Seminal Works and Historical Roots of Dental Implant Research with the Use of CBCT

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Purpose: The objective of this study was to identify the highly cited references that drove the research on implant dentistry with CBCT. Materials and Methods: The literature database Web of Science Core Collection was accessed to identify a collection of papers on this theme. Cited reference analysis was conducted with the aid of CRExplorer, dedicated bibliometric software. Results: The analysis succeeded in identifying the papers that introduced the very first CBCT machines in the Asian and European markets, respectively; papers that proved the CBCT measurement accuracy, its ability to visualize sinus floor penetration, and its reduced metal artifact relative to conventional CT; papers that gave imaging guidelines for implant cases; and papers reporting bone remodeling at extraction sockets and the possibility of grafting at sites with inadequate bone. Conclusion: These publications together provided solid evidence to support subsequent dental implant research and evaluation by CBCT. Int J Oral Maxillofac Implants 2021;36:731–736. doi: 10.11607/jomi.8669

Keywords: bibliometric, CBCT, image artifact, implant, spectroscopy, sinus grafting

Implant dentistry is a state-of-the-art aspect of modern dentistry that can replace missing teeth and thus restore the functions of the dentition. It requires precision and involves multiple stages from treatment planning to the surgical phase to prosthetic replacement. For instance, the initial stability of an implant is affected by the insertion angle and depth,¹ whereas the biomechanical stress built up in the implant parts and bone strain are affected by the thickness of the implant neck wall.² These examples illustrated that the success of an implant case relies on a combination of evidence-based practice and the competent skills of a well-experienced surgeon.

From preoperative to postoperative assessment of implant sites, the use of radiographic images, particularly the 3D CBCT, is necessary in many cases. There are at least a dozen publications providing guidelines for the use of CBCT in implant cases, and another 50 publications on the indications and contraindications for implant dentistry.³ In 2012, the American Academy of Oral and Maxillofacial Radiology (AAOMR) published a position statement stating that CBCT imaging should be used for the assessment of all dental implant sites.⁴ It is understandable, as CBCT provides cross-sectional and 3D information regarding the bony structures as well as the adjacency of the implant sites to delicate structures such as the maxillary sinus floor and the mandibular canal. With a clear understanding of the implant site, there will be higher levels of safety and success.

In recent years, numerous analyses have been performed on the dental implant literature, such as to identify the most cited articles in implant dentistry⁵,⁶; the extent of collaborations between authors, institutions, and countries⁷; and the recurring and trending themes of the implant literature.⁸–¹² The present study focused on dental implant research with CBCT. Moreover, instead of focusing on the conventional forward citation analysis, the present study adopted the backward approach, that is, to analyze the cited references of a predefined collection of papers.¹³ This approach has gained popularity in recent years, as analyzing the references highly cited by the collection of papers may reveal the seminal works or the historical roots of the field. This approach was previously used to identify the historical roots or pioneer works of particular research fields,¹⁴–¹⁹ including coronectomy,²⁰ and particular authors.²¹ Moreover, sleeping beauties, ie, papers with delayed initial recognition but potentially high impact afterward, were detected with CRExplorer in other fields such as climate change,²² but not yet in dentistry.

Materials and Methods

The Web of Science Core Collection electronic database was accessed in late May 2020 to identify the CBCT papers on dental implants. The following search string was...
Identify a body of literature dealing with CBCT imaging of dental implants from Web of Science database

Extract the bibliographic information of the cited references

Identify three types of cited references using CRExplorer

Seminal works: 10 cited references with highest N_TOP10 value + cited references with > 100 citations not otherwise included

Historical roots: Cited references that accounted for > 20% of citations made to RPYS positive peaks with magnitude > 10 published before year 2000

Sleeping beauties: Cited references classified so by the default algorithm of CRExplorer

Fig 1 A flowchart that illustrates the steps of the cited reference analysis.

RESULTS

The search yielded 1,636 papers: 1,549 articles and 87 reviews. They had more than 20,000 cited references. The oldest cited reference with at least 10 citations from these 1,636 papers was a dry skull study that examined the anatomy and pathology of the maxillary sinus (12 citations).23

For cited reference analysis, the 10 cited references with the highest N_TOP10 value are listed in Table 1. Each of them was among the top 10% of cited references in at least 13 citing years. Three of them introduced new CBCT machines at their times.24–26 Two papers advocated the use of CBCT imaging for implant planning with the ability to assess the condition of the sinus floor and with reduced image artifacts relative to conventional CT.27,28 Two were radiographic guidelines that advised on the specific indications for CBCT imaging for implant cases.29,30 Meanwhile, three studies proved the accuracy of measurements taken in CBCT images and the accuracy of using a stereolithographic surgical guide.31–33 These papers could be considered as the seminal works that laid the foundation of CBCT studies on dental implants.

In addition to these 10 papers, two studies were found to receive more than 100 citations from the analyzed papers, namely, an animal study by Araújo and Lindhe34 and a case report by Boyne and James.35 The former found that tooth extraction sites in dogs would have horizontal bone resorption and that resorption was more pronounced at the buccal aspect. The latter showed the possibility to graft the maxillary sinus floor with autogenous materials.

Figure 2 shows a RPYS spectrogram. Before the year 2000, there were nine peaks (1910, 1928, 1967, 1969, 1972, 1976–1977, 1980–1981, 1986, 1994). Table 2 lists the cited references that accounted for > 20% of citations made to these positive peaks. These cited references dealt with the location of the mandibular canal, sinus anatomy and grafting, ridge resorption following tooth extraction, and calculation of interobserver agreement that is crucial for measurement studies.
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They were the historical roots that stimulated and enabled the conducting of contemporary research using CBCT imaging on dental implants. In addition, there were two more peaks post-2000, namely, in 2009 and 2012. There was no cited reference with > 20% contribution to the peaks. Meanwhile, four sleeping beauties were identified from the cited references (Fig 3). Two of them were systematic reviews, one concluding that implant placement with maxillary sinus floor elevation was a predictable treatment method with a 3-year survival of 90.1%, and the other one concluding that computer-assisted implant placement had a success rate of 97.3% after at least 12 months. For the remaining two studies, one reported inaccuracy of CBCT measurements of cortical bone adjacent to implants, especially when the bone thickness was < 0.8 mm, and one proposed a sagittal root position classification and found that the roots of maxillary anterior teeth were predominantly positioned against the labial cortical plate. These papers were not cited by the analyzed papers for 1 to 3 years since publication.

Table 1 Seminal Works That Laid the Foundation of CBCT Work on Dental Implants (10 Cited References with the Highest Number of Citing Years in Which the References Belong to the 10% Most Frequently Referenced Publications)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Title</th>
<th>No. of citations by the analyzed papers</th>
<th>Main theme of the cited reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mozzo et al (1998)25</td>
<td>17</td>
<td>111</td>
</tr>
<tr>
<td>2</td>
<td>Arai et al (1999)24</td>
<td>16</td>
<td>59</td>
</tr>
<tr>
<td>3</td>
<td>Tyndall and Brooks (2000)29</td>
<td>14</td>
<td>43</td>
</tr>
<tr>
<td>4</td>
<td>Harris et al (2002)30</td>
<td>14</td>
<td>49</td>
</tr>
<tr>
<td>5</td>
<td>Sukovic (2003)26</td>
<td>14</td>
<td>63</td>
</tr>
<tr>
<td>6</td>
<td>Lascala et al (2004)32</td>
<td>14</td>
<td>53</td>
</tr>
<tr>
<td>7</td>
<td>Ziegler et al (2002)28</td>
<td>13</td>
<td>42</td>
</tr>
<tr>
<td>8</td>
<td>Sarment et al (2003)33</td>
<td>13</td>
<td>65</td>
</tr>
<tr>
<td>9</td>
<td>Kobayashi et al (2004)31</td>
<td>13</td>
<td>56</td>
</tr>
<tr>
<td>10</td>
<td>Scarfe et al (2006)27</td>
<td>13</td>
<td>92</td>
</tr>
</tbody>
</table>

Fig 2 Reference publication year spectrogram (RPYS). The gray bar chart shows the citation count of references published in each year. The red wavy line shows the citation differences from the 5-year median. Take year 1986 as an example. The numbers of citations gained by references published in 1984 to 1988 were 113, 196, 316, 196, and 253, respectively. The 5-year median was 196. The peak at 1986 therefore had a magnitude of 316 - 196 = 120.
DISCUSSION

The cited reference analysis was able to identify the papers that introduced the very first CBCT machines in the Asian and European markets, respectively. Other highly cited references covered various aspects of CBCT imaging in implant dentistry, such as its measurement accuracy, ability to visualize sinus floor penetration, and reduced metal artifacts relative to conventional CT. Together with imaging guidelines and studies reporting bone remodeling at extraction sockets and the possibility of grafting at sites with inadequate bone, these publications provided solid evidence to support the subsequent dental implant research and evaluation by CBCT.

As AAOMR recommended, CBCT imaging before bone grafting helps clinicians to define the donor and recipient sites and optimize the surgical planning and therefore minimize patient morbidities. Sinus floor elevation is often needed for placement of implants in the maxillary posterior region that has been partially edentulous and undergoing ridge resorption for a long time. Thickened sinus membrane is associated with an increased risk of membrane perforation during sinus augmentation. Besides, some patients may develop sinusitis following sinus elevation. Therefore, a considerable amount of CBCT research often focused on the morphologic prevalence and variations of the maxillary sinus, a structure highly relevant to implant dentistry, such as the morphology (thickening) of the sinus membrane, and the patency of primary and accessory ostia. Another function of CBCT imaging prior to implant placement is for the fabrication of stereolithographic surgical guides. It was reported that fully guided surgery had greater accuracy than half-guided surgery, and tooth- and mucosa-supported guides had greater accuracy than the bone-supported guide. The present results identified one seminal work related to guided implant surgery. Certainly, the ALARA principle should be observed, and the field of view should be minimized for the CBCT imaging for diagnostic or evaluative purposes. However, the present results did not identify highly cited references related to low-dose protocols of CBCT. Readers may refer to a previous

<table>
<thead>
<tr>
<th>Year</th>
<th>Title</th>
<th>% of citations made to references of that year</th>
<th>No. of citations by the analyzed papers</th>
<th>Main theme of the cited reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1910</td>
<td>Underwood23</td>
<td>85.7</td>
<td>12</td>
<td>A dry skull study that examined the anatomy and pathology of the maxillary sinus</td>
</tr>
<tr>
<td>1928</td>
<td>Olivier53</td>
<td>84.6</td>
<td>11</td>
<td>A paper dealing with the mandibular canal in the adult</td>
</tr>
<tr>
<td>1967</td>
<td>Pietrokowski and Massler54</td>
<td>38.6</td>
<td>32</td>
<td>A study that measured alveolar ridge resorption after tooth extraction by means of plaster dental casts</td>
</tr>
<tr>
<td>1969</td>
<td>Johnson55</td>
<td>20.9</td>
<td>14</td>
<td>A study that measured the dimensional change in the maxilla over a 12-month period after tooth extraction</td>
</tr>
<tr>
<td>1972</td>
<td>NA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1976</td>
<td>NA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1977</td>
<td>Landis and Koch56</td>
<td>22.1</td>
<td>32</td>
<td>A statistics paper that presents a method to calculate interobserver agreement</td>
</tr>
<tr>
<td>1980</td>
<td>Boyne and James35</td>
<td>56.0</td>
<td>102</td>
<td>A case report that showed the possibility to graft maxillary sinus floor with autogenous materials.</td>
</tr>
<tr>
<td>1981</td>
<td>Adell et al57</td>
<td>32.5</td>
<td>40</td>
<td>A 15-year study that reported the successful osseointegration of implants in treating edentulous arches</td>
</tr>
<tr>
<td>1986</td>
<td>Tatum Jr58</td>
<td>27.9</td>
<td>88</td>
<td>A paper that explained how to maximize the use of the alveolar bone in the maxilla to insert an implant and described techniques to increase the amount of bone available in the socket for implant insertion</td>
</tr>
<tr>
<td>1994</td>
<td>NA</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig 3 Four sleeping beauties identified from the cited references.
report that analyzed the highly cited references related to the ALARA principle.\textsuperscript{51}

Though CBCT was invented in the late 1990s, and thus, many of the cited references were relatively new, the cited reference analysis with the aid of CRExplorer was still able to identify the historical roots and seminal works, including the papers that introduced the first CBCT machines. These references may help specialists and researchers in the field of implant dentistry to better understand the origin and rationale of the current evidence-based, research-informed clinical practice. Readers should be aware that in this study, papers were classified as sleeping beauties by CRExplorer instead of using the criteria defined by van Raan.\textsuperscript{52} Moreover, they received delayed recognition only in the studied research field without considering papers outside the field. As such, this study should be complementary to the existing analyses on implant dentistry analysis and demonstrate that cited reference analysis could be a useful approach, in addition to manual tracing, to find missed papers in the process of a systematic review. It should be noted, however, that cited reference analysis cannot serve the purpose of a regular systematic review, and that cited reference analysis cannot identify trends in the research landscape.

CONCLUSIONS

These publications together provided solid evidence to support subsequent dental implant research and evaluation by CBCT.

ACKNOWLEDGMENTS

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REFERENCES


