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Forensic age estimation of living individuals

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Forensic age estimation of living individuals: a novel bibliometric approach to the literature review

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Abstract

This study investigates the trends within the published research up to 2019 in relation to skeletal and dental age estimation in living individuals by using a novel bibliometric analysis which utilizes a specialist, open-source R script. The analysis was performed on a total of 644 papers (627 articles, fifteen conference papers, and two reviews) retrieved using the online database Scopus. The analysis included an investigation of publication trends, authors' affiliations, citation, Open Access publications, authors' keywords, and index keywords. An additional investigation was conducted to study the relation between the methodologies developed and the specific populations that have been tested. The relation between imaging techniques and areas of the body used in these studies was also examined.

Age estimation of living individuals has had an increasing profile over recent decades (Schmeling 2016). Currently, owing to cross-border migration related to sociopolitical developments, the number of individuals who lack valid identity documents to prove their age has increased (Ritz-Timme *et al.* 2000). Depending on the legal age threshold of the country, the assessment of age might be required for criminal proceedings or to ensure that children have access to appropriate rights and resources (Márquez-Grant 2015; Schmeling, Olze, Reisinger & Geserick 2004). For refugees and individuals seeking asylum, age estimation utilizes scientific methodologies to assist in the assessment of the correct status of the applicant (European Asylum Support Office 2018). Furthermore, age assessment is important in cases of human trafficking, adoption, and competitive sports (Schmeling & Black 2010). According to the Study Group on Forensic Age Diagnostics, a three-step procedure should be adopted when estimating the age of an individual: physical assessment and evaluation of skeletal and dental development (Schmeling 2016). Up until recently, the methodologies used to

estimate age were based on the analysis of radiographs (de Sanctis *et al.* 2016; Schmeling & Black 2010), although over time newer methodologies of imaging have been utilized, such as magnetic resonance imaging (MRI).

Specific population studies, available in the literature, have been carried out aiming to test the validity and accuracy of the most common age estimation techniques for different population groups (Doyle *et al.* 2019; Jayaraman, Wong, King & Roberts 2013; Sehrawat & Singh 2017). Intra- and inter-variability factors within and between populations (e.g. socioeconomic background, poor access to food, which can lead to malnutrition, and hormonal diseases that influence and affect skeletal development) should be taken into account as they might affect the age assessment outcome (Ritz-Timme *et al.* 2000; Tomei, Battisti, Martino, Nissman & Semelka 2014). One of the main issues is that older age estimation methodologies, such as Greulich and Pyle (1959) and Tanner *et al.* (Tanner *et al.* 1983; Tanner, Healy, Goldstein & Cameron 2001), were developed using plain radiographs of individuals whose development was being closely monitored throughout the study; however, individuals who require an age assessment (e.g. asylum seekers, unaccompanied minors, and human trafficking victims) may come from a low socioeconomic background where their health status, food intake, and so on, are unknown (Franklin, Flavel, Nobel, Swift & Karkhanis 2015; Schmeling, Reisinger, Wormanns & Geserick 2000; Serinelli *et al.* 2015). In relation to age estimation in the living, these factors can, and do, influence rates of maturation in individuals, consequently leading to either an under- or overestimation of skeletal age (Schmeling *et al.* 2000; Tomei *et al.* 2014).

Despite these potential issues, radiographic methodologies have been tested and utilized worldwide, and are widely accepted. Lately, however, concerns have been raised around the ethicality of using ionizing imaging techniques for forensic age estimation purposes. As stated by the European Asylum Support Office (2018), 'less intrusive/more accurate' age assessment modalities should be adopted as the first choice, following the principle of the best interest of the child. MRI and ultrasound are radiation-free techniques and have been indicated as potentially suitable for age estimation of living individuals (Doyle *et al.* 2019; Schmeling 2016). Therefore, recent research has been focused on the development of new age estimation methodologies using these non-ionizing techniques, especially MRI (Doyle *et al.* 2019; European Asylum Support Office 2018; Schmeling 2016).

Given this background, this study aims to investigate the trends of the literature within the field of age estimation in the living, using a bibliometric approach. This approach allows the in-depth investigation of trends in the research, authors' affiliations, relationships between authors, and most-used keywords. An additional analysis was carried out regarding the investigation of the most commonly used methodologies in relation to the populations on which they have been tested for reliability and accuracy.

Material and methods

Scientific papers relevant to age estimation in living individuals, published until 2019, were searched using the online database Scopus; no year range was selected to ensure that the earliest publications were included in the search. For the purposes of this study, multiple searches were conducted using different combinations of keywords. At the end of each search, the corresponding Excel file, which included a list of papers, was downloaded and renamed with the keywords used for that specific search. Categories

of keywords used included: imaging modality (e.g. *magnetic resonance imaging/MRI* or *computed tomography/CT scan*), body area (e.g. *hand and wrist* or *knee*), and general topic (e.g. *age estimation in the living* or *forensic age estimation*). This investigation therefore identified studies focused on the development of new methodologies and the accuracy and reliability of the forensic age estimation methodologies in different populations, with a focus on the assessment of age up to the 21 years of age threshold.

According to the inclusion criteria, each paper was checked manually to remove any study unrelated to the topic of the investigation. Only papers with the purpose of estimating the age of living individuals from dental and skeletal development (development of new methodologies or testing pre-existing methodologies in different populations) were included in this study. Papers related to the age estimation of adult living individuals or estimation of age at death of skeletal remains were not included.

A total of 644 scientific papers were included in the final analysis. A new Excel file was then generated including only the relevant papers to use for bibliometric analysis. The final Excel file (.csv file) included year of publication, title of the paper, journal, authors' names, authors' ID, authors' keywords, index keywords, number of citations, Digital Object Identifier (DOI), and Scopus Digital Identifier (EID).

Scopus

Scopus is an online database for abstracts and citations that was launched in November 2004 which includes more than 25,000 active journal titles and 56 million abstracts from over 5,000 publishers (updated to August 2020). Furthermore, Scopus has access to 6,700 (out of 7,000) titles covered by MEDLINE, which is a database hosted by the PubMed platform. The journals covered through MEDLINE are indicated in Scopus as 'MEDLINE sourced'. Among the documents covered in Scopus are articles, articles in press (AiP), books, chapters, conference papers, data papers, and reviews. The main subject areas are health sciences, physical sciences, social sciences, and life sciences. To ensure global coverage, Scopus includes titles from all geographical regions, including papers written in other languages (22 per cent), as long as an abstract in English is provided. More than 5,500 journal titles are Open-Access journals.

Statistical analysis

To perform statistical analysis, an R script was used which is available open-source (RStudio, Version 1.2.1335). The statistical analysis aimed to investigate trends in the published research for the period between 1974 and 2019.[1]

Keywords and authors analysis

The first part of the investigation focused on the analysis of the most common keywords used in the field (authors' and index keywords). Authors' keywords and index keywords were analysed and investigated separately, and two different charts were generated. Furthermore, analysis of the keywords allowed the investigation of keywords regarding imaging modality and skeletal areas throughout the years of publication. The second part of the investigation focused on the analysis of the authors. This included the authors' contribution and the relationship between authors and research groups. Publication trends for each year and citations were also included in the analysis.

Imaging modality and dental/skeletal area

The 644 publications were analysed according to which imaging technique was used in the study and the dental/skeletal area examined. Publications were first divided between papers that used only one imaging technique and those which used more than one. The papers that used only one imaging technique were divided into five different categories, one for each imaging modality. The results were then used to create a bar plot using R. This analysis was not carried out with the R script.

Trend of population tested for age estimation in the living methodologies

The 612 papers which were selected from the previous analysis regarding imaging modality and dental/skeletal area were searched and information was extracted concerning the methodology applied, population, sex, and age range of the sample. A new Excel file was created, adding this information to each paper. It was not possible to access every article, resulting in the loss of 198 papers for this section of the review. The final list included 414 papers. The information obtained from the articles were used to create graphs that highlight the relationships between the most common methodologies used in age estimation of living individuals and the population in which these methodologies have been tested. This analysis was not carried out with the R script.

Results

Overview of the data

The total number of publications included in the analysis was 644, of which 627 were articles, fifteen were conference papers, and two were reviews. Table 1 shows an overview of the data gathered from the analysis of the list generated from Scopus and it includes information on publications (total number for each year and type of publication) and information on the authors (total number of authors, new authors for each year, and authors who published only one paper: 'first and only' authors). Also given for each year of publication are the ratio of the total number of authors related to the total number of publications, and percentage of new authors to total authors.

The first paper to appear in the list was the study by Gustafson and Koch published in 1974. There was then a nineteen-year gap until the second publication recorded in the list, which was a study by Mincer, Harris, and Berryman published in 1993. It is clear that the number of publications within this research topic has increased with time. The first increase can be seen to have occurred in 2007, when seventeen papers were published compared to six papers in 2006. The second peak occurred in 2014, with sixty-two publications compared to the forty-one published in 2013. The highest number of publications occurred in 2019 (eighty-seven articles), followed by 2018 (sixty-four articles).

Out of the total number of publications (644) for the reviewed period (1974-2019), only fifty studies were Open Access (OA) (7.76 per cent). The first OA publication recorded in the list was authored by Liversidge and Marsden and published in 2010, followed by the study by Nur *et al.* published in 2012. Figure 1 shows the relation between articles published and OA publication, using the Scopus search, throughout the years of publication. The highest number of OA publications was recorded in 2019, when 24 per cent of all the publications for that year were OA.

The country affiliation for the authors of each paper was examined (Fig. 2). In three cases out of 644, the authors' affiliation was not recorded, therefore the analysis

Table 1. Number of publications and authors for each year of publication. The ratio of the total authors related to the total number of papers and author percentage is given.

| Year	Publications				Authors				New author %
	Total	Art.	Rev.	Conf.	Total	New	First and only	Ratio	
1974	1	1	–	–	2	0	2	2	0.0
1993	1	1	–	–	3	1	2	3	33.3
1995	2	2	–	–	7	1	6	3.5	14.3
1998	4	3	1	–	15	1	14	3.7	6.7
1999	1	1	–	–	4	0	4	4	0.0
2001	2	1	–	1	7	2	5	3.5	28.6
2002	4	4	–	–	15	6	8	3.7	40.0
2003	7	6	–	1	33	16	7	4.7	48.5
2004	8	8	–	–	36	11	2	4.5	30.6
2005	10	9	–	1	41	4	12	4.1	9.8
2006	6	6	–	–	24	6	9	4	25.0
2007	17	16	–	1	77	18	30	4.5	23.4
2008	29	29	–	–	118	23	40	4.1	19.5
2009	17	15	–	2	71	16	21	4.2	22.6
2010	34	34	–	–	169	32	64	4.9	18.9
2011	34	34	–	–	158	42	58	4.6	26.6
2012	41	41	–	–	178	36	61	4.3	20.2
2013	41	41	–	–	194	17	85	4.7	8.8
2014	62	59	–	3	327	64	119	5.2	19.6
2015	56	56	–	–	290	28	134	5.2	9.7
2016	62	59	–	3	329	48	119	5.3	14.6
2017	54	50	1	3	241	11	127	4.5	4.6
2018	64	64	–	–	302	34	132	4.7	11.3
2019	87	87	–	–	454	21	237	5.2	4.6
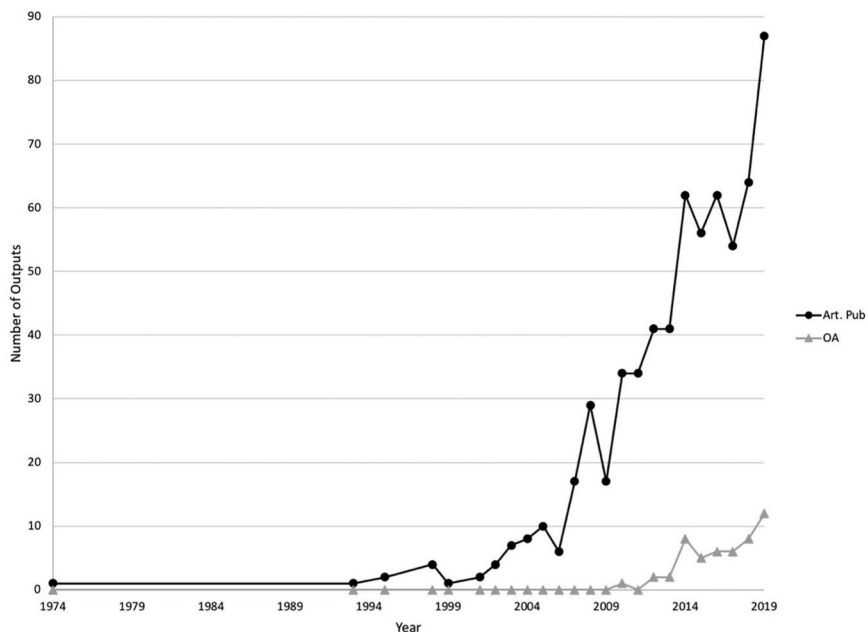
Figure 1. Relation between the number of papers published for each year from 1974 to 2019 (black dots) and how many of these were OA articles, on Scopus (grey triangles).
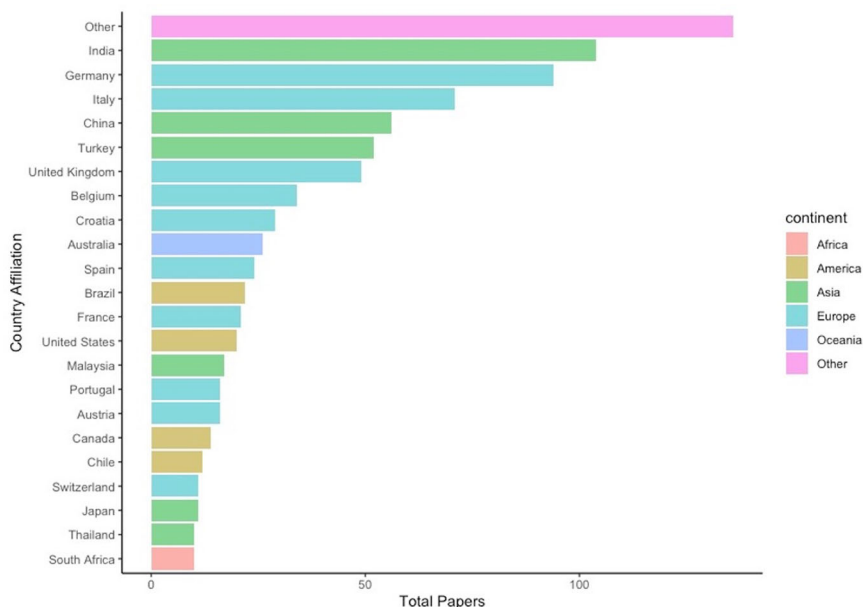

Figure 2. Country affiliation for publications in the years reviewed in this study (1974- 2019). The countries that contributed to fewer than ten papers were included in the category 'others'.

Table 2. Number of countries, the authors' contribution, and the percentage for each continent.

Continent	No. of countries	Authors' contribution	Percentage
Europe	28	424	49.6
Asia	20	294	34.4
Africa	9	28	3.3
America	9	79	9.2
Oceania	2	30	3.5

Table 3. Five most cited papers in the reviewed period (1974-2019).

Year	Authors	Title	Journal	Citation
2010	AlQahtani, Hector & Liversidge	Brief communication: The London atlas of human tooth development and eruption	*American Journal of Physical Anthropology*	338
1993	Mincer, Harris & Berryman	The ABFO study of third molar development and its use as an estimator of chronological age	*Journal of Forensic Sciences*	294
1974	Gustafson & Koch	Age estimation up to 16 years of age based on dental development	*Odontologisk Revy*	244
2004	Schmeling, Schulz, *et al.*	Studies on the time frame for ossification of the medial clavicular epiphyseal cartilage in conventional radiography	*International Journal of Legal Medicine*	224
2006	Maber, Liversidge & Hector	Accuracy of age estimation of radiographic methods using developing teeth	*Forensic Science International*	211

was carried out on 641 papers. The affiliation of each author was documented, for a total of 855 affiliations across sixty-eight countries. It can be seen that the country that contributed the highest number of publications was India, with 104 out of 855 (12.1 per cent), followed by Germany, with 95 (11.1 per cent), and Italy, with 70 (8.2 per cent). Europe is the continent with the highest authors' contribution, with 424 out of 855 (49.6 per cent). Table 2 shows data for each continent.

Citation
The numbers of citations for each publication were also analysed; the top five most cited papers are shown in Table 3. The first top four papers are all studies in which the authors developed new methodologies for age estimation: AlQahtani, Hector, and Liversidge (2010), Mincer *et al.* (1993), and Gustafson and Koch (1974) are studies related to dental age estimation, whilst the study published by Schmeling, Schulz, *et al.* (2004) is related to the development of Schmeling's methodology for the medial end of the clavicle. The last publication, by Maber, Liversidge, and Hector (2006), presents a study on the application of the methodologies developed by Demirjian, Haavikko, and
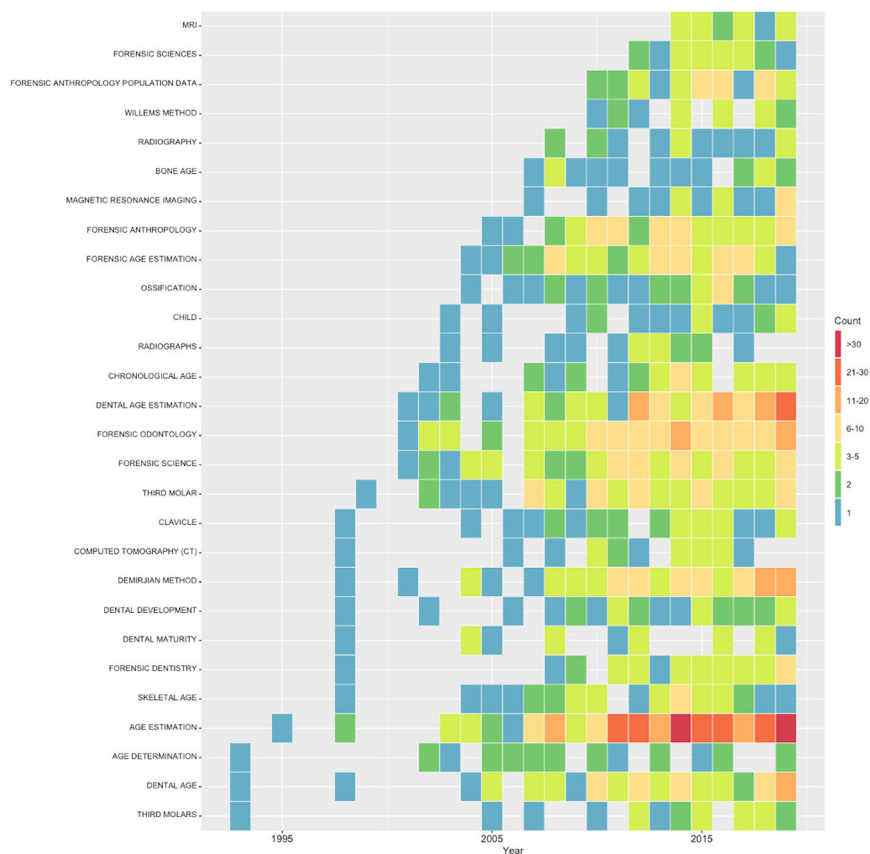
Figure 3. Trends of authors' keywords throughout the years of publication reviewed in this study (1974-2019).

Nolla to Bangladeshi and British Caucasian children between 3.99 and 16.99 years of age.

Authors' keywords

The total number of authors' keywords present in the list is 918. Figure 3 shows the chart generated from the R script which represents the trends of the most commonly used authors' keywords. 'Age Determination', 'Third Molars', and 'Dental Age' were the first keywords to be used in relation to the paper published by Gustafson and Koch (1974) on age estimation using dental development for individuals up to 16 years of age. 'Age Estimation' was the keyword that was found most commonly, appearing 269 times, after its first use in relation to a paper published by Kullman, Martinsson, Zimmerman, and Welander (1995) about age estimation of young adults using computerized measurements of the mandibular third molar. 'Dental Age Estimation' and 'Forensic Odontology' follow as the next most commonly used keywords, being used respectively 118 and 111 times after their first appearance in a paper published by Willems, van Olmen, Spiessens, and Carels (2001) in which the authors

revisited Demirjian's eight-teeth methodology using dental radiographs of a Belgian population.

For keywords that refer to different types of imaging techniques, 'Radiography/Radiographs' was used thirty-six times and appeared for the first time in relation to a study by Liversidge, Lyons, and Hector (2003) that tested the accuracy of three age estimation methodologies using dental radiographs. 'Computed Tomography (CT)' was found to have been used twenty-one times after its first appearance in relation to a study by Kreitner, Schweden, Riepert, Nafe, and Thelen (1998). 'MRI'/'Magnetic Resonance Imaging' was found forty-one times, with its first use in relation to a paper published by Schmidt, Mühler, Schmeling, Reisinger, and Schulz (2007). Both Kreitner *et al.* (1998) and Schmidt *et al.* (2007) estimated age using the medial end of the clavicle.

The most common anatomical area mentioned in keywords was 'Third Molar/Molars', which appeared ninety-one times. 'Third Molar/Molars' first appeared in Gustafson and Koch (1974). The keyword 'Clavicle' appeared thirty-one times, with the first time in Kreitner *et al.* (1998). Other skeletal areas, such as hand/wrist or knee, which are frequently found in age estimation studies, do not appear in the chart.

An analysis of authors' keywords relating to age estimation methodologies showed that only two related keywords appear in the graph: the 'Demirjian Method' (used ninety-three times) and the 'Willems Method' (used eighteen times). The use of the keyword 'Demirjian Method' first appeared in 1998 for a study by Koshy and Tandon (1998) on the applicability of Demirjian's methodology in children from the south of India, whilst 'Willems Method' was used for the first time in 2010 for the publication by El-Bakary, Hammad, and Mohammed (2010) on the comparison of two dental methodologies as applied to an Egyptian population.

Index keywords
An analysis of index keywords showed a total number of 1,238. Figure 4 shows the chart generated from the R script which represents the trends of the most commonly used index keywords throughout the years. The most common keywords detected are 'Human/Humans' with 972 entries, followed by 'Male', 'Female', and 'Adolescent', found, respectively, 538, 525, and 522 times. As per authors' keywords, the first index keywords to appear in the chart are the ones generated for the paper published by Gustafson and Koch (1974), among which were 'Dental Age Estimation', 'Age Estimation', 'Panoramic Radiography', and 'Tooth Development'.

Index keywords related to radiographs ('Radiography', 'Panoramic Radiography', 'Wrist Radiography', 'Hand Radiography', etc.) appeared 801 times. As stated before, the first appearance for 'Panoramic Radiography' was related to the paper by Gustafson and Koch (1974). 'Hand Radiography' first appeared in 2006 in the study about reference data for the Thiemann-Nitz methodology published by Schmeling, Baumann, Schmidt, Wernecke, and Reisinger (2006); whilst 'Wrist Radiography' appeared for the first time in 2009 in the papers published by Büken *et al.* (2009) and Zhang *et al.* (2009), with the first being a study on the comparison of three age estimation methodologies and their reliability among Turkish children, and the second a study on the difference in skeletal development and age estimation among Chinese children and adolescents living in five different cities. CT-related ('Computer Assisted Tomography', 'Multidetector Computed Tomography') appeared a total of thirty-nine times. As per
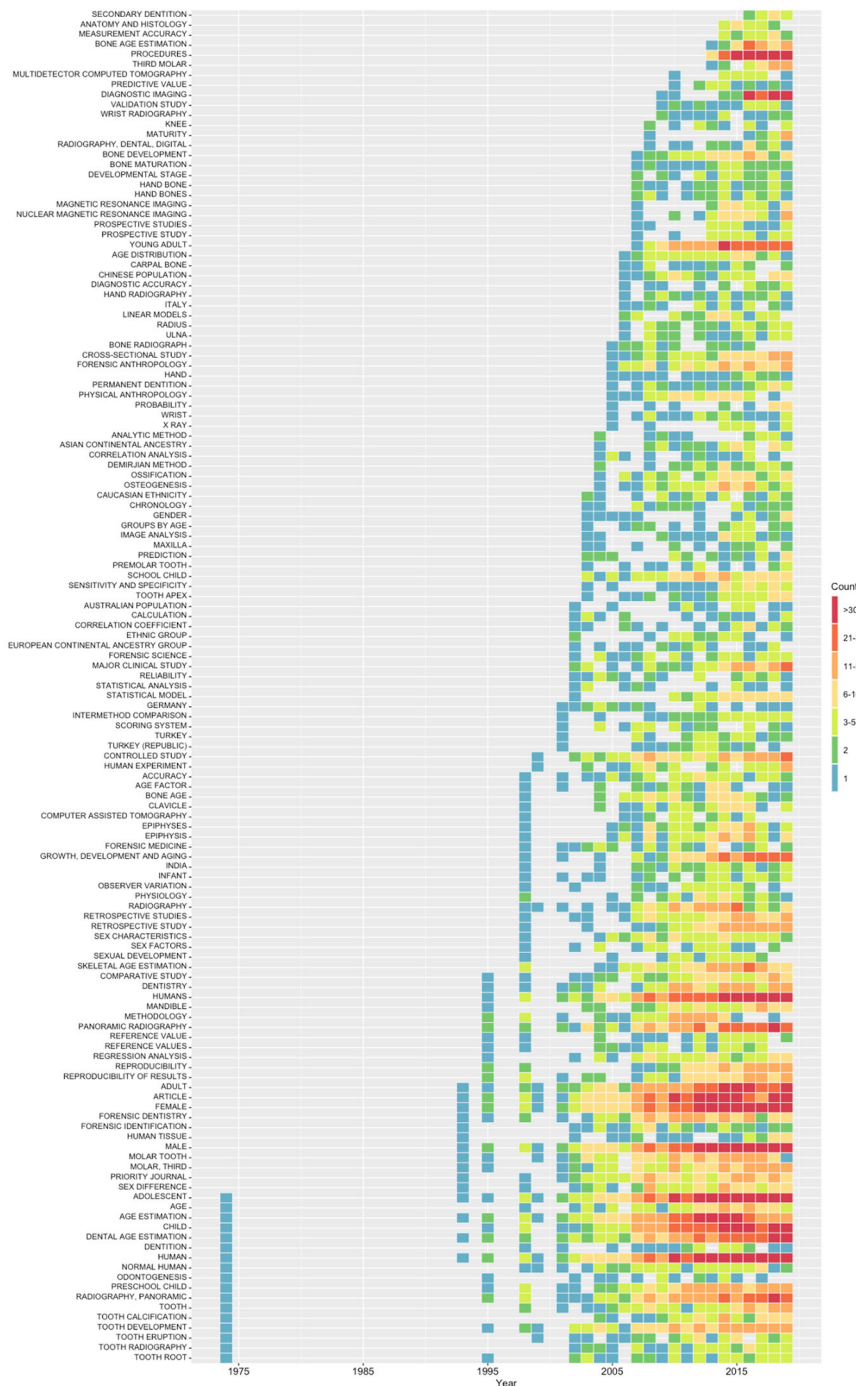
Figure 4. Trends of index keywords throughout the years of publication reviewed in this study (1974-2019).

authors' keywords, the first appearance was recorded in relation to the study by Kreitner *et al.* (1998).

MRI-related keywords ('Magnetic Resonance Imaging/Nuclear Magnetic Resonance Imaging') were found a total of eighty-two times. As for the authors' keywords, their first appearance was in relation to the paper published by Schmidt, Mühler, *et al.* (2007). However, after 2013, they appear to be used more consistently.

For keywords relating to skeletal and dental areas, it was possible to obtain more information from index keywords than authors' keywords. The keyword 'Clavicle' appeared forty-five times. As already noted for authors' keywords, the first appearance was recorded in 1998 in relation to the study on the medial end of the clavicle by Kreitner *et al.* (1998).

The keyword 'Knee' appeared eighteen times, and first appeared in 2008 in relation to two different studies: the first one was a study on the correlation between chronological age and skeletal age in an Irish population by O'Connor, Bogue, Spence, and Last (2008); the second was a study by Marak, Sangma, Singh, and Kharrubon (2008) on age estimation of a Northeastern Indian population using plain radiographs of the elbow, wrist, knee, and pelvis.

Keywords which referred to the hand/wrist area were found a total of 168 times. The first keywords to appear were 'Hand' and 'Wrist' in 2005 in relation to the study by Orlanducci *et al.* (2005) on the precision and reliability of age estimation methodologies among children. 'Carpal Bone', 'Radius', and 'Ulna' were first used in 2005 in relation to a study by Cameriere, Ferrante, Mirtella, and Cingolani (2005) on the use of the skeletal development of the hand/wrist area as an age indicator. 'Hand Bone/Bones' keywords appeared in 2007 for the first time in relation to the paper by Schmidt, Koch, Schulz, Reisinger, and Schmeling (2007) on the comparison of the applicability of Greulich and Pyle and Thiemann-Nitz methodologies.

The index keywords 'Bone Development/Bone Maturation' appeared 103 times. 'Bone Development' first appeared in 2007 in relation to the paper published by Li, Ye, Wang, Ye, and Zhang (2007) on the development of hand and wrist bones of 14-year-olds from a Chinese population; the keyword 'Bone Maturation' first appeared in the paper published by Büken, Şafak, Yazici, Büken, and Mayda (2007) on the application and reliability of the Greulich and Pyle methodology among Turkish children.

Keywords related to dental development/area were used a total of 438 times. The keyword 'Tooth' first appeared in relation to the paper published by Gustafson and Koch (1974); whilst 'Third Molar' and 'Molar Tooth' first appeared in 1993 with the publication by Mincer *et al.* The keyword 'Dental Age Estimation' appeared 311 times; this keyword first appeared in the paper published by El-Bakary *et al.* in 2010 on the comparison of two methodologies for dental age estimation in Egyptian children.

Regarding index keywords that mention age estimation methodologies, the only keyword was 'Demirjian Method' – recorded thirty-five times – which appeared for the first time in 2004 in relation to the study on dental maturity in a population in the south of France by Chaillet and Demirjian (2004) and the paper published by Chaillet, Willems, and Demirjian (2004) on dental maturity and age estimation among a Belgian population.

Authors

A total number of 3,095 authors contributed to publications between 1974 and 2019 (Table 1), of which 454 contributed to two or more studies. For each year of publication,
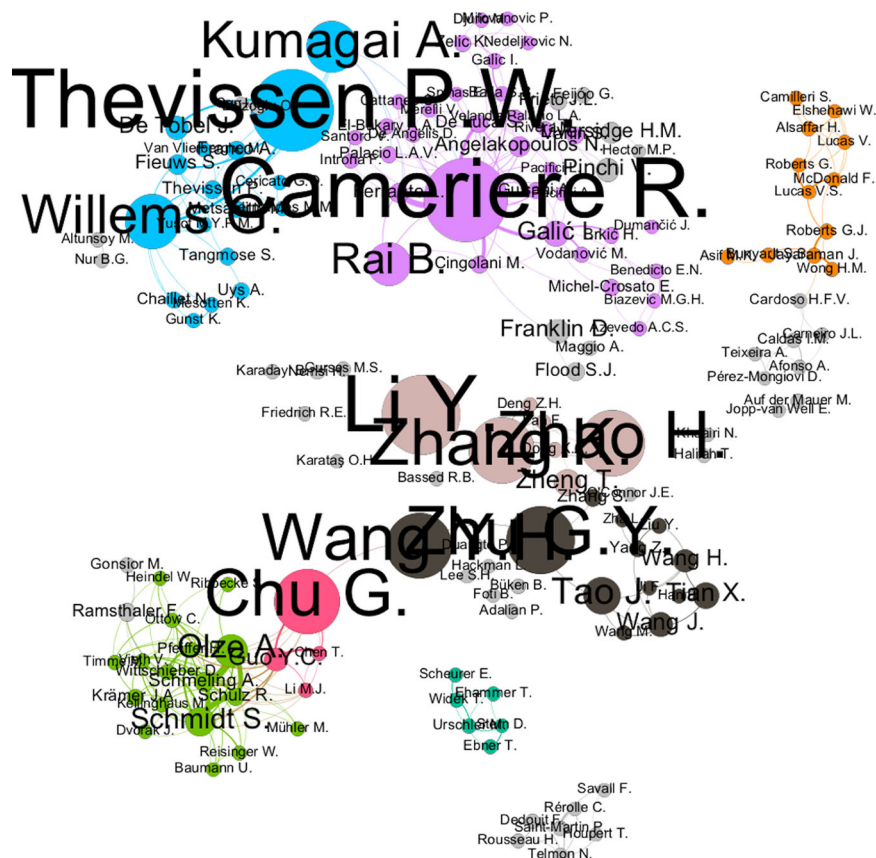
Figure 5. Co-authorship graph created using Gephi (v 0.9.2).

the number of authors who published more than once in the period reviewed and authors who contributed to only one publication were also included. Overall, for each year, there are a greater number of authors who contributed to only one publication compared to authors who published more than one paper. The average ratio is 4.24 authors per publication, with the highest being 5.3 in 2006. Figure 5 shows the co-authorship (edges) between authors (nodes).

Imaging techniques
Using the list generated by Scopus, the publications were divided into five different categories depending on the imaging modality used in the studies. The papers were divided into studies that used only one imaging technique and studies that used more than one imaging technique. There were 612 studies out of the total of 644 (95.03 per cent) which used only one imaging technique. Out of 612 publications, orthopantomogram (OPG) was the most prevalent radiographic imaging technique (63.2 per cent), followed by radiographs of other skeletal areas (20.9 per cent). Ultrasound was the imaging technique least represented (1.96 per cent) (Table 4).

In thirty-two studies (4.97 per cent), more than one imaging modality was used. Among these, the majority used radiography: twenty-six studies out of thirty-two (81.25

Table 4. Total number of papers divided by imaging modality for each year of publication.

Year	Publications					
	Total	Radiography	OPG	MRI	CT scan	Ultrasound
1974	1	–	1	–	–	–
1993	1	–	1	–	–	–
1995	2	–	2	–	–	–
1998	4	–	3	–	1	–
1999	1	–	1	–	–	–
2001	2	–	2	–	–	–
2002	4	–	4	–	–	–
2003	7	–	7	–	–	–
2004	8	1	7	–	–	–
2005	9	1	8	–	–	–
2006	6	3	2	–	1	–
2007	16	3	12	1	–	–
2008	27	11	15	–	–	1
2009	17	6	10	–	–	1
2010	33	5	23	1	4	–
2011	33	7	21	–	4	1
2012	37	8	28	1	–	–
2013	38	15	16	2	1	4
2014	62	12	33	10	5	2
2015	52	13	28	6	5	–
2016	57	12	30	7	6	2
2017	53	9	34	6	3	1
2018	59	8	47	3	1	–
2019	83	14	52	14	3	–
Total	**612**	**128**	**387**	**51**	**34**	**12**

per cent). Out of the remaining six studies, five studies used two imaging techniques, and one study used three imaging techniques. The paper published by Schulz, Mühler, Resinger, Schmidt, and Schmeling in 2008 used radiography and CT scan to analyse the ossification stages of the medial clavicular epiphysis. In 2013, Tangmose, Jensen and Lynnerup published a paper comparing the developmental stages of the medial clavicular end using MRI and CT scan. The study published by P. Baumann *et al.* in 2015 used OPG and MRI for dental age estimation purposes. In 2016, two studies were published that used more than one imaging technique: Kocasarac, Sinanoglu, Noujeim, Yigit, and Baydemir (2016), which used OPG and CT scan, and Fan *et al.* (2016), which used radiography and MRI. Only one study, published in 2010 by Vieth, Kellinghaus, Schulz, Pfeiffer, and Schmeling, used three imaging techniques: radiography, MRI, and CT scan. Ultrasound has never been used with another imaging modality.

Imaging techniques and dental/skeletal areas
An analysis into the relationship between imaging modality and dental/skeletal area studied was carried out for the 612 publications (Table 5). All of the most common skeletal areas had at some point been studied using radiography. The highest number of publications related to the use of OPG in dental age estimation, with 387 studies, followed by sixty-two studies for the use of radiography of the hand and wrist. The most studied skeletal area using MRI was also the hand and wrist, with seventeen publications out of fifty-one (33.3 per cent), followed by the knee, with twelve publications out of

Table 5. Number of publications divided by imaging modality and dental/skeletal area.

	Hand/Wrist	Clavicle	Knee	Teeth	Pelvis	Others	Multiple	**Total**
Radiography	62	10	14	–	17	16	9	128
MRI	17	6	12	5	1	7	3	51
CT scan	–	18	–	7	2	5	2	34
OPG	–	–	–	387	–	–	–	387
Ultrasound	1	5	–	–	2	4	–	12
Total	80	39	26	399	22	32	14	**612**

fifty-one (23.5 per cent). The clavicle was the most common skeletal area studied using CT scan and ultrasound, with eighteen publications out of thirty-four for CT scan (52.9 per cent), and five publications out of twelve for ultrasound (41.6 per cent).

In addition to the use of OPG as a useful technique of visualizing dentition, dental age studies were carried out using CT in seven publications (1.8 per cent), and MRI in five publications (1.2 per cent), for a total of 399 studies. The medial end of the clavicle was the focus of thirty-nine studies, using CT scans (eighteen), radiographs (ten), and MRI (six). The highest number of publications that examined the maturation of the hand and wrist for age estimation utilized radiography as an imaging modality: sixty-two out of eighty (77.5 per cent). The other imaging modalities utilized in the studies of the hand and wrist included MRI (seventeen) and ultrasound (one). There were no publications on hand and wrist development using CT scan.

Other body areas that have been the focus of age estimation studies include the knee, with twenty-six publications, of which fourteen were studies carried out using radiographs (53.8 per cent) and twelve using MRI (46.2 per cent). No publications using ultrasound and CT scan were recorded in the list generated by Scopus. The iliac crest apophysis has also been investigated in twenty-one studies, of which seventeen used radiographs (80.9 per cent), two CT scan (9.5 per cent), two ultrasound (9.5 per cent), and one MRI (4.8 per cent).

Radiographic studies of the foot/ankle, including distal tibia and distal fibula (Singh, Singh, Gorea, Oberoi & Asawa 2013), the foot (Hackman, Davies & Black 2013), and the cervical vertebrae (Cameriere *et al.* 2015), were placed in the category of 'Others'. Using CT scan as imaging modality, publications included three studies on the spheno-occipital synchondrosis (Bassed, Briggs & Drummer 2010; Can *et al.* 2014; Sinanoglu, Kocasarac & Noujeim 2016), one study using the first rib (Moskovitch *et al.* 2010), and one study on the scapula (Nougarolis *et al.* 2017). The four studies published using ultrasound included one paper on the ossification of the fibular distal epiphysis (Schulz, Schiborr, Pfeiffer, Schmidt & Schmeling 2013), one paper on the ossification of the olecranon of the ulna (Schulz, Schiborr, Pfeiffer, Schmidt & Schmeling 2014), one on the ossification of the greater trochanter of the femur (Schmidt, Schiborr, Pfeiffer, Schmeling & Schulz 2014), and one on the fusion of the proximal humeral epiphysis (Sánchez, Codinha, García & Sánchez 2017). For MRI, seven papers included two publications on age estimation using distal tibial epiphysis and calcaneus (Ekizoglu *et al.* 2015; Saint-Martin *et al.* 2013), one using only the distal tibial epiphysis (Saint-Martin *et al.* 2014), one using the spheno-occipital synchondrosis (Ekizoglu, Hocaoglu, Can, Inci & Aksoy 2016), one using the development of the manubrium (Martínez Vera *et al.*

Table 6. Number of papers for which information about population and methodology were available, divided by the dental/skeletal area.

	Clavicle	Hand/Wrist	Knee	Pelvis	Teeth
No. of papers	29 (7%)	52 (12.56%)	14 (3.38%)	11 (2.66%)	308 (74.40%)
Radiography	8	38	8	7	–
CT scan	14	–	–	1	5
OPG	–	–	–	–	299
Ultrasound	3	1	–	2	–
MRI	4	13	6	1	4

2017), and two on the proximal humeral epiphysis (Ekizoglu, Inci, Ors, Hocaoglu, *et al.* 2019; Ekizoglu, Inci, Ors, Kacmaz, *et al.* 2019).

The category 'Multiple' included fourteen publications, of which nine were radiographic studies (64.3 per cent) and three studies used MRI (21.4 per cent). The last two publications used CT scan (14.3 per cent) as imaging modality. No publications using ultrasound were recorded.

Trend of population tested for age estimation in the living methodologies
Analysis was made of the trend of the methodologies for age estimation in the living in relation to populations that have been tested. Only the papers for which population and methodology tested were clearly stated were taken into consideration for the analysis. The dental/skeletal areas included were clavicle, hand and wrist, knee, pelvis, and teeth. The total number of papers was 414. The total number of papers using clavicle was twenty-nine (7 per cent), using hand and wrist was fifty-two (12.56 per cent), using knee was fourteen (3.38 per cent), using pelvis was eleven (2.66 per cent), and using teeth was 308 (74.40 per cent) (Table 6).

The three most common methodologies, Greulich and Pyle (1959), Schmeling, Schulz, *et al.* (2004), and Demirjian, Goldstein, and Tanner (1973), have been further investigated. For the Greulich and Pyle methodology, only the studies that used radiography as an imaging modality were taken into consideration, giving a total of nineteen papers from fourteen different countries. The greatest number from one location were three papers which studied an Italian population. Of the fourteen countries, seven were in Europe, three in Asia, two in Africa, one in Oceania, and one in America. For the Schmeling methodology, only papers that studied the medial end of the clavicle with CT scan as an imaging modality were included, giving a total of ten papers which originated from six different countries. Of the six countries, three were in Asia, two in Europe, and one in Oceania. Finally, the Demirjian methodology was used in a total of 150 papers and tested in forty-six different countries; the highest number of papers, twenty, were studies of a Chinese population. Of the forty-six countries, nineteen were in Europe, thirteen in Asia, seven in the United States, six in Africa, and one in Oceania.

Discussion
This study focused on the investigation of the trends of age estimation in living individuals. The aim was to analyse trends in publication, including changes to OA numbers, the origin of authors, use of index keywords, relation between imaging technique and dental/skeletal area, and trends of methodologies and populations being

studied. To our knowledge, this is the first article in the literature using a bibliometric analysis to analyse the literature on age estimation in the living. The total number of publications present in Scopus was 644, with the highest number of publications seen in 2019. The first paper recorded was published in 1974, after which there was a nineteen-year gap in the Scopus list before publications began again. It is not clear why this gap was present, since we are aware that papers about age estimation were published during this time (e.g. Demirjian & Goldstein 1976).

Gualdi-Russo and Fonti conducted a bibliometric analysis of the forensic anthropology literature between 1979 and 2009. Searching for papers published in the journal *Forensic Science International*, they retrieved 1,589 using PubMed, of which 1,292 papers were published between 2000 and 2009 (Gualdi-Russo & Fonti 2013). More recently, Lei *et al.* (2019) published a bibliometric analysis of the forensic anthropology literature between 2008 and 2017. The topic included all studies related to forensic anthropology and the search was made using Web of Science Core Collection and PubMed. The authors were able to retrieve 1,663 publications published within the reviewed period. Gualdi-Russo and Fonti (2013) and Lei *et al.* (2019) did not mention the number of publications for age estimation in the living among the papers retrieved in their studies; Gualdi-Russo and Fonti (2013) categorized papers about age estimation, along with sex, stature, and ethnic affinity, giving a total of seventy papers between 2000 and 2009. For authors' affiliation, our analysis established that the highest number of publications came from authors based in Europe, with twenty-eight different affiliated countries and 424 contributing authors, followed by Asia, with twenty countries and 294 authors. We found that in terms of individual countries, the most productive was India, with 104 publications, followed by Germany and Italy, with ninety-five and seventy publications, respectively.

A citation analysis was also included, and the top five most cited publications were shown in the results of these: of these five, four were studies on the development of new methodologies, three of which were for dental age estimation, and one for skeletal age estimation. When examining the authors' affiliation, four were from Europe (AlQahtani *et al.* 2010; Gustafson & Koch 1974; Maber *et al.* 2006; Schmeling, Schulz, *et al.* 2004) and one from the United States (Mincer *et al.* 1993). It was not unexpected that the most cited publications were studies presenting new methodologies, considering that three of them, AlQahtani *et al.* (2010), Mincer *et al.* (1993), and Schmeling, Schulz, *et al.* (2004), are widely accepted age estimation methodologies. During our analysis on the trends of methodologies tested on different populations, we found that AlQahtani *et al.* (2010) has been tested on eight populations, using OPG (Alshihri, Kruger & Tennant 2015; Alsudairi & AlQahtani 2019; Baylis & Bassed 2017; McCloe, Marion, da Fonseca, Colvard & AlQahtani 2018; Namwong & Mânica 2019; Pavlović, Palmela Pereira & Vargas de Sousa Santos 2017; Santana, Bethard & Moore 2017). Mincer *et al.* (1993) has been tested on six populations using OPG, one population using MRI, and two populations using CT scan (Alshihri *et al.* 2015; Márquez-Ruiz *et al.* 2017; Martin-de las Heras, Garcia-Fortea Ortega, Zodocovich & Valenzuela 2008; Olze *et al.* 2004; Pilloud & Heim 2019; Widek *et al.* 2019). Finally, Schmeling, Schulz, *et al.* (2004), used to estimate the age from CT scans of the medial end of the clavicle, has been tested in six different populations, giving a total of ten publications; these data are included in the analysis that we carried out for trends of tested methodologies in different populations. We also found that the Schmeling methodology, using MRI of the medial end of the clavicle, was tested in three populations (de Tobel *et al.* 2019; Vieth, Schulz,
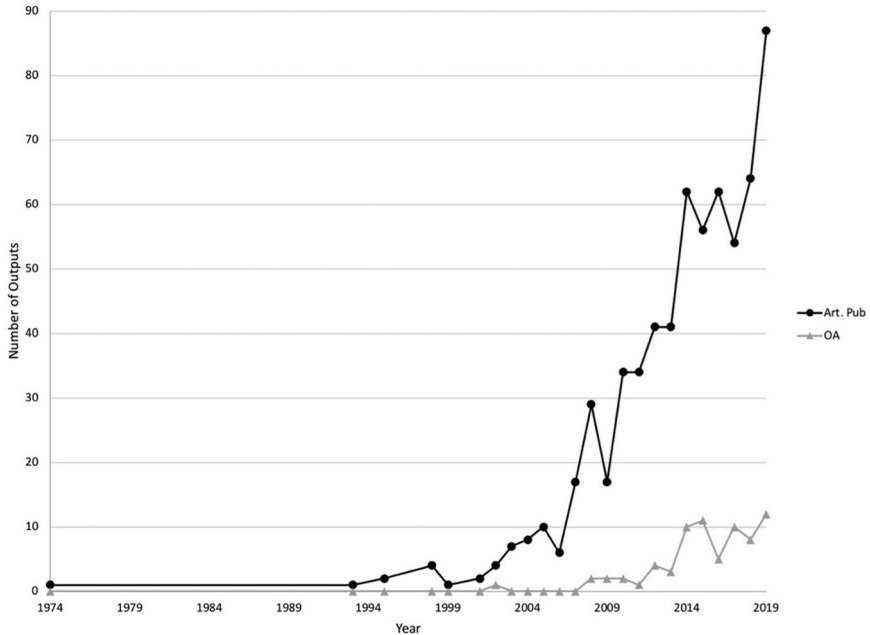
Figure 6. Relation between the number of papers published for each year from 1974 to 2019 (black dots), found on Scopus, and how many of these were OA articles, on PubMed (grey triangles).

Brinkmeier, Dvorak & Schmeling 2014), and, using radiography, in five populations (Cameriere *et al.* 2012; Garg, Singla, Khanna, Dhattarwal & Khanagwal 2019; Marera & Satyapal 2018; Wittschieber *et al.* 2015; 2016). Moreover, this methodology is widely used for age estimation of other skeletal regions as well (e.g. hand and wrist and knee), and we found that it was tested in one population, estimating age from skeletal development of the hand and wrist, using MRI and radiography, and in two populations using MRI of the knee (U. Baumann *et al.* 2009; El-Din, Mostafa, Tantawy & El-Shafei 2019; Ottow *et al.* 2017; Schmidt, Vieth, Timme, Dvorak & Schmeling 2015).

During the analysis of OA publication, we noted that some papers that were categorized as OA were not included. Therefore we decided to compare the OA publications on Scopus against OA publications on PubMed (Fig. 6). Out of the total number of publications (644), OA papers searched using PubMed numbered seventy-one, against the fifty recorded by Scopus. The first OA publication, recorded on PubMed, is the study published by McKenna, James, Taylor, and Townsend in 2002 on the application of Demirjian's methodology to South Australian children; whilst the first OA paper found in the list generated by Scopus is the study by Liversidge and Marsden published in 2010. Table 7 shows the differences in numbers between OA publications using Scopus and PubMed. As in Scopus data, the highest number of OA publications is recorded for 2019 (16.9 per cent). The discrepancy in OA information between Scopus and PubMed might be due to a difference in the number of journals which are OA in the two databases. Nonetheless, as demonstrated in Figure 1, Figure 6, and Table 7, the number of OA publications is increasing with time.

Table 7. Number of OA publications divided for each year, for Scopus and PubMed.

Year	Total publication	OA Scopus		OA PubMed	
		OA	Ratio	OA	Ratio
1974	1	–	–	–	–
1993	1	–	–	–	–
1995	2	–	–	–	–
1998	4	–	–	–	–
1999	1	–	–	–	–
2001	2	–	–	–	–
2002	4	–	–	1	0.25
2003	7	–	–	–	–
2004	8	–	–	–	–
2005	10	–	–	–	–
2006	6	–	–	–	–
2007	17	–	–	–	–
2008	29	–	–	2	0.06
2009	17	–	–	2	0.11
2010	34	1	0.03	2	0.05
2011	34	–	–	1	0.02
2012	41	2	0.05	4	0.09
2013	41	2	0.05	3	0.07
2014	62	8	0.12	10	0.16
2015	56	5	0.08	11	0.19
2016	62	6	0.09	5	0.08
2017	54	6	0.11	10	0.18
2018	64	8	0.12	8	0.12
2019	87	12	0.13	12	0.13

When investigating the use of keywords, Lei *et al.* (2019) identified the top twenty keywords used for forensic anthropology. In this case, the authors found 201 keywords for age estimation, including studies for age estimation of skeletal remains and living individuals. In our study, we conducted an analysis of both authors' and index keywords. We decided to conduct two separate analyses to observe if there were any differences between keywords chosen by the authors themselves, which are controlled terms, and keywords added by Scopus, using thesauri that are licensed or owned by Elsevier, which can be defined as uncontrolled terms. In our study, the variation in index keywords (1,238) was higher than the total number of authors' keywords (918). As expected, in our study, the first keywords to appear were 'Age Determination', 'Third Molars', and 'Dental Age' related to the first paper found in the list generated by Scopus, Gustafson and Koch (1974), which is on dental age estimation. 'Dental Age Estimation' and 'Forensic Odontology' were the second and third keywords most used by authors. This finding is in agreement with the majority of the publications found on Scopus in relation to dental age estimation (399 studies out of 612, 65.2 per cent). The most used keyword was 'Age Estimation', which appeared 269 times (29.3 per cent). From the graph (Fig. 3) it is also possible to see that the use of these three keywords increased with time. The only anatomical areas to appear in the chart were 'Third Molar/Molars' and 'Clavicle'; keywords related to other common areas used for age estimation (e.g. hand and wrist or knee) did not appear in the chart. Their absence does not mean that these keywords were not used by the authors, but it means that, most likely, their

use was limited and therefore below the fifteen times that was the threshold used in the R script to create the graph.

As expected, four different imaging modalities used for age estimation were identified: radiography, CT scan, ultrasound, and MRI. Although OPG is a type of radiography, in this study we created a different category since it was easier for the analysis of the data considering that OPG is used only for dental age estimation. Over the years, the number of papers using OPG increased, as did the number of papers using MRI. The highest number of publications using radiography and ultrasound was recorded in 2013, whilst the highest number for CT scan was recorded in 2016. These findings confirm the fact that the research is shifting towards the use of non-ionizing techniques. There were very few papers that used ultrasound, with just a total of twelve publications throughout the reviewed period, and no publications present in the list for the last two years (2018-19). Despite the reduction in the use of ionizing radiation imaging methodologies, OPG and radiography of other skeletal areas are still commonly used for research on age estimation in the living. The most common areas that have been used during the reviewed period are teeth (399 papers) and hand and wrist (eighty papers), followed by medial end of the clavicle (thirty-nine papers), knee area (twenty-six papers), and pelvis (twenty-two papers). Other skeletal areas have been identified during the analysis; however, since there were fewer publications, they have been allocated in the category 'Others'.

When studying the relationship between methodologies and populations, Jayaraman *et al.* (2013) systematically reviewed papers published between 1973 and 2011 that used Demirjian's methodology. In their review, the authors used PubMed, Embase, and Cochrane databases to search the papers using the terms 'Demirjian' and 'Dental Age', for a total of 274 publications. In our study, we found 150 publications related to the application of Demirjian's methodology, although neither the original publication by Demirjian *et al.* (1973) nor that by Demirjian and Goldstein (1976) was included in the list generated from Scopus. We analysed data from three main methodologies. According to our data, Demirjian's methodology was the most commonly tested in populations around the world, being tested in forty-six different countries, of which the majority were from Europe (41.3 per cent), followed by Asia (28.3 per cent). Other dental age estimation methodologies tested included AlQahtani *et al.* (2010), Cameriere, Ferrante, and Cingolani (2006), Mincer *et al.* (1993), Olze *et al.* (2010), and Willems *et al.* (2001). We also analysed data for the Greulich and Pyle (1959) and Schmeling, Schulz, *et al.* (2004) methodologies. As highlighted in the results and previously in the discussions, Greulich and Pyle's methodology using radiography had been tested on fourteen populations, whilst Schmeling, Schulz, *et al.*'s methodology using CT scan had been tested on six populations. However, there are other methodologies, not included in the results, that deserve to be mentioned in this study. The TW2 (Tanner-Whitehouse 2) methodology (Tanner *et al.* 1983) had been tested on three populations: Australian, Italian, and Benin (Maggio, Flavel, Hart & Franklin 2016; Pinchi *et al.* 2014; Santoro, Marini, Fuzio, Introna & de Donno 2019); whilst the TW3 (Tanner-Whitehouse 3) methodology (Tanner *et al.* 2001) had been tested on five populations: Thai, Turkish, Australian, Brazilian, and Brazilian (Benjavongkulchai & Pittayapat 2018; Büken *et al.* 2010; Maggio *et al.* 2016; Ortega-Pertuz, Haiter-Neto & Costa 2015; Pinchi *et al.* 2014). The methodology developed by Cameriere *et al.* (2005) had been tested on four populations: Slovenian, Italian, Egyptian, and Australian (Cameriere, Ferrante, Ermenc, Mirtella & Štrus 2008;

de Luca *et al.* 2016; El-Bakary *et al.* 2014; Reynolds, MacGregor, Alston-Knox & Gregory 2019).

In this study, we used Scopus to search publications related to age estimation in the living, generating an Excel file that included the main information for each paper and that worked with a specially created R script. Even if PubMed is a commonly used database, such as in the studies published by Gualdi-Russo and Fonti (2013) and Lei *et al.* (2019), Scopus has access to 6,700 journal titles covered by MEDLINE and includes titles from all over the globe, including papers written in languages other than English (22 per cent). The only main discrepancy between the two databases related to the numbers of OA publications. As underlined previously in the discussions, we compared the Scopus information with information gathered from PubMed, and we found that the data did not match, resulting in a higher number of OA papers on PubMed than on Scopus. This might be explained by the fact that PubMed and Scopus provide a different number of OA journals.

Conclusion

With the present study, we investigated the trends of publications of age estimation in the living using an open-source R script and Scopus as a search database. Our results include a detailed analysis of publications, authors, authors' and index keywords, citation, imaging modality, dental/skeletal areas, and population studies present in the literature in the reviewed period between 1974 and 2019. We recommend that future studies include publications from PubMed as well so as to compare the results using the two different databases.

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Estimation médicolégale de l'âge d'individus vivants : une nouvelle approche bibliométrique de la revue de la littérature

Résumé

La présente étude examine les tendances des recherches publiées jusqu'à 2019 concernant l'estimation de l'âge osseux et dentaire d'individus vivants, au moyen d'une nouvelle analyse bibliométrique utilisant un R Script spécial en *open-source*. Cette analyse a été menée sur un total de 644 publications (627 articles, 15 actes de conférences et 2 revues) trouvées dans la base de données en ligne Scopus. Elle incluait l'examen des tendances des publications, des affiliations des auteurs, des citations, des publications libres de droit, des mots-clés des auteurs et des mots-clés d'index. Une analyse supplémentaire a été menée sur le lien entre les méthodologies élaborées et les populations spécifiques testées. Le lien entre les techniques d'imagerie et les parties du corps utilisées dans ces études a également été examiné.

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