	Group		Chi-square	p-value
		Dentist N (%)	Student N (%)		
Strongly agree	55 (12.5)	14 (8.7)	41 (14.6)	4.834	0.305
Agree	118 (26.8)	47 (29.2)	71 (25.4)		
Neutral	167 (37.9)	62 (38.5)	105 (37.5)		
Disagree	82 (18.6)	33 (20.5)	49 (17.5)		
Strongly disagree	19 (4.3)	5 (3.1)	14 (5)		

DISCUSSION

The position of forensic odontologist as DVI operation manager or member is still in its early stages in India. Thus, to incorporate FO as an integral member in DVI operations in India, there needs to be robust planning and preparedness at the policy level in each state in India. The present study was conducted to initiate the process and develop a protocol based on the findings. The study aimed to assess the knowledge and awareness of DVI among Indian dentists.

FO is a very new discipline of dentistry in India, with a lot of room for growth. The DCI has included it in the Bachelor of Dental Surgery (BDS) curriculum. FO is not currently taught as a separate subject in the DCI curriculum. Still, it has been related to two other branches: oral medicine and radiology and oral and maxillofacial pathology.[8] FO is likely to become a separate dental field in India, much as it has in the western world.[9] One of the reasons why many dentists in India are not linked with a forensic medicine department or autopsy facility is that forensic medicine still needs to be recognized as a distinct speciality. It is, however, trending in the right direction, as more people opt for fellowship and training in FO.

The participants were well aware of all the types of disasters. A slew of disasters in recent years has hit India. [10] As a result, the participants were well-versed on the subject. In our study, the earthquake was a major concern for the mass casualty incident, in contrast to the Yemini population, were the participants mostly chose violence due to armed conflicts and terrorism. In their study, only 8.5% of people were concerned about earthquakes. A significant number of participants in our study were not concerned about the infectious diseases. This was in contrast to the Yemeni population based studies, which reported epidemics (36.6%) as anticipated national disaster in Yemen. In the present study, the participants were more concerned about transport accidents such as air crashes which was in contrast to Yemeni population (2.2%). It may be due to Yemen's country context of internal conflict and complex emergencies, which elicited different responses than the present study. [11-13]

In our study, there was a varied response to the phases of the DVI. Most were aware of the PM phase compared to the other phases. It may be because most of the community associates forensics with PM examination. In this field, some form of training or prior experience working with the DVI unit is needed to acknowledge different phases. These findings are consistent with the fact that the majority of survey participants had no previous experience working in the mortuary or DVI operations, which coincides with the study done by Rathod et al.[14]

The dentists had a poor understanding of the AM and PM Interpol forms' colours. The results reflected the participants' lack of training: if they had been trained or exposed to DVI courses, the AM and PM form colour answers would have been more unanimous. Although more than half of the dentists chose yellow as the colour of the AM forms, only a few dentists were aware of the colour of the PM forms, so it's doubtful whether the participants were genuinely aware of it or ticked it by chance.

Although most studies conclude that dentists are unaware of the AM dental data. [15] The present study showed that the participants were quite aware of the various types of AM dental data. The majority of the participants chose all the types of AM data, which is contrary to the studies done by Yasar et al.[16] where the participants chose treated teeth (74.7%), radiographs (57.4%), photographs (22.7%) and models (12.3%) respectively as valuable AM records. However, in the study done by Zikir and Mânica, [17] participants chose dental charts (48%) as the most commonly used AM dental data during human identification operation. In the present study, the participants showed a lack of knowledge about the potential member who could collect AM dental information. Thus, during a natural calamity in India, many errors and mismanagement during AM data collection by the agencies and National Disaster Management Authorities (NDMA) could be anticipated. The task force members recruited for DVI operations may be subjected to disorientation if not trained ahead of DVI operations. This scenario may be explained by the fact that the curriculum in India does not include practical work and hands-on training in DVI, similar to Turkey. [18,19]

In the present study, more than half of the participants chose 2 dentists as the minimum number required for the PM dental examination. The experts also suggest the combination of 3 forensic dentist or 2 forensic dentist along 1 dental hygienist, with sufficient knowledge in forensics as a prerequisite for dental examination. [20] In our study, the dentists, were well aware of the instruments needed for the PM dental examination. Because it was a closed question, it was outside the scope of the study to determine whether the dentists were aware of the science behind the selections, or if it was because of similar instruments seen in crime dramas.

The majority of the participants chose teeth as the primary identifier. It could be because the participants were dentists, who are usually well sensitized to the forensic value of teeth.

The majority of the dentists in our study were aware of the dental traits that could be used in human identification. A good number of participants also chose dental anomalies, such as shape of the teeth, midline diastema, as valuable tool in human identification. This was in contrast to Jayakumar and Mânica, [21] studies which demonstrated alarmingly poor charting of dental anomalies by the dentists in south India . The difference in the response could be attributed to small sample size, including a few states of south India. However, the present study had a large sample size that included all of India, which increased the likelihood of incorporating more dentists. Although dental anomalies have been reported to be utilized in human identification [22,23] only a few dentists chart them in their dental practice. [21] A dentist must be aware of the forensic value of dental anomalies, as each minute detail recorded in dental charts can aid in identification. [24-25]

In the present study the participants had a varied response regarding utilization of one concordance in human identification. It may be due to the fact that there is no clear cut demarcation and depends on case to case. According to a study, 1–12 concordant was regarded as an acceptable standard and gave better outcomes, however, the authors conclude the article by advising the specialist to treat each case individually. If the evidence is strong enough, a single concordant may be enough to prove a case, while numerous weak pieces of evidence may be combined to produce a different result. [26]

In the present study, the participants had a varied response regarding the perception of post-traumatic disorder in individuals with first-hand experience in the management of the dead. For all the members of the DVI operation after completion of each process: It is advisable for psychosocial support both during and after completing challenging tasks. Compared to the general population, these workers probably have more robust psychological defences against extreme stress, but they are also being exposed to it more and more. Thus, it's mandatory to incorporate mental health balance mechanisms in mass fatality management plans. [27]

Only a few places in India have accepted dental team members as part of their usual mortuary responsibilities. Human identification could be more systematic if the National Disaster Management Authority took the initiative to hire a dentist for DVI operations. The results of this study show that general dentists are highly aware of the importance of FO in DVI. It is possible to sensitize more dentists by incorporating training and awareness programs into undergraduate courses. Given the uncertainty of the future of natural calamities, the country should develop a policy that includes a pair of dentists in all DVI operations as part of its disaster preparedness plan.

The scope and potential of an FO have been underestimated over time, resulting in insufficient examinations, misdiagnosis, loss of crucial evidence, incorrect perceptions, and incorrect conclusions. In India, including a forensic odontologist on the DVI team or even constituting a DVI team in the first place is a high priority when it comes to planning for the management of the dead.

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Age-at-death assessed with Lamendin's original and population-specific models in a modern Brazilian osteological collection

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The authors declare that they have no conflict of interest.

KEYWORDS

Age at death;
Age estimation;
Forensic Dentistry;
Lamendin;
Teeth

J Forensic Odontostomatol 2022. Dec;(40): 3-45:51
ISSN :2219-6749

ABSTRACT

Background: Estimating the age at death is a common procedure in the fields of forensic human identification and anthropological/archaeological investigations. Root translucency and periodontosis are regressive parameters used to estimate the age of adults, more specifically in Lamendin's method – established in 1992 in a French population. This study aimed to test the applicability and validity of Lamendin's method in a Brazilian osteological collection.

Methods: The sample consisted of 74 single-rooted teeth obtained from 50 skeletal remains (mean age: 53.20 ± 16.17 years) from Southeast Brazil. Lamendin's method was applied to enable a comparison between chronological (CA) and estimated ages (EA). A new population-specific equation was designed for the studied sample and the outcomes were compared with those obtained with Lamendin's original equation.

Results: The original methods led to a general underestimation of 11.32 years (8.83 years in males and 15.91 years in females). The method had a better performance among individuals between 40 and 59 years (mean differences between CA and EA: 4.8 years). The population-specific equation led to a mean overestimation of -2.04 years in males, and a mean underestimation of 3.77 years in females. Underestimations were considerably higher in other age groups.

Conclusion: Despite the apparent improvements, both the original and the population-specific equations revealed coefficients of concordance that were constantly low between CA and EA. These outcomes suggest restrictions to the application of Lamendin's method in the forensic field, especially for human identification. The method, however, seems to be applicable for anthropological/archaeological applications.

INTRODUCTION

The lack of developmental features in adults makes dental age estimation a challenging procedure in the forensic field.[1] Attrition, deposition of secondary dentin, periodontosis, cementum apposition, root resorption, and root translucency represent regressive dental features commonly assessed in adults.[2,3] While some of the features can be assessed by means of radiographic examination, such as the deposition of secondary dentin (visualized through the progressive reduction of the pulp chamber of root canal),[4] other features, such as cementum apposition require invasive techniques for proper assessment.[5] When it comes to invasive techniques, their application is only postmortem (restricted to cadavers and skeletal remains) and can be destructive or not.[6] Destructive techniques require tooth sectioning for the direct macroscopic or microscopic visualization of internal dental features.[7] In this process, tooth specimens are destroyed and, for this reason, these techniques are not always applicable to archeological samples (given their historical value). Gustafson's[2], Johanson's,[3] and Dalitz's[8] approaches are examples of invasive-destructive methods used for dental age estimation. Non-destructive techniques, on the other hand, enable the assessment of regressive age-related features with a visual inspection of external features – reason why these techniques can be tested in osteological collections of museums, educational institutions, and anthropological facilities.[9] Lamendin's[10] method (1992) advocates the use of periodontosis and root translucency as regressive features for the estimation of the age at death.

Over the last 30 years, Lamendin's method has been tested in samples from several countries,[11] including France,[12] the United States,[13] Peru,[14] Brazil,[15] Argentina,[16] and Greece.[17] A systematic review from 2015 rated the method "effective" for the assessment of the age at death but revealed error rates that increase considerably after the age of 60 years.[11] Based on the methodological heterogeneity of the eligible studies and the different outcomes across studies, the authors encouraged the population-specific validation of Lamendin's method in order to understand better how it will respond.[11] Specifically in Brazil, Lamendin's method has been tested in a sample of 49 teeth collected from 26 dry skulls.[15] The authors observed that the method performs better among young adults and should be used carefully given the higher error rates among individuals between 45 and 60 years.[15] A deeper look into the Brazilian population, however, is necessary given the continental size of the country and the large population.

In order to explore this gap, the present study aimed to perform an observational (cross-sectional) research on the use of Lamendin's method to assess the age at death of Brazilian dry skulls of females and males with known documental information. This study takes into account Lamendin's original formula and the possibility of calculating a population-specific model.

MATERIAL AND METHODS

Ethical approval was obtained from the institutional committee of ethics in human research (protocol: 49933621.1.0000.5374; approval number: 080986/2021). The study method was observational, analytical, and cross-sectional.

The sample consisted of 74 unirradicular permanent teeth of 50 dry human skulls of Brazilian females and males (mean age: 53.20 ± 16.17 years). Per age category, the teeth were divided as follows: 9 teeth in the age interval between 25 and 39 years, 38 teeth between 40-59 years, 18 teeth between 60-79 years, and 9 teeth between 80 and 89 years. The skulls belonged to identified skeletal remains of the modern Osteological Collection FSLM. The collection has skeletal remains donated from individuals that were born in the early twentieth century (30's) and has a database of personal information that includes the date of birth, date of death, sex, and self-declared ancestry (classified into white, black, and mixed). The skeletal remains donated to the collection come from the Southeast region of Brazil, predominantly from the State of Sao Paulo.

The inclusion criteria consisted of unirradicular teeth from modern skulls of female and male Brazilians. The exclusion criteria consisted of decayed teeth,[16] fractured crowns, restorations or prosthetic crowns, teeth with anatomic variations, and teeth from individuals missing a complete set of documental information in the collection database. Teeth that met the eligibility criteria were manually dislodged from the sockets before they were measured[18] (and positioned back to the socket after analysis).

The main observer, a forensic odontologist with 5 years of experience in practice, analyzed the entire sample set according to Lamendin's[10] method. The analysis included measurements of root translucency (T), root height (H), and periodontosis (P). All the measurements were performed on the labial surface of each tooth using a sliding caliper set in millimeters. Root translucency was measured against a lightbox with proper lux units[19]. The T measurement is performed from the apex of the root to the maximum height of the translucent region observed within the root. The H measurement also starts from the apex and extends to the cemento-enamel junction on the labial surface of the root. Finally, measurement *P* takes into account the degradation of soft tissue on the root surface and is assessed from the cemento-enamel junction towards the apex following a yellowish discoloration of the root (darker than enamel, but lighter than the dentinal root)[15]. During the assessment of *P*, soft surface probing was implemented to eventually detect a rough area on the root and contribute to the measurement. The measurements were tabulated for the application of Lamendin's original formula.

After 30 days, the main observer repeated the measurements (T, H and P) in 20 teeth (24%) randomly selected from the sample. These measurements enable the calculation of intra-observer agreement tests. In parallel, a second observer was recruited (another forensic odontologist with 5 years of experience in the field) to analyze the same 20 teeth so the inter-observer agreement tests would be calculated. The reproducibility within (intra-) and between (inter-) observers was quantified with the Intraclass Correlation Coefficient (ICC).

The age estimated with Lamendin's original formula was compared with the know chronological age using Lin's coefficient of concordance. The concordance was tested for the general sample, and for the sample categories based on sex (male/female), self-declared ancestry (classified into white, black, and mixed), and age group (25-39, 40-59, 60-79, 80-89 years). Lin's coefficient of concordance established a scale from -1 to 1, in which the latter represents full concordance. In addition to the concordance estimates, we calculated the concordance's confidence interval (95%). Pearson's correlation coefficient was used to assess the correlation between *T*, *H* and *P* variables and the chronological age. The null hypothesis is that the correlation coefficient is 0 (on a scale between -1 and 1) – indicating a lack of correlation. The test the null hypothesis, *p* values were calculated considering the significance level of 5%. Finally, a linear regression model was adjusted considering the estimated age as the outcome and *T*, *H* and *P* as the predictors. An equation to predict the chronological age was designed for the present sample. Based on the new equation, comparisons between estimated and chronological ages were performed again (and quantified with Lin's coefficient of concordance) considering the pre-established categories based on sex, self-declared ancestry, and age group.

RESULTS

ICC showed intra-observer agreement values of 0.984, 0.996, and 0.997 for the variables *T*, *H*, and *P*, respectively. Inter-observer agreement values were 0.774, 0.840 and 0.957, respectively (Table 1).

Table 1. Intraclass correlation coefficient for the intra- and inter-observer agreement considering translucency (*T*), root height (*H*), and periodontosis (*P*)

Parameters	Agreement			
	Intra-observer		Inter-observer	
	ICC	IC95%	ICC	IC95%
Translucency	0.984	0.960; 0.993	0.774	0.521; 0.902
Root height	0.996	0.989; 0.998	0.957	0.898; 0.982
Periodontosis	0.997	0.994; 0.999	0.840	0.647; 0.932

The comparison between chronological and estimated ages for the general sample led to a mean difference (underestimation of 11.32 years) (Lin's coefficient of concordance = 0.149). In males (n = 48 teeth), the mean difference was 8.83 years, while in females (n = 26 teeth), the difference was 15.91 years (Lin's coefficient of concordance = 0.270 and -0.018, respectively). Regarding the self-declared ancestry, the mean differences between chronological and estimated ages were 13.87, 10.35, and 7.28 years, for self-declared whites, black and mixed, respectively (Lin's coefficient of concordance was below 0.199). Analyses based on age groups showed mean differences of -10.22 years for the age group 25-39 years, and 4.8 years for the individuals between 40-59 years. For older age groups, the mean difference between chronological and estimated ages was considerably high, and Lin's coefficient of concordance was below 0.200. (Table 2).

Table 2. Application of Lamendin's original equation, and respective estimated ages per sex group, age group, and self-declared skin colour group

		Age			Concordance	
	n	**CA (SD)**	**EA (SD)**	**ME**	**ϱ**	**CI95%**
Total	74	53.20 (16.17)	46.89 (5.91)	11.32	0.149	0.047; 0.250
Sex						
Male	48	55.79 (16.57)	46.96 (5.64)	8.83	0.270	0.145; 0.396
Female	26	62.65 (14.69)	46.75 (6.50)	15.91	-0.018	-0.165; 0.129
Skin colour						
White	36	60.53 ± 16.69	46.66 ± 5.98	13.87	0.160	0.030; 0.290
Mixed	20	56.00 ± 19.85	45.65 ± 6.70	10.35	0.199	-0.012; 0.409
Black	18	56.00 ± 9.35	48.72 ± 4.57	7.28	-0.088	-0.343; 0.166
Age group						
25-39	9	30.22 ± 4.79	40.44 ± 3.20	-10.22	0.079	-0.078; 0.237
40-59	38	52.68 ± 4.82	47.88 ± 4.40	4.8	0.200	-0.004; 0.405
60-79	18	70.78 ± 6.77	47.22 ± 6.28	23.56	-0.011	-0.073; 0.051
80-89	9	84.33 ± 3.12	48.46 ± 9.00	35.87	0.036	-0.001; 0.073

Age expressed in years; n: sample size; CA: chronological age; EA: estimated age; CI: confidence interval.
SD: standard deviation; ME: mean error = chronological age − estimated age.
ϱ: Lin's coefficient of concordance.

Pearson's correlation coefficient (r-values) for the variables *T*, *H*, and *P* were 0.238 (p = 0.041), -0.071 (p = 0.548), and 0.362 (p = 0.002), respectively. Based on the outcomes of the original formulae and the correlations values detected in our study, an adjusted equation was obtained for our sample: Age = 31.13 + (0.97*P) + (0.26*T).

The new equation increased Lin's coefficient of concordance to 0.310 in the general population. The difference between chronological and estimated ages was -2.04 years for males (Lin's coefficient of concordance = 0.458) and -3.77 years for females (Lin's coefficient of concordance = -0.037). In self-declared whites, black and mixed, Lin's coefficient of concordance was between 0.269 and 0.362. Analyses based on age groups showed the smallest mean differences between chronological and estimated ages for the age groups 40-59 years (-6.32 years) and 60-79 (10.41 years). The remaining age groups had significantly higher age differences (Table 3).

Table 3. Application of the population-specific original equation, and respective estimated ages per sex group, age group, and self-declared skin colour group

		Age			Concordance	
	n	**CA (SD)**	**EA (SD)**	**ME**	**ϱ**	**CI95%**
Sex						
Male	48	55.79 ± 16.57	57.84 ± 6.86	-2.04	0.458	0.321; 0.595
Female	26	62.65 ± 14.69	58.88 ± 7.13	3.77	-0.037	-0.335; 0.260
Skin colour						
White	36	60.53 ± 16.69	58.01 ± 6.78	2.52	0.269	0.065; 0.474
Mixed	20	56.00 ± 19.85	55.98 ± 6.95	0.02	0.362	0.143; 0.581
Black	18	56.00 ± 9.35	61.05 ± 6.53	-5.05	0.337	-0.003; 0.676
Age group						
25-39	9	30.22 ± 4.79	48.90 ± 3.27	-18.68	0.047	-0.016; 0.109
40-59	38	52.68 ± 4.82	59.00 ± 5.21	-6.32	0.171	-0.007; 0.349
60-79	18	70.78 ± 6.77	60.37 ± 6.86	10.41	-0.065	-0.286; 0.155
80-89	9	84.33 ± 3.12	59.79 ± 9.36	24.54	0.066	-0.004; 0.136

Age expressed in years; n: sample size; CA: chronological age; EA: estimated age; CI: confidence interval.
SD: standard deviation; ME: mean error = chronological age − estimated age.
ϱ: Lin's coefficient of concordance.

DISCUSSION

Estimating the age at death of adult skeletal remains is a challenging procedure in forensic odontology. The scarce dental parameters available for age estimation normally increase the error rates compared to developmental parameters used in children and adolescents. Lamendin's method emerged as an option to anthropological and forensic investigations that require the estimation of the age at death. This method was tested and validated by population-specific studies worldwide. The present study revisited the method 30 years after its publication to investigate the Brazilian population.

When it comes the discussion of the methodology addressed in our study, it must be clarified the Lamendin's methods was selected because it is considered a simple tool with an overall performance that is acceptable in practice. The method is invasive, since it requires extraction of the tooth from the socket, but is non-destructive – which allowed us to accomplish sampling from a modern osteological collection (preserving cultural, social, and historical values). A systematic literature review[11] on Lamendin's method listed several studies that sampled teeth from osteological collections. This scenario enables a controlled comparison between estimated and chronological age since the latter can be accurately retrieved from death records.

The preliminary outcomes of the present study showed important underestimation in the total sample, which is justified by the low concordance between chronological and estimated ages. The difference was nearly twice higher in females. These outcomes are similar to those presented by Lopes et al.[15], which revealed mean underestimations of 7.65 years in Brazilian males (our study = 8.83 years) and 11.28 years in females (our study 15.91 years). Ubelaker and Parra[14] also found higher mean differences between chronological and estimated age in Peruvian females. From the perspective of South American populational studies, authors from Argentina[16] have explained that the apparent influence of sex in adult age estimation using Lamendin's method may be justified by the unbalanced distribution of males and females across studies. This may be the case of our study, in which 48 (54%) and 26 (46%) specimens of males and females were collected, respectively. The same was observed in the study by Lopes et al.[15] (60% males and 40% females) and Ubelaker and Parra[14] (61.12% males and 38.88% females). Our outcomes became more similar to those obtained by Garizoain et al.[16] only after applying the new equation designed for our sample. In this case, the equation led to means differences between chronological and estimated ages of -2.04 (overestimation) and 3.77 (underestimation) for males and females, respectively. Of course, these outcomes must be carefully interpreted because they solely reflect the internal performance of our equation. A similar adjustment of the method was accomplished by Lopes et al.[15] leading to improved applications for their sample. Future external testing (validation) is needed to translate the method performance to other samples. Sampling osteological collection arbitrarily by analyzing all the available skeletal remains is a common practice. The overcome the influence of sex in future analysis, we assessed age at death using skin colour and age group subcategories regardless of sex.

The subgroup analysis based on self-declared skin colour was based on the study of Prince and Ubelaker.[13] The authors compared groups of black and white individuals and observed higher error rates among black females (9.63 years), followed by white females (8.46 years), white males (7.66 years) and black males (7.17 years). In our study, we used three self-declared skin colour groups, and we found lower error rates in blacks (7.28 years), followed by mixed skin colour (10.35 years), and whites (13.87 years). In our study, statistically significant differences between skin colour were not detected. This outcome may suggest a broader application of the methods across specimens with different ancestry. The scientific literature corroborates this finding by explaining that Lamendin's original mean error rates maintained similar outside the French population – indicating that there a "*minimal impact*" of population variation over the studied parameters (translucency and periodontosis).[14] Hence, equations based on skin colour were not designed in our study.

Regarding the age group subcategory, we observed the best outcomes of Lamendin's original method among individuals between 40-69 years (underestimation of 4.8 years), followed by those between 25-39 years (overestimation of -10.22 years). In the older age groups, the estimated age was too far (over 20 years of difference) from the chronological age. Our outcomes converge with those presented by Lopes et al.[15], which found better performances of the method among younger individuals. It must be noted that both the present and the previous[15] studies respected the constant of Lamendin's original equation to set eligibility criteria based on age. In other words, individuals younger than 25.53 years were not sampled in Brazilian studies. This quality-control procedure is not unanimous in the scientific literature and can lead to skewed statistics. From an international perspective, our results are similar to those obtained in samples of skeletal remains from the United Kingdom in the age interval between 25-49 years.[21] According to the authors[21], Lamendin's method led to mean errors of 10.9 years or less among young adults, while the error rates increased considerably in older age groups. It must be noted, that the application of our population-specific equation led to error rates that were more appropriate in middle-aged adults, namely from 40-59 years, and even in older adults between 60-79 years.

A consistent phenomenon in our study was the low values observed with Lin's coefficient of concordance, which can endorse the fact the regressive age estimation parameters used in adults are indeed limited for age estimation. Lamendin's methods, for instance, is based on parameters that never reached a Pearson's correlation coefficient higher than 0.362 (constantly weak) in our sample. These outcomes indicate that chronological age (and hence age at death) can be investigated from translucency and periodontosis, but their accuracy may not be as good as necessary for forensic application. The field of physical anthropology can benefit from the estimation of the age at death to understand historical and cultural events, but the application of Lamendin's method in the present sample showed limitations to be considered if a forensic question needs to be answered, for example in cases of human identification during criminal investigations.

CONCLUSIONS

Lamendin's original method reached the best error rates among young adults – with overestimations of around 10 years in adults between 25-39 years and around 5 years in adults between 40 and 59 years. Self-declared skin colour did not play a significant part on method's performance, while sex seemed to have an effect that could be related to sample distribution. The development of a population-specific equation led to evident improvements of the method performance among adults in the age interval between 40-79 years, but this equation solely reflects the response of the methods adjusted for the present sample.

So far, applications for historical-anthropological practice seem to be acceptable, while the method shall not be applicable for criminal forensic practice in human identification given the current level of evidence available.

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Histo-morphologic and gravimetric changes of teeth exposed to high temperatures - An in-vitro study

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The authors declare that they have no conflict of interest.

KEYWORDS

Teeth,
Temperature,
Odontology,
Fire,
Histology,
Dentinal tubules

J Forensic Odontostomatol
2022. Dec;(40): 3-52:61
ISSN :2219-6749

ABSTRACT

Background: Fire intelligence is the multidisciplinary basis of reconnaissance, which includes determining the origin, cause, and identification of fire victims. Fire is a destructive force capable of inflicting significant damage. Destruction of soft tissue in fire disasters makes victim identification nearly impossible. Teeth are hard and resilient and withstand such conditions. Analyzing the precise morphological, stereomicroscopic, histological, and gravimetric findings can extract valuable information from dental evidence in forensic investigations.

Materials and Methods: Thirty-six mandibular premolar teeth extracted for therapeutic purposes were exposed to high-temperature gradients. Macroscopic, stereomicroscopic, histological, and dry weight analyses were performed at each temperature gradient.

Results: The colour of teeth changed from yellowish orange to metallic black bronze to chalky white. Stereomicroscopy showed intact teeth at 100°C, gradual micro-cracks at 500°C, and a fully fractured crown at 900°C. Decalcified sections revealed dilatation of dentinal tubular pattern at 300°C. Dentinal tubules showed appearance of vapour bubbles at 400°C, resulting in loss of typical architecture. In the ground sections, alterations in scalloping nature of dentino-enamel junction, coalescing radicular dentinal tubules, and sand cracking appearance of teeth were noted at 100°C, 300°C, and 900°C, respectively. Significant reductions in the weight of the teeth samples were observed with higher temperatures.

Conclusion: From the morphological, histological, and gravimetric changes in a tooth caused by fire, it might be possible to determine the temperature and duration of fire exposure, and the cause of the fire.

INTRODUCTION

Unidentified human remains can be accurately identified using dental identification and is commonly accepted as evidence in Court. Dental evidence typically survives much better than soft tissue evidence such as facial characteristics or fingerprints. Human teeth are the hardest substance in the body because teeth are calcified and are resistant to environmental conditions that destroy soft tissue evidence. As a result, the teeth cannot be damaged by water immersion or decay and only minimally degrade over time. The association of human casualties with fire accidents is a common scenario in forensic investigations. Various fire sources, such as fuel explosions, bomb explosions, airplane accidents, etc., expose the human body to high temperatures, resulting in soft tissue mutilation, making human identification difficult.[1] Teeth can also be destroyed by heat when temperatures exceed 1000 °C, and the teeth are not protected by the soft tissue of the cheeks and lips. The most important task a pathologist can perform during an autopsy is determining the cause of death. In terms of legality, law enforcement agencies must prove beyond a reasonable doubt that the deceased died from causes other than natural causes. Teeth exposed to heat change their structure and morphology. The aim of the present study is to examine macroscopic, stereomicroscopic, histological, and gravimetric changes in teeth exposed to heat at different temperatures ranging from 100 °C to 900 °C.

MATERIAL AND METHODS

The present observational study was conducted after obtaining clearance from the institutional ethical committee (IEC No:-PMS/IEC/2016/10). The samples included in the study were thirty-six mandibular premolar teeth that were extracted for orthodontic purposes from patients with an age range of 15 to 25 years. The study sample teeth were divided into four groups of nine each. The samples in each group were exposed to controlled temperatures ranging from 100 °C to 900 °C in a burn-out furnace (Unident), and then analysed. Group 1 was analysed visually for changes in colour and morphologic changes in crown and root. Group 2 was analysed stereomicroscopically for macroscopic changes using a Magnus MLX stereomicroscope (2X magnification), and digital photographs were taken using a Nikon SLR5500. Ground sections were prepared from Group 3 using Arkansas stone (thin sections of 2 mm were prepared) and fixed on microscope slides. Subsequently, the images were captured with a photomicrograph. In group 4, the samples were first decalcified with OSTEOMOLL (decalcifier solution, Merck), sections of 3 µm thickness were prepared using a Leica semi-automatic microtome, and stained with hematoxylin and eosin. The decalcified sections were analysed using a Labomed SP-Achro microscope and photomicrographs. For gravimetric analysis before and after the exposure to temperature, the teeth were weighed using a precision electronic balance (model KD-HN).

RESULTS

Morphological analysis showed the following changes in colour and macroscopic structure at different temperatures. (Figure:1 showed the colour and morphological changes of crown and root). At 100°C, a band appeared on the crown. At 200°C, the colour of the crown changed to a slightly grey and white appearance. At 300 °C, the colour of the crown and root changed to a brownish-orange shade, and cracks were visible on the tooth. At 400°C, the crown had turned into a metallic blackish bronze colour, while the root had turned charcoal black. The crown and root appeared to be intact, with a vertical crack on the crown surface. At 500 °C, the colour of the crown changed to shiny grey black with blackish areas. The crown part showed chipping of the enamel shell, pitting, pits, and grooves. A portion of the dentine was lost. The colour of the root and crown changed to grey at 600 °C. The entire crown fractured, and surface roughness was visible on the apical 1/3rd of the tooth. The crown and root had a grey-blue outer surface at 700 °C, while the enamel's inner surface was grey, and the dentine was black. The coronal 1/3rd of the root was fractured. At 800 °C, the outer surface of the crown appeared to be greyish blue in colour, and the inner surface was bluish grey along with deep white cracks in the crown area. The crown and root fractured and appeared very brittle. At 900°C, the crown and root colour changed to chalky white. The crown fractured into fragments, and the apical 1/3rd of the root appeared thin. (Table:1)

Stereomicroscopic analysis of teeth exposed to different temperatures showed structural changes. (Figure:2 showed stereomicroscopic appearance of teeth exposed to 100°C to 900°C). At 100°C, the enamel showed a mottled appearance and roughness at the tip of the root.

At 200°C, the micro-cracks were visible at the crown and root, and the cervical portion showed roughness. At 300 °C, the crown displayed a brownish band of discoloration and enamel loss in the cervical margin, as well as surface irregularities. The root showed micro-cracks from the cervical margin to the root tip and a scorched appearance at the root tip. At 400°C, the crown portion was split longitudinally and showed a crusted appearance. The cervical margin of the tooth showed a gun powder-like appearance. The root exhibited micro-fractures and a crack line from the cervical margin to the root tip. The upper 1/3rd part of the root showed a "matted appearance." At 500°C, the crown showed the enamel split from the cervical margin, peeling of the cementum layer, and along with the dentine structure, the crown was lost. The enamel portions of the crown came out like a cap at 600°C, and the following changes were visible: the micro-cracks became more prominent, the surface layer showed pits, and the cemental layer was completely lost. The crown portion split apart from the root, and the dentino-enamel junction was marked with a line at 700 °C. At 800°C, the tooth was fractured into multiple fragments. At 900°C, the tooth showed a chalky white appearance.(Table 2)

Figure 1. Colour and morphological changes of crown and root

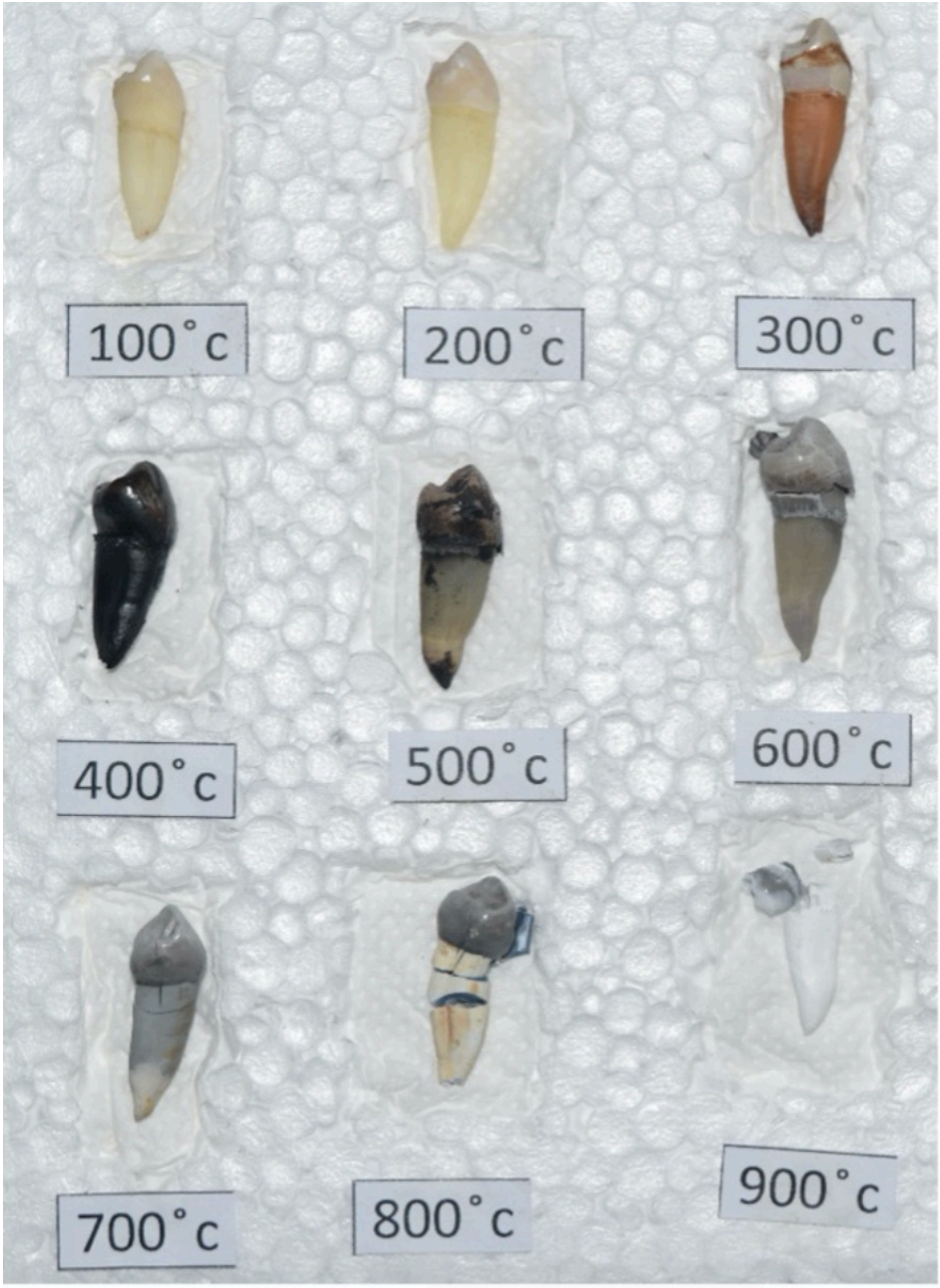

Table 1. Colour and morphological change in crown and root

Temperature	Colour changes of crown and root		Morphological changes of crown and root
	Colour of Crown	**Colour of Root**	
100°C	Band like appearance	No colour change	No structural variations
200°C	Slight greyish white	No colour change	Crown - cracks appeared.
300°C	Band like brownish orange	Brownish orange	Crown - cracks
400°C	Metallic blackish bronze	Charcoal black	Crown-- intact, Vertical crack. Root-intact grainy on apical 1/3rd and cervical line
500°C	Glistening greyish black with blackish areas	Greyish black with apical 1/3rd blackish area.	Crown--enamel shell cracking off, pitting defects, pit and grooves. A portion of dentine was lost.
600°C	Grey in colour	Dark greyish in colour	Entire crown fracture, surface roughness on apical 1/3rd
700°C	Outer surface greyish blue in colour. Inner surface – enamel greyish dentine black.	Greyish blue in colour, apical 1/3rd yellowish white. Root tip of teeth ivory in colour	Fractured at coronal 1/3rd of the root.
800°C	The outer surface is greyish blue in colour. Inner surface bluish greyish white.	Outer yellowish white, Inner surface – bluish	Deep cracks on the crown portion. Tooth fractured with crown and root – fragile
900°C	Outer and inner surfaces chalky white in colour.	Outer and inner surfaces chalky white.	Crown fractured into fragments with roughness, thin apical 1/3rd of the root.

Figure 2. Stereomicroscopic appearance of teeth exposed to 100°C to 900°C

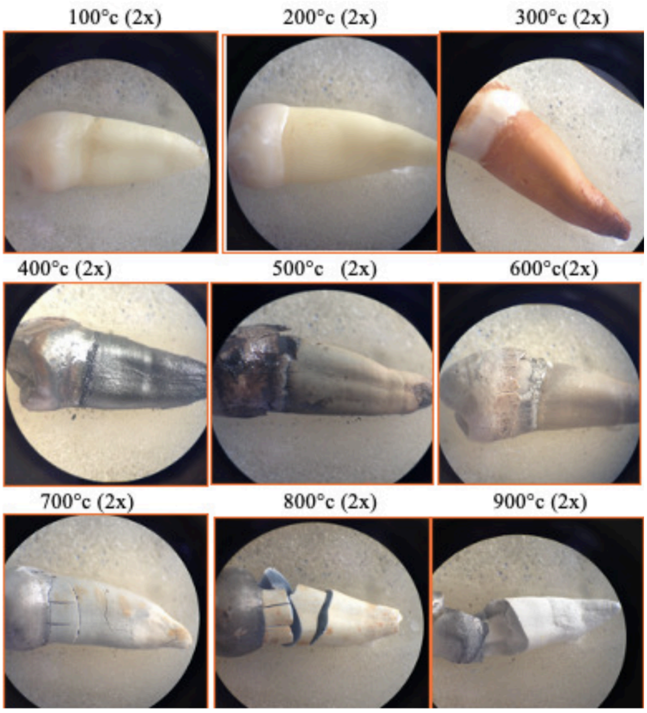

Table 2. Stereo microscopic analysis

Temperature	**Stereo microscopic analysis of crown and root**	
	Crown	**Root**
100°C	The mottled appearance of enamel	Roughness on the tip of the root. Cervical band/ discoloration.
200°C	Micro-cracks on crown and root	Roughness in the cervical area
300°C	Brownish band of discoloration of loss of enamel in the cervical margin of surface irregularities.	Micro-cracks from cervical margin to root tip and scorched appearance root tip
400°C	Splits longitudinally, crusted appearance. The cervical margin shows a gun powder appearance.	Micro-fractures, crack line from cervical margin to root tip, upper 1/3rd part showed matted appearance. Lined appearance in the middle area. Rough apex.
500°C	Enamel splits from the cervical margin, eggshell cracking, micro-cracks increase.	Peeling of root surface layer -the cementum, layer of dentine structure lost. Tip of root charred. Structural loss.
600°C	Enamel comes out like a cap; micro-cracks are prominent, pits on the surface, more crack lines appear; band-like crack on the cervical area	loss of cementum.
700°C	Portion splits apart, enamel appears grey, and dentino-enamel junction can be demarcated with a line	Fracture lines
800°C	Fragile	Vertically and horizontally. Multiple fractures.
900°C	Completely shattered, chalky white appearance.	Irregular surface, fracture of crown and root.

Ground sections of teeth were analysed up to 800°c. (Figure.3 showed histological analysis (ground section) of teeth exposed to 100°C to 900°C). At 100°C, the tooth section showed alterations in the scalloping nature of the dentino-enamel junction. At 200°C, the radicular dentinal tubular pattern was distorted. The radicular dentinal tubules coalesced, and the apical portions of the dentinal tubule structure deformed at 300°C. The enamel and dentine surface of the tooth section had a fur-like appearance at 400°C. The tooth section appeared amorphous and blackish at 500°C, with irregular margins. It had a sand cracking appearance at 600°C. At 700°C, the section showed an amorphous appearance. The tooth section appeared greyish black amorphous with irregular margins at 800°C. (Table 3)

Decalcified sections of teeth were evaluated up to 400°C. (Figure.4 showed histological analysis (decalcified section) of teeth exposed to 100°C to 900°C). At 100°C, the sections showed normal architecture. At 200°C, the apical 1/3rd of the radicular dentine showed changes in dentinal tubular pattern. Dentinal tubules dilated when heated to 300 °C. At 400°C, the loss of normal architecture and dentinal tubules resulted in the appearance of vapour bubbles.(Table 4)

From gravimetric analysis (Figure. 5 showed gravimetric analysis of teeth samples 100°C to 900°C), it was identified that at each temperature before and after exposure, a consistent reduction in the weight of the teeth was observed at above 300°C, with a steep decrease from 400°C to 900°C (Table 5).

Figure 3. Histological analysis(Ground Section)of teeth exposed to 100°C to 900°C

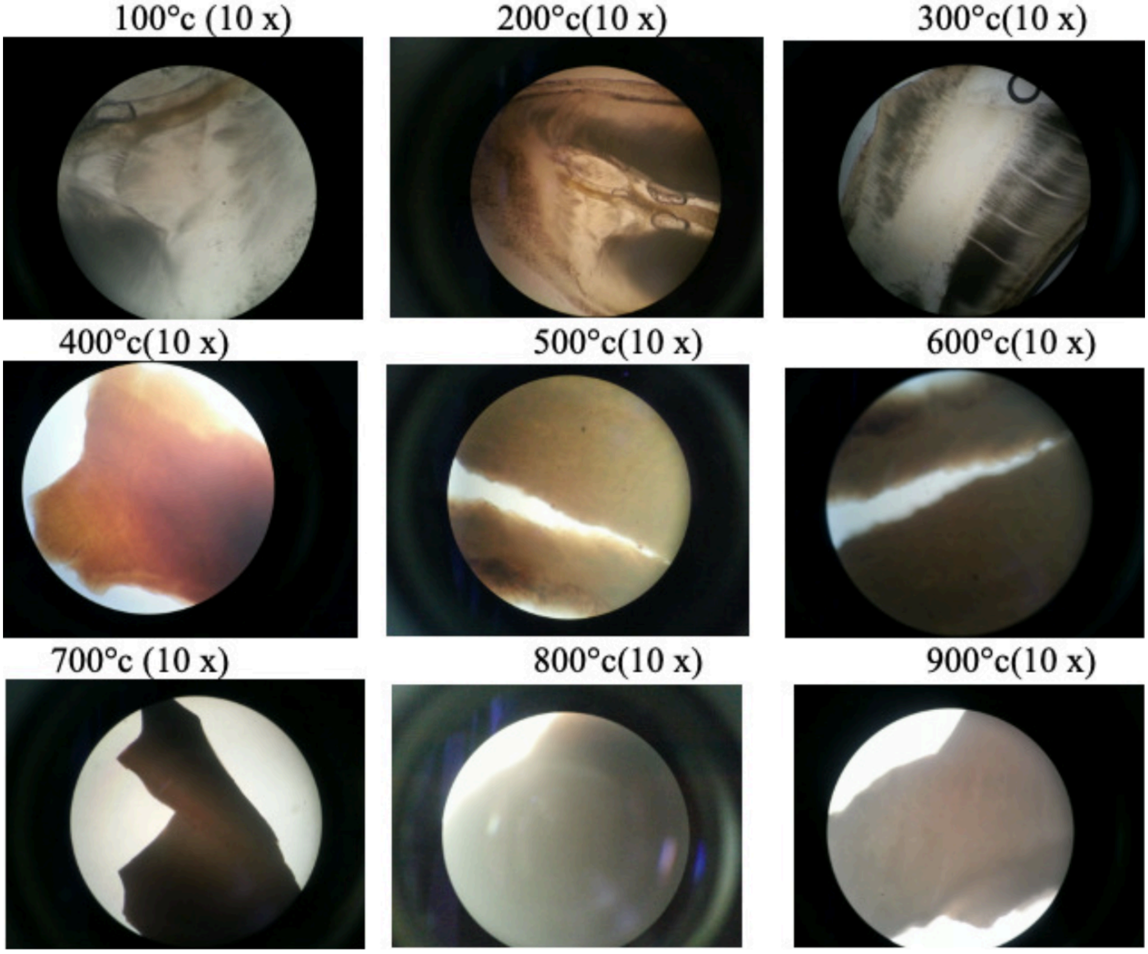

Table 3. Histological analysis(ground section)

Temperature	Histological analysis (Ground Section)
100°C	Alterations in the scalloping nature of dentino-enamel junction
200°C	Radicular dentinal tubules structure and pattern distorted
300°c	Radicular dentinal tubules were coalesced. Apical portions of dentinal tubule structure deformed
400°c	Appears dark brownish in colour, enamel, and dentine surface fur-like appearance
500°c	Amorphous blackish with irregular margins
600°c	Sand cracking appearance
700°c	Amorphous
800°c	Greyish black amorphous irregular margins

Figure 4. Histological analysis (Decalcified Section) of teeth exposed to 100°C to 900°C

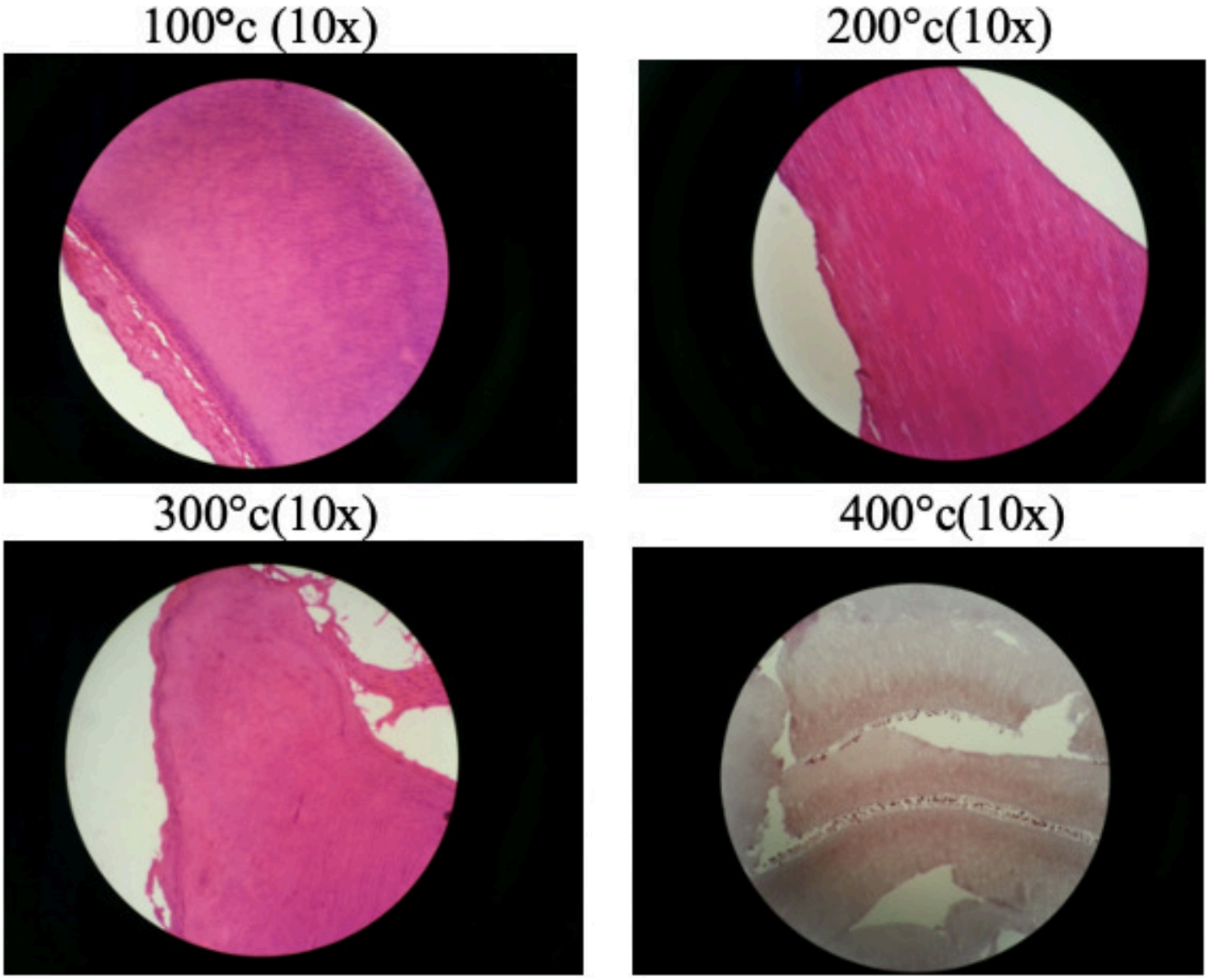

Table 4. Histological analysis (decalcified section)

Temperature	Histological analysis (Decalcified section)
100°C	Normal architecture
200°C	Apical 3^{rd} of radicular dentine shows changes in dentinal tubular pattern
300°c	Dilated dentinal tubules
400°c	Loss of normal architecture, dentinal tubules show vapour bubble appearance.
500°c and above	Teeth disintegrated completely during decalcification

Figure 5. Gravimetric analysis of teeth samples 100°C to 900°C

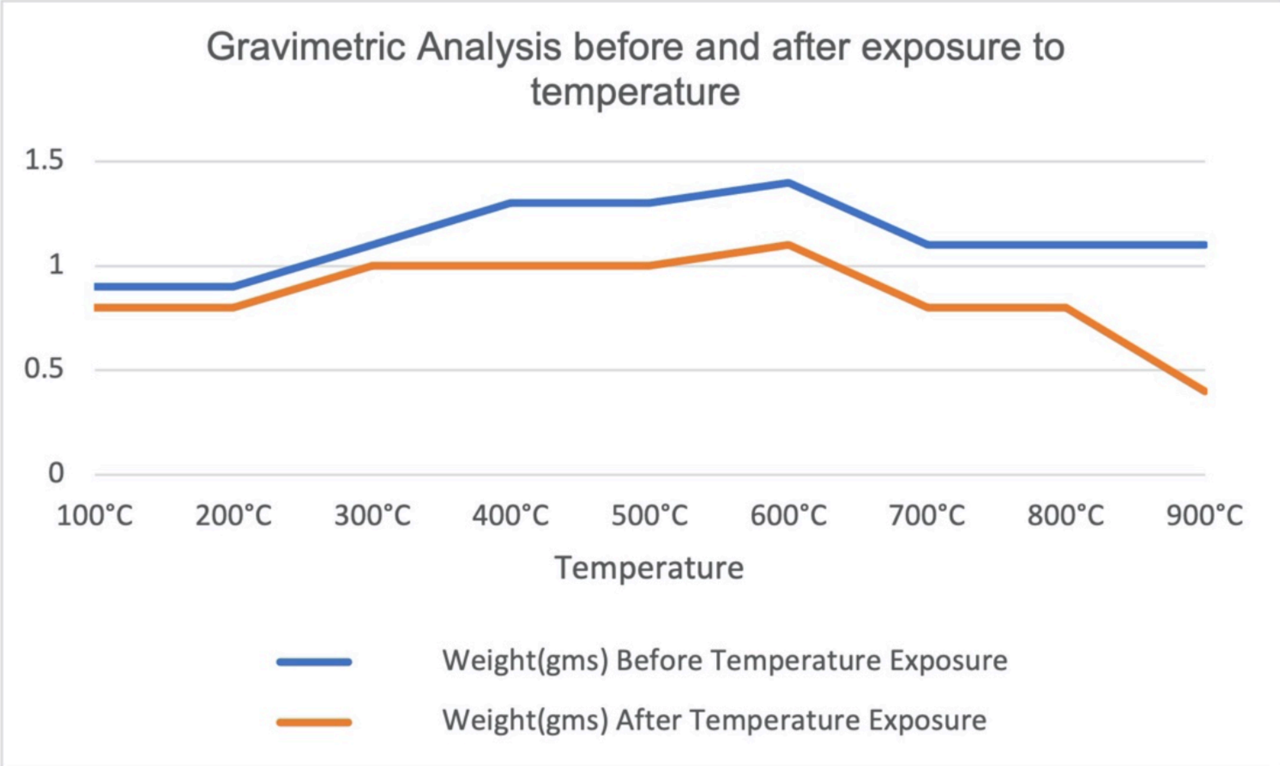

Table 5. Gravimetric analysis of teeth samples

Temperature	Weight (gms)	
	Before Temperature Exposure	After Temperature Exposure
100°C	0.9	0.8
200°C	0.9	0.8
300°C	1.1	1.0
400°C	1.3	1.0
500°C	1.3	1.0
600°C	1.4	1.1
700°C	1.1	0.8
800°C	1.1	0.8
900°C	1.1	0.4

DISCUSSION

Teeth are the hardest structure in the human body and can provide valuable dental evidence in the forensic investigation of fire accidents. Studies by Anderson on odontological identification in fire victims showed that 50 % of the victims had no injury, while 25% of cases showed injuries to the anterior teeth only. The present study revealed that the tooth withstands temperatures of up to 900°C and can provide evidence for forensic investigation.[2,3]

The temperature might vary for different fire accidents; some of the sources of fire accidents such as domestic fire reach temperatures of 649°C, burning of kerosene: 65°C to 220°C, burning of gas cylinders: 100°C to 200°C, car accidents: 220°C to 990°C, incinerator: 850°C to 1093°C, combustion of gasoline: 800°C to 1100°C, cremation: 871°C to 1009.3 °C and airplanes: 1000 °C to 3000 °C. However, chemical fires can exceed several thousand degrees. [4]

In the present study, the morphological, histological, and gravimetric changes of teeth exposed to high temperatures were evaluated. Colour change was the most distinguishing morphological feature for each temperature range from 100 °C to 900 °C. Specific colour changes from yellowish orange to charcoal black, passing through greyish blue and chalky white, were observed in the crown and root. Similar changes were described by Merlati G, Priyanka, Patidar KA, and Moreno et al. [5-8]

From the stereomicroscopic evaluation of the study, it was observed that the teeth were affected from 300°C with the progressive formation of micro-cracks, enamel splits, peeling of dentine and cementum, and fracture of crown and root at 900°C. The findings of the present study were comparable to the study conducted by Dhobley et al.[9]

Most of the currently available evidence is based on the morphological and stereomicroscopic analysis of charred tooth residues. There is an apparent lack of data on the ground sections and decalcified sections on teeth. In the present study, the authors evaluated the ground and decalcified sections. It was also observed that the ground sectioning of teeth was possible up to 800°C, beyond which the teeth became powdered. It showed an altered histological pattern of the dentinal tubules with amorphous changes at elevated temperatures. The teeth were decalcified up to 400°C; above that, the teeth completely disintegrated in the decalcifying solution. The dentinal tubules showed the appearance of vapour bubbles in the decalcified section, similar to that reported by Prakash et al.[10] No previous studies were conducted on gravimetric changes in burnt teeth. The present study determined that the weight of teeth exposed to temperatures over 300°C steadily decreased, with a steep decline between 400°C and 900°C. Small tooth fragments can be identified from the remains of the fire, and the exposure temperature can be reliably estimated. It was found that the teeth shattered into large particles at lower temperatures and at higher temperatures, the teeth shattered into numerous smaller particles. A similar observation was reported by Karkhanis.[11]

CONCLUSIONS

In the present study, the authors demonstrated structural changes at different temperatures in human teeth and thus provided valuable information about the thermal stress in teeth. The distinctive features of teeth exposed to different temperatures indicated the source of the fire and served as significant scientific evidence in forensic analysis.

ACKNOWLEDGEMENT

The authors acknowledge Dr.PS Thaha, Chairman, PMS College of Dental Science and Research, for providing the facilities and infrastructure and K. Somarajan, technician (Former Research Assistant, Government Medical Colleges, Kerala), PMS College of Dental Science and Research.

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