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Scoping Review

Smartphone applications used in orthodontics: A scoping review of scholarly literature

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ABSTRACT

Mobile applications (apps) play an increasingly important role in day to day life. With the number of orthodontic-related apps continuing to increase, and the rapid development of artificial intelligence, the potential to yield tremendous benefits to both clinicians and patients is apparent. However, if orthodontic apps are to become mainstream and obtain greater acceptance, scientific validation and investigation of these apps are to be undertaken. This scoping review aimed to determine the scope and extent of the published literature on mobile apps in orthodontics, as well as identify the types of studies published, and summarize the outcomes studied- thus also giving direction for future research in a rapidly evolving subject area.

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1. Introduction

The slide and swipe culture symbolizes life in the 21st century [1,2]. The past decade has seen mobile phones become the primary means of communication and internet access. Worldwide, the number of smartphone users has continued to increase from 2.5 billion in 2016 to 3.5 billion in 2020 [3]. Meanwhile mobile app revenues have increased from $218.2 billion to $581.9 billion in the same amount of time [4]. It is not surprising then, that mobile applications (apps) play an increasingly important role in day-to-day life. However, the role of apps in health care, and orthodontics in particular, has achieved only limited popularity and acceptance thus far. The potential to yield tremendous benefits to all stakeholders is apparent; however, if greater acceptance is to be obtained, orthodontic apps require validation and proven treatment benefits.

The number of orthodontic apps, across the Google Play Store and Apple App Store, has increased steadily with time until recently. The first study on the number and type orthodontic apps was performed by Singh [5] in 2013, who found only 19 apps on the Google Play Store and Apple App Store. In 2014, this number had jumped to 119 [6]. By 2017, Gupta and Vaid [7] had discovered 354 apps. The most recent study by Siddiqui et al. [8] in 2019, put the number of orthodontic apps at 305, which for the first time had decreased. These apps, both patient- and clinician-focused, vary tremendously in genre and objective. Despite the large number of orthodontic apps, very few have been studied to investigate their veracity.

Over the past 2 decades, scoping reviews have become a somewhat popular approach for reviewing literature and have been widely used within the health care sector. In the orthodontic literature, however, very few scoping reviews have been undertaken [9]. A scoping review is usually performed to study the extent, range, and type of research within a topic area and helps

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to direct future research. Scoping reviews become especially beneficial when conducted on novel topics with fast-evolving evidence, in which a scarcity of randomized controlled trials (RCTs) prevent systematic reviews from having meaningful conclusions [10]. This is such a case for mobile apps in orthodontics. This scoping review therefore aims to determine the scope and extent of the published literature on mobile apps in orthodontics, identify the types of studies published, and summarize the outcomes studied.

2. Materials and methods

A scoping review of the published literature was performed following the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines. A review protocol was created to address the research questions, but was not previously published. EMBASE, PubMed, and Google scholar databases were searched from January 2010 until June 2020. The initial date was chosen because the use of mobile apps for orthodontics is a relatively new phenomenon, and smartphones and mobile apps have only gained popularity at the turn of the decade. In hindsight, the earliest study to meet our criteria was published in 2014. The search terms used were "orthodontic" AND ("app" OR "application" AND/OR "smartphone") and the results were limited to studies published in the English language. Studies were considered suitable for selection based on the following criteria:

- Study type: RCTs, case-controlled trials, retrospective and prospective studies, and cross-sectional studies.
- Participants: Patients aged 10 years and older receiving orthodontic treatment.
- Intervention: Any type of orthodontic treatment, method, or approach using an app.
- Comparison: Any type of comparison, mode of orthodontic treatment method, or approach.
- Outcomes: All outcomes.
- Exclusions: Opinion or review articles, case reports, articles on techniques, and studies with fewer than 10 participants.

The abstracts of all suitable articles were evaluated by one reviewer (I.H). The full texts of those articles meeting the selection criteria and those that were ambiguous were then obtained for screening. A second reviewer (N.R.V) aided in resolving uncertainty regarding final inclusion until consensus was reached. The data were extracted onto a spreadsheet that contained the first author and year of publication, study type, participants, interventions, comparison, outcomes (both primary and secondary), method of measurement, focus group, and outcome domain. The primary and secondary outcomes were determined from within the text of the study. If not explicitly mentioned, the aim, sample size calculation, or first reported outcome in the results section was used. Any other outcomes reported were designated as secondary outcomes. The outcome domains were chosen after review of the results and refined by two reviewers (I.H. and N.R.V). The outcome domains were thus categorized as apps used for reminders, diagnosis, and/or remote monitoring. These were further grouped into patient- and clinician-centric apps.

3. Results

3.1. Search and selection of studies

The initial search using the strategy resulted in 33 records after exclusion of duplicates. After review of the abstracts, 25 full-text articles were evaluated for eligibility and 17 articles fulfilled the selection criteria (Fig. 1). The articles included in the scoping review are displayed in Table 1, and excluded articles, with reasons, are shown in Table 2.

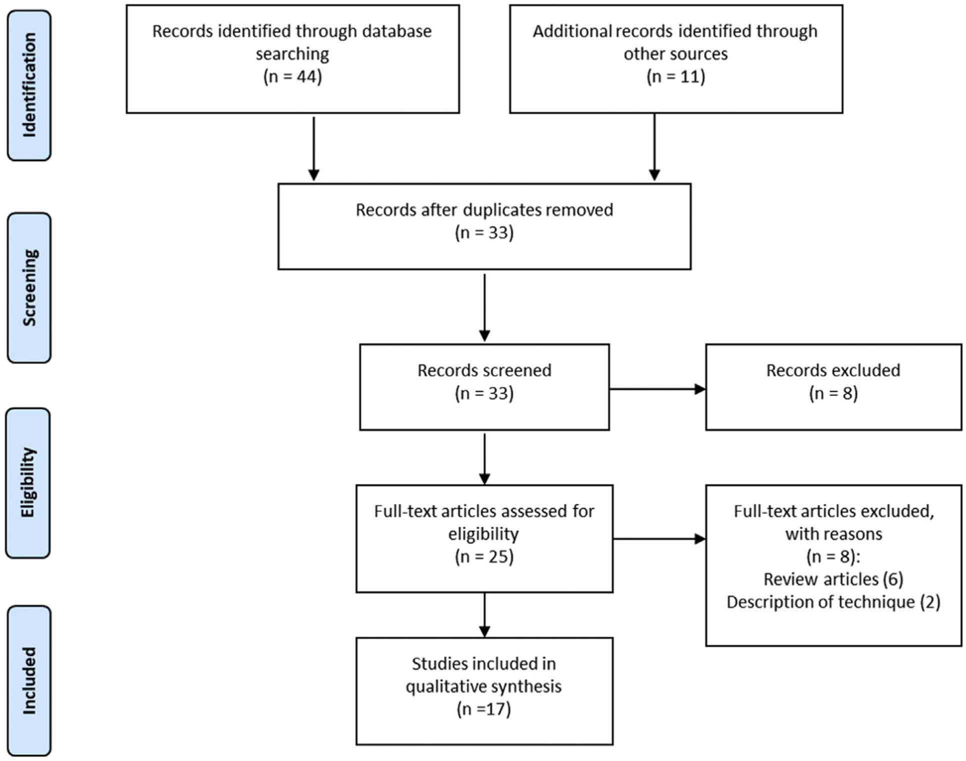

Fig. 1. PRISMA flowchart.

Table 1
Characteristics of included studies (n = 17)

Author	Study type	Participants	Intervention	Comparison	Outcome (primary)	Outcome (secondary)	Method of measurement	Focus group of apps	Outcome domain
Abdul Khader [11] 2020	Case-control	40 randomly selected cephalometric radiographs of patients younger than 15 years	Analyses using OneCeph: app-based tracing	Analyses using manual tracing	Accuracy and reliability of an app-based cephalometric software (OneCeph)		Cephalometric Measurements of the Tweed triangle	Clinician	Diagnostics
Aksakalli [12] 2017	Case-control	20 randomly selected cephalometric radiographs	Analyses using CephNinja and SmartCeph Pro (app-based)	Analyses using Dolphin Imaging software	Accuracy and reliability of app-based (CephNinja) and PC-based (Dolphin) cephalometric software		Cephalometric Measurements	Clinician	Diagnostics
Alkadhi [13] 2017	RCT	44 patients undergoing orthodontic treatment aged 12 or older	App with OH reminders 3 times a day	Verbal OH instructions during routine orthodontic visits	Oral hygiene		Clinical measurements using plaque index and gingival index (Loe and Silness)	Patient	Reminders
Deleuse [14] 2020	RCT	38 patients aged between 12 and 18 with full fixed appliances	Interactive oscillating/ rotating electric toothbrush connected to an app	Oscillating/rotating electric toothbrush alone	Oral hygiene		Clinical measurements using plaque index and gingival index (Loe and Silness)	Patient	Reminders
Goracci [15] 2014	Case-control	20 cephalometric radiographs	Analyses using SmileCeph (app)	Analyses using manual tracing and NemoCeph (PC)	Accuracy and reliability of an app-based (SmileCeph) cephalometric software		Cephalometric measurements	Clinician	Diagnostics
Hansa [16] 2020	Retrospective cohort study	155 consecutively treated Invisalign patients	Treatment with Dental Monitoring (app)	Treatment without Dental Monitoring	Treatment duration, number of appointments, number of refinements, total number of refinement aligners, and time to initial refinement	Patient perspectives of DM	Records review and questionnaire	Patient; Clinician	Remote monitoring
Kumar [17] 2020	Case-control	100 cephalometric radiographs of consecutively treated orthodontic patients	Analyses using CephNinja (app)	Analyses using NemoCeph (PC)	Accuracy and reliability of an app-based (CephNinja) cephalometric software		Cephalometric measurements	Clinician	Diagnostics
Kuriakose [18] 2019	Case-control	20 consecutively treated patients with Hyrax expander	Measurements from Dental Monitoring (app)	Measurements from an intraoral scanner and intraoral measurements	Accuracy of maxillary intermolar width	Posterior crossbite correction	Digital model Measurements, Clinical measurements	Patient; clinician	Remote monitoring
Li [19] 2016	RCT	224 orthodontic patients	Received regular reminders and educational message via WeChat group	Received conventional management	Effect on duration of tx	Effect on failed and late attendance, bracket failure and oral hygiene	Records review and clinical measurements using plaque index and gingival index	Patient	Reminders
Livas [20] 2019	Case-control	50 cephalometric radiographs of consecutively treated orthodontic patients	Analyses using CephNinja and OneCeph (apps)	Analyses using Viewbox (PC)	Accuracy and reliability of app-based (CephNinja and OneCeph) cephalometric software		Cephalometric measurements	Clinician	Diagnostics
Morris [21] 2019	Case-control	10 typodonts	3D digital models generated by Dental Monitoring (app)	3D digital models generated by the iTero Element intraoral scanner	Accuracy of the 3D digital models		Digital model measurements	Patient; clinician	Remote monitoring
Moylan [22] 2019	Case-control	12 patients between the ages of 10 and 17 years treated with RME	Measurements from Dental Monitoring (app)	Measurements from a plaster model	Accuracy of maxillary intercanine and intermolar width		Digital and plaster model measurements	Patient; clinician	Remote monitoring

(*Continued on next page*)

Table 1 (*Continued*)

Author	Study type	Participants	Intervention	Comparison	Outcome (primary)	Outcome (secondary)	Method of measurement	Focus group of apps	Outcome domain
Sayar [23] 2017	Case-control	55 randomly selected cephalometric radiographs of orthodontic patients	Analyses using CephNinja (app)	Analyses using manual tracing	Accuracy and reliability of app-based (CephNinja) cephalometric software		Cephalometric measurements	Clinician	Diagnostics
Scheerman [24] 2020	RCT	132 orthodontic patients between ages 12 and 16	Use of the WhiteTeeth app	Usual care only	Oral hygiene		Al-Anezi and Harradine plaque index and Bleeding on Marginal Probing Index	Patient	Reminders
Underwood [25] 2015	Cross-sectional	189 patients	Patients using BrushDJ (OH app)		Perception of BrushDJ (OH app)		Questionnaire	Patient	Reminders
Zotti [26] 2016	RCT	80 orthodontic patients	WhatsApp group–based competition and instruction to share monthly oral hygiene selfies with other participants	Received conventional management	Oral hygiene	White spot lesions and caries	Clinical measurements, plaque index and gingival index (Loe and Silness)	Patient; clinician	Reminders; remote monitoring
Zotti [27] 2019	RCT	60 post-orthodontic patients	WhatsApp group-based competition, with photos showing the occlusion every week	Received conventional management	Orthodontic stability/relapse		Study cast measurements, intercanine width	Patient; clinician	Reminders; remote monitoring

3D, three-dimensional; RCT, randomized controlled trial; OH, oral hygiene; DM, dental monitoring; tx, treatment; RME, rapid maxillary expansion.

3.2. *General characteristics of included scoping reviews*

The included publications ranged in date from 2014 to 2020. One study was published in 2014; one in 2015; two in 2016; three in 2017; zero in 2018; five in 2019; and five in the first 7 months of 2020. With respect to type of studies performed, six RCTs were identified (35%), nine were case-controls (53%), one cohort study (retrospective) (6%), and one cross-sectional (6%) (Fig. 2).

3.3. *Outcome domains of included studies*

There were six studies (35%) based on apps used for diagnostics, and all were cephalometric apps. The most commonly investigated apps were CephNinja (studied four times), OneCeph (twice), SmartCeph Pro (once), and SmileCeph (once). Seven studies (41%) using apps for reminders were present, with the primary outcome of four of them being oral hygiene (OH), one was patient perception of an OH app, one investigated the effect on treatment duration, and one studied the effect on postorthodontic stability. The apps used for reminders were varied and included popular messaging apps such as WhatsApp and WeChat. Four studies (24%) investigated dedicated remote monitoring apps and all four studied Dental Monitoring (Fig. 3). Twelve studies were based on clinician-centric apps, and 11 were patient-centric. These were not mutually exclusive, as some apps were both patient- and clinician-centric.

4. Discussion

Only 17 studies were found investigating the effects and functionality of orthodontic apps. Although our search criteria included years 2010 to 2020, the first study that fit our criteria was published in 2014. The number of studies have generally increased year-on-year with the exception of 2018, from one study in 2014 to five in the first half of 2020. This increase reflects the larger trend of increases in the number and usage of orthodontic apps, as well as the continuous digitization in orthodontics.

The domain outcome with the greatest representation in the literature was apps used in reminder therapy (41%). This is in accordance with the total number of apps in this genre found in the Apple App Store and Google Play Store [7]. This is a broad genre and overlaps somewhat with practice management software. Patient reminders have been shown to improve compliance [27], reduce the number of missed appointments [33–35], improve OH [13,26,35–37], reduce white spot lesions [26], and reduce treatment times and bracket failure. [19] App-based oral hygiene reminders need not be a specialized orthodontic app. In fact, two studies [19,26] used WhatsApp and WeChat messages in various ways to improve compliance and OH. The advantages of using these apps for reminder therapy are their low costs and simple implementation. Small changes to a private practice to implement some type of reminder therapy can make significant improvements to the

Table 2
Studies excluded from the scoping review (n = 8)

Author	Reason for exclusion
Baheti [6] 2014	Review article
Gupta [7] 2017	Review article
Hansa [28] 2018	Review/opinion article
Mamillapalli [29] 2016	Description of technique
Phatak [30] 2019	Review article
Rao [31] 2018	Review article
Singh [5] 2013	Review article
Scheerman [32] 2018	Description of technique

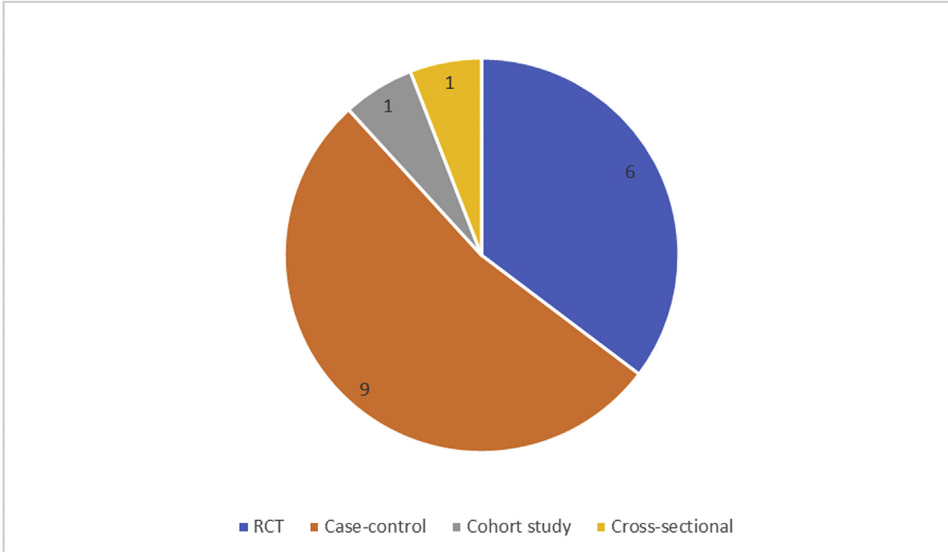

Fig. 2. Distribution of study types.

aforementioned areas. This area of research may occupy more space in published literature in the coming years.

Thirty-five percent of the apps studied were used for diagnostics; all were cephalometric apps. CephNinja and OneCeph seemed to be the most popular app studied for cephalometrics and have generally been found to be accurate and reliable [11,12,17,20]. These apps tend to mimic conventional PC-based programs (which have been proven to be accurate [38–40]), and thus should theoretically also be as accurate. One of the pitfalls of app-based cephalometry is their lack of integration with practice management software. It may be cumbersome for a private practice to use a separate app solely for cephalometric analysis without integration with the patients' other records. A more prudent use of app-based cephalometry may be for cloud-based orthodontic software to develop an accompanying app that would allow for seamless syncing of patient records across devices.

With the rapid development of artificial intelligence (A.I.) and machine learning [41], we can foresee greater integration of A.I. and orthodontic apps in aiding diagnostics and treatment planning [42–45]. A.I. has already been used for automated cephalometric tracings [46,47], and may soon find itself common practice in mobile apps [48]. In fact, WebCeph [49], a cloud-based A.I.-driven orthodontic platform, is currently available free to clinicians and offers automatic A.I.-driven cephalometric landmark identification, tracing, and analysis. The validity of this software, however, is yet to be tested.

Remote monitoring encompassed 24% of the included studies, and all studies investigated Dental Monitoring. These studies verified the accuracy of measurements obtained using the Dental Monitoring app and its movement-tracking algorithm. Hansa et al. [16] concluded that its use reduced the number of office visits for Invisalign patients, and also had a generally positive perception by

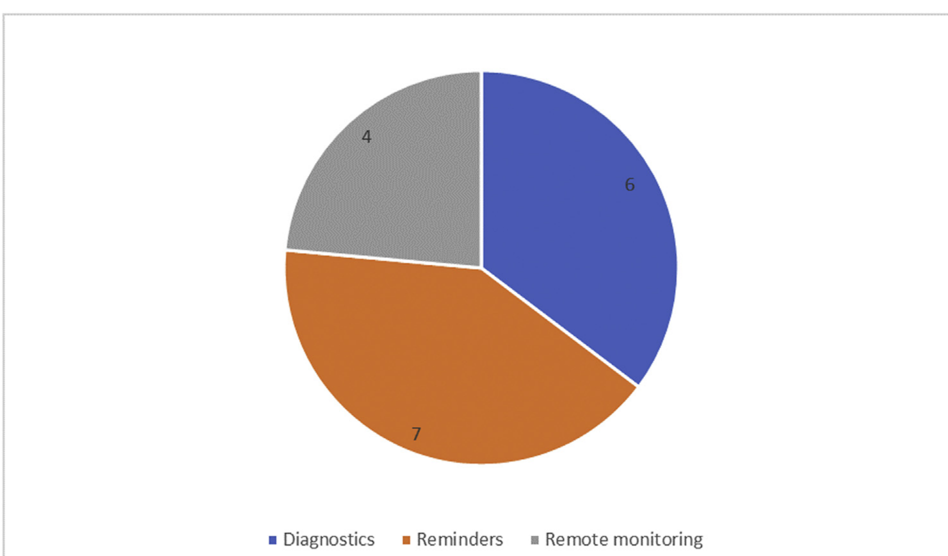

Fig. 3. Distribution of outcome domains studied.

users. The use of remote monitoring has the potential to improve chairside efficiency and may well be beneficial during the COVID-19 pandemic [50,51]. No studies have been performed on the financial viability of Dental Monitoring, however. Studies by Zotti et al. [26,27] and Li et al. [19] have incorporated a simpler aspect of remote monitoring, by using popular messaging apps (WhatsApp and WeChat) to share photos and reminders, which offers a free, albeit limited, alternative to Dental Monitoring.

Overall, there were only 17 studies investigating this novel area of orthodontics, and only six were RCTs. There were a small number of outcome domains identified in the included studies. Apps used in orthodontics for purposes other than reminders, cephalometry, or remote monitoring have not been studied. Some examples of such apps include model and space analysis, treatment planning for interceptive orthodontics, force system calculators, and Index of Treatment Need and Peer Assesment Rating calculators.

The past decade has been revolutionary for mobile devices, and this trend will likely continue well into the foreseeable future and beyond! Words like automation, A.I., and machine learning are already a part of the orthodontic glossary [41]. The words of futurist Ray Kurzweil [52] exemplifies 21st century orthodontic trends: "…we won't experience 100 years of progress in the 21st century—it will be more like 20,000 years of progress (at today's rate)." It is only prudent that, like everything else in the orthodontic armamentarium, every technological application is also subjected to clinical audits and scholarly scrutiny [53].

4.1. Limitations

Pertinent studies may have been missed if they were published in a language other than English or in databases not searched in this study. Similarly, some studies may not have been found due to the search terms used.

An app, by definition, is essentially software designed specifically for mobile devices and includes phones, tablets, and watches. These apps are particularly suited to consumers, and may be most appropriately used for reminder therapy or aiding in remote monitoring. With browser-/cloud-based orthodontic software becoming more popular, these can now be accessed from any device with a browser and Internet connection. This blurs the line between traditional PC-based and mobile-based diagnostic software; hence, some studies that may have used cloud-based diagnostic software, and are functional on mobile devices, were not included, and is thus a limitation of our review. Future reviews, whether scoping or systematic, may have the difficult task of identifying and including studies investigating cloud-based software.

5. Conclusions

- This scoping review indicates that only limited research (17 studies) has been undertaken on apps used in orthodontics.
- Six studies were RCTs (35%), nine were case-controls (53%), one was a cohort study (retrospective) (6%), and one cross-sectional study was found (6%).
- Six studies (35%) were based on apps used for diagnostics, and all were cephalometric apps. Seven studies (41%) investigating apps used for reminders were present. Four studies (24%) investigated dedicated remote monitoring apps, and all four studied Dental Monitoring.
- Apps used for orthodontic purposes other than reminders, diagnostics (cephalometry), or remote monitoring have not been studied.

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