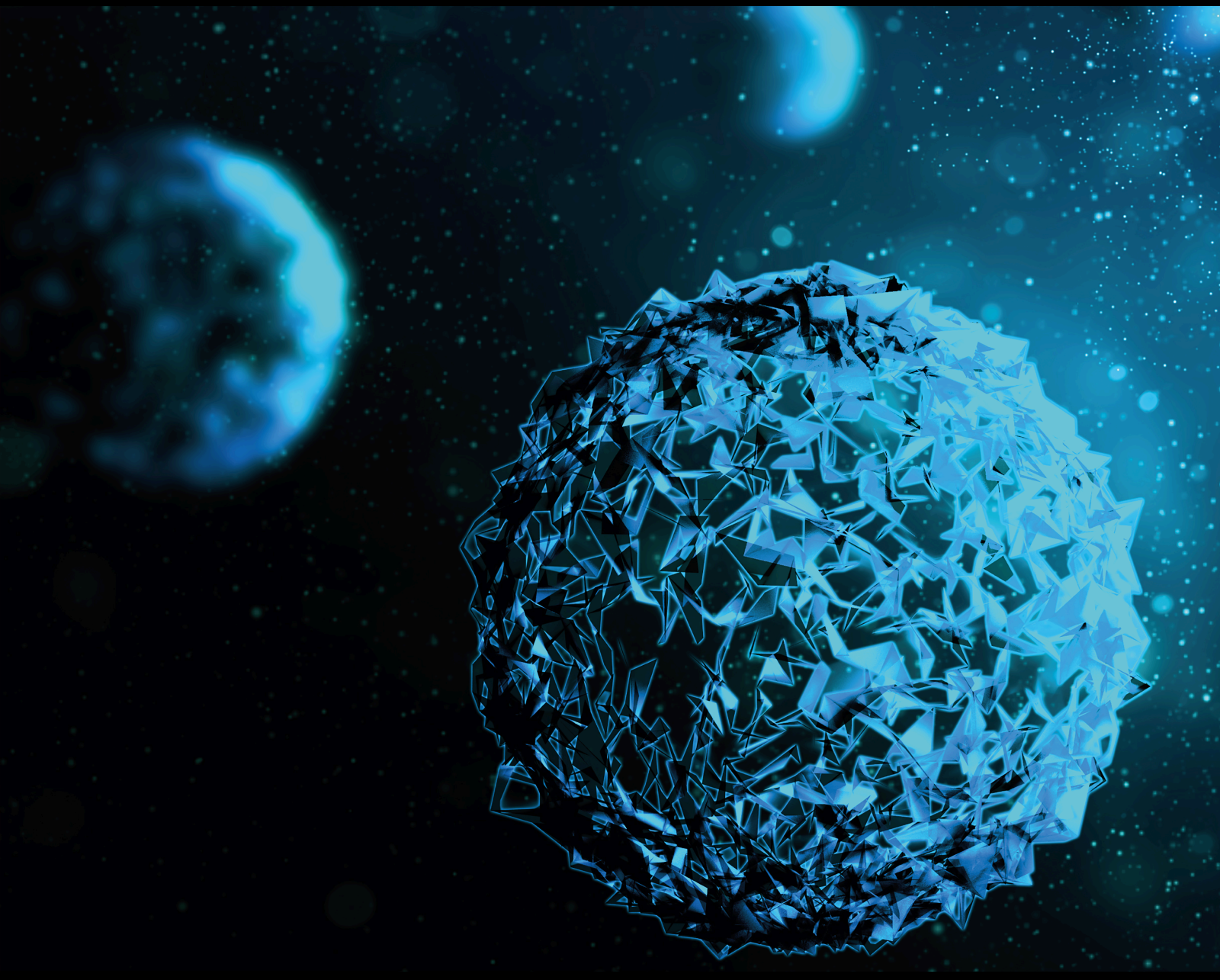
BioMed Research International

Teledentistry: Current Applications, Trends, Future Scope, and Problems

Lead Guest Editor: Mohammad Khursheed Alam
Guest Editors: Ammar A. Siddiqui and Nafij Bin Jamayet



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Review Article

Rehabilitation Professional and Patient Satisfaction with Telerehabilitation of Musculoskeletal Disorders: A Systematic Review

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Telerehabilitation offers an alternative healthcare delivery remotely in a patient's environment at a lower cost, better accessibility, and equivalent quality to the standard approach. Several studies had examined the effectiveness of telerehabilitation inpatients with musculoskeletal disorders, and although there is evidence that it is at least equally effective as the standard care, the patient and rehabilitation professional satisfaction with the delivery method is not conclusive. A systematic review was conducted to study the patients' and rehabilitation professionals' satisfaction with telerehabilitation for musculoskeletal disorders. A search for relevant studies on 29 April 2021 was carried out in Medline/PubMed, Scopus, and Web of Science (WOS). The search terms included "telerehabilitation," AND "satisfaction" AND "musculoskeletal disorders," "telehealth," "telemedicine," "patient experience," and "pain". Fifteen eligible studies with 12,341 patients were included in this systematic review. A report was included if it (a) assessed the satisfaction of patients or professionals or both as one of the outcomes of a telerehabilitation intervention, (b) included adults 18 years and above with musculoskeletal disorders, and (c) is an intervention study using a quantitative approach. The quality of studies was assessed using the critical appraisal checklist tool developed by Joanna Briggs Institute (JBI). Most of the studies reported that patients were satisfied with both telerehabilitation and face-to-face intervention. However, few studies reported that patients were more satisfied with telerehabilitation compared to face-to-face of intervention. Patients in one study had preferred the incorporation of telerehabilitation and face-to-face sessions. Two of three studies had reported overall satisfaction with telerehabilitation by the professionals. Overall, there is evidence that patients and rehabilitation professional are satisfied with telerehabilitation compared to face-to-face consultation.

1. Introduction

Telerehabilitation is the provision of rehabilitation services from a provider to a patient via a telecommunication system and information technology [1]. Such an alternative approach attracts the attention of the healthcare community because of several advantages. It saves time and cost related to travelling to and waiting at the healthcare centre, facilitates and improves access to services, and promises equal quality services to the public [2]. Telerehabilitation has been shown to be successfully performed and effective for people with medical conditions such as stroke, breast cancer patients, cardiopulmonary, and musculoskeletal disorders (MSDs) [3–6].

Patient satisfaction is one of the secondary but very important outcomes in healthcare delivery. Patients are the

main source of information to report on the quality of service provided, that is whether the standards of patient care and treatment received met the expectations. Telehealth platform changes with advancing technology and the mode of delivery can change dramatically; for example, from voice to video to multiperson conference, but regardless of the changes, a consistent patient-provider relationship must be formed [7]. As telehealth use increases, it becomes increasingly important to maintain patient satisfaction similar to the standard approach. Telehealth developers should be flexible to accommodate the patients' and healthcare professionals' perspective and needs; these should be monitored regularly. The success of a telehealth program heavily relies on patient satisfaction [7]. A variety of components underlying the satisfaction have been addressed in different studies that may include overall satisfaction and satisfaction with the application and services [8–10]. Moreover, to achieve optimal outcomes of the treatment and satisfaction of the patient, it is imperative to maintain a strong relationship between patient and professionals [11]. Therefore, it is important to take the satisfaction of both patients and the professionals for a successful and sustainable telehealth programs.

A recent systematic review reported that the evidence for the efficacy of telehealth interventions in improving musculoskeletal pain-related outcomes is comparable to the standard face-to-face interventions [12]. According to healthcare workers, online services can be a helpful addition to face-to-face therapies for chronic pain. Patients are also enthusiastic about telehealth approaches to healthcare delivery [7]. Patients who received exercises through telerehabilitation after shoulder joint replacement reported feelings of "closeness at a distance," freedom, and increased awareness about their "body and self" [13]. Likewise, there were good levels of patient satisfaction with telehealth delivery for cognitive behavioral therapy, exercise, and pain-coping interventions [14].

A broad range of research on telemedicine, or immersive video consultations, has been conducted in various locations around the world. Telemedicine commentators often emphasize the need for more research on the protection, efficacy, and cost-effectiveness of healthcare delivery. As a result of the abundance of publications about patient satisfaction in the telemedicine literature, which are overwhelmingly optimistic, there is a tendency to believe that research in telerehabilitation is relatively of a less priority and a new area that should be focused. There is a good body of literature that examined the patient and professional satisfaction with telerehabilitation. It is imperative to take the perspectives of patients to increase the access, acceptance, and adherence with telerehabilitation in MSD management. To date, there has been no comprehensive systematic review on the satisfaction of patients and professionals with telerehabilitation for musculoskeletal disorder management. The current systematic review is aimed at determining the satisfaction of patients and professionals with telerehabilitation as compared to traditional face-to-face intervention for musculoskeletal disorders.

2. Methods

We follow the PRISMA guidelines to conduct this systematic review [15]. The PRISMA 2020 checklist can found in supplementary file 1. The study protocol was registered with PROSPERO (CRD42021252078).

2.1. Review Question. Based on PRISMA guidelines, the search questions were built on PICO format as follows: are professionals and patients satisfied with the telerehabilitation as compared to the face-to-face rehabilitation of musculoskeletal disorders? PICO format for the review questions is explained as follows: the population (patients with musculoskeletal issues)/(professionals dealing musculoskeletal issues), the intervention (telerehabilitation), comparison (face-to-face), and outcome (satisfaction).

2.2. Search Strategy. We searched the electronic databases from January 1980 to April 2021 reports in the English language. Databases searched include PubMed, Scopus, and Web of Science (WOS). The search terms were "telerehabilitation", "satisfaction," and "musculoskeletal disorders." We also included common synonyms: "telehealth," "telemedicine," "patient experience," and "expectations," "pain." Additional searches were carried out on Google Scholar and ResearchGate platforms. The search string for each variable has been provided as supplementary file 2. Moreover, the references of the included studies were also explored to find the relevant literature meeting the inclusion criteria. Two authors (JA and AAS) independently screened the abstracts based on the inclusion and exclusion criteria.

2.3. Inclusion and Exclusion Criteria. A report was included if it (a) assessed the satisfaction of patients or professionals or both as one of the outcomes of a telerehabilitation intervention, (b) included adults 18 years and above with musculoskeletal disorders, and (c) is an intervention study using a quantitative approach. A report was excluded if it is (a) not in English language and if they are (b) review articles, case reports, qualitative studies, book chapters, and articles with low quality.

3. Results

3.1. Study Selection. A total of 1091 studies were identified from Scopus ($n = 141$), Web of Science ($n = 425$), and PubMed ($n = 525$). An additional 51 reports were identified from Google Scholar, Research Gate, and reference list of the searched articles. A total of 149 duplicate studies were removed using the Reference Management Software Package (Endnote X9). A total of 728 were excluded because the studies did not meet the inclusion (satisfaction was not assessed = 291, not within the age range = 15, and not intervention study = 314) and exclusion (non-English report = 5 and not relevant report = 103) criteria. The full text of 41 studies was reviewed, and 26 studies were excluded due to missing data about satisfaction ($n = 17$), low-quality articles ($n = 5$), and review articles ($n = 4$). A total of 15 studies were included in systematic review after ensuring that those are fulfilling the

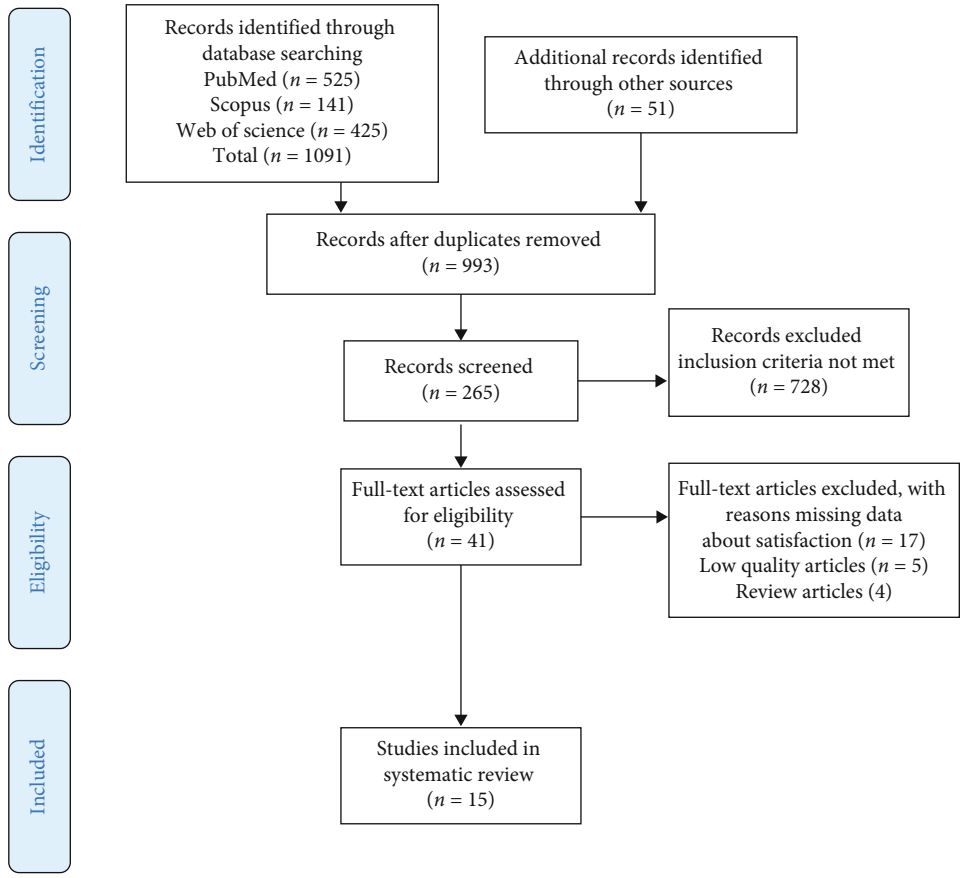

Figure 1: PRISMA flow diagram showing study identification and selection process.

inclusion criteria of the study. Figure 1 shows a schematic of the study identification and selection process.

3.2. Data Abstraction. Two field-based experts (JA and AAS) reviewed the full text of the report independently and used a data extraction form to record information relating to the author, year of the report, location of study, number of subjects, study design, methodology, study population, technology explored, and measures of satisfaction and findings of the study. Cohen's kappa for inter rater reliability was calculated as.74 showing substantial agreement. Disagreements were resolved by consensus and discussion or involved arbitration by the last author (MKA).

3.3. Synthesis of Results. In our review, content analysis was performed to synthesize the results. We examined articles that reported patient and professionals satisfaction. The different parameters of satisfaction were categorized into overall satisfaction, satisfaction with application, satisfaction with services, satisfaction, and patient-provider relationship. We performed a physical count of these variables to find the consistency. All parameters were displayed in number of occurrence. Moreover, the heterogeneity was also observed including sample size, study design, risk of bias, setting of studies, and outcome measures.

3.4. Quality Assessment. We utilized tools developed by the Joanna Briggs Institute (JBI) critical appraisal checklist to assess the quality of RCTs, case-control studies, cohort studies, non-RCTs, and case series [16, 17]. The JBI has well-established reliability and validity to assess the risk of bias in studies [16, 18]. Two authors independently evaluated the quality of each study. The JBI score was calculated for each study using the checklist, and score was presented as percentages. The study with a JBI score of 20-49% was considered high risk of bias and with 50-79% and 80-100% moderate and low risk of bias, respectively (Figure 2).

3.5. Article Characteristics. There were 15 eligible studies with a total of 12,341 participants. Sample sizes ranged from 3 to 10264 patients. All studies were from the developed countries including five from the United States, four from Europe, three from Canada, two from Australia, and one from Israel. There were 6 RCTs, 3 non-RCTs, 3 case-series studies, and 2 cohort studies and 1 quasiexperimental trial. Most studies ($n = 10$) used asynchronous mode through while others used synchronous videoconference mode ($n = 4$) and a combination of both ($n = 1$).

3.6. Patient Satisfaction. The majority of the studies included satisfaction of telerehabilitation as one of the secondary objectives ($n = 11$), and few studies included satisfaction in

		Risk of bias domains														
		1	2	3	4	5	6	7	8	9	10	11	12	13	Overall	JBI score
1.	Bini SA and Mahajan J 2017[a]	X	X	+	X	-	-	+	+	+	+	+	+	-	-	70
2.	Culliton, Sharon E., et al. 2018[a]	+	-	+	+	+	-	+	+	+	+	+	+	+	+	84.6
3.	Doiron-Cadrin, Patrick, et al. 2020[a]	+	+	+	-	-	+	+	+	+	+	+	+	+	+	84.6
4.	Tousignant, Michel, et al. 2011[a]	X	X	+	+	+	-	+	+	X	+	+	+	-	-	61.53
5.	Nelson, M., et al. 2020[a]	+	+	+	X	+	+	+	+	X	+	+	+	+	+	84.6
6.	Salazar-Fernandez, Clara Isabel, et al. 2012[b]	+	+	+	+	X	+	+	+	+					+	88.9
7.	Katt, Brian M., et al. 2012[d]	+	+	-	-	-	+	+	X	+	+	+			-	66.6
8.	Mayer, Naomi, et al. 2021[b]	+	+	X	+	+	+	+	-	+					-	77.8
9.	Tsvyakh, Andriy I., and Andriy J. Hospodarskyy 2018[c]	+	+	+	+	+	+	-	+	-	+				+	80
10.	Moffet, Hélène, et al. 2017[a]	-	-	+	-	-	+	+	+	+	+	+	+	+	-	69.2
11.	Pani, Danilo, et al. 2017[b]	+	+	-	+	+	+	+	+	+					+	88.9
12.	Jansen-Kosterink, Stephanie, et al. 2015[c]	+	+	+	+	+	+	-	+	+	+				+	88.9
13.	Bailey, Jeannie F., et al. 2020[d]	+	+	+	X	-	-	+	+	+	+	+			-	72.7
14.	Peterson, Seth. 2018[c]	-	+	-	+	+	+	+	+	+	+				+	80
15.	Cottrell, Michelle A., et al. 2019[b]	+	+	+	+	+	-	+	+	+					+	88.9

a. RCT (n = 6)
b. NRCT (n = 4)
c. CSS (n = 3)
d. CS (n = 2)

+ Low
- Moderate
X High

Figure 2: Risk of bias assessment based on Joanna Briggs Institute (JBI) critical appraisal tool.

their primary objective ($n = 4$). All the included studies reported the findings on patient satisfaction. Patient satisfaction was reported in both the intervention (telerehabilitation) and face-to-face groups.

The measures of satisfaction include overall satisfaction, satisfaction with application, satisfaction with services, and patient-provider relationship. A broad range of satisfaction was assessed and ranged from overall satisfaction ($n = 6$), satisfaction with application ($n = 4$), satisfaction with services ($n = 4$), satisfaction and patient-provider relationship ($n = 11$). These parameters were assessed in percentages.

The majority of the studies reported that patients were satisfied with both telerehabilitation and face-to-face [8–10, 19–22]. Three studies reported that patient satisfaction with telerehabilitation was significantly higher than that with face-to-face care [13, 21, 23]. One study reported that the patients preferred having an incorporated program that includes both telerehabilitation and face-to-face sessions [24] (Table 1).

3.7. Professional Satisfaction. There was evidence from the studies for the satisfaction of professionals with telerehabilitation. Of 15 included studies, only 3 (20%) studies assessed the satisfaction of the professionals, 2 of those had reported that there was satisfaction of professionals with telerehabilitation services [8, 22]. However, a study reported less satisfaction when dealing with new patients and favored a blended program including face-to-face visits and telerehabilitation [24] (Table 2).

3.8. Risk of Bias. Based on Joanna Briggs Institute (JBI) critical appraisal tool, the majority of the studies ($n = 9$) were categorized as having a low risk of bias and 6 studies, moderate risk of bias. Details about the risk of bias are shown in Figure 2.

4. Discussion

The current systematic review found that patients in the majority of the studies are satisfied with both telerehabilitation and conventional delivery method of treatment for MSD [8–10, 19–22]. Satisfaction with telehealth approach also has been reported in systematic reviews on teledermatology [30], telepsychiatry [31], and telemedicine for stroke [32].

The current review is providing promising results about satisfaction that are in line with the other clinical cases dealt with telerehabilitation. In poststroke telerehabilitation, professionals and patients reported high level of satisfaction and acceptance with remote intervention through Internet-based video conference in their home setting [3, 33]. Moreover, a study on stroke survivors reported a better relationship of patients with their providers in telegroup [34]. Patient satisfaction with telerehabilitation is imperative as it influences compliance and motivation towards intervention as patients are more engaged with their rehab professionals and confidence level is enhanced.

The high level of satisfaction with telerehabilitation among the professionals found in two studies is consistent with earlier reports [30, 32]. Three areas of satisfaction assessed, patient performance, patient-provider relationship, and quality of technology are related to the capability of professionals to adapt and accept of the new technology in their practice. However, professionals in one study are less

Table 1: Patient satisfaction with telerehabilitation.

	Authors (years)	Country	Study design & quality of evidence[a]	Sample size	Study papulation	Technology explored	Variables assessed	Study demonstrate satisfaction	Findings
1	Bini and Mahajan, 2017 [10]	USA	RCT,1	28 (intervention, $n = 13$; face-to-face, $n = 15$)	Post TKA	Asynchronous video-based mobile application	(i) Satisfaction with the experience (ii) Overall satisfaction	Yes (TR = FTF)	Patient satisfaction was high for both groups with no difference
2	Culliton et al., 2018 [19]	Canada	RCT,1	319 (intervention, $n = 154$; face-to-face, $n = 165$)	Post TKA	Online e-learning tool	(i) Patient Acceptable Symptom State (PASS) question (ii) Satisfaction with current health state	Yes (TR = FTF)	78.6% in the intervention and 78.2% in the control groups were satisfied
3	Doiron-Cadrin et al., 2020 [20]	Canada	RCT,1	22 (intervention, $n = 11$; face-to-face, $n = 11$)	Pre TKA/THA	Reacts lite application	Telecommunication applications	Yes (TR = FTF)	Patient satisfaction was excellent toward telerehabilitation without any significant association between the groups
4	Tousignant et al., 2011 [8]	Canada	RCT,1	42 (intervention, $n = 22$; face-to-face, $n = 20$)	Post TKA	Video conferencing	(i) Healthcare satisfaction questionnaire (ii) Satisfaction with the relationship with the healthcare professional (iii) Satisfaction with the services delivered, (iv) Satisfaction with the general healthcare organization	Yes (TR = FTF)	Patient satisfaction was observed in both groups (tele and comparison) without any significant association between the groups
5	Nelson et al., 2020 [21]	Australia	RCT,1	69 (intervention, $n = 34$; face-to-face, $n = 35$)	THA	eHAB application	(i) Satisfaction questionnaire of the rehabilitation program (ii) Overall satisfaction	Yes (TR > FTF)	In both groups (intervention & tele), overall satisfaction was high but the score regarding ease of attending appointment was high in the intervention group as compared to telegroup
6	Salazar-Fernandez et al., 2012 [25]	Spain	NRCT,2	992 (intervention, $n = 282$; face-to-face, $n = 710$)	Temporomandibular joint disorders	Store-and-forward telemedicine system (SFTMS)	(i) Telemedicine again (ii) Feel uncomfortable (iii) Prefer to be treated quickly (iv) Travel saving (v) Hours of lost-work saving	Yes (TR = FTF)	283 patients reported that they would like to consult by teleconsultation again There was no record of uncomfortable incidence from any patient with teleconsultation

Table 1: Continued.

	Authors (years)	Country	Study design & quality of evidence[a]	Sample size	Study papulation	Technology explored	Variables assessed	Study demonstrate satisfaction	Findings
7	Katt et al., 2012 [24]	USA	PCS,2	167 (follow-up, $n = 111$; new, $n = 56$)	Upper extremity conditions	A telephone call or video	(i) Quality of time spent with the provider, preference of telehealth versus an in office encounter, or a combination of both	Yes (TR = FTF)	Both patient and physician responded that they are very satisfied with the telehealth sessions but some patients should have telerehabilitation program incorporated with some face-to-face evaluation sessions as they were less satisfied while evaluating new patients
8	Mayer et al., 2021 [26]	Israel	NRCT,2	18 (intervention, $n = 9$; face-to-face, $n = 9$)	Upper limb function after fractures	Biofeedback system of elbow motion	(i) Patient satisfaction questionnaire	Yes (TR = FTF)	The telerehabilitation group reported a higher level of enjoyment of the self-practice with less support from family members and no difference was found regarding satisfaction level between two groups
9	Tsvyakh, 2018 [23]	Ukraine	CSS,4	74 (intervention, $n = 48$; face-to-face, $n = 26$)	Injuries of the lower extremities	Home remote monitoring by using a smartphone	(i) Overall satisfaction	Yes (TR > FTF)	Patient satisfaction was higher for the telerehabilitation as compared to traditional rehabilitation due to the reason of time saving and cost of rehabilitation
10	Moffet et al., 2017 [9]	Canada	RCT,1	182 (intervention, $n = 84$; face-to-face, $n = 98$)	Post TKA	Videoconferencing system	(i) Relationship with the professional (ii) Delivery of services (iii) Organization of services	Yes (TR = FTF)	Overall satisfaction was high in both groups without any difference in both groups
11	Pani et al., 2017 [13]	Italy	NRCT,2	40 (intervention, $n = 20$; face-to-face, $n = 20$)	Hand function impairment in rheumatic patients	Sensorized tools for hand exercises	(i) Satisfaction of the product (ii) Associated services	Yes (TR > FTF)	Most of the patients were satisfied with the services and accepted the telerehabilitation system
12	Jansen-Kosterink et al., 2015 [27]	Netherlands	CSS,4	60 (intervention, $n = 41$; face-to-face, $n = 19$)	CLBP	Teleconference	(i) Rate satisfaction with service (ii) Recommend the service to another patient	Yes (TR = FTF)	About 70% telerehabilitation scored 6 or higher score on a scale from 0 to 10 and 36% reported that they would like to recommend the telerehabilitation services to another patient
13	Bailey et al., 2020 [28]	USA	RCS,3	Back pain ($n = 6468$), knee pain ($n = 3796$)	Low back & knee pain	Hinge health app installed	Overall satisfaction	Yes (TR = FTF)	There was an overall satisfaction among patients in Digital Care Program (DCP) with a final satisfaction score of 8.97/10

Table 1: Continued.

	Authors (years)	Country	Study design & quality of evidence[a]	Sample size	Study papulation	Technology explored	Variables assessed	Study demonstrate satisfaction	Findings
14	Peterson, 2018 [29]	USA	CSS,4	3	CLBP	Mobile phone application with synchronous audio and video booster sessions	Overall satisfaction	Yes (TR = FTF)	The overall satisfaction with the telerehabilitation program was very high
15	Cottrell et al., 2019 [22]	Australia	NRCT,2	61 (intervention, $n = 46$; face-to-face, $n = 15$)	LBP & neck pain	Mobile phone application	(i) Cost (ii) Access (iii) Time (iv) Overall satisfaction	Yes (TR = FTF)	(i) The overall satisfaction between two groups was similar (ii) The satisfaction level was high for responses relating to access, cost and time saving, and overall experience in TR group (iii) The satisfaction of professionals regarding appointments was averaged 4.1 out of 5 points

TR: telerehabilitation; FTF: face-to-face; RCT: randomized clinical trial; NRCT: nonrandomized clinical trial; CCS: case-control study; CSS: case-series study; RCS: retrospective cohort study; PCS: prospective cohort study CLBP: chronic low back pain; LBP: low back pain; TKA: total knee arthroplasty; THA: total hip arthroplasty. [a]Level of evidence. (1) Properly designed RCT or systematic review with meta-analysis; (2) well-designed controlled trial without randomization, prospective study, or comparative cohort trial; (3) case-control study or retrospective cohort study; and (4) case-series or cross-sectional study.

Table 2: Professional satisfaction with telerehabilitation.

	Authors (years)	Country	Quality of evidence[a]	Sample size	Study papulation	Technology explored	Type of provider	Overall satisfaction	Findings
1	Tousignant et al., 2011 [8]	Canada	RCT,1	42 (intervention, $n = 22$; face-to-face, $n = 20$)	Post-TKA	Video conferencing	Physiotherapists	Yes	Physiotherapists were highly satisfied regarding the following: (i) Goal achievement (ii) Patient-therapist relationship (iii) Overall session satisfaction (iv) Quality and performance of the technological platform
2	Katt et al., 2012 [24]	USA	RCS,3	167 (follow-up, $n = 111$; new, $n = 56$)	Upper extremity conditions	A telephone call or video	Physicians	Yes	Physician responded that they are very satisfied with the telehealth sessions but reported that some patients should have telerehabilitation program incorporated with some face-to-face evaluation sessions, as they were less satisfied while evaluating new patients
3	Cottrell et al., 2019 [22]	Australia	NRCT,2	61 (intervention, $n = 46$; face-to-face, $n = 15$)	LBP & neck pain	Mobile phone application	Rehab professionals	Yes	The satisfaction of professionals regarding appointments was high (averaged 4.1 out of 5 points)

TR: telerehabilitation; FTF: face-to-face; RCT: randomized clinical trial; NRCT: nonrandomized clinical trial; RCS: retrospective cohort study; LBP: low back pain; TKA: total knee arthroplasty; THA: total hip arthroplasty. [a]Level of evidence. (1) Properly designed RCT or systematic review with meta-analysis; (2) well-designed controlled trial without randomization, prospective study, or comparative cohort trial; (3) case-control study or retrospective cohort study; and (4) case-series or cross-sectional study`.

atisfied with telerehabilitation when dealing with new patients but were satisfied with it in the follow-up sessions as they reported that certain conditions are hard to asses through telehealth when a radiograph is needed [24].

The above findings suggest that telehealth is an accepted service delivery method by patients and health care professionals but it is not without limitation. It may not be suitable for an initial consultation because in some cases physical examination, blood sample, and radiographic imaging are required to make a definitive diagnosis but more suitable for follow-up sessions. Telerehabilitation is more effective if a patient's record is available to the provider during a consultation session. A combination of face-to-face and telehealth consultation is perhaps a reasonable option to address the issue.

Apart from the advantages of telerehabilitation in reducing cost, time, and disparities in access and satisfying the expectation of patients and professionals [35], it also serves as a rational option for service delivery method during the current COVID-19 pandemic. The health authorities are opting the telehealth to prevent the spread of infection among communities [36, 37]. The approach reduces the number of physical visit and contact between patients and other individuals during travel and at the healthcare centre and thus lowers the risk of infection [38]. As the health professional and patient relationship is a core element for successful treatment using telehealth, the gap has to be reduced by improving the communication skill of the provider and instilling the confidence of patients in the professionals [39]. Other issues that need consideration in improving the relationship include feasibility, acceptability, and utility [40]. These core factors indicate the willingness and capabilities of professionals to deliver the healthcare services to their patients. Accessibility, awareness, and skills relating the teletechnology among patients also influence the usage and success of telehealth delivery. The patient's expectations are also met with telerehabilitation [41]. Hence, it is imperative to enhance the efforts to use e-health technology in rehabilitation settings.

This is the first systematic review relating to satisfaction with telerehabilitation that is providing sound scientific knowledge to the body of literature and useful for policymakers for future clinical decision-making. However, it has some limitations; thus, interpretation of the findings should be made with caution. There is wide variation in the measures of assessment and reporting of patients and

professionals' satisfaction despite the evidence being supportive of telerehabilitation. In this systematic review, we found heterogeneity in terms of study design, setting of studies, and outcome measures but there is consistency in the satisfaction and effectiveness with telerehabilitation services Meta-analysis was not performed due to pooling of the results of different outcome measures which could lead to heterogeneity and bias meta-analysis [42]. The evidence thus far is from the developed countries, and its performance in the developing and underdeveloped countries has yet been reported; thus, further research on telerehabilitation in these countries is recommended.

5. Conclusion

In our systematic review, we contributed a substantial amount of literature about satisfaction with telerehabilitation that is relatively a new area to be explored. The findings of this review point out that telerehabilitation has similar level of satisfaction that is comparable with a face-to-face consultation among patient and professionals alike.

Data Availability

All the data related to the manuscript are included within the article.

Conflicts of Interest

The authors declare no conflict of interest.

Supplementary Materials

[1] PRISMA 2020 checklist (supplementary file 1). [2] Search strategy (supplementary file 2). *(Supplementary Materials)*

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Research Article

Implementation of a Teledentistry Platform for Dental Emergencies for the Elderly in the Context of the COVID-19 Pandemic in Chile

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Objectives. To develop and implement a "semi-presential" technology platform to support urgent and priority dental care for the elderly in the context of the COVID-19 pandemic among the Chilean population. *Methods*. A dental mobile clinic was implemented along with the development of a technological platform designed to support emergency and priority dental procedures, including teleconsultation with specialists. Under strict biosafety protocols, dental care was provided in five Chilean regions between February and May 2021. Sociodemographic, medical, and dental data were recorded. *Results*. A total of 135 patients over sixty years old, with a mean age of 72 years, were treated, 48 males and 87 females were attended between February and May 2021 in five different regions of Chile. 53.3% required immediate or urgent treatment, and 24.4% were derived to specialists from whom 60.6% needed immediate or urgent treatment. 74.3% of teleconsultations were derived to an oral pathology specialist. *Conclusion*. It was shown that a "semi-presential" technology platform implemented in a mobile dental clinic can help elderly people who are impeded to look for traditional dental assistance during a pandemic.

1. Introduction

SARS-CoV-2 is transmitted through respiratory route (secretions and aerosols) from symptomatic and asymptomatic infected individuals. Due to its rapid spread, several countries implemented control measures, such as the restriction of mobility and quarantines [1]. Due to the nature of the dental practice, it is necessary to establish strict biosafety protocols to prevent cross infection, especially when dental procedures that potentially generate aerosols are performed. Attention has been limited to priority consultations or dental emergencies [2]. Thus, both the fear of contagion by leaving their homes and a higher mortality risk for elderly people due to their intrinsic vulnerability lead to a lack of

proper attention to several dental conditions, compromising their health and quality of life [3]. In fact, dental infections and emergencies rose considerably in the context of the COVID-19 pandemic [4].

Currently, the COVID-19 pandemic has increased the challenges related to the provision of health services to the elderly population, considering these services are institutionalized or not. The need of stronger public policies, more economic resources and qualified personnel became evident in order to attend the complex necessities of this age group that require greater attention with emphasis in oral health [5]. Late oral cancer diagnosis is a frequent problem in Chile, and the difficulty to normally attend to controls could increase this severe cause of death among the elderly [6]. A great deal of innovation has been required in dental attention protocols to avoid neglecting proper dental health attention and to continue providing adequate services to this vulnerable population. Teledentistry has gained momentum and validity during the present pandemic, becoming a powerful tool which, through the use of technology, offers solutions that allow for continuous attention, reaching diagnosis and providing online or remote treatment, also facilitating the education and orientation of patients in oral health issues. All of this contributes to avoiding the risk of infection by keeping the patients away from crowded high-risk areas such as dental offices and hospitals [7] and also allows for the early detection of lesions that may result in oral cancer.

Bearing this situation in mind, a novel semipresential platform to support urgent and priority dental attention for elderly people in the context of the COVID-19 pandemic was developed and deployed by our research team. The platform allowed for real-time or asynchronous interaction between the patient and a team of specialists that support the attention provided by a general dentist in a mobile dental clinic with digital equipment that can move close to or right in front of the patient's place of residence, permitting prompt diagnosis and providing care to elderly people who were confined to their places of residence due to the implemented lockdown measures at that time. In Chile, as in many other parts of the world, there has been an increase in elderly population due to lower mortality and birth rates [8]. In fact, it is estimated that more than 30% of the population will be older than 60 by 2050 [9]. Chile is also the only country in Latin America with a life expectancy of over 80 years old. The increase of oral cancer cases might be derived from this higher life expectancy, and a late diagnostic can be associated to the pandemic, due to the impossibility of a normal presential clinical evaluation. This pilot study not only focuses on the resolution of current dental health challenges but also focuses on the generation of attention protocols through teledentistry that would enhance future dental care coverage for the elderly population and contribute to the early detection of possible malignant lesions.

The main objective of this study was to develop and deploy a technological semipresential platform to support emergency and priority dental attention for elderly patients in the context of the COVID-19 pandemic in the Chilean population. With that purpose, we developed and deployed a pilot teledentistry program using a digital/technological platform that would allow for an online or remote interaction between a patient and a multidisciplinary team of dental specialists and geriatricians, who would provide support to a general dentist onboard a mobile clinic in the resolution of dental emergencies in five regions of Chile.

2. Materials and Methods

Between June 2020 and January 2021, a web-based platform in conjunction with a mobile app for teledentistry was specially designed for the attention of the elderly population aiming to facilitate the recording of medical and dental anamnesis and to allow for interconsultation with different dental specialists and geriatricians. This web platform was implemented in a mobile dental clinic to provide dental care to elderly patients in 5 regions of Chile between February and May 2021. This platform was advertised to the elderly patients through seminar sessions given to personnel from the National Service for the Elderly (SENAMA-Chile). The study was developed as part of the project "Semi-presential technological platform to support urgent and priority dental care for the elderly in the context of the COVID-19 pandemic in the Chilean population" supported by the Ministry of Science, Technology, Knowledge and Innovation of Chile through the National Agency of Research and Development (ANID). Ethical approval for carrying out this project was granted by the Universidad de la Frontera Ethics Committee, decision 090/20 (Project ANID 0766 2020, National Research and Development Agency).

2.1. The Platform Concept and Architecture. A conceptual design of the web-based platform was made that included a visualization of process-level interfaces and workflows. The design of the technological architecture included the definition of the components of the system, interface language (Spanish), and technologies, along with the construction of the software modules with their respective functional verification. Each of the stages was approached following an iterative and incremental methodology, based on good software development practices, that ensured the control, verification, and quality of software development. The software interface was developed in a modular design and includes anamnesis modules and a novel 3D standardized model for indexing relevant information for each case (Figure 1). A specially designed digital representation system for oral lesions was included in the platform design, allowing for a proper visualization by the specialist in order to provide an accurate diagnosis.

2.2. Patients. A sample calculation was performed considering a minimum number of patients to provide dental assistance in the context of the project, this sample being representative of the Chilean population. The allocation for five regions was determined proportionally to the resident population according to the projections made by the National Statistics Institute (INE) of Chile. These regions were considered representative due to their location in the north (Antofagasta), center (Santiago and Talca), and south

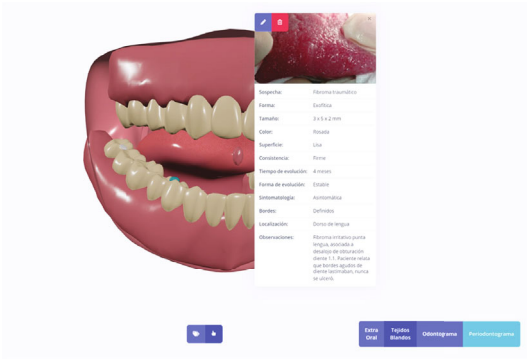

Figure 1: Platform module interface, 3D standardized model, labeled with a presumptive diagnosis (intraoral examination, soft tissues)

of Chile (Concepción and Temuco). A number of complementary patients were considered, in order to ensure the number of patients required by location established by the study. Descriptive statistical analysis was performed with R-project, 4.0.3 version.

Inclusion criteria considered elderly population (over 60 years) with a dental emergency or requiring some kind of priority dental care. Requirements to provide dental care in a mobile clinic were specified as follows: sufficient mobility to access a dental chair in a mobile clinic; the patient and/or their caregiver must be able to handle a smartphone or some other electronic device connected to the Internet that allows for an application (an App for Android devices) to be downloaded and installed; patients with chronic diseases must be under pharmacological treatment according to medical indications; patients must be capable of receiving verbal instructions and must complete a triage prior to the provision of dental care. The professional team who operated the system underwent proper training. An operational schematic of the attention and platform use workflow for the development of the study is shown in Figure 2.

Patients were enrolled by specialized personnel (social workers) from the National Service for the Elderly (SENAMA-Chile). Data considered for the patient's registration included their full name, national ID number, date of birth, contact phone, address, and also their caregiver or close family member's full name and contact phone number. Patient confidentiality was granted by anonymization of personal information prior to data treatment.

A Dental Care Triage was performed, considering that any of the following conditions or more than one had to be present: severe dental pain refractory to analgesic therapy; recent trauma (direct blow involving teeth or mouth, accompanied by severe pain); oral bleeding; significant swelling of any anatomical part of the mouth, face, or neck; pigmented lesions or wounds in any part of the mouth that had not disappeared in a month; loss or fracture of restorations (fillings) or dental prostheses; and injuries to the oral mucosa due to dental prosthesis mismatch and dental treatment required prior to critical medical procedures that cannot be postponed (e.g., patient who would undergo radiotherapy requiring a previous tooth extraction). Infographic material was used to facilitate the patient's understanding. Patients who were users of anticoagulant drugs had chronic diseases without treatment or were in antineoplastic treatment or dialysis were excluded, unless a medical indication to be treated was provided.

Type of dental treatment required was classified as (1) no treatment needed, (2) need for dental cleaning, (3) nonimmediate treatment needed, (4) immediate treatment needed, and (5) urgent care needed [10]. Interconsultations were electronically sent to specialists in oral pathology, periodontology, oral rehabilitation, oral imaging, temporomandibular joint disorders, and geriatrics. The specialist provided an answer on the same platform either synchronously or asynchronously. More complex procedures that could not be provided in situ, such as surgical biopsies, were performed by specialists (also members of the project team) in external reference centers. Postdischarge follow-up was performed through an Android mobile app to be installed on the patient's or caretaker's smartphone. Customized information, including educational videos and dental recommendations, was sent to each patient or caretaker through this app after obtaining their informed consent.

3. Results

The target population of this study was senior Chilean citizens living in the regions of Antofagasta, Metropolitana, Maule, Bío-Bío, and Araucanía, given the feasibility of implementing the teledentistry platform in these geographical areas. Nonetheless, within each region, we followed a probabilistic sampling design to select which districts were to be included in the study. Given financial constraints, we used a sample size of 135 which were allocated using a proportional allocation with respect to the region population size. Figure 3 shows the selected districts within each region and their respective allocations that are as follows: 79 patients from the Maipú district in Región Metropolitana, 18 patients from the Concepción district in Región del Bío-Bío, 15 patients from the Temuco district in Región de la Araucanía, 12 patients from the Antofagasta district in Región de Antofagasta, and 11 patients from the Talca district in Región del Maule.

Data was collected from patients by the general dentist and a dental assistant. Information was recorded on the platform that was named Geriatric Dental Specialties Teleplatform (TEGO by its acronym in Spanish: "Teleplataforma de Especialidades Geriátrico Odontológicas"). Recorded data included sociodemographic variables (gender and age), work status (retired and not retired), health plan (FONASA, ISAPRE, or CAPREDENA), residence status (living alone, with family, or in a senior residence), and the vulnerability level (lowest 40%, between 40% and 60%, 60% and higher). FONASA is a public National Health Fund, ISAPRE corresponds to private social security institutions, and CAPREDENA is a military national defence provident fund. The vulnerability level is measured through the "Household Social Registry," which is a database that has all the necessary information of people and households to support the process of application and selection of the beneficiaries of the state institutions in Chile.

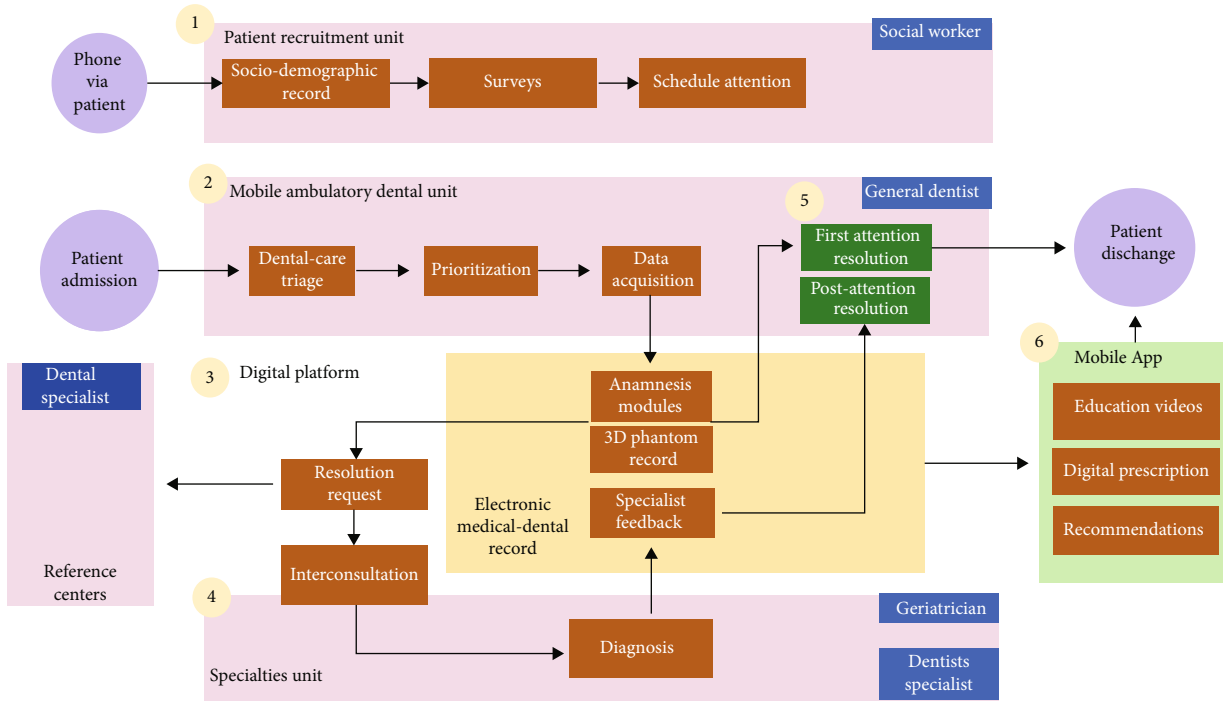

Figure 2: Operational schematics of the attention and platform use workflow to support dental-medical care for the elderly in the context of the COVID-19 pandemic. Pink boxes: macroprocess or units; green boxes: software; blue boxes: professional in charge of the macroprocess or unit; orange boxes: subprocess.

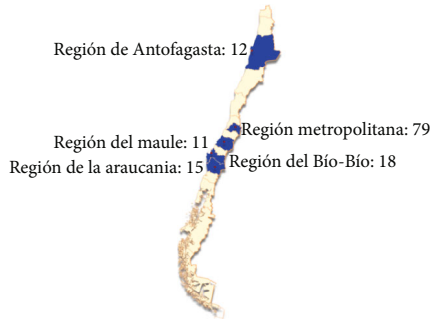

Figure 3: Map showing selected regions of Chile for the study. Patients enrolled and treated between February and May 2021.

In this study, 135 patients were treated in the context of the project, with a mean age of 72 years. Number of patients was defined mainly considering available resources from the project and distributed according to a proportional calculation given the total population of the selected region. COVID-19 security protocols were used following instructions from the Chilean Ministry of Health. 48 patients were male and 87 were female. As seen in Table 1, most patients included in this study live in the capital region due to the proportional allocation used (58.52% of patients). As for work status and health plan status, most patients were retired (75.56%) and had a national health plan fund (FONASA, 97.03%). As for residence status, most patients lived with either family members or in a senior living facility (72.59%). Finally, most patients belonged to the second quintile of the population according to income (77.03%), this categorization plays an important role in Chilean public policies as it is a necessary condition to receive certain governmental benefits [11].

To determine the type of dental care provided to the patients (urgent or priority dental care), the following categories were used: dental cleaning needed (3 patients), no immediate dental treatment needed (60 patients), immediate dental treatment needed (36 patients), and urgent treatment needed (36 patients). 33 patients needed interconsultation to different specialties.

In Table 1, a brief statistical summary of the patients involved in this study and the type of dental care needed have been provided. Table 2 shows the frequency of interconsultation by specialty and region, with 26 interconsultations sent to oral pathology, 5 to geriatrics, 2 to temporomandibular joint disorders, 1 to oral rehabilitation, and 1 to oral radiology. Table 3 shows the frequency of interconsultation by urgency and region. Among oral pathology interconsultations, 12 reactive lesions (fibroma, frictional keratosis, mucocele), 5 infectious lesions (subprosthetic stomatitis, median rhomboid glossitis, chronic periodontitis), 4 vascular etiology lesions (vascular malformation), 3 pigmented lesions (amalgam tattoo and smoking-related melanosis), and 3 potentially malignant lesions (leukoplakia, erythroplakia, and lichen planus) were diagnosed. Details are shown in Table 4.

4. Discussion

The results of this study have shown that teledentistry using a web platform specially designed to allow for the remote

Table 1: Summary of sociodemographic variables of patients involved in this study by region. Standard deviation of age is provided in parenthesis. ∗The lower the percentage, the higher the level of vulnerability.

Sociodemographic variables	*n*	Bío-Bío	Araucanía	Maule	Metropolitana	Antofagasta
Mean age (years)		70.67 (5.28)	69.87 (8.49)	71.55 (6.33)	72.67 (6.34)	70.84 (5.42)
Gender						
Male	48	9	8	6	23	2
Female	87	9	7	5	56	10
Pension						
Retired	102	15	11	9	56	11
Not retired	33	3	4	2	23	1
Health plan						
FONASA	131	18	15	11	75	12
ISAPRE	2				2	
CAPREDENA	2				2	
Residence status						
Living alone	37	1	5	1	30	
Living with family	88	16	10	1	49	12
Senior residence	10	1		9		
Vulnerability level						
Lowest 40%∗	104	14	13	11	60	6
Between 40% and 60%	23	2	2	0	13	6
60% and higher	8	2			6	

Table 2: Frequency of interconsultation by specialty and region of Chile.

Medical specialities	*n*	Bío-Bío	Araucanía	Maule	Metropolitana	Antofagasta
Oral pathology	26	4	5	2	14	1
Oral rehabilitation	1	1				
Geriatrics	5		1		3	1
Oral radiology	1				1	
Temporomandibular joint disorders	2				2	

Table 3: Frequency of interconsultation by urgency and region of Chile.

Urgency	*n*	Bío-Bío	Araucanía	Maule	Metropolitana	Antofagasta
Dental cleaning needed						
Interconsultation	1				1	
No interconsultation	2		1		1	
No immediate treatment need						
Interconsultation	12	4	1		5	2
No interconsultation	48	7	6	4	25	6
Immediate treatment need						
Interconsultation	8			1	7	
No interconsultation	28	3		5	18	2
Urgent treatment needed						
Interconsultation	12	1	5	1	5	
No interconsultation	24	3	2		17	2

Table 4: Age, sex, pathology groups, and localization of 27 oral lesion interconsultations ($n = 26$).

Variable		
Age		Mean (SD)
		72 (6.5)
		n (%)
Sex	Men	11 (42)
	Women	15 (58)
Pathology	Reactive lesions	12
	Infectious lesions	5
	Vascular lesions	4
	Pigmented lesions	3
	Potentially malignant lesions	3
		27
Localization	Vermilion	2
	Labial mucosa	4
	Jugal mucosa	5
	Palate	2
	Gums	5
	Tongue	8
		26

interaction between a general dentist attending elderly patients and a staff of different dental specialities and geriatricians is an excellent alternative to provide dental care for this population that is particularly vulnerable and frail. Dental care for the elderly in Chile is provided mainly by the public health system [8]. Several conditions limit this activity due to the high demand of this type of care, poor state of oral health, and the reduced possibility of offering sufficient coverage for the elderly. The COVID-19 pandemic brought an additional difficulty due to the existence of a strict government plan of confinement that included extensive lockdowns and the reduction of mobility in an attempt to avoid or diminish the risk of contagion among the population, even forbidding the functioning of dental clinics in some regions of the country by local sanitary authorities, which happened for extended periods of time in the Región de la Araucanía, in the south of Chile for example, which generated a lot of controversy among the community of dental professionals in the country [12, 13, 14].

This study has shown that it is possible to bring dental care for the elderly to the place where they reside and provide appropriate dental assistance in a secure manner using a mobile dental clinic equipped with a modern technological platform specially designed for this purpose. Another possible application for this type of platform and mobile unit could be dental care for adults with tetraplegia or other neurodegenerative or neuromotor conditions. A few studies aimed at the home care of this population through the use of telemedicine technologies, similar to what has been proposed in this study [15, 16].

The application of teledentistry might be favoured by a collaborative setting between health, information technology, and education sciences, facilitating the generation of innovative solutions that can turn into technologies with a more efficient social impact [17]. The irregular Chilean geography and its unequal distribution of specialized dental services for elderly people in urban and rural areas bring a persistent difficulty in access possibilities to centers of specialized dental care, which is intrinsically deficient for this population [8]. For older citizens, who live in senior living facilities in Chile, limitations in mobility and lack of staff and vehicles to aid in their transportation to health centers add to this problem. Thus, the implementation of home care with the assistance of technology and mobile clinics is a viable tool for the dental care of people who, due to their vulnerability, must avoid leaving their places of residence or having unnecessary appointments with health professionals, but can still opt for a prompt and adequate care [18].

It is interesting to note that 26.6 % of the patients were categorized as urgent treatment needed. The solution given to these patients contributed to at least partially recovering a certain state of wellness in terms of oral health that could not have occurred without this intervention. Additionally, a similar percentage of patients was categorized as immediate need, although not urgent. This analysis concluded that more than fifty percent of patients required dental treatment in a priority fashion, whose problem would have persisted without this intervention, considering that 97% of the patients are insured by FONASA, the public National Health Fund, and that 75.5% of the patients were retired.

Loneliness is a situation frequently observed among elderly people in Chile [19]. A contribution to psychological wellbeing could be perceived among patients who received attention during the study. The fact of visiting the patient's place of residence itself to provide the assistance implied an act that was well valued by them, also taking in consideration that 27.4% lived alone and 77% belonged to the most vulnerable group of the population, with the lowest incomes.

Besides caries and periodontal disease, oral pathologies are frequent in elderly people [20]. Interconsultations were well valued by patients since they provided prompt solutions to their ailments. In this study, 35 interconsultations were performed by specialists, 26 of them by the oral pathologist. Considering the risk of oral cancer among the elderly people, this is an important factor as a probable method to achieve an early oral cancer diagnosis, aimed at a more preventive than palliative approach [21, 22]. An important percentage of potentially malignant oral lesions and oral cancer might be studied through methods of telediagnosis, aided by real-time or asynchronous online communication between the treating dentist onboard the mobile clinic and the pathologist working remotely through the web-based platform. In cases in which it was necessary, a biopsy study was arranged in some of the referral university centers according to the region/district in which the patient resided. As a main conclusion, it has been demonstrated that a mobile dental care unit is an appropriate solution to provide care for older adults who are prevented from looking for dental assistance in traditional health centers. Furthermore, considering the current COVID-19 pandemic and potential new outbreaks, it is also a good alternative care option to diminish the risk of contagion by providing assistance at the patient's place

of residence. It can also be concluded that the technological platform deployed for the study contributed to the early diagnosis of risk pathologies in confined patients such as oral cancer in the context of the COVID-19 pandemic. It can be suggested that the implementation of this kind of dental assistance in a permanent way can be of great significance in contributing to good oral health and the well-being of the elderly. The implementation of technological platforms and apps installed on the users' mobile devices monitoring the oral health of elderly people might also be recommended, since it permits the education of their caretakers and the training of health care staff, also optimizing the dental coverage of specialist care.

5. Conclusion

It was shown that a "semi-presential" technology platform implemented in a mobile dental clinic can help elderly people who are impeded to look for traditional dental assistance during a pandemic. It contributes to reduce the risk of contagion, and it could be of great significance as a permanent solution to improve the oral health and general quality of life of the elderly population. It also contributes to the early diagnosis of risk pathologies such as potentially malignant disorders, thus preventing oral cancer occurrence.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Research Article

An Evaluation of the Usefulness of YouTube® Videos on Crown Preparation

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Background. You Tube is one of the most commonly used online sources for sharing information and knowledge. Academic topics or clinical data shared on this platform is not peer reviewed or evaluated by subject specialists for accuracy. No study was found in the literature examining the validity of crown preparation videos available at this platform. *Objective*. To evaluate the authenticity of the content and quality of the crown preparation videos uploaded on the YouTube. *Methods*. The systematic search for YouTube videos was carried out over a period of one year from January 2020 until February 2021. The keywords or phrases and tags used were crown preparation, PFM crown preparation, all ceramic crown preparation, and dental crown preparation. The videos were shortlisted on the basis of inclusion and exclusion criteria to select educationally useful videos in terms of content and quality. *Results*. Three subject specialists evaluated the videos on crown preparation three times to shortlist only 12 (11%) educationally useful videos out of 109 relevant videos. These 12 videos met the preset inclusion criteria. *Conclusion*. Although YouTube is the most popular social media platform used as the source of information by the students, the majority of uploaded content lacks authenticity. This study found that crown preparation videos uploaded by the faculty members or subject specialists can be considered as the reliable source.

1. Introduction

The undergraduate dental education, as with any other educational program, needs to adapt evolving techniques and materials in the curriculum in order to fulfill the changing needs of the dental practice [1]. Albeit the intricacies of the dental care have increased significantly over the last century, the strategy of teaching medicine has barely changed [2]. Recently, there is a universal interest in the assessment of the learning strategy since its adoption [2, 3].

The predoctoral dental syllabus generally targets the development of psychomotor dexterity of students in their initial clinical years [3]. This approach is particularly pertinent in prosthodontics in which preclinical practical expertise plays a significant role [4]. Students are therefore, exposed to the technical part of the skills to improve the understanding of clinical procedures [3, 4]. Courses which focus on the improvement of dental laboratory skills are commonly studied in the preclinical years, as these assist in the preparation of students for clinical prosthetic dentistry [2, 4]. According to Alqahtani et al., an in-person illustration to a little gathering has been proven to be helpful in teaching dental laboratory expertise [5]. It enhances courage and assurance in the student, boosts conversation abilities, and contributes to deeper knowledge and better learning of procedures as compared to didactic training [5, 6]. Nonetheless, the same authors have reported that the live demonstration teaching strategy has multiple disadvantages like student's dependence on the teacher, problem in visualization of the technique, and slight fluctuation of the technique between

various trainers [5, 6]. Furthermore, the efficacy of demonstrations relies on the number of students supervised by each teacher and the measure of time spent on the demonstration [5]. In addition, though the demonstrations of the procedures are done only once, some students might require multiple demonstrations to learn the fundamental skills [5]. One study also concluded that the conventional educational techniques lead to psychological stress, which might have an impact on severity of nervous exhaustion, anxiety, and distress among students [6].

The preference of video-assisted clinical instruction in dentistry (VACID) over conventional education for learning practical skills has been reported in some studies [7, 8]. Akhlaghi et al. utilized video recordings to educate the patients and students and reported that the students have shown more acceptance towards this strategy which is likely ascribed to the better observation of clinical techniques and enhanced understanding of details [7]. They concluded that VACID has shown better outcomes as compared to traditional methods for education in dentistry [7, 8].

Towards the end of 2019, the coronavirus disease surfaced as an acute respiratory infectious disease in China which was later declared by the World Health Organization (WHO) as a pandemic with high fatality and morbidity rates [9, 10]. The prevailing conditions lead to the popularity in idea of e-learning in dentistry [11]. e-Learning incorporates an assortment of different modalities and terms like learning through internet, mobile education, computer-based learning, distant learning, e-instructing, arbitrate learning, and reflective and virtual learning [8, 11]. With present day innovation, students can easily reach out to the content of lectures while staying at home. This does not require the physical attendance at institutes, thus reducing the chances of transmission of infection [8, 12]. In certain forms, internet-based education aids in self-learning among students and further modifies their approach for knowledge acquisition [8, 13, 14].

During these situations, YouTube audio-visual recordings became convenient and an accessible alternative to the study materials [8, 15] and more acceptable as a teaching strategy [11, 15]. YouTube videos can be found on various topics and by variable sources. This study assumed that there are potential variances concerning the quality of available videos of complete crown preparation. The authors were looking for crown preparation videos with good visualization of the preparation steps along with sound educational narration and content as per universally accepted standard text books [16, 17].

Therefore, the aim of this study was to evaluate the quality and reliability of the information provided in the crown preparation videos currently available on YouTube. No study was found in the literature that has reported the efficacy of YouTube videos on the topic of crown preparation.

2. Material and Methods

2.1. Criteria for Identification of YouTube Videos and Importance of Selection. The research was conducted as a cross-sectional analysis. The systematic search for YouTube videos was carried out over a period of one year from January 2020 until February 2021. The keywords or phrases and tags used were crown preparation, PFM crown preparation, all ceramic crown preparation, and dental crown preparation.

2.2. Data Collection and Assessment of Quality of YouTube Videos. The following data was collected about the videos: name of the uploader and publisher of the video, video title, YouTube video links, total number of the views of the video, total number of likes or dislikes of a video, total number of positive and negative comments (if any) related to the video, date of uploading, total length of the video, video quality, sound quality, the prepared tooth by using the FDI notation system, type of preparation, the type of prepared tooth, qualification of the presenter, primary or permanent tooth, the language used by the presenter, and the quality of English language. For data collection, we explored "http://www.youtube.com" using the google chrome web browser. Inclusion and exclusion criteria helped in shortlisting only 12 videos out of 109 available videos.

2.3. Inclusion/Exclusion Criteria (Figure 1). All videos that fulfilled the predetermined criteria were included. Content must be relevant and scientifically valid reflecting an acceptable knowledge about crown preparation. The videos must include crown preparation (animation or actual preparation on extracted teeth or in clinic on the patient) as well as presented (if there is a presenter) in comprehensible English language. The videos presented by the faculty members and on tooth preparation done on permanent teeth (natural or ivorine) were included. The authors agreed to include videos that followed the ideal crown preparation parameters. The contents regarding crown preparations to be present in the videos were expected to be based on standard guidelines as described in standard text books for fixed prosthodontics and recently reported in the literature [16–18]. The amount of reduction for all ceramic crown preparations was expected to be the following: axial reduction (1.5 mm), occlusal/incisal reduction (2 mm), functional cusp bevel (posterior teeth), marginal design (deep chamfer/radial shoulder), taper between axial/proximal walls (6°), and smooth finish and rounded line angles.

British as well as American accent, both were considered acceptable for inclusion in the study. Minor variations were ignored. If the video was in the English language (and not any other language, i.e., Chinese, Arabic, French, etc.) and the purpose was clearly understood, it was included in the study. The main factor to be assessed was the comprehensible English language. Senior faculty members who have been involved in teaching the subject in English for five or more years were involved in the assessment of videos.

Out of the available videos, poor quality videos (in terms of sound or picture quality below 480 pixels) and non-English language videos were excluded. Among the videos with exactly the same or duplicated content, the videos with lower views were excluded. Videos with more than 5 negative comments were excluded. Other videos in the exclusion criteria were the ones providing information without

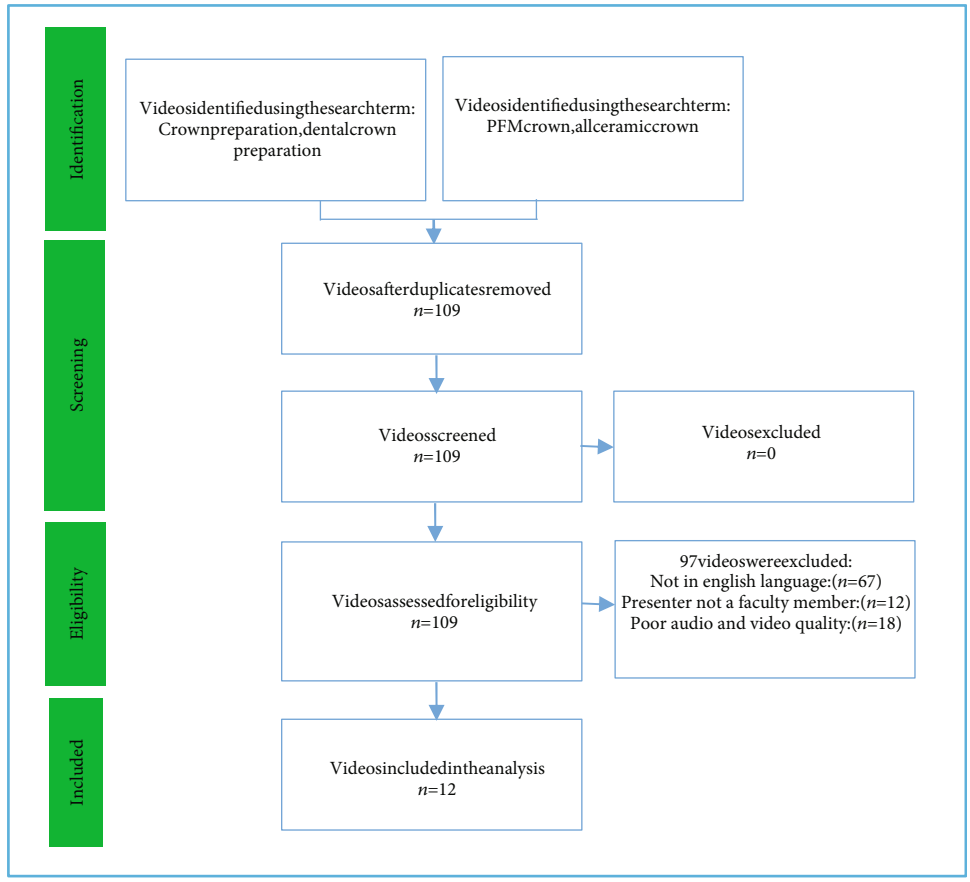

Figure 1: Search strategy.

scientific justification. Two of the most commonly recommended books for fixed prosthodontics, *Contemporary Fixed Prosthodontics* and *Fundamentals of Fixed Prosthodontics*, were kept as the standard [17, 18].

3. Data Analysis

The data gathered from YouTube videos was summed up utilizing a standard form and entered in Microsoft Excel 2016. Data analysis was performed on SPSS version 24.0. Descriptive statistics like mean and standard deviation were used to present the output of analyzed data. For the analysis of variance, statistical t-test was applied to find out the t -value and determine significant differences. Pearson's correlation coefficient (r) was used to find a correlation of like versus dislikes. P value of less than 0.05 was statistically significant at 95% confidence interval.

4. Results

After initial evaluation of the 109 shortlisted YouTube videos by three subject specialists, 42 (38.5%) videos were considered as relevant and were in the English language. Out of these 42 videos, 30 (71.43%) videos were excluded due to poor sound or picture quality, not presented by a faculty member, tooth preparation was not done on permanent teeth, negative comments were more than five in number, or the information about crown preparation was not adequate. Only 12 out of 109 videos (11%) were found to be educationally useful and possessed relevant information about crown preparation, and one out of these 12 videos was animated (Table 1). The links, views, likes, dislikes, and comments of all the 12 videos that met the inclusion criteria are presented in Table 2.

Total mean duration of these educationally useful videos was 971.67 s (SD = 459.66) (Table 3). The mean views/day of all the included videos in the current study were 43.55 (SD = 64.31). A mean of "likes" was 165.25 (SD = 239.01) for the 12 videos included in the current study, which showed that the average number of likes of the educationally useful "crown preparation videos" differs according to comment or not ($t = -3.63$, $P = 0.02$). The average number of "likes" for videos by the viewers/day was 1.12 (SD = 1.62). Probably because login information is required to "like," "dislike," or comment on any YouTube video, so most of the users just view the videos and cannot mark on "like" or "dislike" and also could not make any comments.

The mean of "dislike" of educationally useful videos was 5.92 (SD = 9.25) which also showed that not much difference of opinions was present with the comment or not comment ($t = -0.97$ and $P = 0.35$).

In Table 3, concerning the positive comments of the each educationally useful video, the mean was 2.50 (SD = 3.78), and the mean of negative comments was 0.08 (SD = 0.29) in the current study.

Table 1: Detailed information of all 12 videos included in the study.

S. No.	Author (publisher/ uploader)	Length (min)	SEC	Viewer/ day	Like/ day	Like/ viewer	Dislike/ day	Dislike/ viewer	Positive comment/like	Negative comment/ dislike
1	Glidewell Dental	15:40	940	102.97	3.16	0.03	0.08	0.00	0.02	0
2	Glidewell Dental (animated)	8:28	508	69.36	2.29	0.032	0.051	0.00	0.02	0.2
3	Glidewell Dental	8:14	494	205.16	4.94	0.02	0.20	0.00	0.02	0
4	UofU dentistry/ education	22:07	1327	3.28	0.08	0.03	0	0	0	0
5	UofU dentistry/ education	11:24	684	2.80	0.10	0.04	0	0	0	0
6	UofU dentistry/ education	15:33	933	5.06	0.01	0.00	0.14	0.02	0	0
7	The E-Dentist	13:00	780	0.20	0.00	0.02	0	0	0	0
8	UofU dentistry/ education	7:33	453	1.99	0.08	0.04	0	0	0	0
9	Stevenson Dental Solutions	23:50	1430	99.39	1.84	0.019	0.02	0.00	0.015	0
10	Dentist 4 smile	12:48	768	0.01	0	0	0	0	0	0
11	Ruiz Dental Seminars Inc.	32:09	1929	4.04	0.11	0.028	0	0	0	0
12	Stevenson Dental Solutions	23:34	1414	28.31	0.81	0.029	0.01	0.00	0.01	0

Table 2: Links, views, likes, dislikes, and comments of the 12 videos that met the inclusion criteria.

S. No.	Link	Total view	Like	Dislike	Positive comment	Negative comment	Video score	Video merit
1	https://www.youtube.com/watch?v=jP5d7PIk5-8	9,734	291	7	5	0	95.30	62.5
2	https://www.youtube.com/watch?v=J7LiA291R6s	6,797	224	5	5	1	95.63	26.67
3	https://www.youtube.com/watch?v=fos6C_YaRUQ	23,798	573	21	9	0	92.92	42.85
4	https://www.youtube.com/watch?v=V7dBz91xU7Q	528	13	0	0	0	100	0
5	https://www.youtube.com/watch?v=I7HPEzT3b5g	361	13	0	0	0	100	0
6	https://www.youtube.com/watch?v=7EHnV9xWzd4	870	1	26	0	0	-92.59	0
7	https://www.youtube.com/watch?v=da3eeSq4KlI	45	1	0	0	0	100	0
8	https://www.youtube.com/watch?v=qSJsVL7-9Qs	287	12	0	0	0	100	0
9	https://www.youtube.com/watch?v=Q0fJtRvq2Q4	37,074	685	9	10	0	97.40	10.52
10	https://www.youtube.com/watch?v=pKSaQG8p2Q0	3	0	0	0	0	0	0
11	https://www.youtube.com/watch?v=0gLPwHrWwcE	678	19	0	0	0	100	0
12	https://www.youtube.com/watch?v=7PBB8aeVWrA	5,295	151	1	1	0	98.68	5.55

Table 3: Mean sum and relevant knowledge of 12 videos that met the inclusion criteria.

Themes	Mean	(SD)	T	(P)
Total views	7100.75	(11683.18)	-2.64	(0.06)
Like	165.25	(239.01)	-3.63	(0.02)
Dislike	5.92	(9.25)	-0.97	(0.35)
Total comments	13.08	(27.01)	-1.96	(0.12)
Positive comments	2.50	(3.78)	-3.72	(0.02)
Negative comments	0.08	(0.29)	-1.00	(0.37)
Days	177.08	(78.80)	0.14	(0.89)
Video length	971.67	(459.66)	0.09	(0.93)
Viewer/day	43.55	(64.31)	-3.37	(0.03)
Like/day	1.118	(1.62)	-3.66	(0.02)
Like/viewers	0.0240	(0.01)	-0.65	(0.53)
Dislike/viewers	0.0027	(0.01)	0.72	(0.49)
Dislike/day	0.0422	(0.07)	-1.29	(0.23)
Positive comments/like	0.0064	(0.01)	-6.02	($P < 0.001$)
Negative comments/dislike	0.0167	(0.06)	-1.00	(0.37)
Video score	76.15	(65.06)	-1.57	(0.17)
Video merit	38.89	(48.89)	-14.00	($P < 0.001$)

Video scores = $((like - dislike)/(like + dislike)) * 100$. *Video merits* = $((positive\ comments - negative\ comments)/total\ comments) * 100$.

The correlation between the total 12 educationally useful videos, the number of views, and the number of viewers/day was positive and high, and the result was statistically significant ($r = 0.78$, $P < 0.001$). Likewise, a significant correlation was found between the total views and the like/day ($r = 0.68$, $P = 0.02$), a significant correlation was found between the total views and the positive comments/like ($r = 0.65$, $P = 0.02$), significant correlation was found with video merit ($r = 0.75$, $P = 0.01$), but no correlation was found with video scores ($r = 0.27$, $P = 0.40$) (Tables 2 and 4). The total likes of all the 12 videos and the number of views/day showed a statistically significant correlation ($r = 0.88$, $P < 0.001$), and a significant correlation was also found between the total likes and the like/day ($r = 0.81$, $P < 0.001$). However, no correlation was found between the video scores ($r = 0.33$, $P = 0.20$) and video merits ($r = 0.37$, $P = 0.14$). Also, a significant correlation was found between the total dislikes and dislike/day ($r = 0.95$, $P < 0.001$) as presented in Table 4.

5. Discussion

This research offers the evaluation of already available YouTube videos on the topic of crown preparation with particular focus on the quality and information in the videos and viewers' engagement, upgrading the knowledge of students to promote efficient learning.

The evolution of digital platforms for learning has led the instructors to think diversely and to upgrade the learning and teaching strategies [12]. In the current era of the pandemic, YouTube is becoming a popular information resource for the dental and healthcare community [12]. As reported by Krawczyk et al., YouTube is one of the most used sources of learning and sharing information [19].

The authors believe that this is the first report on the usefulness of YouTube videos on the topic of crown preparation. In this study, a detailed evaluation of these videos and information presented is carried out to determine their educational value. It was observed that a good number of recordings related to the crown preparation were created and uploaded anonymously with no details of the creator whether the content creator is a faculty member or not [1, 19]. Also, some videos did not follow standard procedures as given in text books and were considered unsafe to be carried out by students.

This study also observed that the viewers who liked the video also dropped a positive comment, indicating that if the information being delivered is correct, from some reliable source, and contributes to learning of the viewer, such a video will generate more comments and likes. Similar observations were reported by Ahmad and colleagues [20]. This study also suggested that educationally valuable and informative content that was delivered by specialists or doctors linked to any institutes, organizations, hospitals, clinics, or agencies was useful and helped in improving skills and knowledge of the viewers. This finding was in accordance with other studies by Ahmad et al. and Azer et al. [20, 21].

Generally, the studies show support for video-based learning as it is considered an efficient learning tool [20–23]. Moreover, it has been established in earlier studies that video-based education is an efficient way of learning [20, 23]. In addition, the students attending the lectures or practical supplemented with video learning and practicing the learnt skills on patients achieved better skills and learning strategies [20, 21].

Our research showed that the videos on YouTube that were considered useful based on likes and dislikes totaled the video score of 76% (Table 2). This means that these

Table 4: Correlation between the likes/dislikes, comments, video score, and merit of 12 videos.

	Viewer/day	Like/day	Dislike/day	Positive comments/like	Negative comments/dislike	Video score	Video merit
Total views	.78** ($P < 0.001$)	.68* (0.02)	0.38 (0.23)	.65* (0.02)	-0.01 (0.98)	0.27 (0.40)	.75** (0.01)
Like	.88** ($P < 0.001$)	.81** ($P < 0.001$)	0.46 (0.13)	.77** (0.00)	0.08 (0.81)	0.33 (0.30)	.84** ($P < 0.001$)
Dislike	0.57 (0.05)	0.52 (0.08)	.95** ($P < 0.001$)	0.32 (0.31)	-0.03 (0.92)	-0.52 (0.08)	0.32 (0.32)
Positive comments	.91** ($P < 0.001$)	.85** ($P < 0.001$)	0.50 (0.10)	.84** ($P < 0.001$)	0.21 (0.52)	0.32 (0.31)	.82** ($P < 0.001$)
Negative comments	0.13 (0.70)	0.23 (0.48)	0.04 (0.90)	.59* (0.05)	1.00** ($P < 0.001$)	0.14 (0.67)	0.18 (0.58)

*Correlation is significant at level 5%.; **correlation is significant at level 1%.

videos are informative and can be used as a self-learning source by the students, which is in accordance with other studies [23]. Educationally useful and academically authentic videos on YouTube are beneficial for professionals as well as students and improve the learning possibilities utilizing both audio and visual aids, and the animations further build up the interest in the subject [8, 20, 22]. According to another research, learners utilize their self-study time or time spent on the internet to learn techniques from the available interesting and clear videos [22, 24].

Our study confirms the findings of other studies [15, 22] that most of the viewers of crown preparation videos were either dental students or dental professionals and very few were from the general population. Moreover, it was observed that most of the comments dropped are to inquire about the information in the videos and not just appreciation [22]. This study also noted that majority of the viewers did watch the video but did not comment, like, or dislike as in another study [22]. The reason for this may be that to like or dislike, sign-in to the site is required, and for comment, the identity of the viewer has to be revealed [15, 22].

The merit score of crown preparation videos as devised from positive or negative comments was 38.9%. The negative remarks on the videos were mostly addressed to further improve the quality and to use accurate and relevant keywords for search of the video [22, 25], whereas the positive remarks mentioned about the quality of knowledge and information provided, clarity, and presentation skills [22, 25]. Recently, due to the pandemic, there has been a shift towards digital learning and increased use of the internet and specifically YouTube to acquire knowledge and learn skills [13, 22]. The goal of delivering knowledge online is attainable, given that all the dental professionals and specialists make efforts to provide improved quality content and information for the students [13, 22].

The authors believe that the topic of "crown preparation" is appealing only to the dental community. Hence, the YouTube videos identified and included in this study were not very high in number. Another limitation is that the content assessable on YouTube varies, and recordings are uploaded and removed constantly. Subsequently, the results may change depending upon the time period of search. In the future, the research can be done to adopt a longitudinal or field-based approach to evaluate the value of YouTube as a mode of learning for students. For further improvement in video-based distant learning, virtual simulators can be used along with video-based education to replicate the clinical condition and enhance practical skills. This will not only provide learners with a realistic situation but also give feedback to both, the instructor and students [26].

6. Conclusion

When used for educational purposes, YouTube can enhance the learning experience. It provides enhanced auditory and visual learning by use of eye-catching animations, videos, and pictorial explanation of content. Although the practical skills can only be learnt on simulators, extracted teeth, or on patient, but background knowledge plays a key role in accurate performance of the procedure. The viewers should be vigilant about the origin of the information being watched to avoid any misleading information. Moreover, the content creators should be more responsible when creating the videos to pass on the authentic knowledge from the educational point of view to make online learning via the YouTube platform more beneficial.

Data Availability

The data is available on request from the corresponding author.

Conflicts of Interest

The authors declare no conflict of interest.

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Research Article

Teledentistry as a Supportive Tool for Dentists in Diagnosing MRONJ in Northern Cyprus

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Objective. This web-based survey, as a tool of teledentistry, is aimed at assessing the level of knowledge, attitudes, and awareness regarding MRONJ among dental professionals in Northern Cyprus. *Methods*. An online self-administered questionnaire about MRONJ was sent to all dentists in Northern Cyprus through Google Forms. The first part of the questionnaire consists of demographic and professional information, and the second part included questions about knowledge and awareness questions about MRONJ. The SPSS software was used for statistical data analysis. A Chi-square test was performed to compare between the groups. The significance level was set at $p < 0.05$. *Results*. A total of 112 dentists participated in this survey. The participants showed an insufficient level of knowledge regarding MRONJ, as only 56.6% of the participants stated that they had general knowledge about MRONJ. Regarding the practical questions of the survey, the participants showed poor knowledge about implant and tooth extraction procedures while a patient is using antiresorptive or antiangiogenic drugs, particularly the usage of oral antiresorptive or antiangiogenic drugs for less than 3 years. Participants showed adequate knowledge in terms of usage area of medications and administration of them. *Conclusion*. Teledentistry can be used as a supportive tool for dentists in diagnosing MRONJ. Similar to previous studies, the knowledge and awareness of MRONJ of dentists in Northern Cyprus were found to be inadequate. There is a significant need to provide more professional information as part of undergraduate programs so that the next generation of dentists can practice more confidently.

1. Introduction

Teledentistry is the use of health information about health technology and telecommunications for oral healthcare, education, consultation, and public knowledge to improve oral health [1].

Teledentistry is the remote facilitating of oral care, education, and guidance as a substitute to direct face-to-face contact with any patient or colleague. After years, teledentistry has been validated to be useful for a remote dental screening, providing consultation, making the diagnosis. Teledentistry is found to be comparable to real-time guidance in rural areas with limited access to facilities and long-term healthcare facilities. It makes use of Information and Communication Technology (ICT), especially of the Internet, to transfer clinical information [2, 3].

ICT used in partnership with the Internet has become an important element of academic life in universities. Internet-based teledentistry education permits people to choose the time, place, and type of education [4]. As with many parts of telemedicine, teledentistry usage has been steadily increasing. Telehealth has been supported by many institutions to perform a critical role in preserving communication with patients [5].

In today's circumstances of continuing the COVID-19 pandemic, the essential goal is to avoid person-to-person contact because it spreads by droplet, fomite, and contact transmission. The word "tele" means "distant," and thus,

teledentistry provides the need for social distancing as has been advocated by health authorities all across the world to stop the spread of the SARS-COV-2 virus [2].

Medication-related osteonecrosis of the jaw (MRONJ) is a common serious side effect of using antiresorptive (AR) (bisphosphonates (BP) or denosumab) or antiangiogenic (AA) drugs. These drugs are used in the treatment of hypercalcemia and bone metastases in cancer patients (e.g., multiple myeloma) or to prevent fragility fractures in osteoporosis patients [6].

MRONJ can be considered if the following situations are present: the use of antiresorptive or antiangiogenic agents for current or previous treatment, exposed bone or bone that can be probed through a fistula in the maxillofacial region for at least 8 weeks, and no history of head and neck radiation therapy [7].

Antiresorptive (BP or denosumab) drugs reduce the resorption of bone, pain, and fracture risk in patients with bone disease. On the other hand, antiangiogenic drugs affect angiogenesis which impedes healing. These medications alter bone remodeling by connecting to mineralized bone tissue and by the adverse impact on osteoclast function [8]. In 2003, it was first accepted that bisphosphonate-related osteonecrosis of the jaw is a side effect for patients who are using intravenous bisphosphonates as treatment of malignant diseases with bone metastases [9]. The duration and type of treatment, as well as medical anamnesis, could affect the risks for the patients [10].

The epidemiology and pathogenesis of MRONJ are still unknown; however, a growing body of evidence indicates that MRONJ is a multifactorial process associated with retarded epithelial regeneration, diminished vascularity, and failure of bone remodeling processes. Several risk factors have been stated, including duration of used medications, route of administration (for example, the risk is significantly higher with intravenous medications), dentoalveolar surgery, age, and systemic diseases. Moreover, remarkable development has been achieved in terms of the prevention of MRONJ by studying local risk factors such as the presence of inflammatory, dental-periodontal, and/or peri-implant diseases [11–13]. Figures 1 and 2 show the intraoral and radiological appearance of MRONJ.

MRONJ can be classified and staged with a system proposed by The American Association of Oral and Maxillofacial Surgeons (AAOMS) in 2014, which has been generally used since that time [14].

Dentists have an important role in the prevention and early diagnosis of MRONJ. The treatment can be difficult and can lead to serious types of pain and lessened quality of life. Many studies have shown that preventive oral hygiene procedures incorporated with effective dental health practices are correlated with a lower rate of MRONJ. In light of this situation, the American Society of Clinical Oncology and Cancer Care Ontario made the following suggestion: "A dental evaluation is recommended, where appropriate, before initiation of bisphosphonates, and any pending health or oral problems should be dealt with before starting treatment [14, 15]. Therefore, dental practitioners must have sufficient knowledge of MRONJ, its potential complications, and treatment planning in patients at risk of MRONJ [13].

Recent researches from dentists around the whole world reveal that most of these participants have inadequate knowledge about MRONJ as an adverse effect of these drugs [10, 13, 16–20]. Awareness and knowledge about MRONJ are essential for all dentists to diagnose "at at risk" patients for suitable consultation and management [17].

In diagnostic dentistry, it can be challenging to diagnose oral lesions accurately, especially in rural communities with limited access to specialized dental care. Thus, teledentistry may fill this gap and develop the standard of oral care [21].

With the number of patients on bisphosphonates and other antiresorptive drugs increasing, dental practitioners can play an important role in the prevention of MRONJ in patients receiving bisphosphonate therapy, and there are no previous survey reports about dentists' knowledge concerning bisphosphonate therapy in North Cyprus.

Therefore, this cross-sectional web-based survey, as a tool of teledentistry, is aimed at assessing the level of knowledge and awareness among dental professionals in Northern Cyprus regarding MRONJ.

2. Materials and Methods

This descriptive cross-sectional study was performed using Google Forms, and the link was sent through e-mails or WhatsApp groups to all dentists in Northern Cyprus from March to May 2021. The survey study is designed to assess the awareness, knowledge, management, and practice of all dentists concerning MRONJ patients. The inclusion criteria of the study were being a dental specialist or general dentist. The exclusion criteria of the survey were being a dental student or intern. A cover letter explaining the aim of the survey and identifying the research team was also included in the web form. The study was approved by the Research and Ethics committee (IRB Number: 24/21) conforming to the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The participants were made aware of the study aim, the importance of the survey, and the researcher's name. To ensure confidentiality, the participants were informed that their names were not required on the questionnaire.

The multiple-choice questionnaire was sent to 160 dentists, out of which 112 responses were obtained. The self-administered questionnaire was modified from previously corroborated questionnaires that had been used in similar reports [13, 16–18, 20]. When the participants had any questions, they were answered by e-mail, and they were asked to mark their answers and complete them by themselves.

This questionnaire consists of two main parts. The first section consists of 4 demographic and professional questions including gender, age, years of experience (1-10, 10-20, or >20), and specialization (general dentist or specialist). The second part consists of 18 knowledge and awareness questions about MRONJ (commercial names, therapeutic indications of medication, route of administration and risk factors, and clinical features of MRONJ and questions like case study).

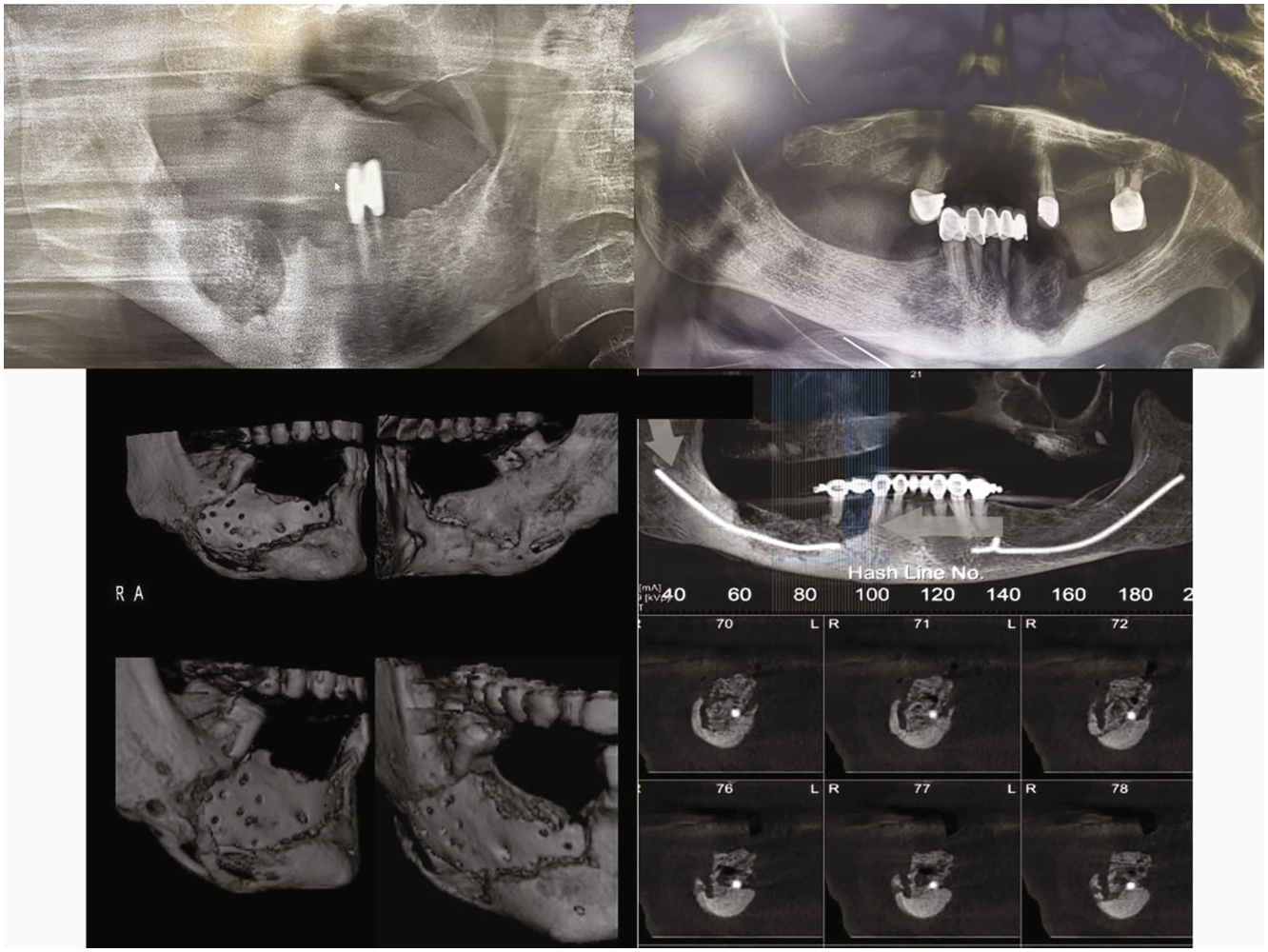

Figure 1: Panoramic and cone beam computed tomography images of MRONJ.

Figure 2: Intraoral image of MRONJ.

2.1. Statistical Analysis. Responses obtained from this survey study were performed descriptively. All responses were presented in the form of frequencies and percentages. Comparisons were made by using the chi-square test. All statistical analyses were performed with SPSS for Windows version 15.0 (SPSS Inc., Chicago, IL). The significance level was set at $p < 0.05$.

3. Results

3.1. Demographic Information. A questionnaire link was sent to a total of 160 dentists in Northern Cyprus, out of which 112 dentists responded. 64% of the participants were female, and 36% were male. The mean age of the participants was 32.2 (range 23-66). Participants were categorized according to specialization where 46.5% of the participants were general dentists and the rest of the participants had a postgraduate degree, specialized in either Dentomaxillofacial Radiology, Dentomaxillofacial Surgery, Periodontology, Orthodontics, Pedodontics, Endodontics, Restorative Dentistry, or Prosthodontics. 78.9% of the participating dentists had between 1 and 10 years of experience. Table 1 shows the detailed demographic and characteristic information of the participants.

3.2. Knowledge and Awareness of Participants. 56.6% of the participants stated that they had general knowledge about

Table 1: The detailed demographic and characteristic information of participants.

	Frequency	Percent (%)
Gender		
Male	41	36
Female	73	64
Area of speciality		
General dentistry	53	46.5
Dentomaxillofacial Radiology	2	1.8
Dentomaxillofacial Surgery	10	8.8
Periodontology	8	7
Endodontics	6	5.3
Prosthodontics	13	11.4
Orthodontics	5	4.4
Pedodontics	10	8.8
Restorative Dentistry	7	6.1
Years of experience		
1-10 years	90	78.9
10-20 years	8	7
>20 years	16	14

MRONJ, and 11.5% stated that they did not know, while 31.9% indicated that they were not sure about their knowledge. According to the area of specialty in orthodontics, pedodontics, and restorative specialties, less than 35% of the participants in each specialization stated that they knew MRONJ. 52.4% of the specialists and 47.6% of the general dentists expressed that they knew MRONJ. The relationship between knowledge about MRONJ and the area of specialty can be seen in Table 2. There was no significant relationship between general knowledge about MRONJ and years of practice ($p > 0.05$).

The participants were asked about the usage area of AR and AA drugs; the results showed that osteoporosis was the most stated answer with the rate of 83.2%, followed by bone metastasis (73.5%), multiple myeloma (39.8%), osteogenesis imperfecta (23.9%), and anemia (0.9%) (Figure 3). According to the area of specialty, the results showed that only 2 participants (1 general dentist and 1 oral surgeon) stated anemia for bisphosphonate usage, whereas more than 70% of the participants in every specialty answered osteoporosis except pedodontics. Bone metastasis and osteogenesis imperfecta are considered as an answer in every specialty area almost equally except general dentists, orthodontics, and endodontics. These three specialties showed lower percentages. Osteoporosis and bone metastasis showed almost equal percentages of answers in the range of years of experience. On the other hand, multiple myeloma and osteogenesis imperfecta showed lower percentages in dentists with more than 20 years of experience.

Fosamax (73%) and Zometa (61%) had the highest percentage for the question regarding medications that can produce osteonecrosis. Figure 4 shows the details of the answers for medications that can produce osteonecrosis.

The results were compared with years of experience, and no significant difference was found between the answers and years of experience. In addition, answers were compared between general dentists and specialists, and the results showed that there was a significant difference in terms of the answers regarding Actonel and Bonviva between general dentists and specialists ($p < 0.05$). Specialists stated that Actonel and Bonviva are medications that can produce osteonecrosis more than general dentists (Table 3).

93% and 78.1% of the participants expressed that AR and AA drugs can be administered orally and intravenously, respectively (Figure 5). There was no significant difference according to the area of specialty. On the other hand, in terms of years of experience, a significantly higher proportion of dentists with 1-10 years of experience selected IV as an answer (86.5%) compared with dentists who had 10-20 years (44.4%) and <20 years of experience (54.5%) ($p < 0.05$) (Table 3). Only 25.9% of the participants indicated that they were familiar with at least one guideline for MRONJ treatment. 73.2% of the participants responded posterior mandibular to this question, followed by the anterior mandibula (17%), posterior maxilla (6.3%), and anterior maxilla (3.6%). There was no significant difference between years of experience and areas of specialty. 84.4% of the participants stated that patients with IV AR and AA drug usage had a greater prevalence of MRONJ than oral users (15.6%). All specialties except pedodontics selected IV administration as the answer with a rate of more than 84%. Only 55.6% of the pedodontics specialty participants chose IV as their answer.

61.4% of the participants agreed with the phrase of good oral hygiene reduces the risk of MRONJ while 22.8% said that they were not sure, and 15.8% of the dentists disagreed with oral hygiene and the MRONJ relationship. The percentage of "not sure" answers increased in line with the number of years of experience.

3.3. Practical Questions (Table 4 Shows the Detailed Results). About the question about tooth extraction:

(i) *Taking AR and AA Drugs Intravenously before the Tooth Extraction Procedure*. 36.8% stated that they would suspend the bisphosphonate treatment for 3 months and then proceed with the treatment, whereas 30.7% stated that would administer no treatment, 27.2% stated they were not sure, and 5.3% indicated that they would carry out the treatment

(ii) *Using AR and AA Drugs Orally for Less than 3 Years*. 45.3% stated that they would suspend the bisphosphonate treatment for 3 months, and 29.5% said they were not sure, while the results for no treatment and carry out the treatment were the same (12.6%)

(iii) *Orally for More than 3 Years*. 41.2% stated that they would suspend the AR and AA drug treatment for 3 months, 28.1% said they would apply no treatment,

Table 2: Knowledge about MRONJ according to the specialties.

			Specialty									
			General dentist	Dentomaxillofacial Surgery	Orthodontics	Periodontology	Endodontics	Prosthodontics	Pedodontics	Dentomaxillofacial Radiology	Restorative Dentistry	Total
Knowledge about MRONJ	Yes	*N*	30	9	1	5	4	7	3	2	2	63
		% within speciality	56.60%	100.00%	20.00%	62.50%	66.70%	53.80%	30.00%	100.00%	33.30%	56.30%
	No	*N*	4	0	2	0	1	1	3	0	2	13
		% within speciality	7.50%	0.00%	40.00%	0.00%	16.70%	7.70%	30.00%	0.00%	33.30%	11.60%
	Not sure	*N*	19	0	2	3	1	5	4	0	2	36
		% within speciality	35.80%	0.00%	40.00%	37.50%	16.70%	38.50%	40.00%	0.00%	33.30%	32.10%
Total		*N*	53	9	5	8	6	13	10	2	6	112
		% within speciality	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

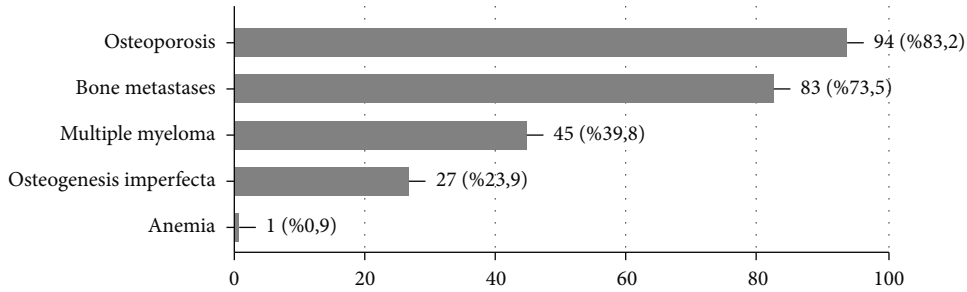

Figure 3: Percentage of participants' answers related to the usage area of bisphosphonates.

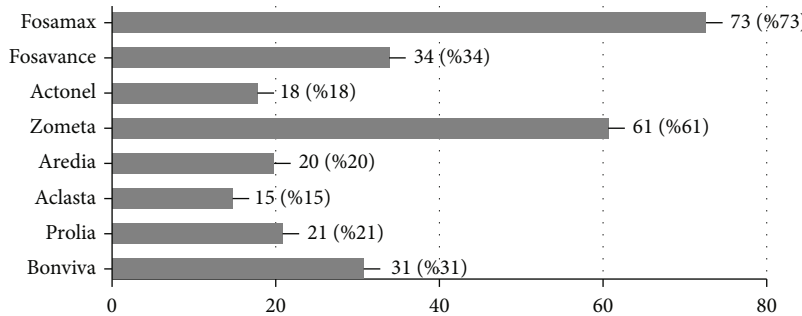

Figure 4: Percentage of participants' answers related to medications that can produce osteonecrosis.

Table 3: Knowledge of different AR and AA drugs by participants and comparison of administration of bisphosphonates with years of experience. Italic shows statistical significance ($p < 0.05$).

Medication	Dentists (%)	Specialists (%)	p value	Years of experience				
Alendronate (Fosamax ©)	56.6%	71%	$p > 0.05$	Administration	1-10	10-20	>20	p value
Zoledronic acid (Zometa ©)	50.9%	53.3%	$p > 0.05$	Intravenously	86.5%	44.4%	54.5%	$p = 0.001$
Risedronate (Actonel ©)	5.7%	25.0%	$p = 0.009^*$	Intramuscularly	10.1%	0	18.2%	$p > 0.05$
Ibandronate (Bonviva ©)	17%	38.3%	$p = 0.013^*$	Oral	91%	100%	100%	$p > 0.05$
Denosumab (Prolia ©)	17	16.7%	$p > 0.05$	Subcutaneously	1.1%	11.1%	0	$p > 0.05$

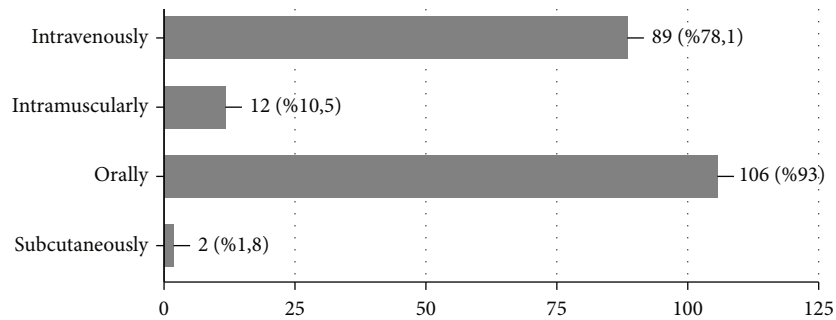

Figure 5: Percentage of participants' answers to the administration of AR and AA drugs.

24.6% were not sure, and 6.1% stated that they would carry out the treatment

Regarding the question about implants:

(i) *Taking AR and AA Drugs Intravenously before Implant Replacement*. 45.6% of the participants stated no treatment as their answer, 28.1% stated that they were not sure, 24.6% said they would suspend the AR and AA drugs treatment for 3 months and then proceed with the treatment, and 1.8% responded that they would carry out the treatment

(ii) *Using AR and AA Drugs Orally for Less than 3 Years*. 32.6% of the participants were not sure about this question, 29.5% stated no treatment, 28.4% said

Table 4: Guideline for tooth extraction and implants in patients with BP treatment and percentage of right answers among general dentists and postgraduate dentists with years of experience.

	IV AR and AA drugs	Oral AR and AA drugs < 3 years	ORAL AR and AA drugs > 3 years
Tooth extraction	Right answer: no treatment	Right answer: carry out treatment	Right answer: suspend AR and AA drugs for 3 months
	General dentists: 28.3%	General dentists: 14.3%	General dentists: 39.6%
	Specialists: 31.7%	Specialists: 12.1%	Specialists: 40%
	$p > 0.05$	$p > 0.05$	$p > 0.05$
	1-10 years exp. = 34.8%	1-10 years exp. = 10.8%	1-10 years exp. = 41.6%
	10-20 years = 0%	10-20 years = 33.3%	10-20 years = 33.3%
	>20 years = 9.1%	>20 years = 18.2%	>20 years = 45.5%
	$p < 0.05^*$	$p > 0.05$	$p > 0.05$
Implants	Right answer: no treatment	Right answer: carry out treatment	Right answer: suspend AR and AA drugs for 3 months
	General dentists: 41.5%	General dentists: 8%	General dentists: 39.6%
	Specialists: 43.3%	Specialists: 11.9%	Specialists: 26.7%
	$p > 0.05$	$p > 0.05$	$p > 0.05$
	1-10 years exp. = 40.4%	1-10 years exp. = 8.2%	1-10 years exp. = 32.6%
	10-20 years = 33.3%	10-20 years = 33%	10-20 years = 44.4%
	>20 years = 54.5%	>20 years = 9.1%	>20 years = 27.3%
	$p > 0.05$	$p > 0.05$	$p > 0.05$

they would suspend the AR and AA drugs treatment for 3 months and then proceed with the treatment, and finally, 9.5% said they would carry out the treatment

(iii) *Orally for More than 3 Years*. 41.2% stated that they would suspend the AR and AA drug treatment for 3 months, 28.1% stated no treatment, 24.6% were not sure, and 6.1% responded that they would carry out the treatment

4. Discussion

The theory of teledentistry was initially introduced by the American Army as part of the Total Dental Access Project in 1994. The main aim was to increase the productivity of dental services delivered to soldiers. Currently, teledentistry is commonly accepted in the fields of dental education, public awareness, and research activities [1, 21].

Through advancing technology, there has been a radical adjustment in offering oral health care to patients. One such modification is because of the budding field of teledentistry. It can be of different types such as patient–dentist, dentist–specialist, dentist–data storage bank, students–dental education, and dentist–research center [22].

The application of teledentistry in oral medicine and diagnosis was evaluated through research performed in Northern Ireland, where the authors used a prototype teledentistry system as part of a service advancement scheme and the authors expressed that teledentistry may serve as an alternative way to administer referrals in oral medicine [23].

Diagnosis of oral lesions could be discussed via teleconsultation, which is contributing to a greater resolution of clinical cases. The challenging diagnosis of oral lesions is one of the reasons for the delayed diagnosis of malignant lesions [24].

The advantages of the web-based self-administered survey are appealing to surveyors because they allow for rapid improvement and administration of surveys, low cost, fast data collection, and analysis. Internet surveys may be suggested for the use of clinical and academic research settings with improved speed and effectiveness of data collection compared with verbal or paper survey methods [25].

On the other hand, comparatively high nonresponse rates than traditional methods of data collection and concerns regarding the reliability and validity of the data obtained could be disadvantages of a web-based survey. Additionally, participants could be hesitant to use web-based surveys because safety and confidentiality issues may also play a role [26].

In this manner, a web-based survey as a tool of teledentistry helps in the diagnosis of MRONJ by providing communication between dentists.

MRONJ is more common in cancer patients (1.8–5% incidence) than osteoporosis patients (0.01–0.03% incidence); this is partly due to the medical condition, but also the doses and potency of AR or AA drugs used. It can lead to debilitating effects due to unexplained causes [27, 28]. The first series of cases of osteonecrosis of the jaw related to medications were reported by Marx at the University of Miami in 2003 and involved 36 cases of painful bony exposure in the maxilla and mandible that were not responding to any surgical or medical treatment in patients receiving intravenous bisphosphonates [29]. Globally, the percentage of people aged older than 65 years has increased because of a lengthened average lifetime [30]. Therefore, this has led to an increase in the number of patients with osteoporosis,

which increases the use of antiresorptive drugs, heightening the risk of an increased number of MRONJ cases [31]. The increase in the incidence of MRONJ highlights the importance of the knowledge and awareness of dentists about MRONJ. This study surveyed dentists in Northern Cyprus to evaluate their awareness, knowledge, and risk factors regarding MRONJ.

The results of this evaluation were concerned in terms of the knowledge on MRONJ among the participant dentists. There was no significant difference concerning the level of knowledge among respondents with higher degrees (specialists) compared with general dentists.

The responses to the first and basic question of the questionnaire, which was about the knowledge of MRONJ, indicated that just 56.6% of the participants had heard about the disease and the majority of participants could not recognize the commercial names of antiresorptive or antiangiogenic drugs. This was evidence of poor knowledge of MRONJ among the surveyed dentists. Previous studies have also reported very poor knowledge on MRONJ among dentists, as in our study [13, 16–18, 20, 32]. Rosella et al. [33] suggested that greater educational efforts should be implemented regarding MRONJ in undergraduate degree programs. Thus, the results of our study and similar researches could be attributed to insufficient education about MRONJ at the undergraduate level.

MRONJ negatively affects the life quality of patients, which can lead to morbidity in affected patients. Thus, dentists should not only have sufficient knowledge and awareness about MRONJ but also adequate knowledge regarding the suitable treatment strategies in patients undergoing antiresorptive or antiangiogenic drug therapy. Fortunately, AAOMS has established very distinct guidelines regarding MRONJ staging and treatment planning of patients at risk of this eviscerating disease. However, only 25.9% of the participating dentists were familiar with the guidelines, which is a similar finding to several studies that reported that the majority of dentists were not familiar with any guidelines [18, 20, 34].

Escobedo et al. [20] and Al-Hussain et al. [35] reported that knowledge of MRONJ treatment and management decreases with years of experience, especially among professionals with more than 20 years of experience. Similarly, de Lima et al. [36] found that participants with less than 5 years of experience had the highest scores for the risk factors related to the development of MRONJ. On the other hand, Miranda-Silva et al. [32] reported that the MRONJ knowledge scores tended to increase with years of experience. In our study, there were only significant differences according to years of experience in the administration of antiresorptive or antiangiogenic drugs and treatment strategies in tooth extraction while the patient was using BPs. The results showed that for these two questions, dentists with 1-10 years of experience had significantly better knowledge. For other questions, there was no significant difference according to years of experience.

In previously reported studies, in the evaluation of knowledge regarding the therapeutic indications for bisphosphonates, antiresorptive, or antiangiogenetic, osteoporosis was the most stated answer by participants followed by cancer treatment for bone metastases and multiple myeloma and osteogenesis imperfecta [13, 33, 34, 37]. These previous reports verify the results of this survey that osteoporosis was the main therapeutic indication stated by the dentists, followed by cancer treatment of patients with metastatic bone tumors, multiple myeloma, and osteogenesis imperfecta and anemia.

Al-Hussain et al. [35] reported a survey conducted with general dentists and specialists. Based on the results, it was concluded that participants were precautious about performing oral surgery on patients taking BPs. In that study, participants who achieved higher scores in knowledge recommended that greater educational information should be given to dentists regarding MRONJ complications. Our study results also support this outcome. More educational material about MRONJ should be provided to undergraduate students. The prevention of MRONJ requires more information than just adequate awareness and knowledge on MRONJ. It is a reality that patients have insufficient knowledge about the drugs they are using.

Communication between professionals is essential for MRONJ patients and their quality of life; communication must become routine to enhance patient care and correctly handle patients at risk of developing MRONJ.

There were several limitations in the present survey. Firstly, the number of participants was relatively low due to the small community of dentists in Northern Cyprus. Moreover, 78.9% of participants had between 1 and 10 years of experience. Only 16 of the dentists who participated in the survey had more than 20 years of experience. The lack of experienced participants had a significant impact on the outcomes of this study. Furthermore, this was a self-administered questionnaire so the responses may not have revealed the actual knowledge of the participating dentists. Despite these limitations, we believe that this survey has provided helpful information on the level of MRONJ awareness and knowledge among dentists around the world.

5. Conclusion

Teledentistry can be used as a supportive tool for dentists in diagnosing MRONJ. Similar to previous studies in other countries, the knowledge and awareness of MRONJ among dentists practicing in Northern Cyprus were found to be inadequate. Such alarming results demonstrate that more professional information must be given in undergraduate programs so that the next generation of dentists can practice more confidently and effectively with MRONJ patients. Moreover, experienced dentists should refresh their knowledge with seminars and educational programs.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethical Approval

All procedures performed in studies involving human participants were following the ethical standards of the institutional and/or national research committee (Ministry of Health, TRNC, Ethical Com. (IRB Number: 24/21)) and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Consent

Consents for publication were obtained from the patients.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Authors' Contributions

All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by MF. The first draft of the manuscript was written by MF and KO, and both authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Research Article

Accuracy of Dental Photography: Professional vs. Smartphone's Camera

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There is a scant literature on the accuracy of dental photographs captured by Digital Single-Lens Reflex (DSLR) and smartphone cameras. The aim was to compare linear measurements of plaster models photographed with DSLR and smartphone's camera with digital models. Thirty maxillary casts were prepared. Vertical and horizontal reference lines were marked on each tooth, with exception to molars. Then, models were scanned with the TRIOS 3 Basic intraoral dental scanner (control). Six photographs were captured for each model: one using DSLR camera (Canon EOS 700D) and five with smartphone (iPhone X) (distance range 16-32 cm). Teeth heights and widths were measured on scans and photographs. The following conclusions could be drawn: (1) the measurements of teeth by means of DSLR and smartphone cameras (at distances of at least 24 cm) and scan did not differ. (2) The measurements of anterior teeth by means of DSLR and smartphone cameras (at all distances tested) and scan exhibited no difference. For documentational purposes, the distortion is negligeable, and both camera devices can be applied. Dentists can rely on DSLR and smartphone cameras (at distances of at least 24 cm) for smile designs providing comparable and reliable linear measurements.

1. Introduction

Nowadays, photography is playing a major part in the medical field, specifically in documentation [1–8]. The importance of digital photography has been brought to light during the COVID-19 pandemic where all interpersonal interactions relied mainly on online communication. Remote online medical consultations began to show a growing potential, and Telehealth became crucial for delivering virtual medical and educational support in all fields [9].

The use of photographs in dentistry has offered an updated perception of daily clinical practice. Apart from educational purposes, photography can be employed in treatment planning, tracking the evolution of the treatment, documenting, evaluating, communicating, publishing, lecturing, and marketing, artistic pictures, insurance, or legal purposes [10–13]. The Digital Smile Design (DSD) process is a methodical procedure relying on photographs and software analysis to determine esthetic outcomes; it has been used in the conception of esthetically pleasing smiles, from

restorative dentistry to orthodontic treatment plans [14, 15]. Photographs are being captured by either a DSLR or a smartphone camera. Acquired photographic information has been described as an "objective and efficient communication tool among dentist, patient, and technician," that can be used for smile design and mock-up techniques [16, 17].

For any clinician, practicality comes first and foremost, especially for frequently repeated procedures. In terms of feasibility, mobile dental photography (MDP) seems to be favorable in comparison with DSLR photography on account of smartphones' cost-effectiveness, considerably lighter weight, and faster learning curve [18]. The rate of dentists relying on the use of their smartphones' cameras, instead of professional DSLR cameras, is increasing exponentially because of the easy access and manipulation of the former [19].

DSLR cameras have specific settings and characteristics that dictate the protocols of capturing a photograph since it allows the photographer to control and change features such as aperture, exposure time, and international organization of standardization (ISO) sensitivity [18]. On their end, smartphone cameras perform automatic adjustments allowing the user to take a picture no matter the circumstances which can be both beneficial and disadvantageous at the same time. On the one hand, mobile phone facilitates the process of taking a picture [20], but on the other hand, if the user does not know how to properly manipulate the camera, the photograph can be captured in conditions that compel image distortion [21]. In fact, barrel effect is one of the problems that dentists face: it happens when the camera is too close to the subject and results in distorted image proportions. To eliminate this problem, the camera should be placed further away from the object; henceforth, the correct handling of the smartphone camera is essential [18].

With the growing importance of photography in the dental field, it seemed interesting to assess its accuracy and hence determine to what extent it is reliable for both DSLR and smartphone cameras. Therefore, the purpose of this study was to compare linear measurements of plaster models photographed with DSLR camera and smartphone's camera with linear measurements of digital models obtained with the intraoral dental scanner.

Two null hypotheses were tested: (1) there is no statistically significant difference among the linear measurements of teeth from digital images of the plaster model obtained from a DSLR, a smartphone's camera, or an intraoral dental scanner, and (2) the distance of the smartphone's camera to the object does not significantly affect the linear measurements in a photograph.

2. Material and Methods

2.1. Material. A total of thirty patients aged between 18 and 30 years with preserved natural dentition in maxillary teeth were selected for this study. Patients with gingival recessions, orthodontic anomalies, or prosthetic restorations in maxillary teeth, were excluded from this study. All signed a consent form accepting that their records can be used for educational purposes and studies. The study protocol was approved by the Institutional Review Board of Saint-Joseph University (FMD-202; ref.# USJ-2019-234).

2.2. Study Design. Dimensions recorded with the intraoral dental scanner were considered standard references because of the intraoral scanner's relatively determined accuracy [22–24]. Linear measurement's distortion was evaluated according to tooth placement, by comparing the width and height measurements of different teeth (central, lateral, canine, first, and second premolars) in photographs taken with the different devices. Moreover, this study compared the measurements in photographs captured at different distances between the smartphone camera and the plaster model.

Linear measurements of digital images of teeth from plaster models were evaluated according to the following factors: (1) device used: a DSLR (Canon EOS 700D with 100 mm macro lens) and a smartphone's camera (iPhone X); and (2) distance between the smartphone's camera and the object: 16 cm, 20 cm, 24 cm, 28 cm, and 32 cm. The sample size for each test had a power of at least 0.8 at a significance level of 0.05.

2.2.1. Traditional Model Preparation. Thirty maxillary impressions were taken using standard trays and alginate impression material (Tropicalgin, Zhermak, Germany). The impressions were then immediately casted with type III dental stone (Elite Ortho, Zhermak, Germany). After setting, two reference lines (vertical and horizontal) were marked on each tooth from the right second premolar to the left second premolar, using a 0.3 mm pencil. The vertical lines were drawn from the zenith point perpendicularly to the middle of the incisal edge of the incisors or to the tip of the canine and premolar teeth. The horizontal lines were marked at the height of contour of each tooth.

To compute dimensions on a given scale, one fixed dimension should be included in all plaster casts' photographs. The known width (0.8 cm) of a prefabricated rectangular sticker was used as the fixed reference dimension for scale computation. A sticker was placed on the center of each cast's base in frontal view (Figure 1).

2.2.2. Scanning Procedure. The models were first scanned with the 3Shape TRIOS scanner (TRIOS 3 Basic, 3Shape, Copenhagen, Denmark) for the control group, following the manufacturer's scan strategy protocol [25]. The three-dimensional (3D) scan of the cast had to be transferred into a two-dimensional (2D) representation so that linear measurements could be compared between the scan and the photographs. To do so, a frontal view of the scan had to be chosen so that it matches the frontal view depicted on the photographs. A see-through 2D square with gridlines dividing the square into thirds was superimposed on the scan, and the frontal view was chosen when the edges of the scanned model fit in the square and the base of the model coincided with the lower horizontal line of the grid.

2.2.3. DSLR Photographs. DSLR cameras were positioned on a tripod while the plaster cast models were placed on a fixed stand. Six photographs were captured for each model: one photograph with the DSLR camera (Canon EOS 700D with

Figure 1: Photographs of the same model with the different camera devices. (a) Scan with grid lines to determine the positioning of the model. (b) Scan of the plaster model (dcm format to see the marked reference lines). (c) Photograph captured with iPhone X at 16 cm. (d) Photograph captured with iPhone X at 20 cm. (e) Photograph captured with iPhone X at 24 cm. (f) Photograph captured with iPhone X at 28 cm. (g) Photograph captured with iPhone X at 32 cm. (h) Photograph captured with Canon EOS 700D (100 mm macrolens).

100 mm macrolens) and five photographs that were captured using a smartphone (iPhone X) whereby the settings were the same (Figure 1).

The picture size was chosen with a 1 : 1 aspect ratio for screen size (meaning that the width and height of the screen were equal, giving a square picture size), and grid lines dividing the screen into thirds were displayed on the screen. The lower horizontal line of the grid was superimposed over the base of the models. Each device's center of focus was directed to the incisor point, and the additional focal points were directed to the tips of the canines. All casts were captured by one operator to ensure standardization of the procedure.

The settings were fixed with a shutter speed of 1/125 and an aperture of F-22. The distance between the camera and the models was determined such that the cast's edges fit in the 1 : 1 camera frame, all while the cast was in focus.

2.2.4. Smartphone Photographs. A feature of the iPhone X is that shutter speed and aperture size were automatically calibrated depending on the distance between the camera and

the cast. The cast's edges had to also fit in the square camera frame of the phone. Five photographs were taken at different distances (determined after a pilot study): 16 cm, 20 cm, 24 cm, 28 cm, and 32 cm.

2.2.5. Photograph Assessment. Afterwards, all photographs along with the chosen frontal view of each scanned model were assessed with the free software ImageJ (U.S. National Institutes of Health, Bethesda, Maryland, USA) with an accuracy of 0.01 mm. First, using the software, the width of the sticker (0.8 cm width) was marked on each photograph. The system measures this distance in pixels and sets a scale that automatically computes the measurements into the specified length unit (cm). Then, relying on the already drawn vertical and horizontal reference lines, teeth heights and widths were marked, and their measurements were recorded using the tool Measure Analyze. Measurements were taken in the same sequence for all the photographs, starting with the right second premolar and ending with the left second premolar (Figure 2).

2.3. Statistical Analysis. Data normality was verified using Shapiro–Wilk's test and the homoscedasticity using Levene's test. Statistical analyses were carried out according to the different experimental designs at a significance level of $\alpha = 0.05$. The statistical tests were done using Sigma Plot 12.0 software. The width and height of each tooth were analyzed separately by means of a one-way ANOVA and Tukey test.

3. Results

The width of the first and second premolars significantly differed depending on the camera and the distance used (Table 1) ($p < 0.001$). For these teeth, values obtained from photographs captured with the smartphone camera at the distances of 24 cm, 28 cm, and 32 cm from the subject were statistically similar to those obtained with the DSLR camera. Moreover, values obtained from scans of premolars were statistically different from those relying on photos with mobile camera at the distance of 16 cm and 20 cm.

Comparison between teeth height in different photographs showed that there is no statistically significant difference ($p > 0.05$) (Table 2).

4. Discussion

The present study reported that the values measured using a DSLR and a smartphone camera recorded the same results for the frontal view of the scanned model. No statistically significant difference was found for neither width measurements (from canine to canine), nor height measurements (for all teeth) for both cameras. Additionally, there was no statistical difference between scans, DSLR, and smartphone cameras at distances greater than or equal to 24 cm. Thus, the first null hypothesis stating that there is no statistical difference between the two devices (DSLR and smartphone) can be partially rejected; it is true when the smartphone is at a distance of at least 24 cm from the object.

The only statistical difference between the two devices appeared for premolars' widths when the smartphone camera was at close distances of 16 cm and 24 cm. So, the second null hypothesis can be partially rejected since the distance of the smartphone's camera to the object affected the measured values of the first and second premolars' widths.

Photographs can help evaluate and assess smile esthetics while taking into consideration patient and clinician preferences [26, 27]. The treatment planning for esthetic cases relies mostly on frontal dental photographs where measures of teeth dimensions and proportions can be executed. Photograph analysis and processing techniques are increasingly being used for determining optimal thresholds of teeth shapes and dimensions along with soft tissue proportions [28–30]. The average widths of maxillary teeth in frontal view can be used to obtain esthetically pleasing smiles [31]. Moreover, digital imaging can be used for color measurements since it provides improved communication between the dentist and the laboratory technician [18]. The color matching ability of the observer showed a large variation, and photograph reliability in color matching was considered effective [32]. It was found that the application of photographs resulted in digital shade selection with a threshold within acceptable values. The used photographs can either be captured with a DSLR or a smartphone in adjunction to a suitable light since both devices gave similar reliable results [33]. The use of additional accessories for digital photography such as polarizing filters has also proved useful in shade matching [34]. These accessories are not exclusively used on DSLR cameras. Interestingly, the application of a crosspolarizing filter on a smartphone camera results in a more color-standardized photograph [35].

The digital approach in smile design has increasingly developed in the past years, given the growing role played by technology in daily life. DSD has become an interesting tool in esthetic dentistry. Computer and software resources are facilitating treatment planning and end-result predictions [36]. Many smile design systems already exist, like DSD, Cara Smile, Rebel Simplicity, Planmeca Romexis Smile Design, Aesthetic Digital Smile Design, Smile Designer Pro, and VisagiSMile [36–39]. Each smile design system has its own approach to analyzing a patient's smile and elaborate a treatment plan for an esthetically pleasing result [17, 39–41]].

Smartphone cameras are frequently being used by dentists since numerous studies focused on smartphone photographs and videos. This could be due to the fact that smartphone cameras are more practical giving their accessibility where a smartphone is a cheaper, lighter, and easier alternative for a DSLR camera, and it possesses the ability to record high quality photographs and videos [18]. Both tested cameras were chosen due to their availability, popularity, and quality of images. Moreover, Canon EOS 700D was chosen because it was used in other in vivo studies for teeth dimension measurements.

The current study compared the accuracy of 2D photographs between different devices. The results helped in evaluating the reliability of the photographs depending on the used device and its distance to the subject. It is known that when a camera device gets closer to a subject, more distortion occurs, especially on the picture's borders [42]. In this

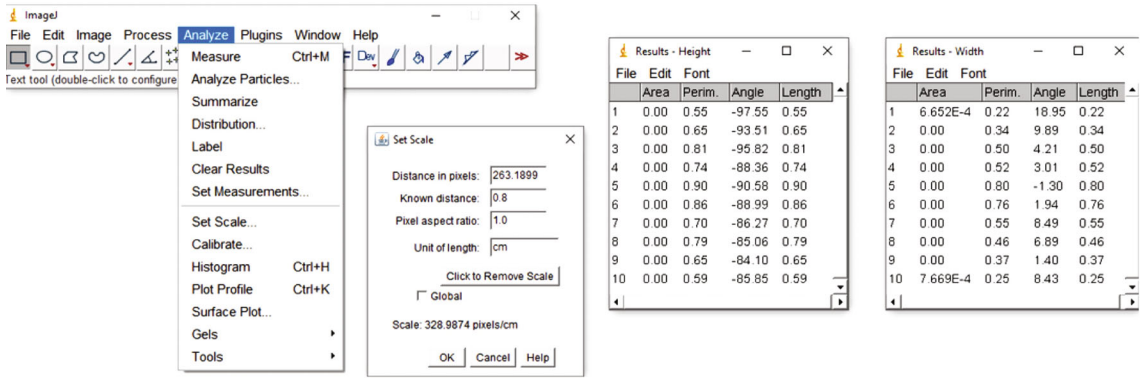

Figure 2: Example of setting a scale and measuring teeth heights and widths using ImageJ tools.

Table 1: Mean (SD) in cm of the width of teeth obtained from different photographs.

Teeth	Scan	DSLR	16 cm	20 cm	24 cm	28 cm	32 cm
15	0.25 (0.05)^{a}	0.24 (0.06)^{ab}	0.17 (0.06)^{c}	0.20 (0.07)^{bc}	0.22 (0.07)^{ab}	0.23 (0.06)^{ab}	0.23 (0.06)^{ab}
14	0.29 (0.04)^{a}	0.29 (0.06)^{ab}	0.22 (0.06)^{c}	0.25 (0.06)^{bc}	0.26 (0.06)^{ab}	0.28 (0.05)^{ab}	0.28 (0.05)^{ab}
24	0.29 (0.04)^{a}	0.27 (0.05)^{ab}	0.22 (0.05)^{c}	0.24 (0.05)^{bc}	0.25 (0.05)^{ab}	0.27 (0.05)^{ab}	0.27 (0.05)^{ab}
25	0.26 (0.06)^{a}	0.23 (0.07)^{ab}	0.19 (0.06)^{c}	0.20 (0.06)^{bc}	0.21 (0.06)^{ab}	0.23 (0.06)^{ab}	0.24 (0.06)^{ab}

SD: standard deviation. Dental teeth are in international nomenclature. For teeth 13, 12, 11, 21, 22, and 23, differences between photographs were not statistically significant ($p > 0.05$). For each row, different lowercase letters indicate statistically significant differences ($p < 0.05$).

Table 2: Mean (SD) in cm of the height of teeth obtained from different photographs.

Teeth	Scan	DSLR	16 cm	20 cm	24 cm	28 cm	32 cm
15	0.53 (0.09)^{a}	0.54 (0.09)^{a}	0.50 (0.07)^{a}	0.52 (0.08)^{a}	0.52 (0.08)^{a}	0.53 (0.08)^{a}	0.53 (0.08)^{a}
14	0.60 (0.07)^{a}	0.61 (0.07)^{a}	0.58 (0.08)^{a}	0.59 (0.07)^{a}	0.60 (0.07)^{a}	0.60 (0.07)^{a}	0.61 (0.07)^{a}
24	0.62 (0.08)^{a}	0.62 (0.07)^{a}	0.59 (0.08)^{a}	0.61 (0.08)^{a}	0.61 (0.08)^{a}	0.62 (0.08)^{a}	0.63 (0.08)^{a}
25	0.56 (0.07)^{a}	0.56 (0.07)^{a}	0.53 (0.06)^{a}	0.55 (0.06)^{a}	0.55 (0.07)^{a}	0.55 (0.07)^{a}	0.56 (0.07)^{a}

SD: standard deviation. Dental teeth are in international nomenclature. For teeth 13, 12, 11, 21, 22, and 23, differences between photographs were not statistically significant ($p > 0.05$). For each row, different lowercase letters indicate statistically significant differences ($p < 0.05$).

study, the 100 mm macrolens was used with the Canon EOS 700D because a longer distance was needed to put the subject in focus; so, minimal distortion occurred. For the smartphone camera, and because it can manage to adjust its camera settings automatically, different distances have been tested.

From a documentational point of view, independent of the camera device or the distance to the teeth, all photographs proved to be efficient. They can all provide sufficient and reliable information. No significant statistical difference was found between the two recordings (DSLR and smartphone cameras), and the accuracy of both was determined to be satisfying for clinical application [43].

Regarding measurement accuracy, the results showed that for teeth height, no statistical difference was noticed: photographs captured with the DSLR camera and the smartphone camera at all distances gave teeth height measurements statistically similar to the values obtained with the intraoral scanner. These results were accurate for all teeth independent of their position on the dental arch.

For width measurements, the results were tooth-dependent. Concerning the teeth from canine to canine, photographs captured with the DSLR camera and the smartphone camera at all distances gave values statistically similar to those measured with the intraoral scanner. Both cameras can be used at any distance, giving reliable and accurate measurements that can be used for smile design.

However, this study proved that the case was different for width measurements of premolars. This can be explained by the fact that premolars are more distally located on the curved dental arch; so, more distortion can affect them since they are located close to the edge of the photograph. In fact, photographs captured with the DSLR camera and the smartphone camera at a distance of 24 cm, 28 cm, and 32 cm gave premolar width measurements statistically similar to each other, but differing from the values obtained with the intraoral scanner. When it comes to photographs taken with the smartphone camera at a distance of 20 cm, the difference becomes statistically significant and even more so at 16 cm.

Clinical studies evaluating the variables examined in this article are scant. Moreover, randomized controlled clinical trials must be conducted to provide better insight into the

accuracy of digital photography (DSLR and smartphone cameras) in terms of precision and trueness. Little information exists regarding the use of smartphones for photography in the dental field. Additionally, the impact of different sensors (for DSLR and smartphone cameras) is a factor that can influence smile evaluation on frontal view photographs [44].

Only maxillary casts were included in this study since measurements of teeth dimensions on photographs are mainly used for smile designs which in its turn tend to focus on maxillary teeth. Nonetheless, teeth measurements can be used in orthodontic treatments; therefore, mandibular casts will also be included in future studies. The reliability of DSLR and smartphone cameras can be assessed for factors other than dimension accuracy, such as shade or color evaluation. A similar study can also be conducted using a different type of smartphone, or even another study comparing dimension accuracy for photographs of patients' faces. Furthermore, since smartphone videos are already being used to record lip dynamics, to produce a 2D smile frame, and even to take dental impressions, further studies should be conducted to evaluate the accuracy of these videos. More research should be directed towards testing other DSLR cameras or smartphone cameras since the continuous evolution of camera specifications and photography technologies can alter the findings of the study.

5. Conclusions

Within the limitations of the present study, the following conclusions can be drawn:

(1) The measurements of teeth by means of DSLR and smartphone cameras (at distances of at least 24 cm) and scan did not differ

(2) The measurements of anterior teeth by means of DSLR and smartphone cameras (at all distances tested) and scan exhibited no difference

For documentational purposes, the distortion is negligible and both camera devices can be applied in clinical scenario. Moreover, dentists can rely on DSLR and smartphone cameras (at distances of at least 24 cm) for smile designs providing comparable and reliable linear measurements.

Data Availability

All data are included in the manuscript. If needed, authors can provide all study documentation.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

A Convolutional Neural Network for Automatic Tooth Numbering in Panoramic Images

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Analysis of dental radiographs and images is an important and common part of the diagnostic process in daily clinical practice. During the diagnostic process, the dentist must interpret, among others, tooth numbering. This study is aimed at proposing a convolutional neural network (CNN) that performs this task automatically for panoramic radiographs. A total of 8,000 panoramic images were categorized by two experts with more than three years of experience in general dentistry. The neural network consists of two main layers: object detection and classification, which is the support of the previous one and a transfer learning to improve computing time and precision. A Matterport Mask RCNN was employed in the object detection. A ResNet101 was employed in the classification layer. The neural model achieved a total loss of 6.17% (accuracy of 93.83%). The architecture of the model achieved an accuracy of 99.24% in tooth detection and 93.83% in numbering teeth with different oral health conditions.

1. Introduction

Modern dentistry employs computer-assisted procedures in common dental treatments such as surgical planning, post-operative assessment, mechanized dental implants, and orthodontic planning [1].

The numbering of teeth in dental radiology is a routine evaluation that takes up time. Nowadays, dental images have been used combined with artificial intelligence in many applications such as dental diagnosis and dental treatment [2, 3]. Numbering teeth is required, for example, to identify human dental images, in routine dental procedures, maxillo-facial surgical applications, and teeth generic modelling [4].

A large number of studies have been developed employing deep learning to reduce the workload of professionals and to recognize certain features [5]. Neural networks used for image recognition have evolved over time: initially started using Regions with Convolutional Neural Networks (R-CNNs) for classification tasks and continued with the use of fast R-CNN for classification and detection [6, 7]. Presently, deep learning methods based on convolutional neural networks are being widely used in the field of medical image analysis [8]. This study is employed to detect and number teeth in panoramic images.

The objective of this study was to modify the neural network used in a previous study by the authors [9], which

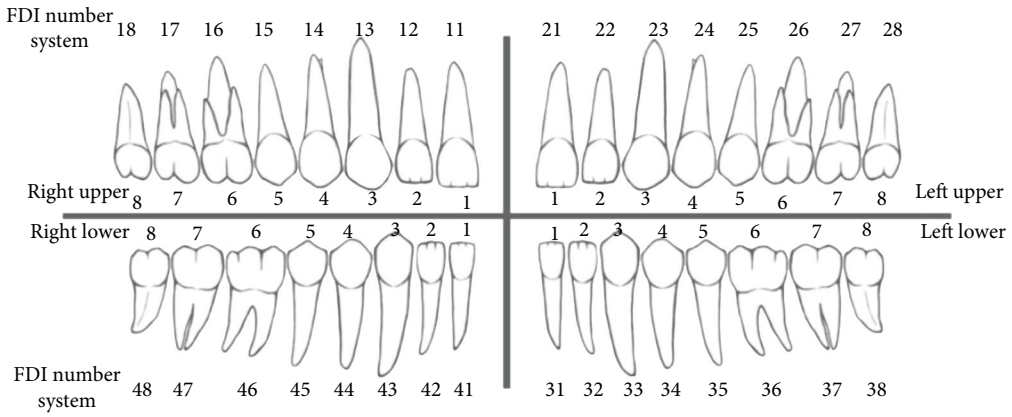

Figure 1: FDI classification system: Q1: 11–18 = right upper 1–8, Q2: 21–28 = left upper 1–8, Q3: 31–38 = left lower 1–8, Q4: 41–48 = right lower 1–8; 1. Central incisor. 2. Lateral incisor. 3. Canine. 4. First premolar. 5. Second premolar. 6. First molar. 7. Second molar. 8. Third molar.

Table 1: FDI distribution in the total image database.

Q1		Q2		Q3		Q4		Total
FDI	Count	FDI	Count	FDI	Count	FDI	Count	
11	1992	21	1990	31	1996	41	1996	7974
12	1959	22	1963	32	1999	42	1999	7920
13	1956	23	1956	33	2011	43	2011	7934
14	1863	24	1859	34	1959	44	1959	7640
15	1838	25	1828	35	1921	45	1921	7508
16	1778	26	1768	36	1661	46	1661	6868
17	1793	27	1765	37	1741	47	1741	7040
18	947	28	979	38	1015	48	1015	3956

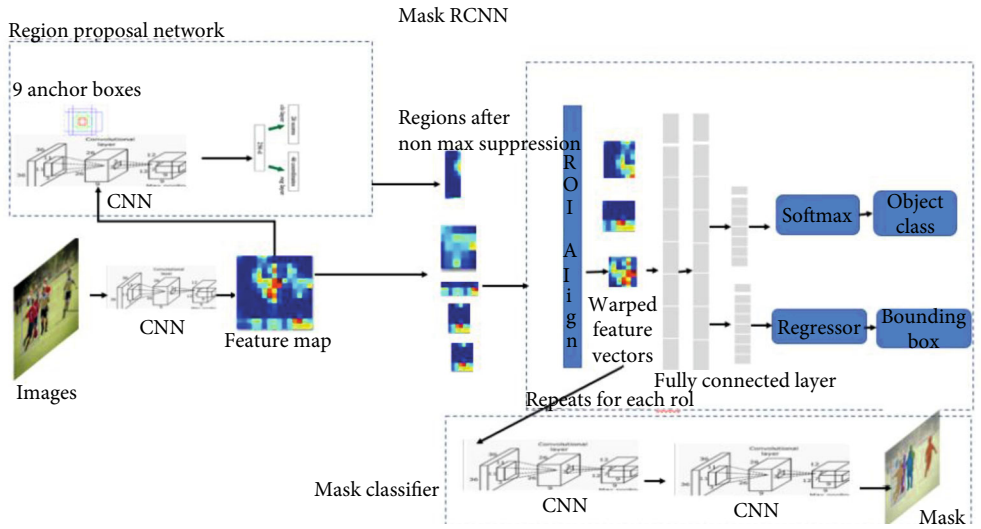

Figure 2: General Mask RCNN architecture.

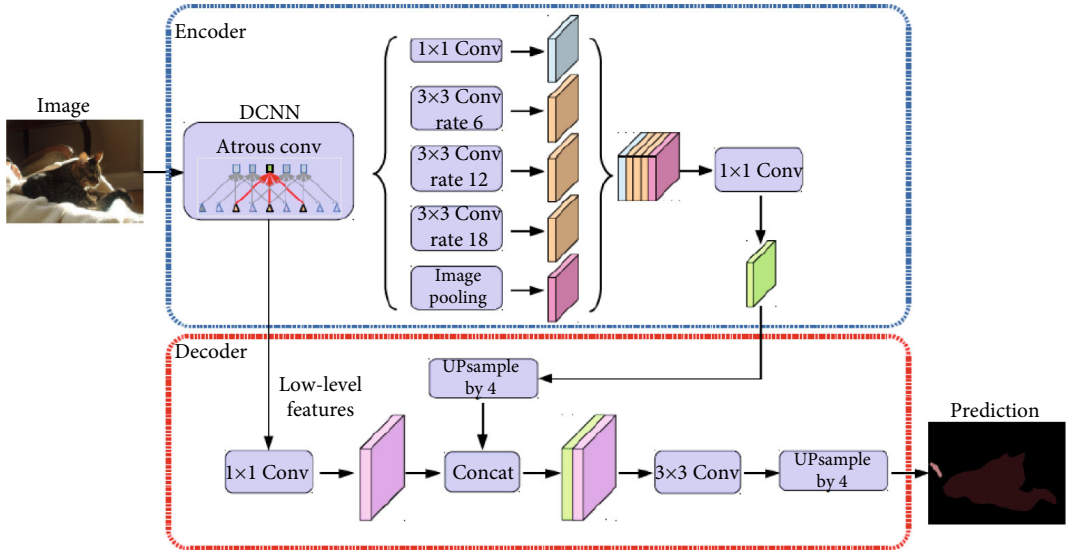

Figure 3: General ResNet Atrous architecture.

Table 2: Final parameters of the model.

Matterport configuration class	
Name	CoreDXnet II
Backbone	Resnet101
Batch size	2
Detection min confidence	0.75
Learning momentum	0.9
Steps per epoch	200

obtained a precision of 99.24% in detecting the presence or absence of a tooth, to be used in the numbering of teeth in a panoramic image according to the Federation Dentaire Internationale (FDI) teeth numbering system.

2. Materials and Methods

2.1. Study Design. This study used a dataset of anonymized and categorized panoramic dental images. A CNN was first constructed to detect the presence or absence of teeth on the radiography and was later modified to number teeth according to FDI classification. Reporting of this study follows the STARD guideline [10].

2.2. Image Dataset. Panoramic images were taken from Asisa Dental S.A.U. centers in the Community of Madrid (Spain). These images are completely anonymized by CareStream Health Spain SA (Pozuelo de Alarcón, Madrid, Spain). No additional information such as name, gender, age, or when the image was taken appears in the database. Data collection was ethically approved (Ethics Committee of Research with Regional Medicines of the Community of Madrid (CEIm-R)) on June 15, 2018. The requirement to obtain informed consent from patients was waived by the ethics committee.

The inclusion criteria of the image database employed in the present study were adults older than 18 years. The exclusion criteria of images were edentulous patients, those images with temporary teeth and poor definition, images with removable prostheses, or images with only the presence of implants, computerized axial tomography (CAT), and radiography with overlap or objects out of the imaging plane.

Each image was revised by two examiners with more than three years of experience in general dentistry. The examiners evaluated the image database through a visualization program created to collect the information. The inclusion criteria were panoramic images from adults older than 18. The exclusion criteria were images of edentulous patients, those with temporary teeth, poor definition, with removable prostheses, or with only presence of implants. Computerized axial tomographies (CAT) were also excluded. Radiographies with overlap or objects out of the imaging plane were excluded.

For this study, the 5,121 8-bits images employed in a previous published manuscript by the authors [9] were used to start the image database in the present study. A set of 2,230 correctly demarcated samples was obtained. Of these 2,230 samples, those with 28 or more teeth were selected. It was possible to identify 1,617 samples with these characteristics, from which those that had metallic parts were filtered, of which 1,217 samples suitable for training and validation of the final FDI detection and assignment model were obtained (Figure 1).

The number of existing teeth in the 2,230 images, distributed by their FDI, is detailed in Table 1. As can be seen, for all quadrants, the number of pieces 1 to 7 is quite homogeneous. However, in the case of piece 8, it is not always categorized by the experts, and there are also fewer cases.

2.3. CNN Architecture. The categorized panoramic radiographs are used as an input for the neural network architecture presented. The system outputs the bounding boxes and the teeth number for all detected teeth on the image.

The algorithms were running backend on TensorFlow version 1.14 and Tensorflow 2.2., and the operating system

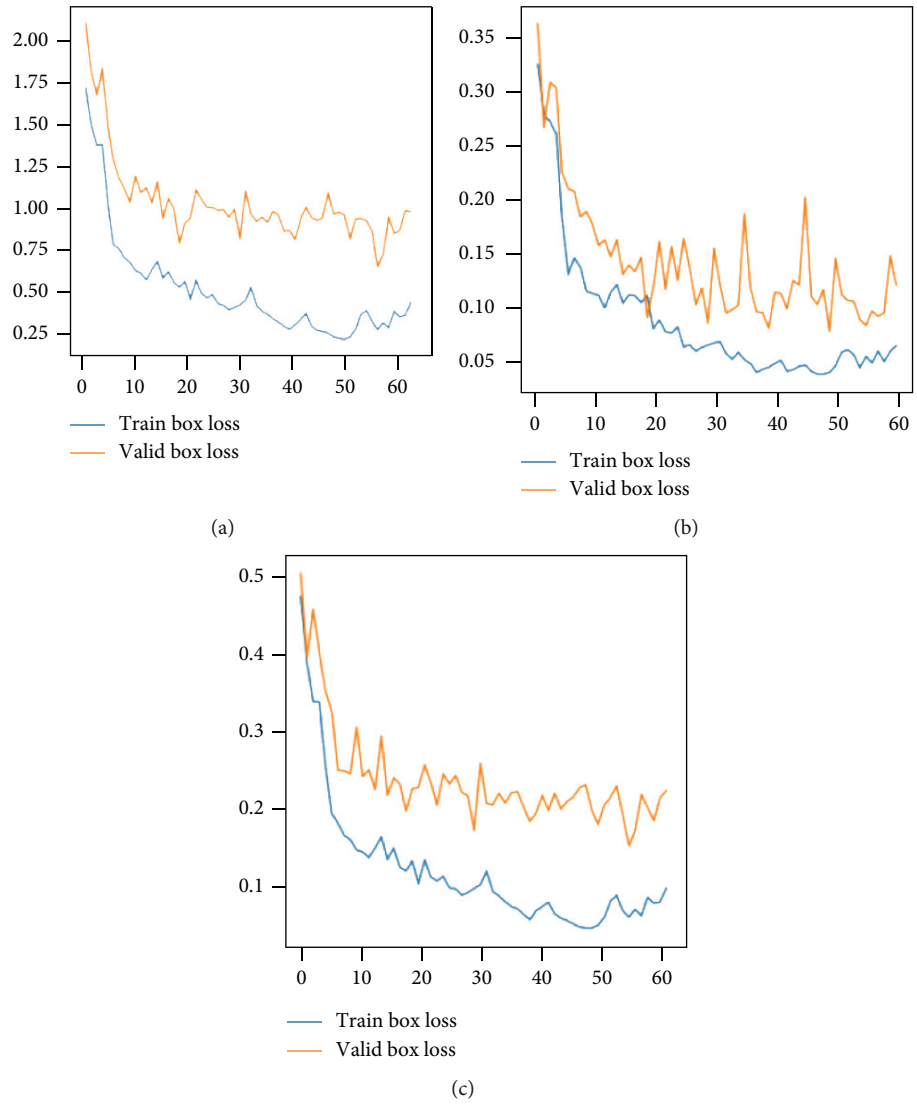

Figure 4: Metrics evolution: (a) total loss, (b) class, and (c) box loss of the model.

was Windows 10 and Ubuntu 18.4. In the final step, it was tested in the cloud (AWS) on instance p3.8large (4 GPU's Tesla V100, 64 GB GPU memory, instance memory: 244 GB, vCores of instance: 32), with the deep learning AMI using the virtual environment of conda tensorflow_p36.

The neural network consists of two main layers: object detection and classification, which is the support of the previous one and transfer learning.

The same Matterport Mask RCNN employed in our previous study was employed [9] in the object detection (Figure 2).

A ResNet101 was employed in the classification layer (Figure 3). The classification layer was the same as the previous study [9] although to improve the automatic teeth numbering a new classification level was included (COCO).

To take advantage of the precision in the location obtained in our previous study of tooth detection, it was decided to use transfer learning for this model and thus take advantage of all hyperparameters obtained. This contributed not only to a shorter training time but also to greater precision.

3. Results

3.1. Training Process. The goal of this study was to see the feasibility of correctly recognizing 32 different FDIs. Therefore, there were 33 classes (32 + background). However, employing the symmetries of the teeth in the quadrants, it was decided to work with 8 class + backgrounds, and later, a postprocess was added.

To train this neural network, 53 workouts were carried out with a minimum of 60 epochs and a maximum of 300 epochs. The duration of each execution was between 3 and 7 hours, depending on the epochs and the learning rates used in each one of them.

For each training/validation group, the learning rate and the number of epochs were varied. The number of epochs in each group varied between 4 and 20, and the learning rate was between 0.012 and 0.0014286. Depending on the chosen

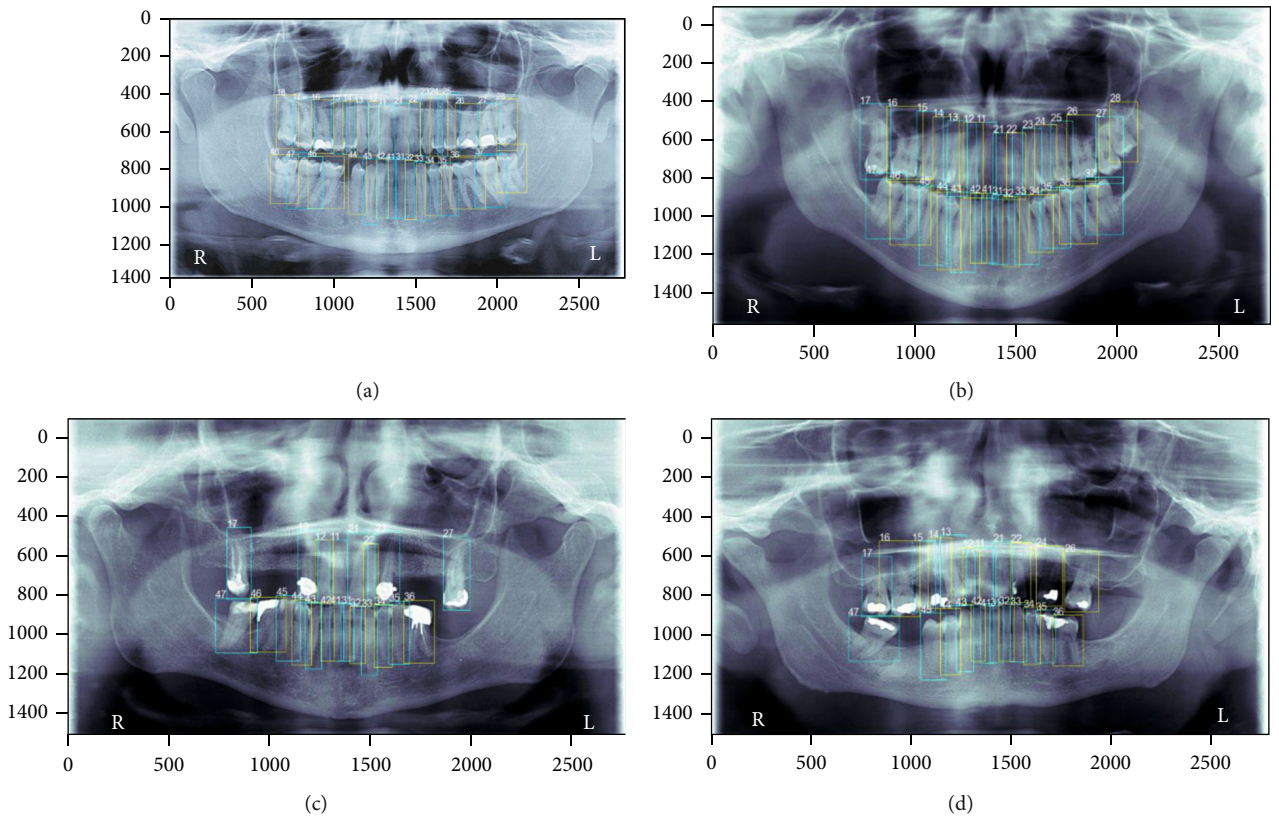

Figure 5: Tooth numbering: (a) image with all teeth; (b) image without teeth 46 and 36; (c) image with 21 teeth and some metallic parts; (d) image with 23 teeth and some metallic parts.

combination, and especially on the strategy applied in the selection of the validation group, it was possible to observe how many epochs to use.

3.2. Tooth Numbering Results. The neural model achieved a total loss of 6.17% (accuracy of 93.83%). This result was obtained with the parameters detailed in Table 2.

The evolution graphs of the selected metrics, both training set and the validation set, are shown in Figure 4. As can be seen in the deviation of the validation curves over the training ones in Figure 4, there is no overtraining. The blue line represents the training data's behavior, and the orange line represents the validation data's behavior.

3.3. Some Tooth Number Examples without Anomalies. Figure 5 shows the results of tooth numbering of two images without anomalies. Figure 5(a) shows a panoramic image with all teeth and without anomalies with a correct automatic numbering of each of the teeth. Figure 5(b) shows a panoramic image without anomalies but with the absence of two teeth with a correct automatic numbering of each of the teeth.

3.4. Some Tooth Number Examples with Anomalies. Figure 6 details some examples of the results provided by the neural network with some anomalies. Figure 6(a) is an image with 28 teeth with teeth absence detected. In this case, the absence corresponds to tooth number 36 and 46, and the absence of piece 36 is detected, but tooth 46 is not detected, and tooth 46 is numbered as 47. Figure 6(b) shows an example where the absence of 47 is detected, but nevertheless, the part exists. Figure 6(c) is an example in which wisdom teeth are not identified in the 1st and 4th quadrants. In Figure 6(d), tooth number 28 is not detected, and the pontic is considered as one piece.

4. Discussion

This study is aimed at building a convolutional neural network to number teeth using panoramic radiographs. A Matterport Mask RCNN, ResNet101, and a transfer learning from this model were employed to achieve the objective of having the best possible accuracy. The architecture of the model achieved an accuracy of 99.24% in tooth detection and 93.83% in numbering teeth.

The neural network employed in this study was first constructed to automatically detect the presence or absence of a tooth with an accuracy of 99.24%, according to a previous author's manuscript [9]. Therefore, it was modified to add a new task which is tooth numbering employing FDI classification.

Convolutional networks have extensively been applied with very good results in image recognition tasks in several fields as medical image analysis [11], mainly in tooth detection and numbering in dental radiographs.

Several published studies have analyzed dental images with image-processing algorithms to reach high accuracy in tooth classification. These algorithms employed to classify

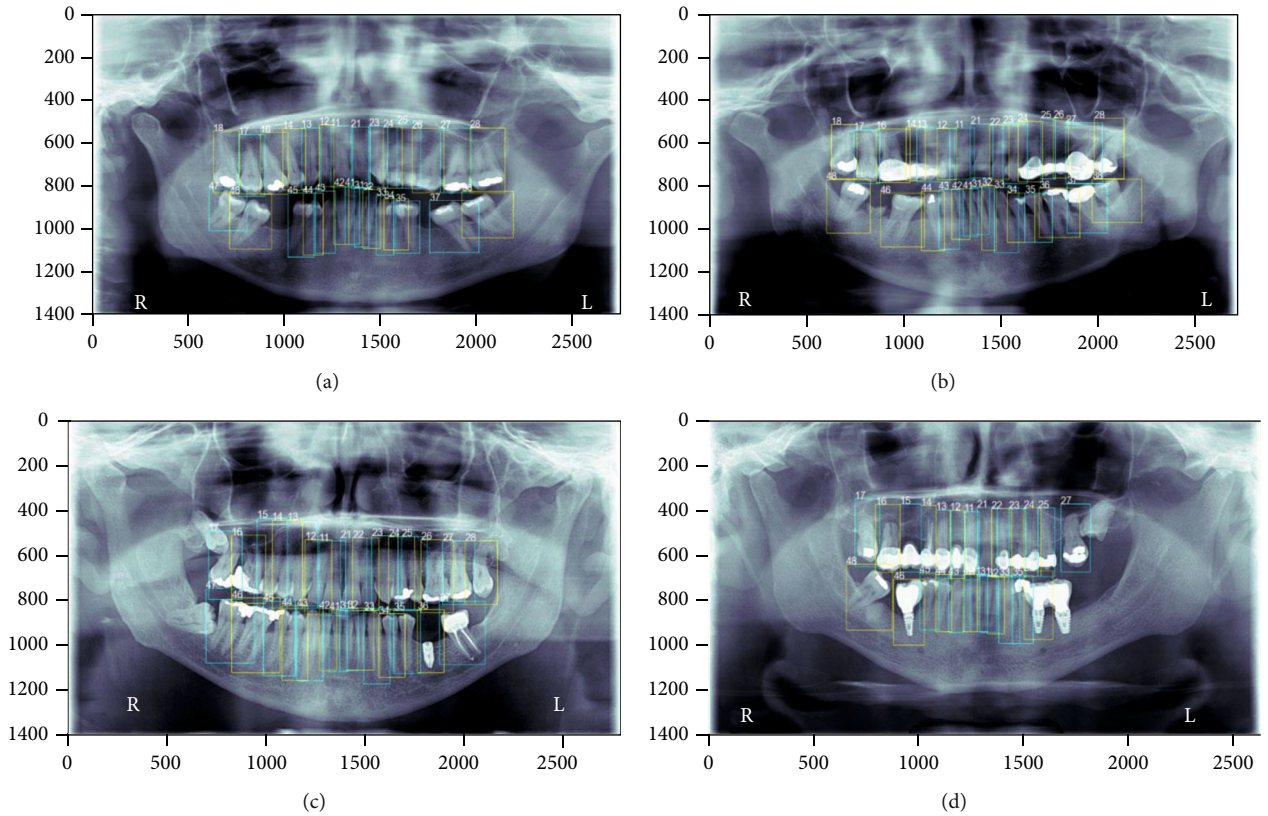

Figure 6: Tooth numbering: (a) image with 28 teeth with only one of the two teeth absence detected; (b) image with an absence tooth detected although the tooth exists; (c) image with two wisdom teeth not detected; (d) image with error tooth detection and pontic detected as one piece.

teeth are Fourier descriptors [12], textures [13], Bayesian techniques [12], among others.

Hosntalab et al. [4] employed multistage technique to classify teeth in multislice CT (MSCT) images. The algorithm employed had three stages: segmentation, feature, and tooth classification performed by a conventional supervised classifier. A difference with the architecture proposed in this study is that this study has two layers and a transfer learning. The main advantage between both studies is that the classification result in our architecture does not rely on the accuracy of hand-crafted feature extraction algorithms.

Bitewing images are commonly used to number a tooth employing artificial intelligence [5, 14]. Chen et al. [5] employed a faster R-CNN to number teeth in periapical images. The image database in this case was 1,250 images, and teeth were numbered following the FDI system. The precision of the neural network in detecting the tooth was 98.8%, but the precision in numbering the tooth boils down to 71.5%. As in our study, the precision in tooth detection is higher than in their numbering. However, our proposed network achieves greater precision in both tasks than the one proposed by Chen et al.

Yasa et al. [14] analyzed 1,125 bitewing images with a faster R-CNN with the goal of identifying and number teeth. The proposed neural network achieved a precision of 0.9293 in tooth numbering.

Tuzoff et al. [15] employed 1,574 anonymized panoramic radiographs to detect and number teeth according to the FDI notation with a faster R-CNN algorithm. The precision in this case was 99.41% in tooth detection, and a specificity is 0.9994 in teeth numbering.

Yuniarti et al. [16] used 16 images (6 bitewing and 10 panoramic) to detect and number teeth with a method that achieved an accuracy of 91.6% in detection and 81.5% in numbering.

Sathya and Neelaveni [17] identify and number teeth in radiographic images with a transfer learning approach using AlexNet with TL. This study achieved an accuracy on molar teeth of 94.16% and 94.06%, in premolars of 93.75% and 94.25%, in canines of 86.5% and 87%, and in incisors of 91.5% and 89.5% in maxilla and mandible, respectively.

Estai et al. [18] classify permanent teeth on 591 orthopantomogram images employing CNNs and achieved a precision of 0.99.

Bilgir et al. [19] developed a Faster R-CNN to automatically number teeth on a database of 2,482 panoramic radiographs. This study achieved a precision of 0.9652.

Orhan et al. [20] employed cone-beam computed tomography (CBCT) images to detect periapical pathosis.

The mains strengths of this study are the number of images analyzed, with a total of 5,121 X-rays, which were categorized by two experts with more than three years of experience in general practice. In this sense, it is important to take into account the concordance between examiners, detailed in the previously published manuscript [9]. In addition, our neural network was trained the model with natural roots, dental implants, filled teeth, endodontic treatments, among others, so most of the clinical situations are included.

Image database contains 8,000 panoramic images with a great variety of health conditions. However, some anomalies have been obtained. For example, some of the images showed the absence of several teeth, and the network correctly identified that those teeth were missing and obtained the correct numbering. However, in other cases, the network detected the absence of a tooth, but the numbering proposal was wrong. On the other hand, the network is capable of correctly numbering teeth that contain metal parts, or any other treatment performed on it such as filled teeth, but in the case of the prosthetic crown, it detects a single tooth. This is due to how the examiners selected these types of situations.

5. Conclusions

Based on the final accuracy achieved both in detecting and numbering teeth, it is possible to conclude that the convolutional neural network proposed can be used in real clinical practice. The architecture of the model achieved an accuracy of 99.24% in tooth detection and 93.83% in numbering teeth.

Data Availability

The image data used to support the findings of this study have not been made available because of patient privacy.

Conflicts of Interest

The authors declare no conflict of interest.

Authors' Contributions

All authors have read and agreed to the published version of the manuscript. M.P-P. and J.G.V. are responsible for the conceptualization and methodology; M.P-P., J.G.V., and A.B.T. for data curation; A.B.T. for software; M.P-P. for writing—original draft preparation; C.H.M-M. for writing—review and editing; M.P-P., J.G.V., C.H.M-M., and C.I. for visualization; C.I. for supervision; and C.H.M-M. and C.I. for funding acquisition.

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Research Article

The Teledentistry, Impact, Current Trends, and Application in Dentistry: A Global Study

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Objective. The present study was aimed at assessing the impact of teledentistry, its application, and trends in uplifting dental practice and clinical care around the world. *Material and Methods*. The present observational study comprised of an electronic survey distributed among dental professionals around the globe. The validated survey form consisted of a total 26 questions with 5-point Likert scale response. The questionnaire used was divided into four domains: usefulness of teledentistry for patients, its usefulness in dental practice, its capacity to improve the existing practice, and the concerns attached to its use. The statistical analysis was performed using SPSS-25. ANOVA test was used to assess the effect of independent variables on dependent variables. A p value of ≤ 0.05 was taken as statistically significant. *Results*. A total of 506 dental professionals participated in the study with the response rate of 89.39%. More than half of the participants (50-75%) endorsed that teledentistry is a useful tool for improving clinical practice as well as patient care. Two-thirds of the participants (69.96%) considered that teledentistry would reduce cost for the dental practices. On the other hand, about 50-70% of dental professionals expressed their concerns regarding the security of the data and consent of patients. The most preferred communication tool for teledentistry was reported to be videoconference followed by phone. The majority of participants recommended the use of teledentistry in the specialty of oral medicine, operative dentistry, and periodontics. There was a significant difference between the age, experience of dentists, and their qualifications with domains of teledentistry. *Conclusions*. The overall impact of dental professionals towards teledentistry was positive with adequate willingness to incorporate this modality in their clinical practice. However, the perceived concerns pertaining to teledentistry are significant impediments towards its integration within the oral health system. An in-depth study of its business model and cost-benefit needs of time, especially in the context of developing countries, in order to avail the optimum benefits of teledentistry.

1. Introduction

Since the advent of telehealth technology decades ago, the fields of medicine and dentistry have seen substantial scientific advances. The use of telehealth-associated modalities has transfigured diagnosis, therapies, and surgery in the field of dentistry [1]. In that regard, teledentistry (TD) is a form of telehealth utilizing a combination of telecommunications and dentistry, which involves the exchange of clinical information and relevant imaging over remote distances for consultation and treatment planning. Teledentistry is a novel field with a massive potential for uplifting clinical care and dental education with its innovative approach [2].

The first practical application of TD has its root in a US project launched in 1994 to assess the dental health of the servicemen of United States army [3]. The term TD was formally used for the first time in the literature by Cook in 1997. The initial description pertaining to TD was confined to videoconference and its associated role in consultation and diagnosis from long distance [4]. With rapidly improving technology in the 21st century, the term TD expanded its ambit to include the subdomains such telediagnosis teleconsultation, teletriage, and telemonitoring [5]. According to the American Dental Association, TD comprises of four basic modalities that include synchronous, asynchronous, remote patient monitoring, and mobile health. The synchronous modality utilizes virtual video call in order to facilitate real-time interaction between the dental practitioner and patient, while the asynchronous approach deals with diagnosis and examination through the transfer of data via videos, radiographs, and intraoral imaging [6].

The COVID-19 pandemic caused due to the spread of SARS-COV-2 virus has posed a menacing challenge to the healthcare systems across the world. Due to its transmission via droplets and air, the traditional face-to-face interaction between the dental practitioners and patient entails a risk of viral transmission [7]. In such circumstances, TD has proven itself to be a boon; it has circumvented the traditional face-to-face dentist-patient interaction by providing an effective substitute for the purpose of online consultation, exchange of investigations, and planning treatment [8]. Ample evidence has universally accepted TD as a viable modality that provides minimal cost, reduced stress of transportation, and better access to specialist practice [9].

Numerous studies have been conducted in various countries regarding the perceptions, effectiveness, and applications of TD at national level. Estai et al. assessed the perception of Australian dentists on the use of TD and concluded that an overwhelming majority of dentists (80%) agreed regarding the beneficial outcomes of using TD for both dentists and patients [10]. A Canadian study conducted by Palmer et al. showed similar results where the majority of orthodontists supported the use of digital and electronic technology in dental practice [11]. A recent questionnaire-based study carried out in Saudi Arabia reported that a substantial proportion of respondents agreed with the fact that TD would improve dental practice through enhancing communication with peers, guidance, and referral of new patients despite the concerns of data privacy and security [12].

So far, the current literature is devoid of a global survey that is focused upon assessing the usefulness of TD in provision of dental care. A study incorporating the impact of TD and current trends among dental practitioners at global stage needs to time in order to evaluate the application and effectiveness of TD in different countries and their respective dental healthcare systems. Therefore, the current study was aimed at evaluating the impact of TD, its application, and trends in improving dental practice and patient outcomes.

2. Materials and Methods

2.1. Study Setting and Ethical Consideration. The present study was approved by the ethical review committee of Altamash Institute of Dental Medicine, Karachi. The study was carried out at numerous countries.

2.2. Sample Size and Study Design. The sample size was calculated through OpenEpi software. Consider the usefulness of teledentistry for patients, with a mean score value of9.64 ± 4.26[12] and with a 95% confidence interval and the power of test 80%. The total estimated sample size was 506 participants. The study design was descriptive observational that comprised of convenient sample of 506 dental professionals.

2.3. Questionnaire Design and Distribution. An electronic and validated questionnaire was disseminated among the selected dental professionals between June and July of 2021 through e-mail and other social media applications (WhatsApp®, Facebook®, Instagram®, skype®, Imo messenger®, snapchat®, and LinkedIn®). The permission from dentists to participate in the study was sought out before the questionnaire dissemination. The dentists working in dental hospitals, clinics, and institutes were approached through phone calls and emails for this purpose. The questionnaire used in this study was adopted after a prior permission, from a similar study conducted in the Kingdom of Saudi Arabia by Al Khalifa and AlSheikh [12]. The questionnaire consisted of two parts related to participant's general information and different domains of teledentistry. The first part of the questionnaire covered professional, demographic information, and communication method preferences. The second part of the questionnaire was based on five-point Likert-type responses. This part was comprised of a total of 26 questions, which were further divided under four domains that encompassed: data security concerns by the dental professionals, teledentistry and practice improvement, the usefulness of teledentistry for dental practice, and its usefulness for dental patients.

There was a brief description of the questionnaire's purpose with a definition of teledentistry and its benefits and possible uses in daily practice. The consent agreement was incorporated within the questionnaire. The regular reminders (after an interval of week) were sent to the nonrespondents via e-mail and other social media networks, after initial distribution of the questionnaire. In response, 566 forms were received back from the participants, out of which

60 incomplete forms were excluded from the study. A total of 506 forms were included in the study.

2.4. Statistical Analysis. The SPSS-25 was used for statistical analysis. Descriptive statistics were performed for frequency, percentage, mean, and standard deviation of demographic variables; qualification of participants; experience; place of practice; and use of teledentistry in different specialties. ANOVA test was applied to see the effect of independent variables (age, gender, qualification, and years of experience) on dependent variables (domains of teledentistry). A p value of ≤ 0.05 was taken as statistically significant.

3. Results

This observational study consisted of 506 participants. The response rate of participation was 89.39%. There was 266 (52.56%) female and 240 (47.43%) males in this study. The age range of participants was from 20 to 64 years. There were 340 (67.2%) participants from 20- to 34-year age bracket, 133 (26.3%) belonged to 35 to 44 years, 13 (2.6%) were from 45- to 54-year age group, and 20 (4.0%) were from 55- to 64-year age bracket. Qualification-wise, the majority of the 259 (51.2%) participants were general dental practitioner, and 172 (34.0%) participants were consultant/-specialist. Regarding the experience, majority of the 306 (60.5%) participants had 1–5-year experience, 104 (20.6%) participants had 6–10 years' experience, and 55 (10.9%) participants had 11–15 years of experience.

In this study, the majority of the responses were recorded from South Asia 183 (36.16%), 65 (12.84%) from continental Europe, 87 (17.19%) from Western Asia, 34 (6.71%) from East Asia, and 29 (5.73%) from the United States of America as shown in Figure 1.

Furthermore, most of the dentists 247 (48.81%) worked in a private setup, while 122 (24.11%) worked in a public sector and the remaining 137 (27.07%) were working in academic institutes. In this study, majority of the respondents 191 (37.7%) worked 35–49 hours per week, whereas 170 (33.6%) worked 1–19 hours per week, and 118 (23.3%) worked 20–34 hours. Regarding the daily use of the internet in clinical practice, the majority 249 (49.2%) selected 2–4 hours, while 168 (33.2%) participants were using it for less than 1 hour.

Table 1 presents the concern of participants about data security and patient consent. In this regard, the majority of the 410 (81.02%) participants were concerned about gaining patient consent, whereas 54 (10.7%) were not feeling either way. However, most of the 471 (93.08%) respondents were concerned about the confidentiality of online data sent by patients but 28 (5.53%) were not concerned. When asked about digital forgery, more than three-fourths (79.64%) of the participants were concerned about it and 35 (6.91%) were not concerned about digital forgery. Furthermore, the majority of the 436 (86.16%) participants were concerned about hardware and software incompatibility in teledentistry, although 28 (5.53%) were not concerned about it. Regarding the reliability of teledental equipment, many of the 436 (86.16%) participants were concerned about it; however, a small number of 14 (2.76%) participants were not concerned.

Table 2 shows the responses on impact of teledentistry to improve dental practice. In this regard, the majority of the 256 (50.6%) participants were not in favor of teledentistry used for clinical diagnosis, whereas about one-fourth (25.29%) of the participants disagreed. Furthermore, more than three-fourths (79.64%) of the participants agreed that teledentistry would help shorten their clinic waiting list, whereas a small number of 47 (9.28%) respondents disagreed. Regarding the question about teledentistry capability to enhance dental guidelines and advice, the majority of the 342 (67.58%) participants were in favor of it, but less than one-fourth (22.9%) were not feeling either way. However, most of the 326 (64.42%) participants agreed that teledentistry will improve the interaction between peers, although 55 (10.86%) disagreed on it. Concerning that teledentistry would provide a safe atmosphere for practicing dentistry (e.g., COVID-19 pandemic), majority of the 416 (82.21%) participants agreed on it but a small number of the 28 (5.53%) participants disagreed. Additionally, more than two-thirds (71.73%) of the participants agreed that teledentistry would make patient's referral more efficient, although 61 (12.05%) disagreed on this.

Table 3 describes the application and usefulness of teledentistry in dental practice. Out of 506 participants, more than half of the participants (51.18%) agreed that teledentistry would enhance clinical training and continuing dental education, while 82 (16.2%) disagreed, and 165 (32.6%) were neutral about that. Regarding cost-effectiveness, the majority of the 354 (69.96%) participants agreed that the teledentistry would reduce costs for the dental practices, while 35 (6.9%) disagreed on it. Concerning teledentistry, it would increase treatment time spent with the patient; most of the 272 (53.75%) participants agreed on it. However, less than one-fourth (17.58%) disagreed. With reference to the question of teledentistry that would necessitate an extra appointment for taking photographs, the majority of the 300 (59.28%) contestants agreed, whereas 96 (18.97%) disagreed. Regarding the inquiry that teledentistry would save time compared with a referral letter, the majority of the 355 (70.15%) participants agreed on it, but a small number of 35 (6.91%) have disagreed. The concern on setup and backup of teledentistry by participants depicted that about 124 (24.50%) dentists believed that it would be an expensive option; however, the majority of the 200 (39.52%) disagreed. Lastly, whether teledentistry would be an adequate diagnostic tool in clinical practice, less than half (40.11%) of the participants agreed, and surprisingly, 193 (38.1%) were neutral.

Table 4 illustrates the application and usefulness of teledentistry for patients. The majority of the 300 (59.28%) participants agreed that teledentistry would save money for patients, while 68 (13.43%) disagreed. Furthermore, most of the 320 (63.24%) participants agreed that teledentistry would improve communication with patients, and 62 (12.25%) have disagreed. However, more than two-thirds (76.67%) of the participants agreed that teledentistry would be helpful for patient education; however, 49 (9.68%) participants disagreed. Moreover, the majority of the 423 (83.59%)

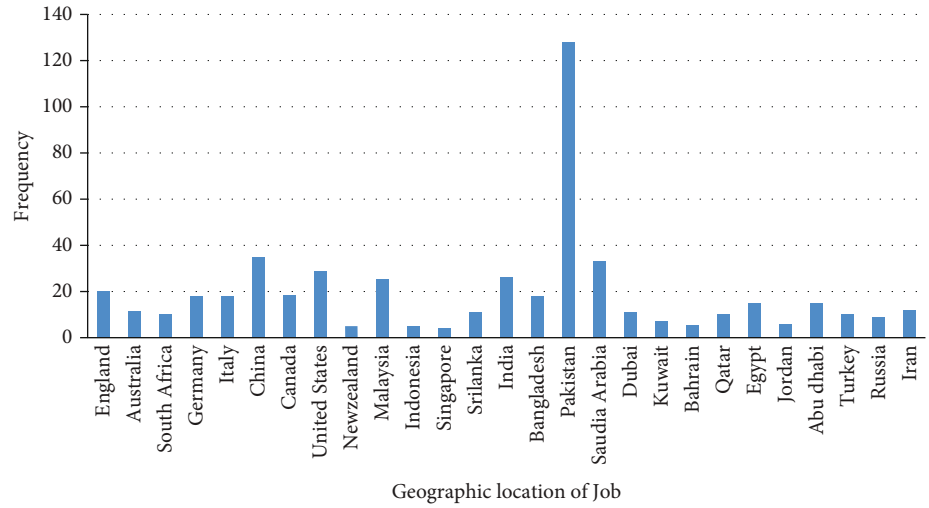

Figure 1: Distribution of responses from different countries.

Table 1: Distribution of responses concerning about data security and patient consent among participants ($n = 506$).

S.no	Item	Very concerned n%	Little concerned n%	Not feeling either way n%	Not particularly concerned n%	Not concerned at all n%
1.	Gaining patient consent for teleconsultation	295 (58.3)	115 (22.7)	54 (10.7)	21 (4.2)	21 (4.2)
2.	Confidentiality when data are sent online	337 (66.6)	134 (26.5)	7 (1.4)	7 (1.4)	21 (4.2)
3.	Potential for digital forgery	303 (59.9)	100 (19.8)	68 (13.4)	21 (4.2)	14 (2.8)
4.	Incompatible hardware and software	272 (53.8)	164 (32.4)	42 (8.3)	7 (1.4)	21 (4.2)
5.	Reliability of teledental equipment	264 (52.2)	172 (34.0)	56 (11.1)	7 (1.4)	7 (1.4)

Table 2: Distribution of responses about the impact of teledentistry to improve practice ($n = 506$).

S. no	Item	Disagree strongly n%	Disagree n%	Neutral n%	Agree n%	Agree strongly n%
1	Teledentistry would help in patient diagnosis	33 (6.5)	95 (18.8)	256 (50.6)	102 (20.2)	20 (4.0)
2	Teledentistry would help shorten the waiting list	7 (1.4)	40 (7.9)	56 (11.1)	363 (71.7)	40 (7.9)
3	Teledentistry would enhance dental guidelines and advice	7 (1.4)	41 (8.1)	116 (22.9)	295 (58.3)	47 (9.3)
4	Teledentistry would improve the interaction between peers	7 (1.4)	48 (9.5)	125 (24.7)	265 (52.4)	61 (12.1)
5	Teledentistry would provide a safe atmosphere for practicing dentistry (e.g., COVID-19 pandemic)	7 (1.4)	21 (4.2)	62 (12.3)	278 (54.9)	138 (27.3)
6	Teledentistry would make patient's referral more efficient	7 (1.4)	54 (10.7)	82 (16.2)	274 (54.2)	89 (17.6)

participants agreed that teledentistry would help to avoid unnecessary travel to dental clinic, but a small number of 28 (5.53%) participants disagreed. More than two-thirds (69.16%) of the participants agreed that teledentistry would be helpful in monitoring the patient's condition, whereas 61 participants (12.05%) disagreed. Additionally, 244 (48.22%) participants agreed that teledentistry would be convenient and well received by patients, 68 (34.43%) disagreed, and 194 (38.3%) were neutral. Nevertheless, the majority of the 342 (67.58%) participants agreed that teledentistry would be useful for patients in remote areas, with 35 (6.91%) participants who disagreed with it. Lastly, more

Table 3: Application and usefulness of teledentistry for dental practice ($n = 506$).

S. no	Item	Disagree strongly n%	Disagree n%	Neutral n%	Agree n%	Agree strongly n%
1	Teledentistry would enhance clinical training and continuing education	7 (1.4)	75 (14.8)	165 (32.6)	210 (41.5)	49 (9.7)
2	Teledentistry would reduce costs for the dental practices	7 (1.4)	28 (5.5)	117 (23.1)	284 (56.1)	70 (13.8)
3	Teledentistry would increase treatment time spent with the patient	7 (1.4)	82 (16.2)	145 (28.7)	230 (45.5)	42 (8.3)
4	Teledentistry would necessitate an extra appointment for taking photographs	14 (2.8)	82 (16.2)	110 (21.7)	273 (54.0)	27 (5.3)
5	Teledentistry would save time compared with a referral letter	7 (1.4)	28 (5.5)	116 (22.9)	307 (60.7)	48 (9.5)
6	Teledentistry would be too expensive to set up	14 (2.8)	186 (36.8)	182 (36.0)	82 (16.2)	42 (8.3)
7	Teledentistry would provide sufficient information about patient illness	28 (5.5)	82 (16.2)	193 (38.1)	163 (32.2)	40 (7.9)

Table 4: Application and usefulness of teledentistry for patients ($n = 506$).

S. no	Item	Disagree strongly n%	Disagree n%	Neutral n%	Agree n%	Agree strongly n%
1	Teledentistry would save money for patients	14 (2.8)	54 (10.7)	138 (27.3)	279 (55.1)	21 (4.2)
2	Teledentistry would improve communication with patients	32 (6.32)	30 (5.92)	124 (24.5)	272 (53.8)	48 (9.5)
3	Teledentistry would be helpful patient education	24 (4.74)	25 (4.94)	69 (13.6)	320 (63.2)	68 (13.4)
4	Teledentistry would help to avoid unnecessary travel to dental clinic	8 (1.58)	20 (3.95)	55 (10.9)	320 (63.2)	103 (20.4)
5	Teledentistry would be helpful in monitoring the patient's condition	7 (1.4)	54 (10.7)	95 (18.8)	322 (63.6)	28 (5.5)
6	Teledentistry would be convenient and well received by patients	34 (6.71)	34 (6.71)	194 (38.3)	188 (37.2)	56 (11.1)
7	Teledentistry would be useful for patients in remote areas	16 (3.16)	19 (3.75)	129 (25.5)	191 (37.7)	151 (29.8)
8	Teledentistry should be covered by dental insurance plans	24 (4.74)	24 (4.74)	199 (39.3)	204 (40.3)	55 (10.9)

than half of the participants (51.18%) agreed that teledentistry should be covered by dental insurance plans, but few of the 48 (9.48%) participants have disagreed.

Table 5 presents the ANOVA test analysis. The analysis showed the statistical significance of the study participants' age, gender, qualification, and work experience with domains of teledentistry. The dentists that belonged to various age groups had a difference in opinion regarding patient's security and consent (ANOVA test; p value = 0.001), impact teledentistry on dental practices (ANOVA test; p value = 0.001), usefulness of teledentistry for patients (ANOVA test; p value = 0.015), and efficiency of teledentistry in dental clinics (ANOVA test; p value = 0.035). Similarly for qualification, a significant difference was found with all four domains of teledentistry studied (ANOVA test; $p = 0.003$, $p = 0.001$, $p = 0.004$, and $p = 0.001$), respectively. The consultants, general dentists, and resident dentists scored lower in data security and patient consent than other domains. As for work experience in years, data security and patient consent, teledentistry impact to improve dental practice and application, and usefulness of teledentistry for patients were statistically significant (ANOVA test; $p = 0.002$, 0.027, and 0.006). This could be explained by observing the mean scores between the groups, where all the experience groups scored less in data security and patient consent domain of teledentistry. On the other hand, there was no statistical significance (ANOVA test; $p > 0.05$) between gender and all domains of teledentistry.

Figure 2 shows the preferred communication tool for teledentistry. The most preferred methods of communication were videoconference 127 (25.09%), phone 124 (24.50%), social media 101 (19.96%) (WhatsApp®, Facebook®, Instagram®, skype®, Imo messenger®, snapchat®, and LinkedIn®), and in person or face to face 87 (17.19%).

Figure 3 demonstrates the use of teledentistry in respect to different dental specialties. The majority of participants 92 (18.18%) recommended the use of teledentistry in the specialty of oral medicine. Teledentistry use was recommended in operative dentistry, the second highest by the participants 60 (11.85%). In periodontics, it was suggested by 55 (10.86%), whereas in pedodontics, 54 (10.67%) participants opted for the use of teledentistry.

4. Discussion

Due to the current ongoing SARS-CoV-2 pandemic, teledentistry is becoming an increasing option which is proving to be beneficial to both the patients and dentists, for their

Table 5: Comparison of independent variables with domains of teledentistry among participants ($n = 506$).

Variable	Data security and patient consent Mean (SD)	Capability of teledentistry to improve dental practice Mean (SD)	Usefulness of teledentistry for dental practice Mean (SD)	Usefulness of teledentistry for patients Mean (SD)
Age (years)				
20–34	7.81 ± 3.91	21.36 ± 4.63	23.87 ± 5.96	28.64 ± 6.64
35–44	9.66 ± 6.28	22.19 ± 5.44	23.44 ± 6.53	30.48 ± 6.29
45–54	9.82 ± 4.64	24.6 ± 5.14	24.76 ± 3.07	28.76 ± 3.07
55–64	5.65 ± 0.48	24.8 ± 3.86	25.4 ± 3.87	32.6 ± 1.92
p value	0.001**	0.001**	0.035*	0.015*
Gender				
Female	7.64 ± 3.68	21.84 ± 4.85	23.99 ± 6.21	29.26 ± 6.69
Male	9.9 ± 6.57	21.67 ± 5.42	23.47 ± 6.14	29.55 ± 5.88
p value	0.103	0.771	0.208	0.181
Qualification				
Consultant/ specialist	7.8 ± 4.17	23.09 ± 5.04	24.76 ± 6.42	30.41 ± 6.06
General dental practitioner	8.43 ± 5.06	21.15 ± 4.6	23.52 ± 5.96	29.14 ± 6.49
Resident/ graduate research	8.93 ± 4.98	21.04 ± 5.25	22.54 ± 5.82	27.54 ± 6.22
Other	7.99 ± 2.05	20.99 ± 1.02	24.13 ± 2.05	27.58 ± 3.59
p value	0.003**	0.001**	0.004**	0.001**
Work experience (in years)				
1–5	7.56 ± 3.73	21.34 ± 4.54	23.88 ± 6	28.9 ± 6.57
6–10	10.01 ± 6.19	22.07 ± 5.9	23.67 ± 5.84	29.35 ± 6.84
11–15	9.18 ± 5.78	23.48 ± 3.85	24.03 ± 4.52	30.81 ± 5.73
More than 16	7.87 ± 4.15	22.14 ± 6.13	24.78 ± 6.51	30.37 ± 3.93
p value	0.002**	0.027*	0.087	0.006**

*p value ≤ 0.05; **p value < 0.000; SD: standard deviation.

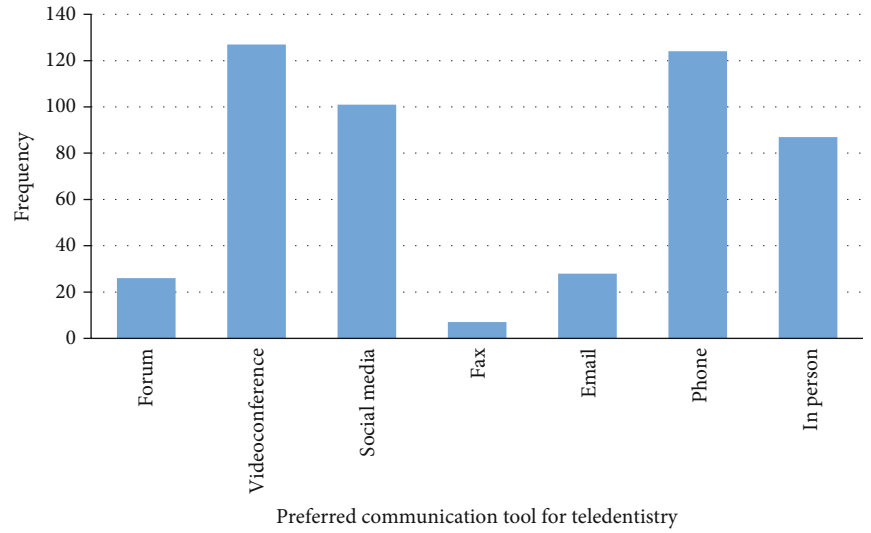

Figure 2: Distribution of preferred teledentistry communication tool among participants ($n = 506$).

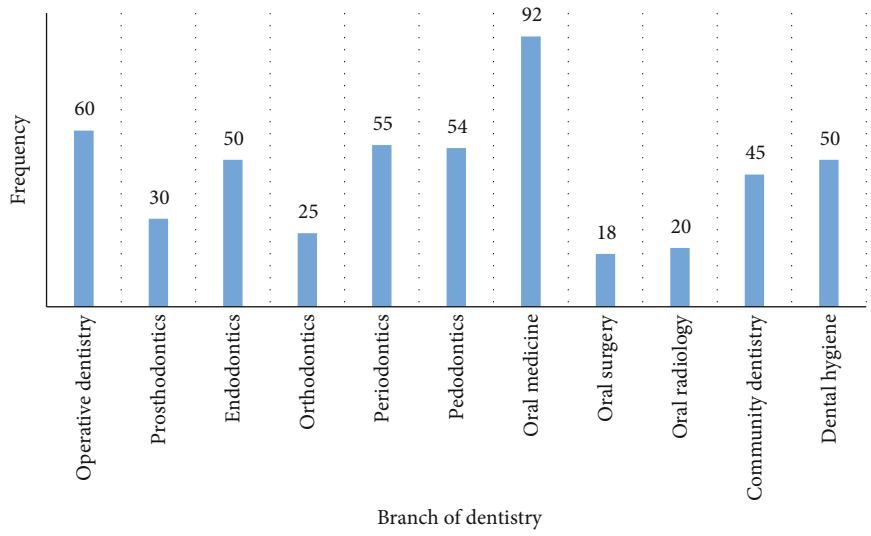

Figure 3: Distribution of teledentistry use in different dental specialties.

own protection. Teledentistry is capable of improving patient's access to oral health and improves delivery of oral health care and perhaps at lower costs as well [13]. Furthermore, teledentistry can also act to bridge the gap between urban and rural healthcare as well.

In this study, the majority of the participants were concerned about patients' personal data being shared over the internet, as their patients were found more comfortable sharing their data in person with dentists. These results correspond with a study with similar results about the concerns for data privacy [14]. For professionals, there is a lot of difference between teledentistry and traditional face-to-face appointments. So, the majority of the participants expressed their concern regarding their clinical diagnosis given by them using the teledentistry platform. However, these results contrast with a study where the majority (80%) of the consultants gave accurate diagnoses using teledentistry [15].

Due to the mode of transmission of COVID-19, a large number of dentists agreed that teledentistry is a safe environment to perform dentistry. These results were coinciding with study literature where dentists reported their readiness in performing teledentistry [12]. Regarding continuing clinical practice and dental education, the majority of the dentists agreed that teledentistry is useful [16]. Moreover, the majority of the dentists agreed that teledentistry is a cost-effective method for consultations, which corresponds to a study by Estai et al. [17]. This is primarily due to a smaller number of resources being used to perform teledentistry as compared to traditional appointments.

Since there are different equipment required for teledentistry, it was found in our study that appointment timings, as well as extra appointments, might be needed for patients. However, these results contrast in literature where it was found that teledentistry reduces the number of face-to-face

appointments with the patients [18]. Concerning the different equipment required for teledentistry, many agreed to it being a less expensive tool. This could be due to the fact that almost all of the people are equipped with mobile phones and internet connection that is required for teledentistry [19]. Keeping in mind the current pandemic situation, the majority of the participants agreed that teledentistry is a better option than visiting a dental clinic and monitoring the patient's condition as well. This might be due to the anxiety related to contracting coronavirus when visiting the clinics [20].

Teledentistry can be particularly useful in remote areas which might not be accessible due to the lockdown situation imposed by governments worldwide. Furthermore, educating patients about their treatment and diagnosis is a vital part of their appointments with doctors. The majority of the participants agreed that teledentistry is a useful tool for patient education. These findings correlate with studies in literature where teledentistry can be beneficial for not only patient education but for dentists and dental students as well [21]. Teledentistry can be used by different dental specialties according to their use. In our study, we found that oral medicine, followed by operative dentistry, and periodontics had its most use of teledentistry. This could be due to a greater number of patients presenting with dental problems that require these specialists.

Teledentistry can be performed using many platforms such as mobile phones, video conferencing, and social media. In our study, we found that video conferencing was the most preferred method followed by phone, although few participants stated that face-to-face appointments are a better option. This could be due to a lack of awareness of the use of technology and the unavailability of tools required for teledentistry [22].

Despite the strengths of this study such as the inclusion of dentists globally, it has some limitations. Firstly, the self-administered questionnaires are prone to self-reported biasness. Lastly, the dentists working in the rural areas can be considered which could provide a better view of teledentistry in such localities.

To help manage the patients in a better way, teledentistry is becoming an emerging way for dentists to treat their patients keeping in mind the current COVID-19 pandemic. Dentists, as well as healthcare professionals, should be taught how to use teledentistry by conducting programs such as continuing dental education and awareness programs to benefit both the dentists and the patients.

5. Conclusion

The present study described that the dental professionals participated in this study have adequate insight and a positive attitude towards the application of teledentistry. Hence, dental professionals can be engaged in the teledentistry approach. However, the study participants showed technical perception, ethical consideration, and patient security concerns towards teledentistry. Although teledentistry is an area of expansion, there are still some barriers to its use. In particular, further research is required on the optimum modalities and the costs and benefits. With this study's limitation, further investigation is needed to understand the implementation and challenges of dental institutes and practitioners.

Data Availability

The raw data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare no conflict of interest.

Authors' Contributions

AM, MSK, DM, and MKA planned and designed the present work and AM, NA, and MSK were responsible for realizing the work. NA, AM, and AL were responsible for the data acquisition and analysis. AM, MSK, AL, MSH, and DM drafted and revised the manuscript. NA, AM, and MKA approved the final version of the manuscript. All authors read and approved the final manuscript. MSH and MKA contributed equally to this work and are corresponding authors.

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Research Article

Teledentistry as a Supportive Tool for Dentists in Pakistan

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The current scenario of the COVID-19 pandemic has forced dentists to seek different options for delivering healthcare services other than the in-person direct examination in clinical practice. Teledentistry is one of the options for remote patient care and monitoring. *Objective*. The present survey was conducted to assess the knowledge and perception of the dentists in Pakistan regarding teledentistry as an emergent supportive tool. *Materials and Methods*. A self-administered, close-ended, and prevalidated survey questionnaire was used, comprising 21 questions, and distributed electronically via e-mail, WhatsApp, and Facebook Messenger to evaluate the knowledge and perception of dentists regarding teledentistry. The data collected was compiled in a systematic manner and analyzed in terms of frequency (yes/no). *Results*. Out of a total of 350 dentists, 325 responded to the questionnaire, and it was seen that 62.5% of them did not have knowledge about teledentistry prior to COVID-19. 65.8% of dentists considered the practice of teledentistry in nonpandemic situations in the future. *Conclusion*. In the present study, it was observed that most of the dental professionals had inadequate knowledge about teledentistry before COVID-19, but the awareness and perception regarding teledentistry were currently satisfactory among the dental professionals in Pakistan. This emerging trend gives a positive hope for the implementation of teledentistry in the healthcare setup of Pakistan in the near future, as it will prove to be beneficial for safe dental practice during times of pandemic and even after.

1. Introduction

At the beginning of the year 2020, a pandemic emerged affecting the entire world. The healthcare system has been critically affected with the rise of COVID-19, which has created a global healthcare concern that greatly halted the normal healthy lifestyle of the patients as well as dentists. Dental treatment invariantly involves close inspection, examination, diagnostic, and therapeutic interventions of the patient's oronasal-pharyngeal region. Therefore, the dental professionals are at high risk of acquiring infection with COVID-19 [1]. During the COVID-19 pandemic, routine dental treatments have been interrupted, and only critical dental procedures and surgeries are being performed.

However, looking at the widespread situation created by COVID-19, this seems that it will not end anytime soon. In fact, the WHO feared that the COVID-19 virus will never go away and will become endemic in our communities [2]. Along with all other health issues, dental practice is also affected, so there is a need of restructuring and introducing new modernized electronic methods of healthcare delivery to pursue dental care with minimal risk of transmission of disease and cross-infection. In addition to these, the primary concern of dentists during the pandemic is the infection control practices and the demand to maintain standard precautions in the care of dental patients, during and even after the period of this pandemic [3].

The term "telehealth" is given to public health and healthcare services, conveyed with the aid of information

technology and communication to provide healthcare at a site distant to the patient to facilitate patient consultation, diagnosis, self-care, and treatment planning. Teledentistry is a subtitle of telehealth which facilitates dental care at a distance with the aid of information technology and communication. Legal and professional obligations in all dental practices that apply to in-clinic care also apply to teledentistry [4].

In addition, dental care is being transformed gradually due to the opportunities provided by the technology. Teledentistry is progressing rapidly with the increased incidence of COVID-19 [5]. In 1997, Cook defined teledentistry as "the practice of using video-conferencing technologies to diagnose and provide advice about dental treatment over a distance" (see [6]).

Teledentistry is not only based on telecommunication but also involves the exchange of clinical information and data. Also, it is important to understand how dentists perceive teledentistry as a supportive tool during the pandemic crisis and how this may affect their future practice of teledentistry, particularly with infection control.

Teledentistry in the current scenario of COVID-19 focuses on "dental triage," the relief of pain or infection, provision of dental care by remote consultation, planning, and scheduling of definitive dental treatment. Technological advances have the potential to improve the current scenario of routine dental practice. It has a variety of uses that include the following:

(1) Help improve oral healthcare access to the patients

(2) Improve the oral healthcare delivery

(3) Help for under-served populations

(4) Increase specialist availability

(5) Economic and time saving

Teledentistry as a method of diagnosis and treatment planning includes all branches of dentistry [7]. Berndt et al. carried on a survey on unprivileged and deprived children, wherein orthodontic treatment was being surveilled from a distance with optimistic results using teledentistry [8]. Another study by Park et al. specified that the advancements and availability of information technology could lead to the use of telemedicine in oral and maxillofacial surgery [9]. Lienert et al. stated that telemedical services were found to be beneficial for dental trauma-related cases in a Swiss telemedical center and proved to be valuable where a specialty dentist was not available [10]. Snow et al. observed that teledentistry permitted distant, cost-effective, and specialist dental consultations for rural Australians [11]. If the projections on the shortages of dentists in the next decade come to pass, teledentistry will be important not only for rural areas but also for our urban and suburban populations [12]. Interprofessional communications will improve dentistry.

However, the research conducted in Pakistan on teledentistry is limited among the dentists for the evaluation of knowledge and awareness regarding teledentistry. Hence, the present study was conducted among the dentists to assess their knowledge and perception regarding teledentistry, provided as a supportive tool for patients' healthcare needs.

2. Materials and Methods

2.1. Study Design and Population. The present study was conducted in a time span of 4 months, between September 2020 and December 2020. The study population comprised 350 dentists from all the 9 specialties of dentistry currently working in Pakistan. Participants of the study included dentists with postgraduate qualifications, consultants and specialists, undergraduate dentists that included trainees and demonstrators, general dentists, and interns from private and government sectors of Pakistan. The respondents were chosen through nonprobability purposive sampling.

2.2. Ethical Approval. As this was a questionnaire-based awareness and perception study, an exemption for ethical approval was taken from the Institutional Review Board. A written informed consent was obtained from all the dentists to whom the questionnaire was circulated.

2.3. Data Collection and Analysis. A self-administered, close-ended, and prevalidated questionnaire, consisting of 21 questions to inquire about dentists' sociodemographic information, knowledge, and perception of dentists regarding teledentistry, was administered [13]. The questionnaire was distributed by a single investigator. The investigator sent the questionnaire using e-mail, WhatsApp, and Facebook Messenger, which was to be filled and submitted online. The questionnaire comprised three parts which included the following:

(i) *Part 1*: sociodemographic details

(ii) *Part 2*: questions relating to knowledge regarding teledentistry use during COVID-19

(iii) *Part 3*: questions relating to perception of dentists regarding teledentistry as a supportive tool during COVID-19

The data was collected, compiled, arranged in a systematic manner, and analyzed in terms of frequencies (yes/no) using SPSS Version 26.

2.4. Inclusion and Exclusion Criteria. Inclusion criteria for this study were as follows:

(i) Registered dentists with at least a Bachelor of Dental Surgery degree, practicing in Pakistan

(ii) Dentists involved in direct dental care of patients

Exclusion criteria for this study were as follows:

(i) Dentists not registered with the Pakistan Medical Commission

(ii) Dentists unwilling to participate in the survey

(iii) Dentists not responding on the predecided dates (September–December 2020) of the study

3. Results

The questionnaire was circulated amongst a total of 350 dentists from all the specialties of dentistry in Pakistan, out of which 325 dentists responded and gave their consent to participate in the survey. The response rate was 92.8%.

Demographically, the ratio of male-to-female respondents was almost equal (53.5% and 46.5%, respectively). Majority of the respondents were from the age group of 25-34 years old (55.1%), with the 18-24-year-old bracket coming in second (26.2%). Therefore, a vast majority of this study's population was based on the younger lot (Table 1).

Table 1: Sociodemographic characteristics.

Sample characteristics	Frequency (%)
Age (years)	
18-24	85 (26.2)
25-34	179 (55.1)
35-44	31 (9.5)
45-54	16 (4.9)
55-64	9 (2.8)
>65	5 (1.5)
Gender	
Male	174 (53.5)
Female	151 (46.5)

It was observed that 62.5% of the dentists did not have knowledge about teledentistry prior to COVID-19, but currently, the majority of them know about teledentistry (68.6%). The general awareness regarding teledentistry was satisfactory among the participants, as can be seen in the response rates in Table 2.

89.2% of dentists believe teledentistry could be useful in facilitating access to oral healthcare during the pandemic, but 65.8% of dentists agreed to practice teledentistry in a nonpandemic situation as well. A relatively high response rate was achieved for whether teledentistry can be added to routine dental practice, with 68.9% of dentists answering in an affirmative.

About 85.8% of the dentists would recommend the government to take the initiative whereby patients could obtain treatment needs from a central facility connected via teledentistry, but at the same time, 47.4% of dentists considered teledentistry not to be a convenient and supportive tool in Pakistan due to the country's major challenges of illiteracy, population below the poverty line, and lack of infrastructure.

4. Discussion

The present cross-sectional study unveiled a topic that earned considerable interest in relation to dynamic advancement in dentistry (teledentistry) among dentists in Pakistan during COVID-19. Teledentistry is not a notion new to mankind and has been developing since 1994, but there have been major new advancements over the years in the field of dentistry. Delivering oral healthcare to the patients has dramatically been influenced during the pandemic, with dentistry considered as a very risky profession in present circumstances. Droplets and aerosols generated during dental procedures, being the main source of transmission, endanger the dental practitioners. Teledentistry during the time of COVID-19 is the only reliable way to provide consultation and treatment using technology [14]. Teledentistry allows long-distance communication by avoiding person-to-person contact, observing social distancing, permitting exchange of clinical information and images, and facilitating remote dental care, patients' education, and guidance which is recommended by healthcare authorities across the world.

The current literature highlights the significance of teledentistry. Teledentistry has numerous subdivisions such as teleconsultation, telediagnosis, telemonitoring, and teletriage, each having important functions relevant to dental practice. Teleconsultation assists in reducing noncritical patient referrals, thus lowering the burden on already strained healthcare systems. Telediagnosis helps in the use of technology to exchange patient records, intraoral images, and radiographic images to diagnose oral diseases remotely [15]. Teletriage emphasizes on patients requiring urgent dental care following remote evaluation of oral health, minimizing the need of nonessential travel, keeping in view the pandemic situation [16].

Teledentistry can benefit both the dentists and patients, but somehow, insufficient data is available concerning dentists' perception about adopting it in Pakistan. This was the main purpose of our study, and the general observation arising from our data is that dentists appreciate teledentistry for its capability to improve patient care and enhance oral health practices, which is unanimous to a similar survey conducted in Canada, where the majority of the dentists were in support of the use of teledentistry in better healthcare delivery [17]. Our results showed that a very small percentage (37.5%) of the dentists had knowledge about teledentistry before COVID-19, but a vast majority (86.8%) were aware that it is the practice of use of computers, internet, and technologies to diagnose and provide advice over a distance. Similar results were seen in surveys conducted in the US, India, and Rwanda, where awareness about teledentistry among dental professionals was very high [18–21].

The role of teledentistry has also been seen and assessed in dental education [8, 22]. In this study, almost 89.5% of dentists agreed on upgradation and implementation of health education by teledentistry. A survey about teledentistry in India observed that 58% of dentists agreed with the statement that teledentistry is good for dental education and training over internet [23]. A study carried out in 2015 stated that 50% of the practicing dentists agreed on the execution of health education by teledentistry [5]. Two main categories of health education by teledentistry are self-instruction and video conferencing. Latif et al. reported in a study in 2016 that the last seminar conducted by the E-Health Association of Pakistan was in 2011, and to date, no further advances have been made in this field [24].

In our study, 63.4% of dentists believe that teledentistry helps in reducing costs for dental practices. 59.7% of respondents in a study carried out in India agreed teledentistry reduces costs for dental practice [13]. A study conducted

Table 2: Responses in knowledge, awareness, and attitude-related questions.

	Knowledge, awareness, and attitude-related questions	Yes (%)	No (%)
Q1	Have you heard about teledentistry before COVID-19?	37.5	62.5
Q2	Do you know what teledentistry is?	68.6	31.4
Q3	Do you think teledentistry is about the practice of use of computers, internet, and technologies to diagnose and provide advice over a distance?	86.8	13.2
Q4	Can teledentistry help to consult with an expert about a specific patient's problem?	87.1	12.9
Q5	Can teledentistry help to monitor the patient's oral health in order to avoid dental visits?	71.1	28.9
Q6	Do you think that teledentistry should be a part of dental education training of dentists?	89.5	10.5
Q7	Can teledentistry facilitate the access of oral healthcare during a pandemic situation?	89.2	10.8
Q8	Do you think that teledentistry can be a good tool for oral hygiene training?	82.8	17.2
Q9	Do you think teledentistry is a convenient form of oral healthcare for both the dentist and patients?	70.2	29.8
Q10	Do you think that patients can be examined accurately via computers and intraoral cameras as in the traditional office setting?	33.2	66.8
Q11	Can teledentistry be applied in any branch of dentistry?	57.5	42.5
Q12	Can teledentistry be added to routine dental practice?	68.9	31.1
Q13	Can teledentistry help in reducing costs for dental practices?	63.4	36.6
Q14	Do you think that teledentistry saves time for the dentist?	68.3	31.7
Q15	In Pakistan, can teledentistry be successful as a supportive tool with major challenges of illiteracy, population below the poverty line, and lack of infrastructure?	52.6	47.4
Q16	Do you think that teledentistry can increase accessibility of the specialists to rural and undeserved communities for their dental needs?	69.5	30.5
Q17	Should teledentistry be a regular practice in nonpandemic situations?	65.8	34.2
Q18	Will you recommend that government should take an initiative whereby patients could obtain advice on treatment need from a central facility connected via teledentistry?	85.8	14.2

by Bauer and Brown also showed similar results [25]. Theoretically, it is logical to think that by assessing the patients over-the-air, not only will the dental costs be minimized but it would be cost-effective and a comfortable way for the patients as well.

About 87.1% of the dentists agreed on consulting or communicating with specialist dental professionals through the internet or mobile phones in this survey. This allows gathering and exchanging informative data with a dental specialist who may have more expertise in a particular area. This data can be used to support the delivery of dental care, diagnosis consultation, and treatment. In comparison to a study on postgraduate dental students in Kanpur, India, only 58.4% of respondents agreed on this point [26]. This will specially be useful for dental professionals in remote areas, who will be able to communicate with specialists or more skilled dental practitioners about specific patients' problems using teledentistry.

In our survey, more than half of the dentists (57.5%) had this perception that teledentistry can be applied in any branch of dentistry. A similar study done in Pakistan depicted that 35.9% of dental professionals held the same perception [9]. Another similar study performed in India recorded that 42% of dentists agreed teledentistry can be applied in any branch of dentistry [6]. Useful applications of teledentistry in various branches of dentistry were observed in a literature review which indicated that benefits can be gained in the fields of Oral Medicine and Diagnosis, Oral and Maxillofacial Surgery, Endodontics, Orthodontics, Prosthodontics, Periodontics, Pediatric, and Preventive Dentistry [4]. Bradley et al. also mentioned the benefits of teledentistry especially in the branch of Oral Medicine [27]. Teledentistry proved to be useful in Endodontics for the diagnosis of periapical lesions as well [28]. In Prosthodontics, diagnosis with treatment planning has been performed by video conferencing [29]. Applications of teledentistry in Orthodontics have also been mentioned in a prior study [8].

According to the present study, awareness regarding teledentistry is high among undergraduate dental professionals as compared to general dentists, interns, and postgraduates, which is similar to a study that stated less awareness among general dentists about teledentistry in comparison to postgraduates and undergraduates [30]. This can be attributed to the fact that the modern curricula at the undergraduate dentistry level is based on newly discovered technology as compared to what was being taught almost half a decade back. Also, the new generation is more inclined towards technology themselves; thus, their growing interest in teledentistry does not come as a surprise.

It was seen that 65.8% of dental professionals believe that teledentistry can offer novel solutions to resume regular dental practice during nonpandemic situations. Teledentistry will prove to be useful for future assistance in planning appointments whereby new patients can be examined via two methods. The initial stage will involve history taking

and consent, and a second stage will include face-to-face visit whereby examination, diagnosis, and treatment can be completed in one visit. The number of in-patient appointments would reduce in hospitals/clinics, thus limiting the spread of COVID-19.

85.8% of dentists suggested that the government of Pakistan should take the initiative that would help patients obtain advice on treatment needs from a central facility connected via teledentistry during COVID-19 and in nonpandemic situations too. Pakistan, still being a developing country, lags behind in technology as compared to other developing countries of the South Asia region. Therefore, a drastic advancement needs to be done in this regard for teledentistry to flourish in the country, and this change will only be brought about if proper steps are initiated at a governmental level in provinces.

One integral aspect to consider here is that dentists, who are involved in teledentistry, must put every effort to ensure the security of their systems and gather data as well as processing of all types of collected data. For example, data encryption, password protection, and user access logs can help in preventing misuse of information of most of the people and ultimately protecting patient confidentiality. Dentists are encouraged to remain aware and be vigilant in terms of the legal needs in their states of practice.

5. Conclusion

This study shows that despite most of the participants having inadequate knowledge about the term "teledentistry" before COVID-19, they expressed positive prospects regarding its use. However, the routine practice is still low in Pakistan due to barriers such as unavailability of advanced technology and lack of education and training of dental professionals. There is a need to enhance the knowledge regarding teledentistry and promote its utilization in order to triage patients in this time of COVID-19, and even after. To ensure implementation of teledentistry, designing new policies and dental education programs is mandatory. Teledentistry may continue to be used after the pandemic as a means of consultation and provide easy access to dental professionals and patients.

Data Availability

The raw data used to support the findings of this study are included within the article.

Conflicts of Interest

There is no conflict of interest from any author.

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Review Article

Artificial Intelligence Techniques: Analysis, Application, and Outcome in Dentistry—A Systematic Review

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Objective. The objective of this systematic review was to investigate the quality and outcome of studies into artificial intelligence techniques, analysis, and effect in dentistry. *Materials and Methods*. Using the MeSH keywords: artificial intelligence (AI), dentistry, AI in dentistry, neural networks and dentistry, machine learning, AI dental imaging, and AI treatment recommendations and dentistry. Two investigators performed an electronic search in 5 databases: PubMed/MEDLINE (National Library of Medicine), Scopus (Elsevier), ScienceDirect databases (Elsevier), Web of Science (Clarivate Analytics), and the Cochrane Collaboration (Wiley). The English language articles reporting on AI in different dental specialties were screened for eligibility. Thirty-two full-text articles were selected and systematically analyzed according to a predefined inclusion criterion. These articles were analyzed as per a specific research question, and the relevant data based on article general characteristics, study and control groups, assessment methods, outcomes, and quality assessment were extracted. *Results*. The initial search identified 175 articles related to AI in dentistry based on the title and abstracts. The full text of 38 articles was assessed for eligibility to exclude studies not fulfilling the inclusion criteria. Six articles not related to AI in dentistry were excluded. Thirty-two articles were included in the systematic review. It was revealed that AI provides accurate patient management, dental diagnosis, prediction, and decision making. Artificial intelligence appeared as a reliable modality to enhance future implications in the various fields of dentistry, i.e., diagnostic dentistry, patient management, head and neck cancer, restorative dentistry, prosthetic dental sciences, orthodontics, radiology, and periodontics. *Conclusion*. The included studies describe that AI is a reliable tool to make dental care smooth, better, time-saving, and economical for practitioners. AI benefits them in fulfilling patient demand and expectations. The dentists can use AI to ensure quality treatment, better oral health care outcome, and achieve precision. AI can help to predict failures in clinical scenarios and depict reliable solutions. However, AI is increasing the scope of state-of-the-art models in dentistry but is still under development. Further studies are required to assess the clinical performance of AI techniques in dentistry.

1. Introduction

Artificial intelligence (AI) is a general term which refers to perform the task of human beings with the help of machine and technology. According to "Barr and Feigenbaum," AI is the part of computer science concerned with designing an intelligent computer system that exhibits characteristics we associate with intelligence in human behavior-understanding language, learning, reasoning, problem solving, and many more [1]. There are subcategories of AI, which is machine learning and its allied fields like deep learning, cognitive computing, natural language processing, robotics, expert systems, and fuzzy logic. Machine learning is a subgroup of AI which enhances automated learning ability without being distinctly programmed. Its primary goal is to allow automated learning without human arbitration. AI models predict future events with the present set of observations [2]. The schematic presentation of AI and a human intelligence model is shown in Figures 1 and 2.

AI, similar to other fields, is transforming as an emerging field of dentistry. AI can perform a number of simple tasks in the dental clinic with greater precision, less staffing, and fewer errors than human counterparts; from booking and coordinating regular appointments to assisting the clinical diagnosis and treatment planning, AI can handle all [3]. The AI application showed high accuracy, sensitivity, specificity, and precision in detection and classification of malocclusion in orthodontics [4]. AI can automatically detect and classify dental restorations on panoramic radiographs along with assistance in the detection of dental and maxillofacial abnormalities such as periodontal diseases, root caries, bony lesions, i.e., BRONJ (bisphosphonate-related osteonecrosis of the jaw) associated with dental extraction, and facial defects [3, 5].

A popular field in machine learning is "deep learning," where multilayered (deep) neural networks are used to learn hierarchical features in the data. Deep learning refers to the process of data (e.g., images) and corresponding labels (e.g., "carious tooth," or "specific area on an image where a caries lesion is present") being repetitively passed through the neural network during training, with the model parameters (so-called weights) being iteratively adjusted to improve the model's accuracy [1]. A deep learning-based convolutional neural network (CNN) algorithm considerably performed well in detecting dental caries in periapical radiographs [6]. It also successfully helped in detecting and classifying impacted supernumerary teeth in patients with fully erupted maxillary permanent incisors on panoramic radiographs [7]. The fully deep, fine-tuned mask R-CNN model performed well in automated tooth segmentation on panoramic images [8]. Additionally, it was also used for detecting apical lesions on panoramic radiographs [9].

Recently, an investigation showed that artificial neural networks (ANNs) could act as a second opinion to locate the apical foreman on radiographs and to enhance the accuracy of working length determination by radiography [10]. In another in vitro study, ANN also aided in the determination of shade, light-curing unit, and composite Vickers hardness ratio of bottom to top composites [11]. AI technology is found useful in assisting debonding probability of composite restorations in restorative dentistry [12].

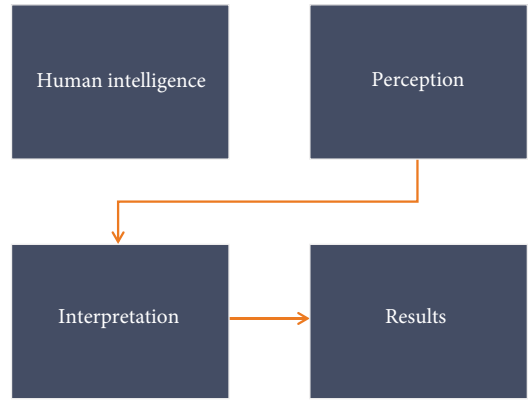

Figure 1: Schematic illustration of human intelligence networking.

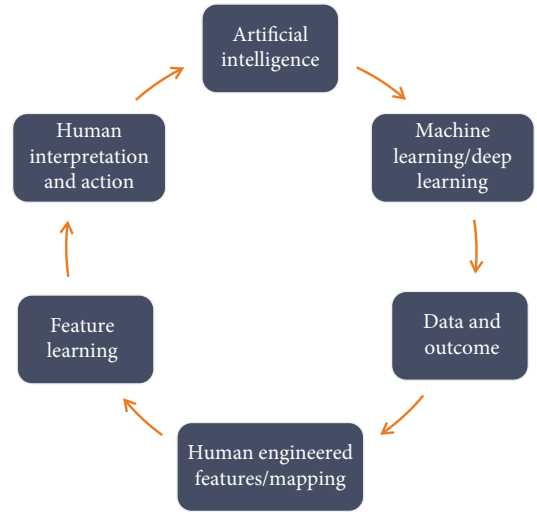

Figure 2: Schematic illustration of artificial intelligence model.

Furthermore, an automated robotic system can fulfill the requirements of typical dental operations with accurate, safe, and three-dimensional (3D) tooth preparation [13, 14]. The AI convolutional neural network (CNN) can be utilized for classifying dental arches and designing removable partial dentures [15]. AI can analyze the impact of orthognathic treatment on facial attractiveness and age appearance. It offers a new feature that permits scoring of facial attractiveness and apparent age objectively and reproducibly [16]. Automated integration of facial and intraoral images of anterior teeth benefits dentists to analyze the shape and position of maxillary anterior teeth [17].

In a nutshell, the last decade has seen a surged with breakthrough in advancement of technology associated with artificial intelligence. However, it is still uncertain how information available in the literature regarding AI can assist in diagnosis, planning, and management of dental diseases. Therefore, to understand the current trends of AI in dentistry and its application, a systematic review was carried out on studies which have discussed different modalities of artificial intelligence, its application, and outcome in dentistry.

2. Materials and Methods

2.1. Focused Question. This systematic review was conducted using PRISMA (Preferred Reported Items for Systematic Review and Meta-analysis) guidelines. Our intended question was "Which artificial intelligence techniques are practiced in dentistry, and how AI is improving the diagnosis, clinical decision making, and outcome of dental treatment?" The question was constructed according to the Participants Intervention Comparison Outcome and Study (PICOS) strategy [18].

Population: patient/simulator faciodental images (two-dimensional image (2D), three-dimensional (3D), radiographs (periapical, bitewing, orthopantomography, and cone-beam computed tomography), CAD/CAM (computer-aided design and computer-aided manufacturing). Virtual dental models.

Intervention: AI techniques (deep learning, natural language processing, and robotics) applied in diagnosis, management, and predicting prognosis of dental treatment.

Comparison: automatic algorithm, testing models, image analysis, and rater opinions.

Outcome: analysis of AI performance, accuracy/precision, sensitivity, rating, CDS: clinical decision support, AUC: area under the curve, and AI applicability in different dental specialties.

Study design type: for this review, we considered both observational (case control and cohort) and interventional (trials) based studies, published in the English language.

2.2. Eligibility Criteria. The subsequent articles were reviewed for inclusion criteria: (1) original articles relevant to AI in dentistry, (2) clinical trials, (3) nonclinical trials, (4) observational studies, and (5) English language articles, whereas review articles, letters to editors, commentaries, grey literature, case reports, and articles with less than 10 participants or specimen were excluded.

2.3. Search Methodology. The medical subject heading (MeSH) terms are artificial intelligence (AI), dentistry, AI in dentistry, neural networks and dentistry, machine learning, AI dental imaging, and AI treatment recommendations; electronic search was carried out with PubMed/MEDLINE, ScienceDirect, Scopus, Web of Science, and Cochrane Collaboration databases. The articles published in the years 2000 to 2020 were targeted. The duration of data extraction was between 10 and 12 weeks. The last search was performed in the month of January 2020. Two calibrated reviewers (N.A. and W.Q.) performed the search. Disagreements and discrepancies were resolved by consensus, and a third examiner (F.Z.) was consulted. All the titles and abstracts were read thoroughly from the articles searched primarily, and nonrelevant studies were excluded. The relevant articles were enlisted and scrutinized for any similar studies which matched our inclusion criteria. For extraction of pertinent results, we read full texts of the included studies and the findings were recorded.

2.4. Quality Assessment of Included Studies. Quality assessment of included articles was carried out according to the standard parameters described in the Cochrane Handbook for Systematic Reviews of Interventions (v5.1.0) [19]. The parameters were patient randomization, blinding procedure, withdrawal/dropout reported; statistical analysis was used and stated clearly, execution of sample size estimation, multiple variables measurement, clear inclusion and exclusion criteria, comprehensible examiner reliability tested and clearly report all expected outcomes. The quality of each study was further classified into low, medium, and high risk of bias. The same 2 review authors autonomously sort out the search to amplify the number of studies recovered. The reviewers surveyed every selected article for the predefined consideration criteria and directed impartial appraisals, and any ambiguity was settled by discussion and agreement or by consultation with a third reviewer (F.Z.).

The Newcastle-Ottawa quality assessment scale (NOS) for case-control studies [20] was used for further analysis of the included articles. The analysis was based on the three core quality analysis parameters: case and group (selection, definition, and representativeness), comparability (comparison of case and control groups; analysis and control of confounding variable), and exposure (outcome assessment, i.e., analysis of golden percentage estimation in patients by different examiners; evaluation of study outcome related to different teeth measurements clinically; use of a universal assessment method for both control and case groups; dropout rate of patients in the included studies). A star system was adopted for rating the included studies. Each item in selection and outcome category received a maximum of 01 star while 02 stars were assigned for comparability if sufficiently reported. Each study total scored from 1 to 8 stars. Due to heterogeneity of the outcome and variables in selected studies, the research team was not able to conduct meta-analysis in the current review.

3. Results

3.1. Search Results. The primary search identified 175 articles based on key terms. Following those, 41 duplicates were removed, and 134 articles were screened based on title and abstracts. The search was further narrow down, and 96 irrelevant articles were excluded. The remaining 38 full-text articles were assessed for eligibility. Additionally, 6 full-text articles were further excluded. The 32 relevant articles were finally included and analyzed in the review. The PRISMA flow diagram for the literature search strategy is described in Figure 3. The excluded studies, in addition to their reasons for exclusion, are mentioned in Table 1.

3.2. General Characteristics of Included Studies. The general characteristics of the included studies are summarized in Table 2. The data were extracted from articles about the proposed study design: the authors' ID, year of publication, study and control groups, area of application in dentistry, assessment methods, follow-up period, and outcome of the study.

The included studies were ranged from the year 2000 to 2020. The studies were from four categories: cohort study [5, 16, 27], case control [28, 29], clinical trials [6–12, 17,

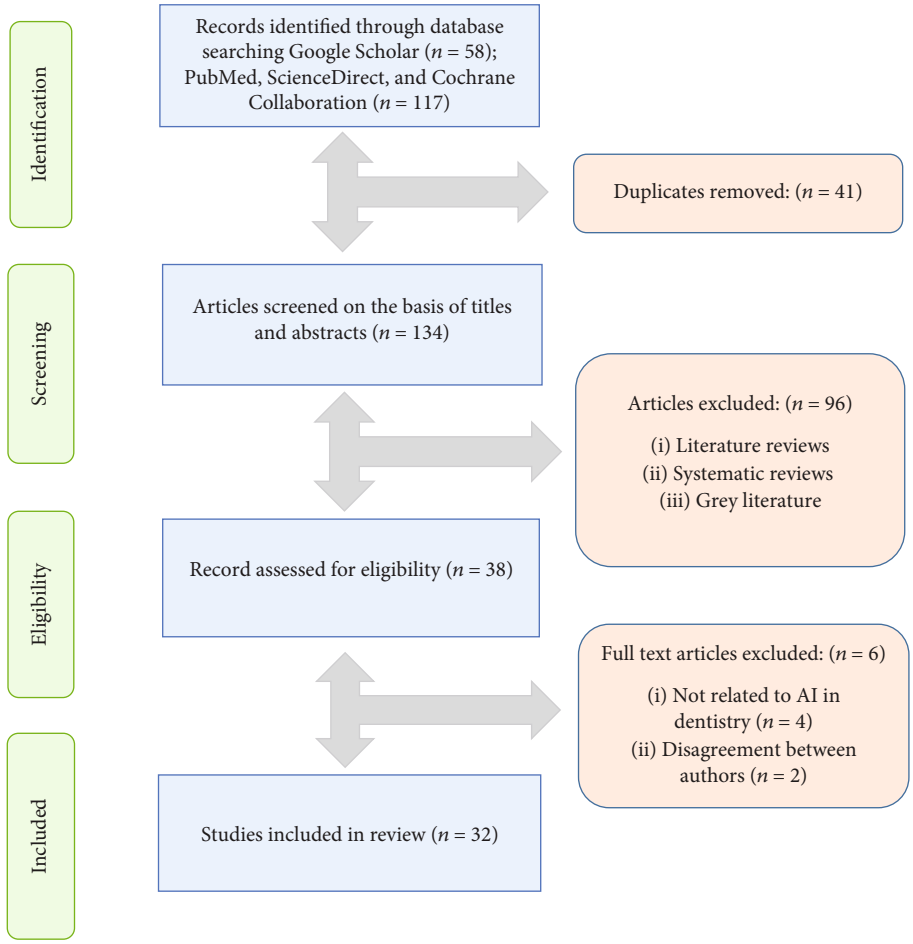

Figure 3: The PRISMA flow diagram for literature search performed in this study.

Table 1: Methodological list of studies excluded from this review and reasons for exclusion ($n = 5$).

Author and year	Reason of exclusion
Gould [21] 2002	Disagreement between authors
Van der Meer et al. [22] 2016	Not AI, it was related to 3D printing guides
Vera et al. [23] 2013	AI-related to dental biotechnology
Leeson [24] 2020	Disagreement between authors
Rekow [25] 2020	Not AI, it was related to digital dentistry
McCracken et al. [26] 2000	Not AI, it was related to computer-assisted learning program

AI: artificial intelligence.

30–43], and experimental trials [13–15, 44, 45]. The follow-up period was mentioned in one study [43]. The various techniques of artificial intelligence was applied in the field oral and maxillofacial surgery [27–29, 38, 45], oral medicine [28], oral radiology [42], esthetic dentistry [17, 44], restorative dentistry [11–13, 34, 36, 40], endodontics [6, 9, 10, 41], oral diagnosis [5–9, 15, 33, 34, 36, 37, 42, 43, 45], orthodontics and orthognathic surgery [16, 35], forensic dentistry [8], gerodontology [39], implantology [43], periodontics [31, 32], and prosthodontics [14, 15, 30].

3.3. General Outcomes of Included Studies. The different modalities of artificial intelligence showed favorable outcomes. The deep learning with CNN's performed well in predicting the debonding probability of CAD/CAM crowns from 3D models [12], and it functioned considerably well in detecting apical lesion and dental caries in periapical (PA) and panoramic radiography [9, 36, 40, 42]. In addition to this, it has been proved to be accurate in predicting the treatment of dental decay based on radiographic images [6].

AI also has been proved to assist dentists in implant treatment starting from diagnosis to surgery by proficient and certain radiological evaluation [43]. Further, AI aided in the detection and classification of impacted supernumerary teeth, in the maxillary incisor region on periapical radiographs [7]. Along with AI, automation of tooth segmentation can be achieved through dental panoramic images [8].

CNN has been used to classify dental arches, and multilayer CNN also improves the radiographic diagnosis of proximal caries [33]. Machine learning computer algorithmic tool also facilitates detecting and classifying dental restoration in panoramic images [5]. ANN has been used to determine accurate working length on radiographs [10]. Likewise, a neural network and web-based system was able to assists in characterization of TMJ health and temporomandibular joint osteoarthritis (TMJOA) at clinical,

Table 2: Characteristics of selected studies ($n = 33$).

Author and year	Study design	Groups		Application	Assessment method	Follow-up period	Outcome
		Study	Control				
Abdalla-Aslan et al. [5] 2020	Cohort study	Machine learning computer vision algorithms	NA	OD	Automatic algorithm was used to detection and classification restoration while vector machine algorithm with error-correcting output codes was applied for cross-validation	NA	Machine learning demonstrated excellent performance in detecting and classifying dental restorations on panoramic images
Bouchahma et al. [6] 2019	Clinical trial	CNN	NM	OD and endodontics	Prediction of three types of treatments; fluoride, filling, and root canal treatments. The model was trained to learn on dataset of 200 X-ray images of patients' teeth collected	NM	DL overall accuracy was 87%. The best prediction was the fluoride treatment with 98%, followed by RCT detection 88% and filling 77%
Kuwada et al. [7] 2020	Clinical trial	DetectNet, AlexNet, and VGG-16	NM	OD	400 images were randomly selected as training data, and 100 as validating and testing data. The remaining 50 images were used as new testing data. Recall, precision, and F-measure were used for detection of impacted teeth	NM	DetectNet and AlexNet appear to have potential use in classifying the presence of impacted supernumerary teeth in the maxillary incisor region on PR, while VGG-16 showed lower values
Lee et al. [8] 2020	Clinical trial	CNN on 20 automated 20 tooth segments	Oral radiologist manually performed individual tooth annotation on the PA	OD and forensic dentistry	846 images with tooth annotations from 30 PA were used for training, and 20 as the validation and test sets. A fully deep learning method using the mask R-CNN model was implemented through a fine-tuning process to detect and localize the tooth structures	NM	It achieved high performance for automation of tooth segmentation on dental panoramic images. The proposed method might be applied in the first step of diagnosis automation and in forensic identification
Ekert et al. [9] 2019	Clinical trial	CNN to detect AL	Six independent examiners detect AL	Endodontics and OD	NN was trained and validated via 10 times repeated group shuffling. Results were compared with the majority vote of 6 examiners who detected ALs on an ordinal scale	NM	A moderately deep CNN showed satisfying discriminatory ability to detect ALs on panoramic radiographs
Saghiri et al. [10] 2012	Clinical trial	ANN	Endodontist's opinion	Endodontics	Working length was determined and confirmed radiographically by endodontists and compared with ANN, and stereomicroscope as a gold standard after tooth extraction in cadaver	NM	ANN was more accurate than endodontists' determinations when compared with measurements by using the stereomicroscope
Arisu et al. [11] 2018	Clinical trial	ANN	NM	Restorative dentistry	Obtained measurements and data were fed to an ANN to establish the correlation between the inputs; composite shade curing units and outputs; tooth number	NM	ANN showed that the light-curing units and composite parameter had the most significant effect on the bottom to top Vickers hardness ratio of the composites

Table 2: Continued.

Author and year	Study design	Groups		Application	Assessment method	Follow-up period	Outcome
		Study	Control				
Yamaguchi et al. [12] 2019	Clinical trial	12 dislodge CAD/CAM composite resin crowns with DL	12 trouble-free CAD/CAM composite resin crowns	Restorative dentistry	Convolution neural network (CNN) technique was used to predict debonding of composite crowns using 2D images captured from 3D stereolithography models	NM	Deep learning with CNN model showed good performance in terms of dislodgement predictability of composite crowns through 3D stereolithography models
Otani et al. [13] 2015	Experimental study	Ten veneer preparation with a robotic arm	Ten conventional veneers prepared by a clinician	Restorative dentistry	Accuracy and precision of veneer preparation were compared for all sites and separately for each tooth surface (facial, finish line, incisal) through 3D images and computation	NM	The robotic arm was able to prepare the tooth model as accurately as the control. However, a better finish line accuracy and precision was showed by the robotic arm
Wang et al. [14] 2014	Experimental study	Automatic laser ablation system for tooth crown preparation	NM	Prosthodontics	A layer-by-layer ablation method is developed to control the laser focus during the crown preparation	NM	The movement range and the resolution of the robotic system meet the satisfying requirements of typical dental operations for clinical crown preparation
Takahashi et al. [15] 2020	Experimental study	CNN	NM	Prosthodontics and OD	1184 images of dental arches were classified into four arch types. A CNN method to classify images was developed using tensor flow and Kera's deep learning libraries	NM	The results of this study suggest that dental arches can be classified and predicted using a CNN
Patcas et al. [16] 2019	Cohort study	CNN was applied in posttreatment photographs of 146 orthognathic patients	Pretreatment photographs of 146 patients	Orthodontics	CNN-based technique was used to compare facial attractiveness and apparent age of patients through pre- and posttreatment photographs	NA	Artificial intelligence can be used to detect facial attractiveness scores and apparent age in orthognathic surgery patients
Li et al. [17] 2020	Clinical trial	50 oral images and 274 anterior through automated photo integrating system	Manual segmentation system	Esthetic dentistry	The facial and intraoral key points were detected by an automatic algorithm and compared with manual segmentation on standard photographs	NM	The proposed automated system can eliminate the need for dentists to employ a laborious image integration process and has potential for broad applicability in the field of esthetic dentistry
Li et al. [44] 2015	Experimental study	BPNN and GA neural network	Traditional neural network	Esthetic dentistry	The weighs and threshold values of GA and BPNN were compared for assistance in tooth color matching in dentistry	NM	GA and BP have practical application and can make teeth color matching objective and accurate
Edinger [30] 2004	Clinical trial	ROSY, a robot-like electronic simulator	NM	Prosthodontics	Accuracy of the simulator was measured for all directions in space by registering eccentric jaw positions on both sides of 10 subjects	NM	Its accuracy may render it suitable for clinical applications

Table 2: Continued.

Author and year	Study design	Groups		Application	Assessment method	Follow-up period	Outcome
		Study	Control				
Meissner et al. [31] 2006	Clinical trial	Automated smart ultrasonic calculus detection system	NM	Periodontics	The detection device is based on a conventional dental piezoelectric ultrasonic hand piece with a conventional scaler insert	NM	It was able to distinguish between different tooth surfaces in vitro independently from tip movements
Meissner et al. [32] 2005	Clinical trial	A novel calculus recognition device applied on 70 extracted teeth	NM	Periodontics	Impulse generator, coupled to a conventional piezo-driven ultrasonic scaler, sends signals to the cementum via the tip of an ultrasound device	NM	This system is able to function correctly, independent of the lateral forces and the tip angle of the instrument
Devito et al. [33] 2008	Clinical trial	Multilayer perceptron neural network	Twenty-five dental specialists with 20 years' experience	OD	Evaluation of proximal caries on radiographic through ANN	NM	AI improves the radiographic diagnosis of proximal caries by 39.4%
Kositbowornchai et al. [34] 2006	Clinical trial	Learning vector quantization (LQV, NN)	NM	Restorative dentistry and OD	Tooth sections and microscopic examinations were used to confirm the actual dental caries status	NM	AI plays a useful and supporting in making dental caries diagnosis
Patcas et al. [35] 2019	Clinical trial	Ten images evaluated by CNN model	Ten images were analyzed by laypeople, orthodontists, and oral surgeon on a visual analogue scale	Orthodontics	Decision on profile and frontal images of cleft patients were compared between CNN technique and conventional rater group to evaluate facial attractiveness	NM	AI can be a helpful tool to describe facial attractiveness and overall analysis were comparable with the rater groups
Lee et al. [36] 2018	Clinical trial	CNN	Four calibrated board-certified dentists	OD and restorative dentistry	A pretrained GoogleNet Inception v3 CNN network was used for preprocessing and transfer learning	NM	CNN provides considerably good performance in detecting dental caries in PR
Vranckx et al. [37] 2020	Clinical trial	CNN and ResNet-101	Manual measurements by 2 observers	OD	CNN and ResNet-101 jointly predicted the molar segmentation maps and an estimate of the orientation lines	NM	Fast, accurate, and consistent automated measurement of molar angulations on dental PR
Lee et al. [38] 2020	Clinical trial	Fifty cases of class2 TMJOA	Fifty cases of normal TMJ	OMFS	The condylar head was classified into 2 categories and tested by making 300 images	NM	AI can be used to support clinicians with diagnosis and decision making for treatments of TMJOA
Hung et al. [39] 2019	Clinical study	Machine learning method ANN was used on bitewing radiograph	Training group consisting of conventional radiograph analysis	Gerontology	Support vector machine (ANN) was used to detect root caries on radiograph by determining AUC	NM	Support vector machine showed 97.1% accuracy, 95.1% precision, 99.6% sensitivity, and 94.3% specificity for root caries detection
Cui et al. [27] 2020	Cohort study	CDS model applied to 3559 patient records	Two prosthodontists' opinion	OMFS	CDS model was used to predict the outcome of teeth extraction through electronic dental records	NA	The machine learning CDS was an efficient tool to predict teeth extraction outcome

Table 2: Continued.

Author and year	Study design	Groups		Application	Assessment method	Follow-up period	Outcome
		Study	Control				
Sornam and Prabhakaran [40] 2019	Clinical study	LB-ABC with BPNN	BPNN classifier	Restorative dentistry	The BPNN classifier is compared with the LB-ABC-based BPNN classifier for dental caries classification	NM	The learning rate generated by the LB-ABC for the BPNN classifier achieved the best training and testing accuracy of 99.16%
Setzer et al. [41] 2020	Clinical study	Evaluation of periapical lesion by DL method	Rating by OMF radiologist, an endodontist, and a senior graduate student	Endodontics	The CBCT segmentation was assessed by DL, CNN detection	NM	DL algorithm trained in a limited CBCT environment showed excellent results in lesion detection accuracy
Cantu et al. [42] 2020	Clinical study	Caries detection on bitewing radiograph with DL	Opinion of four experienced dentists	OD, OR	CNN (U-Net) and Intersection-over-Union were used to detect caries on radiographs	NM	The deep neural network was accurate than dentists
Aliaga et al. [45] 2020	Experimental study	Automatic computation and intelligent image segmentation of 370 radiographs	Expert dentist opinion	OD, OMFS	Automatic computation for analysis of mandibular indices and osteoporosis detection	NM	Automatic computation of mandibular indices and intelligent image segmentation was an efficient and reliable approach for early osteoporosis detection
Kim et al. [28] 2018	Case-control study	Machine learning prediction models for BRONJ after extraction in 125 patients with drug use	Conventional methods, serum CTX level	OMFS/OM	Five machine learning methods such as logistic regression model, decision tree, support vector machine, ANN, and random forest were applied to predict BRONJ at extraction sites	NA	Machine learning showed superior performance in predicting BRONJ compared with serum CTX level and drug holiday period
Dumast et al. [29] 2018	Case-control study	17 tested OA subjects evaluated with deep CNN on 3D images	17 age and sex-matched control subjects without OA	OMFS	Deep neural network classifier of 3D condylar morphology (ShapeVariationAnalyzer, SVA), and a flexible web-based system for data storage, computation and integration (DSCI) of high dimensional imaging, clinical, and biological data	NA	Deep neural network is a useful tool for classification of TMJOA
Sorkhabi and Khajeh [43] 2019	Clinical trial	3D deep CNN and CBCT	Postextraction clinical parameter measurements	OD and implant dentistry	3D CNN method was used to measure alveolar bone density on CBCT images	6 months	3D deep CNN technique can accurately classify alveolar bone. Pattern, which is helpful in dental implant placement and diagnosis

NA: not applicable; NM: not mentioned; OMFS: oral and maxillofacial surgery; OM: oral medicine; OP: oral pathology; OR: oral radiology; OD: oral diagnosis; AL: apical lesion; CNN: convolutional neural networks; ANN: artificial neural networks; 3D: three dimensional; DL: deep learning; CAL: computer-assisted learning; CAD/CAM: computer-aided design/computer-aided manufacturing; 2D: two dimensional; TMJOA: temporomandibular joint osteoarthritis; OA: osteoarthritis; BPNN: back-propagation neural networks; CDS: clinical decision support systems; BRONJ: bisphosphonate-related osteonecrosis of the jaw; LB-ABC: logit-based artificial bee colony optimization algorithm; VGG-16: Visual Geometry Group; PA: periapical radiograph; CBCT: cone-beam computerized tomography; GA: genetic algorithm; serum CTX: serum C-terminal telopeptide; AUC: area under the curve.

imaging, and biological levels [29, 30, 38]. Furthermore, the computer color matching (CCM) technique provides an accurate color matching of dental restorations, together with the automatic laser ablation system for clinical crown preparation [14, 44]. Overall, the above methods if introduced into routine practice can be helpful in diagnosis and treating dental diseases.

3.4. Results of Quality Assessment. According to the standards described in the Cochrane Handbook for Systematic Reviews of Interventions (v5.1.0) [19], the following findings were recorded. Out of the 32 studies [5–17, 27–45] assessed, 1 study employed blinding [6]. In 5 studies, randomizations [5, 7, 34, 37, 39] were performed. The dropout rate was mentioned in 31 studies [5–11, 13–17, 27–45]. The study variables were analyzed for accuracy in 30 studies [5–13, 15–17, 27–29, 37, 39–45]. Sample size was mentioned in 31 studies [5–17, 27–33, 35–45]. The inclusion and exclusion criteria were clearly mentioned in 30 studies [5–15, 17, 27–37, 39–45]. The examiner reliability was also applied in 30 studies [5–13, 15–17, 27–31, 33–45]. Additionally, the outcome of study was prespecified in 28 studies [5–10, 13–17, 27–33, 35–37, 39–45]. The quality of 25 studies was rated as low [5–10, 13, 15, 17, 27–29, 31–33, 39–45, 33–35–37], whereas 7 studies were rated as having a moderate risk of biasness [11, 12, 14, 16, 30, 34, 38]. The quality assessment of the included studies is shown in Table 3.

Furthermore, "the quality assessment of selected studies on NOS [20] was ranging from 4 to 8 stars." A mean score of 7 was achieved for the included studies, as mentioned in Table 4. Thirty-one studies fall in the moderate bias category [5–17, 27–29, 31–45] while 1 study had a high risk of biasness [30].

4. Discussion

The AI digital systems have unquestionably changed the direction of dentistry [46]. The AI modalities: machine learning, deep learning, cognitive computing, computer vision (recognizes the content in photos and videos), and natural language processing (to both analyze and generate human speech with the help of machines), are promising and practiced in dentistry [47]. Along the advent of AI better restoration, options are available with longer shelf life and superior esthetics and function [12, 13]. AI models are bringing greater efficiency and accuracy, capitalizing on the interest, capabilities, and skills of those involved [48]. Effective and efficient interprofessional and clinician-patient interactions have evolved using these new ways, with AI students have new ways of learning through research and the data collected can be efficiently utilized for forensic and epidemiological uses [49, 50]. Extensive research has been carried out on the application, benefits, and comparison of AI with human skills around the globe. The purpose of this systematic review was to investigate the quality and outcome of studies into artificial intelligence techniques, analysis, and its effect in dentistry.

Among the studies reviewed, it was revealed the application of artificial intelligence in dentistry is ample. Studies have found that the implications of AI in practice will facilitate dentists at every step. For instance, a neural network is beneficial in screening for oral cancer and precancer conditions, diagnosing bisphosphonate-related osteonecrosis before surgical removal of teeth and evaluating cervical lymph node metastasis of carcinoma after comparing it with magnetic resonance imaging [21, 28]. Furthermore, the computer color matching (CCM) technique provides an accurate color matching of dental restorations, together with the automatic laser ablation system for clinical crown preparation [14, 44]. The methodology used varied among the studies as to how the data were collected and analyzed and the AI technique developed. Therefore, a comparison of the studies was difficult.

The AI models suggested a positive impact in assisting dental diagnostics. Therefore, it can assist dentists in achieving correct interpretations of dental anomalies and minimizing human error. This review suggests that computer-based neural network plays a supporting role to dental practitioners, in decision making and minimizing errors during execution of dental treatment planning.

Furthermore, the current review proposes AI, a reliable technology for appraising the depth of dental caries, apical lesion diagnosis, working length determination, classification of dental arches, tooth segmentation, TMJ osteoarthritis, and early detection of early osteoporosis in jaws on panoramic radiographs [6, 8–10, 15, 36, 38, 45]. Rekow used a machine-learning algorithm to detect and classify dental restorations on panoramic images [25]. Kuwada et al. revealed that "DetectNet and AlexNet" appeared potentially useful in classifying the presence of impacted supernumerary teeth in the maxillary incisor region on panoramic radiographs [7]. Drevenstedt et al. used voice commands for recording patients' history and data, making suggestions during an ongoing dental procedure, scheduling patients' appointment, reminders for routine checkups, and necessary dental consultations [51]. The artificial neural network (ANN) models using bitewing photographs showed 97.1% accuracy for the dental caries diagnosis, 95.1% precision, a specificity of 94.3%, and a sensitivity ranging from 85% to 99.6% [42]. Sornam and Prabhakaran depicted an accuracy ranging from 85 to 100% using the AI model, "back-propagation neural networks" (BPNN) in dental caries classification [40]. However, comparisons among the studies were difficult because of differences in the methods used.

Despite the fact that the outcome of reviewed studies is auspicious, this study has few limitations. For example, the quality assessment of the literature conceded that there is a possibility of bias. The complexity of a particular system or mechanism, cost, and equipment of each setup need to be considered, including the training required for each AI model. Further research, exposure, and implementation are required. The worthwhile outcomes are not achieved yet due to the unavailability of accurate and sufficient data. In short, challenges exist both in technical and ethical aspects.

Nonetheless, in the future, the AI-based comprehensive care system will analyze big data including faciodental images and other records. AI models will provide reliable information and refined the clinical decision-making

Table 3: Methodological quality assessment results of the included studies ($n = 33$).

Author and year	Randomization	Blinding	Withdrawal/dropout mentioned	Variables measured many times	Sample size estimation	Inclusion/exclusion criteria clear	Examiner reliability tested	Expected outcomes prespecified	Quality of study/bias risk
Abdalla-Aslan et al. [5] 2020	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Bouchahma et al. [6] 2019	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Low
Kuwada et al. [7] 2020	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Lee et al. [8] 2020	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Ekert et al. [9] 2019	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Saghiri et al. [10] 2012	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Arisu et al. [11] 2018	No	No	Yes	Yes	Yes	Yes	Yes	No	Moderate
Yamaguchi et al. [12] 2019	No	No	Unclear	Yes	Yes	Yes	Yes	No	Moderate
Otani et al. [13] 2015	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Wang et al. [14] 2014	Unclear	Unclear	Yes	No	Yes	Yes	No	Yes	Moderate
Takahashi et al. [15] 2020	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Patcas et al. [16] 2019	No	No	Yes	Yes	Yes	Unclear	Yes	Yes	Moderate
Li et al. [17] 2020	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Li et al. [44] 2015	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Edinger [30] 2004	Unclear	Unclear	Yes	Yes	Yes	Yes	No	Yes	Moderate
Meissner et al. [31] 2006	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Meissner et al. [32] 2005	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Devito et al. [33] 2008	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Kositbowornchai et al. [34] 2006	Yes	No	Yes	Yes	No	Yes	Yes	No	Moderate
Patcas et al. [35] 2019	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Lee et al. [36] 2018	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Vranckx et al. [37] 2020	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Lee et al. [38] 2020	No	No	Yes	No	Yes	No	Yes	No	Moderate
Hung et al. [39] 2019	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Cui et al. [27] 2020	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low

Table 3: Continued.

Author and year	Randomization	Blinding	Withdrawal/dropout mentioned	Variables measured many times	Sample size estimation	Inclusion/exclusion criteria clear	Examiner reliability tested	Expected outcomes prespecified	Quality of study/bias risk
Sornam and Prabhakaran [40] 2019	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Setzer et al. [41] 2020	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Cantu et al. [42] 2020	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Aliaga et al. [45] 2020	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Kim et al. [28] 2018	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Dumast et al. [29] 2018	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low
Sorkhabi and Khajeh [43] 2019	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Low

*A study was graded to have a low risk of bias if it yielded 6 or more "yes" answers to the 9 questions, moderate risk if it yielded 3 to 5 "yes" answers, and high risk if it yielded 2 "yes" answers or less.

Table 4: Newcastle-Ottawa scale based quality assessment of selected studies ($n = 33$).

Author and year	Selection	Compatibility	Exposure	Newcastle-Ottawa quality (total)
Abdalla-Aslan et al. [5] 2020	***	*	***	7
Bouchahma et al. [6] 2019	****	*	***	7
Kuwada et al. [7] 2020	***	*	***	7
Lee et al. [8] 2020	***	*	**	6
Ekert et al. [9] 2019	***	*	****	8
Saghiri et al. [10] 2012	***	*	***	7
Arisu et al. [11] 2018	**	*	***	6
Yamaguchi et al. [12] 2019	***	*	****	8
Otani et al. [13] 2015	**	**	***	7
Wang et al. [14] 2014	**	*	***	6
Takahashi et al. [15] 2020	***	**	**	7
Patcas et al. [16] 2019	***	*	**	6
Li et al. [17] 2020	****	*	***	8
Li et al. [44] 2015	***	*	****	8
Edinger [30] 2004	*	*	**	4
Meissner et al. [31] 2006	**	*	***	6
Meissner et al. [32] 2005	***	*	**	6
Devito et al. [33] 2008	***	*	****	7
Kositbowornchai et al. [34] 2006	***	*	**	6
Patcas et al. [35] 2019	***	*	***	7
Lee et al. [36] 2018	***	*	**	6
Vranckx et al. [37] 2020	***	*	***	7
Lee et al. [38] 2020	**	*	***	8
Hung et al. [39] 2019	***	*	***	7
Cui et al. [27] 2020	***	*	**	6
Sornam and Prabhakaran [40] 2019	***	*	***	7
Setzer et al. [41] 2020	***	*	***	7
Cantu et al. [42] 2020	****	*	***	8
Aliaga et al. [45] 2020	***	*	**	6
Kim et al. [28] 2018	***	*	***	7
Dumast et al. [29] 2018	***	*	***	7
Sorkhabi and Khajeh [43] 2019	***	*	***	7

*A study can be awarded a maximum of 1 star for each numbered item within the selection and exposure categories. A maximum of 2 stars can be given for comparability. Each study can be awarded a total of 9 stars. A study was rated to have a low risk of biasness if it received the maximum allowed number of 9 "stars" while moderate risk if it received 8, 7, or 6 "stars" and high risk if it received 5 "stars" or less.

process. Infect AI is expected to establish high-quality patient care, innovative research, and state-of-the-art development in dentistry. Artificial intelligence and machine learning will aid to automation of aesthetic evaluation, smile design, and oral rehabilitation. By far, a change is not easy to adapt, but gradually, the application of AI in dental practice will become a necessity and might drive patient's demand too. AI has the proven ability to rationalize and take actions in the best manner of achieving a specific goal; this automated model can easily execute tasks, from simple to complex in nature.

5. Conclusions

At present, AI has been used vastly in dentistry. It has the potential to revolutionize oral health care by assisting in addressing the weaknesses grimly criticized in conventional dental care.

Based on the findings of this systematic review, it was concluded that

(1) AI techniques assist dental practitioners in numerous ways, from decreasing the chairside time, saving extra

steps, achieving excellent infection control, and providing quality treatment with accuracy and precision

(2) AI can be successfully used for patient diagnosis, clinical decision making, and prediction of dental failures. Hence, it is a reliable modality for future application in oral diagnosis, oral and maxillofacial surgery, restorative dentistry, prosthodontics, orthodontics, endodontics, forensic dentistry, radiology, and periodontics

(3) However, AI is increasing the scope of state-of-the-art models in dentistry but is still under development. Further studies are required to assess the clinical performance of AI techniques in dentistry

Data Availability

The raw data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare no conflict of interest.

Authors' Contributions

NA, FZ, and WQ planned and designed the present work, and MSA was responsible for realizing the work. NA, MSA, FZ, and WQ were responsible for the data acquisition and analysis. NA, MSH, and AM drafted and revised the manuscript. NA, MKA, MSH, and AM approved the final version of the manuscript. All authors read and approved the final manuscript. MSH and MKA contributed equally to this work and are corresponding authors.

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Review Article

Robotic Applications in Orthodontics: Changing the Face of Contemporary Clinical Care

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The last decade (2010-2021) has witnessed the evolution of robotic applications in orthodontics. This review scopes and analyzes published orthodontic literature in eight different domains: (1) robotic dental assistants; (2) robotics in diagnosis and simulation of orthodontic problems; (3) robotics in orthodontic patient education, teaching, and training; (4) wire bending and customized appliance robotics; (5) nanorobots/microrobots for acceleration of tooth movement and for remote monitoring; (6) robotics in maxillofacial surgeries and implant placement; (7) automated aligner production robotics; and (8) TMD rehabilitative robotics. A total of 1,150 records were searched, of which 124 potentially relevant articles were retrieved in full. 87 studies met the selection criteria following screening and were included in the scoping review. The review found that studies pertaining to arch wire bending and customized appliance robots, simulative robots for diagnosis, and surgical robots have been important areas of research in the last decade (32%, 22%, and 16%). Rehabilitative robots and nanorobots are quite promising and have been considerably reported in the orthodontic literature (13%, 9%). On the other hand, assistive robots, automated aligner production robots, and patient robots need more scientific data to be gathered in the future (1%, 1%, and 6%). Technological readiness of different robotic applications in orthodontics was further assessed. The presented eight domains of robotic technologies were assigned to an estimated technological readiness level according to the information given in the publications. Wire bending robots, TMD robots, nanorobots, and aligner production robots have reached the highest levels of technological readiness: 9; diagnostic robots and patient robots reached level 7, whereas surgical robots and assistive robots reached lower levels of readiness: 4 and 3, respectively.

1. Introduction

During the last decade, with the evolution of advanced manufacturing technologies, researching and designing together with the expanding popularity of three-dimensional (3D) imaging modalities, the implementation of robots has made a remarkable advance that has crept into every technological aspect including industrial fields, manufacturing processes, military purposes, medical fields, and research in which orthodontics is no exception. The inherent advantages of robots are their high accuracy and precision, high work efficiency, and stability [1].

Robotics is an interdisciplinary field that integrates computer science and engineering. Robotics is defined as the "intelligent connection between perception and action" [2]. The term robotics was introduced by writer Isaac Asimov in his science fiction book, *I, Robot*, published in 1950 [3]. According to the Robot Institute of America, a robot is defined as "a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or specialized

devices through various programmed motions for the performance of a variety of tasks" [4].

There are many different types of robots that are used in divergent environments and for multiple uses. Although being very diverse in application and form, they all share three basic similarities when it comes to their construction: (1) all robots have some kind of mechanical construction to achieve a particular task, (2) robots have electrical components that power and control the machinery, and (3) robots contain some level of computer programming code which decides when or how to do something [5].

The discipline of orthodontics, since its very inception, has strived to improve the efficacy and efficiency of any kind of treatment delivered to patients. There are numerous enabler smart technologies in robotics that may contribute to the evolution of novel practices in orthodontics. This is especially true in today's new norms of social distancing and remote monitoring after the COVID-19 breakthrough. The pandemic has immensely emphasized the value of robotic implementation in orthodontics, since the risk of orthodontists being infected from COVID-19 secondary to aerosol exposure from an asymptomatic yet positive patient is quite high [6].

Current technological infrastructure in dental offices can be augmented by making use of a smart robot. By attempting to reduce the load, mentally and physically on human assistants, we can target the human factor. Robotic assistants can work tirelessly and can repeat a programmed workflow allowing humans to fulfill other tasks that robots are not able to do, such as direct social interaction with patients, diagnosis and treatment planning, or other work with high cognitive requirements [7].

We are living in an era of complete digital transformation of orthodontic records and 3D simulation of a patient's own problems to reach a correct diagnosis. In the context of robotics, this entails the use of robots for more accurate X-ray imaging and positioning [8, 9]; robotic automated 3D cephalometric annotation [10]; bionic robots for simulation of the stomatognathic system including masticatory and swallowing robots [11, 12], tongue robots [13], mandibular [14] and condylar movement simulation robots [15, 16], and dental articulation robots [17]; and robotic remote control of mandibular advancement appliances in obstructive sleep apnea (OSA) patients in order to efficiently reach the effective target protrusive position [18, 19].

With the entire clinical orthodontic field witnessing a conceptual and technological revolution, education and training are not an exception, where robotics have reinforced the casual educational teaching and training [20]. This goes back to 1969 when the idea of a dental training robot was first described [21]. In addition, there have been a number of attempts at developing masticatory robots for the purpose of providing dental patient training since the early 1990s [22]. Its heuristic value lies in the fact that it is able to perform actual mastication thereby enabling one to understand different scenarios, explore different ideas, develop novel hypotheses, and gain insight into the consequences of variations in masticatory function between and within individuals [23].

The last decade, in particular, has marked magnificent growth in the field of robotic wire bending and robotic customization of CAD/CAM appliances, increasing the effectiveness and efficiency of arch wire bending and treatment. The first developed wire bending robot was the Sure Smile robot by Butscher et al. in 2004 [24]. This was followed by other developed robots used by different labial and lingual customized CAD/CAM appliances like the Sure Smile [25–27], Incognito [28], LAMDA [29], Insignia [30–33], and BRIUS appliances [34].

Nanotechnology has printed profound breakthroughs in orthodontics during the last decade achieving efficient and effective treatment results [35]. This comprises nanomaterials, nanobiotechnology, and nanorobotics which is defined as the discipline of designing and constructing nanorobots whose components are at or near the scale of a nanometer [36]. Nanorobots have been documented in the literature to be used for acceleration of tooth movement in animal studies through the use of nanoelectromechanical systems (NEMS) [37, 38] and nano LIPUS ultrasound devices [39–41]. Moreover, the concept of a smart bracket with an integrated nanomechanical sensor system for 3D force and moment real-time measurement has shown to work well, allowing precise application of force by an orthodontist [42]. Nanorobotic dentifrice delivered by mouthwash or toothpaste has been proposed for better cleaning of teeth [43]. Not only this but also nanosensors have been tested and validated for objective remote monitoring of removable appliance wear [44–46].

A noteworthy contribution of robotics in orthodontics is their applications in implant placement and maxillofacial surgeries including cleft palate surgeries, improving surgical efficiency and precision [47–49]. In 2017, the dental implant navigation robot system manufactured by Neocis Inc, called Yomi, received FDA approval and became the world's first commercially available oral implant robot [50].

The remarkable increase in the number of patients seeking aligners for treatment has led to a flourish of different aligner companies. The ability to consistently fabricate dimensionally accurate, custom-made, and removable orthodontic appliances in large quantities is a manufacturing challenge that has only recently been met through advances in scanning and automation technology. Align Technology uses stereolithography technology to create its reference models. These SLA resin models are loaded into an automated aligner-forming system that heats, forms, and laser-marks sheet plastic over each plastic model. These parts are transported on a conveyor belt to a robotic arm that loads each part into an automated cutting machine for trimming and molds and carves out each custom tray with laser precision [51, 52].

Finally, robots play a vibrant role in the treatment of TMD through massaging robots, mouth opening robots, and neurological rehabilitative exoskeleton robots, promoting active participation of the patient and accurately tracking the progress of a patient over time, by using progressive therapy routines [53–55].

Today's technological advancements allow for more efficient programming schemes for the robots to work in different situations, through the implementation of machine

learning (ML) and artificial intelligence (AI). Machine learning involves the different methods for making use of large amounts of data to learn and self-improve from its own experience [56]. As for artificial intelligence in the context of robotics, it is the field of autonomous and symbolic task planning that is used to automatically plan a sequence of actions to reach a specific goal. Furthermore, by artificial intelligence, robots are able to reason about current situations and new events in order to adapt to new circumstances autonomously [57].

How far have the aforementioned robotic applications in orthodontics found applicability, and what are the future research directions that are proposed based on the results of the researches? This scoping review is aimed at mapping the existing technological robotic applications in orthodontics as reported in orthodontic literature in the last decade.

2. Methodology

A scoping review of literature was carried out by following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines (Figure 1). The study protocol was developed to address the main research question and the study's eligibility criteria (Table 1). The scoping review was performed on MEDLINE, Cochrane Library, EMBASE, PubMed, Google Scholar, Web of Science, and Science Direct to collate the studies on robotics in orthodontics. The various search terminologies used are presented in Table 2. The literature search was dated back to ten years from the time of this review and was limited to English language only (January 2010 to January 2021). Meline [58] had suggested that the time period for the search of "contemporary studies" may be limited to ten years in order to maintain relevancy. IRB was obtained from the European University, DHCC, Dubai, UAE.IRB:EUC/67/2020/54.

The primary research question, "robotics in orthodontics," was further subcategorized into eight domains, as shown below:

(1) Robotic dental assistants

(2) Robotics in diagnosis, management, and simulation of orthodontic problems

(3) Robotics in orthodontic patient education, teaching, and training

(4) Wire bending robotics including labial and lingual wire bending robotic systems and customized fixed appliance robotics

(5) Nanorobots/microrobots for acceleration of tooth movement and for remote monitoring and telecommunication

(6) Robotics in maxillofacial surgeries and implant placement

(7) Robotics in automated aligner production

(8) Rehabilitative robots in management of TMD

"PICO" guidelines were followed to charter the full-text analysis and data extraction of the identified original research. The data included the first author and year of publication, study design, number of participants, intervention, comparison, outcome (primary and secondary), method of measurement, and the domain tested (Supplement 1).

The different presented robotic technologies in orthodontics were assigned a technological readiness level depending on the information provided from the publications [59] (Figure 2). Level 1 was assigned when a basic description of a system principle is observed and reported. When a full concept for a system was formulated, level 2 was assigned. Levels 3 and 4 included in vitro validation, whereas levels 5 and 6 were field validations. When a prototype is demonstrated in the operating environment, technological readiness level 7 is achieved. Level 8 is reserved for qualified complete systems, and level 9 is reserved for when a system has been proven in end-use operations. Furthermore, the application areas were put together in a year-wise categorization in order to point out the advances within the different fields.

3. Results

The initial database and additional search resulted in 1,150 records, of which 133 relevant articles were retrieved in full. 87 studies met the selection criteria following screening and were included in the scoping review (Figure 1).

The studies that were included in the review and excluded studies with reasons are enumerated as supplements to this article.

Robotic wire bending and customized appliances have the largest share with 32%, followed by 22% share by diagnosis and orthodontic simulation using robots, followed by 16% share by robotic use in maxillofacial surgeries, robotic uses in TMD management by 13%, and nanorobotics and telemonitoring by 9%. The least represented were robotic use in orthodontic teaching and education, robotic assistants, and robotic automated aligner production representing only 6%, 1%, and 1%, respectively (Figure 3).

According to the technology readiness level reached of different domains, wire bending robots, nanorobots, TMD robots, and automated aligner productive robots reached the highest level of technological readiness [9]. Robots used in diagnosis and patient robots reached level [7] of technological readiness, whereas surgical robots and assistive robots reached only level [4] and level [3] of technological readiness, respectively (Figure 2).

Upon reviewing the scope of the published literature in the use of robotics in orthodontics over the last decade, 8 main domains can be subcategorized in which robotics could have an application in the orthodontic specialty.

3.1. Robotic Dental Assistants. A prototypical 7DoF robot assistant was proposed by Grischke et al., in 2019. The authors investigated the possibility of active robotic support during treatments by handling of instruments via a multimodal communication framework that is aimed at dentists as users. The users almost reached expert level time after only a short overall interaction time, with the visual gestures being the most difficult to handle, while the web interface and verbal and haptic gestures were more robust, demonstrating

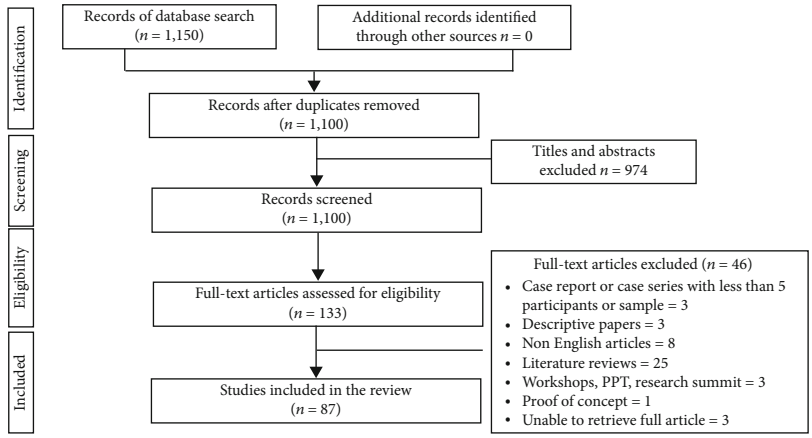

Figure 1: Preferred reporting items for systematic reviews and meta-analyses.

Table 1: Scoping review selection criteria.

Inclusion criteria	Exclusion criteria
Studies including randomized controlled trials (RCTs), controlled clinical trials (CCTs), cohort studies, retrospective studies, and case-control studies on the eight subcategories as enumerated in the text. Descriptive technique article (focused on design description). Any type of comparison with conventional mode of orthodontic treatment, method, or approach. All types of reported outcomes (primary and secondary).	Case reports and studies with less than five participants or sample. Personal opinions, narrative articles, letters to editors, or interviews. Proceedings from research summits. Systematic reviews, meta-analyses, and review articles. Proof of concept, workshops, and presentations.

usability and feasibility beyond a controlled experimental setup [60].

3.2. Robotics in Diagnosis, Management, and Simulation of Stomatognathic System and Orthodontic Problems

3.2.1. Parallel Robot for Dental Articulation. An optimal parallel robot for dental articulation is able to not only solve the traditional problem in dentistry but also to eradicate the technical difficulty of duplicating the positions and motions of the patient jaw in dental practice, reducing dentists' chairside time greatly and increasing the efficacy of dental workflow by reducing the traditional trial-error approach [17].

3.2.2. Robot for X-Ray Imaging. In 2013, a robot equipped with a skull to investigate the influence of head movement to the accuracy of 3D imaging was proposed [61].

3.2.3. Automated Cephalometric Landmark Annotation. A new approach for automatic 3D cephalometric annotation using shadowed 2D image-based machine learning was proposed to overcome the existing serious difficulties in handling high-dimensional 3D CT data, achieving an average point-to-point error of 1.5 mm for seven major landmarks [62]. Also, another study using a patch-based iterative network with a three-layer CNN architecture for automatic landmarking of a CT image showed that landmarks can be automatically calculated in 37.871 seconds with an average acceptable accuracy of 5.785 mm [63].

3.2.4. Robots for Remotely Controlled Mandibular Positioners for Obstructive Sleep Apnea Patients. The concept of a remotely controlled mandibular positioner (RCMP) for single-night titration was introduced to determine an effective target protrusive position (ETPP) for every individual patient within 45 minutes [64], to prospectively predict treatment success and outcome to avoid a titration procedure for weeks or months and to identify favorable candidates for oral appliance therapy [65–67]. The RCMP consists of a controller that receives commands from the device software and, in turn, activates a stepping motor attached to dental trays in the patient's mouth [64].

3.2.5. Robotic Approach to the Reduction of Dental Anxiety in Children. Robotic technology was successfully found to help in the management of younger children by helping them to cope with dental anxiety and stress, making them behave better in the dental office, through the use of robotic technopsychological distraction techniques [68].

3.2.6. Software Simulation System for Dental Orthodontic Robot. Designing a software simulation system for a dental orthodontic robot was proposed by using Blender's secondary development technology, which transforms orthodontic surgery into a simulation operation that can be interactively simulated in a computer through tooth arrangement algorithms and calculations of tooth positions. Also, it can design orthodontic brackets suitable for patients with dentition malformation [69].

Table 2: Table depicting the search terminologies employed for the scoping review.

S/N	Database	Search term 1 (main search term)	Search term 2	Not relevant
S1	(2010-2021 full text, English) MEDLINE, Cochrane Library, EMBASE, PubMed, Google Scholar, Science Direct, Web of Science	Robotic dental assistant		(1) Letters to editors, opinion articles, descriptive papers, interviews (2) Systematic reviews, meta-analyses, and review articles (3) Proof of concept, workshops, presentations (4) Proceedings from research summits (5) Case reports and studies with less than five participants or samples
S2		Robotic orthodontic diagnosis	Robotic simulation of orthodontic problem/masticatory/chewing/tongue/mandibular movement/condylar movement robots/articulation Robotic X-ray/robotic cephalometric landmarking/robotic management of anxiety	
S3		Robotic orthodontic teaching, education, training	Robotic patient	
S4		Orthodontic wire bending robotics	Customized orthodontic wires/customized appliances/customized brackets Sure Smile, Incognito, Insignia, BRIUS, LAMDA	
S5		Nanorobotics/microrobotics	Remote/telemonitoring/telecommunication/smart brackets/objective measurement of compliance/acceleration of tooth movement	
S6		Robot orthognathic surgeries	Robot maxillofacial/implant surgeries/ mini-implant placement	
S7		Robotics in aligner production	Automated aligner/automated attachment	
S8		Robots in TMD	Rehabilitative robots, massage robots, mouth opening robots, neurological rehabilitative robots	

S1 (search 1): robotic dental assistant; S2 (search 2): robotics in diagnosis, management, and simulation of orthodontic problem; S3 (search 3): robotics in orthodontic patient education, teaching, and training; S4 (search 4): wire bending robotics including labial and lingual wire bending robotic systems and customized fixed appliance robotics; S5 (search 5): nano-/microrobots for acceleration of tooth movement and for remote monitoring; S6 (search 6): robots in maxillofacial surgeries and implant placement; S7 (search 7): robotics in automated aligner production; S8 (search 8): rehabilitative robots in management of TMD.

3.2.7. Bionic Robots for Simulation of Stomatognathic System. Masticatory chewing robots have been designed, some with a hybrid neural network approach for kinematic modeling, to reproduce human chewing behavior, cycles, chewing forces acting on teeth, jaw dynamic movements, and reactive forces on the TMJ as well as specifying different chewing patterns [11, 12, 70–74].

Bionic Jaw Motion robots registering and reproducing mandibular movements were investigated. It is based on two components: a jaw movement analyzer and a robotic device that is able to accurately reproduce recorded movements with no mathematical transformations, reducing mechanical tolerances and time as fast as 5 to 10 s [14].

A *tongue soft robot* which can mimic a few movements of the human tongue was designed with a series of embedded chambers using a pneumatic actuation pattern [13].

3.3. Robotics in Orthodontic Patient Education, Teaching, and Training. A humanoid, a full-body patient simulation system (SIMROID), was tested in 2018 among dental students to find out whether a robotic patient was more realistic for the students to familiarize with real patients than the usually used dummies. Students recognized the educational value of the robot patient especially for "risk management" [75]. A patient robot for practicing orthodontic bonding was introduced suggesting that it is useful in orthodontic bonding practice by providing immediate feedback after training and iterative learning [76].

Also, a medical emergency robot was introduced with the aim of helping dental students to get familiar with emergency situations [77, 78]. Another robotic educational equipment described in the literature is the ROBOTUTOR to demonstrate tooth-cleaning techniques to patients. It was found to

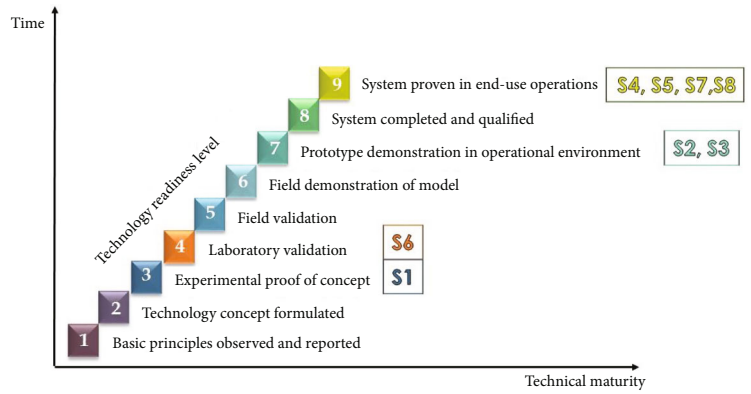

Figure 2: The technological advance of a system may be described using the technological readiness level (TRL 1-9) introduced by Mankins in 1995 [59]. Different robotic applications in orthodontics assigned to different technological readiness levels.

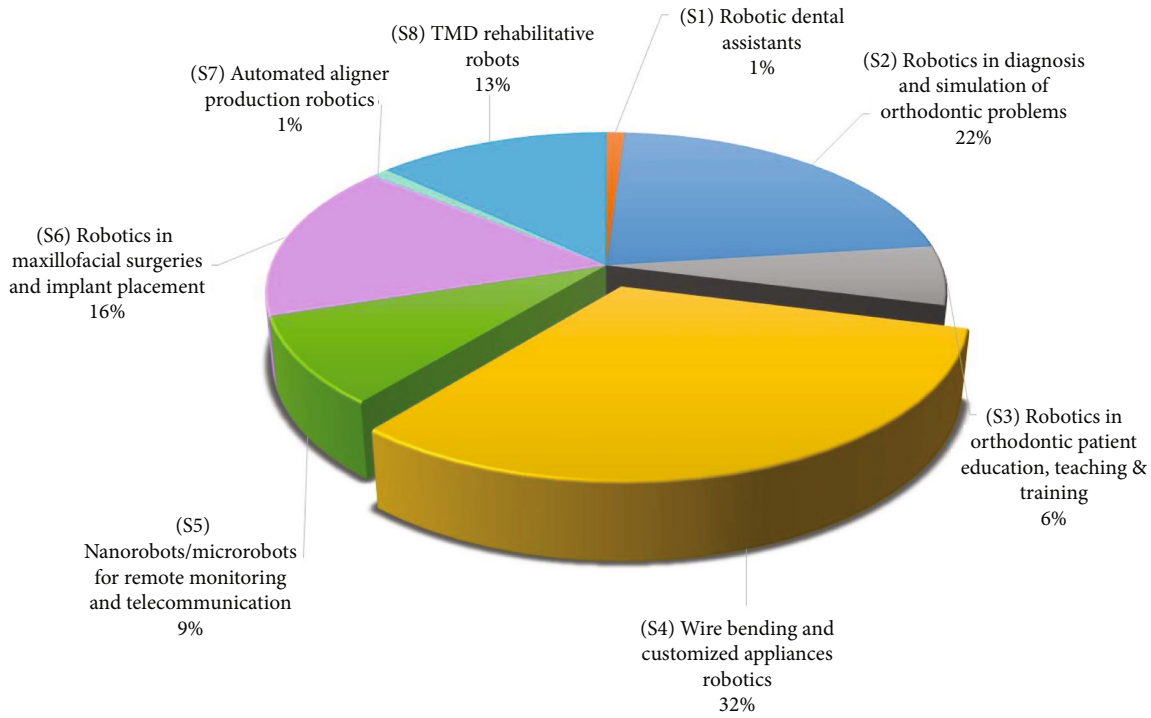

Figure 3: Pie chart showing percentage representation of eight domains of robot applications in orthodontics.

be the most attractive method (according to patient evaluation) for dental health care education compared to other methods (clinician or video audio tutorial) [79].

3.4. Wire Bending and Customized CAD/CAM Appliance Robotics. Accurate arch wire bending is a key technology for fixed orthodontic treatment [80]. Compared with the traditional manual bending system, the accuracy and efficiency of arch wire bending can be improved by using the robot with its precise posture control ability [81].

Different types of arch wire bending robots have been proposed in the last decade including the Motoman UP6 robot, optimizing bending process and properties [80, 82–84], LAMDA system (Lingual Arch wire Manufacturing and Design Aid), bending only 1st-order bends in the XY plane [29], motion planning and synchronized control of the dental arch generator of the multimanipulator automatic tooth arrangement robot [85, 86], Cartesian type arch wire bending robot using the third-order S addition and subtraction curve control method of the motor to bend the arch wire [81, 87], an end effector for arch wire bending robot that could change the pincer automatically, as needed [88], wire bending robots considering the slip warping phenomenon that exists during wire bending, thus compensating for the spring back of the arch wire [89–91] and greatly improving the bending precision, and robots using the Bessel curve to carry out the control point planning and angle planning showing practicality in clinical treatment [92]. Different

descriptive papers analyzed the structural dynamics of bending robots [93] and their various elements [80, 94], verifying the feasibility of the manufacture strategies of formed orthodontic wire fulfilled by different wire bending robotic systems. Additionally, the performance of a more accurate and reliable method of shape setting of superelastic Nitinol tubes has been validated [95].

Moving on to the customized CAD/CAM full appliances including customized brackets and wires manufactured by robots, clinical outcomes were assessed in terms of effectiveness and efficiency in different CAD/CAM systems in comparison to conventional approaches, showing premise in improving or at least achieving similar outcomes to conventional appliances [26, 31, 33, 34, 96]; also, it can reduce overall treatment duration [26, 32, 96, 97].

Upon comparing lingual (Incognito) and labial (Insignia) appliances, it was found that Incognito was more efficacious [28]. In addition, the precision of virtual setup implementation was found to be clinically successful, achieving tooth movement as planned in the setup, with custom arch wires fabricated by different CAD/CAM appliances [27, 97–100], though the accuracy differs with the type of tooth and movement [27].

3.5. Nano-/Microrobots

3.5.1. Nanorobotic Dentifrice (Dentifrobots). Subocclusal dwelling nanorobotic dentifrice delivered by mouthwash or toothpaste could patrol all supragingival and subgingival surfaces, performing continuous calculus debridement. These invisibly small dentifrobots would be inexpensive, safely deactivating themselves if swallowed, and would be programmed for better cleaning of the teeth [43].

3.5.2. Nanosensors for Remote Monitoring of Removable Appliance Wear. [1] Monitoring of Obstructive Sleep Apnea Oral Appliance Compliance. Sleep apnea monitoring devices are being developed for diagnostic and treatment applications as well as monitoring applications. These can be a safe, reliable, effective, feasible, and affordable option to monitor a person's sleeping patterns and to objectively measure compliance in wearing the OSA oral appliances [45, 101].

[2] Monitoring of Compliance of Active and Passive Removable Appliance Wear. Compliance in removable appliance wear is a highly variable, multifactorial issue that requires objective measures to be safely addressed in research designs and in clinical practice [44, 102, 103]. Electronic microsensors, such as the Smart Retainer [104] and the TheraMon [46, 102, 105], seem quite promising since they are easy to use and because they have been proved reliable and accurate enough to measure wear time of removable orthodontic appliances by identifying temperature changes, which are then transformed to wear time information.

They are helpful in modifying patients' motivation and determining the extent of impact of current therapeutic procedures and/or patients' cooperation on the treatment outcome. Moreover, they provide the basis for more individualized wear time recommendations for patients with removable appliances, resulting in a more efficient, shorter, and less painful orthodontic therapy [105].

3.6. Robotics for Implant Placement and Maxillofacial Surgeries

3.6.1. Robots in Implantology. Robots can be used to measure forces and stresses on the implant and between implant and bone and measure the torque and stability to drill the implant site, as well as to place the implant inside the bone with improved accuracy during operation. Different systems include preoperative planning software, surgical robotic arms, stress sensors, coordinate measuring machines, and optical navigators. The systems consist of preoperative and intraoperative stages. The preoperative stage uses the 3D views obtained from the raw images of the patient before surgery followed by the intraoperative stage, which shows 3D orientation of surgical instrument position and trajectories which are displayed on the monitor within a patient's 3D imaging data [106–110].

3.6.2. Robots in Maxillofacial Surgeries. A lot of systems have been proposed comprising surgical robots with optical surgical navigation systems and some kinds of hard tissue lasers that are able to automatically perform an osteotomy operation according to a preformed surgical plan. During the operation, the robot is proposed to register patient movements by real-time tracking. Robotic surgical techniques are being used for milling of bone surfaces, drilling of holes, deep sawing osteotomy cuts, selecting osteosynthesis plates, bending and intraoperative positioning in a defined position, and orthognathic surgery planning [111–117].

Also, the use of a robot for cleft palate repair has attracted the attention of scholars, and preliminary research results have been achieved, improving surgical efficiency and precision while reducing potential secondary injury to the patient as it reduces the damage to the blood vessels, nerves of the palate muscles, and mucous membranes [118, 119].

3.7. Robotics in Automated Aligner Production. In 2011, Hilliard patented a robotic system for forming features in orthodontic aligners, including a control system, a platen for three-dimensional positioning of the aligner, a heating station for selectively heating a small region of the aligner, and a thermoforming station for manipulating the heated region to form a desired feature in the aligner. The control system can include a processor with CAD software to enable a user to design features for aligners. The present invention enables an automated process for installing activation features and other types of features needed for polymeric shell orthodontic aligners to receive auxiliary devices that serve to expand their usefulness, range, and duration of application [120].

3.8. Rehabilitative Robots in Management of TMD. Massaging robots and mouth training robots [121, 122] have been proposed for the implementation of safe and effective maxillofacial massage and exercises to treat patients with myofascial pain and limited mouth opening by decreasing muscle stiffness significantly. Suitable treatment regimens have been discussed and evaluated, reaching an efficacy of 70.3% [123],

with sonographic features, as the frequency of visibility of the distinct echogenic bands the elasticity index ratios, being a guiding predictor of therapeutic efficacy [124].

Moreover, neurological rehabilitative exoskeleton robots have been introduced for the practical rehabilitation of patients with TMD [125, 126]. Different designs were suggested including the use of a soft pneumatic actuator allowing comfortable patient interaction [127]; a shoulder-mounted robotic exoskeleton for better esthetics and portability, incorporating visual feedback into therapy routines to promote active participation with safety design considerations [128]; assisted motion of the jaw using EMG- and ECG-based feedback systems accurately tracking the progress of a patient over time [129]; and central path generator concept for real-time online trajectory generation, allowing the adaption to the environment and changing the chewing pattern in real-time parameters in a smooth and continuous manner [130, 131].

4. Discussion

The scoping review on robotic applications in orthodontics was conducted to evaluate and quantify published orthodontic literature that evaluates uses of robots in orthodontics. A scoping review aids to map the broad outcomes and invention utilization and collates the range of study designs and methodologies implemented. The research question, "What are the uses of robotics in orthodontics?," was divided into eight main domains, and each was addressed with the PICO framework for literature evaluation.

The greatest representation in literature (32%) was by robotic arch wire bending and customized CAD/CAM appliances. It is an anticipated outcome that robotic wire bending and CAD/CAM appliances are the most frequently measured domain because orthodontics since its inception has always tried to improve the efficacy and efficiency of appliances through the change and improvement of many modalities over time from 3D-assisted diagnosis and management to customized CAD/CAM appliances with automated wire bending robots. The use of a robot to bend an arch wire was found to be a rapid, reliable, and reproducible process that increases the treatment accuracy, efficacy, and efficiency when compared to conventional arch wire manufacturing, reducing the treatment time and the patient discomfort [25, 47, 132, 133]. Likewise, using customized brackets manufactured by robots, the treatment effectiveness and efficiency can be improved by overcoming individual tooth morphology variations and by precise virtual planning of individual tooth movements [26, 31–34, 96, 98–100]. This was reflected in the highest level of technological readiness (9) in which the systems were proven in end-use operations [96, 98–100].

The next domain that received significant consideration (22%) is diagnosis and simulation of orthodontic problems using robots. Reaching a correct diagnosis has been always considered the most crucial step in the orthodontic journey. Diagnosis has witnessed dramatic breakthroughs in the last decade with the advent of the digital era that enabled clinicians to use the best available data for evidence-based diagnosis, treatment planning, and execution of treatment. Simulation of the patient stomatognathic structures including masticatory muscles, tongue, and mandibular and condylar movements in real can help the clinicians to better visualize the problem in 3D, making it easier to reach a correct diagnosis [13, 14, 72]. Robots for dental articulation can eradicate technical difficulties of duplication positions and motions encountered in the classical articulator, thus saving time and producing more precise occlusal relationships [17]. Robots for automated cephalometric landmarking save time and decrease the dependence on professional experience [62, 63]. Titration of oral appliances for treatment of OSA patients in a single night within minutes was introduced by robots to overcome the time-consuming trial-and-error procedures. This can help diagnose favorable candidates for oral therapy as well as predict treatment success [64–66]. Though diagnostic robots gained significant consideration in the literature, it is still in level (7) of technological readiness.

Interestingly, 16% share of outcomes reported is on the use of robots in implantology and maxillofacial surgeries. The anatomy of the oral and maxillofacial region is complex, and the esthetic demand in this dental field is high. Therefore, orthognathic surgery needs to be highly accurate and performed with minimal trauma, and this can be accomplished using robotic surgeries. There are systems providing haptic navigated robot technology to provide physical guidance on the position, orientation, and depth of the drill, moreover allowing the practitioners to visualize the surgical site and to register patient movements by real-time tracking, enabling them to change the plan in real time according to the specific circumstances during surgery [50]. Robots provide accuracy in measuring torque values and insertion depth in a more precise manner in mini-implant placement. This minor surgical procedure done by robots reduces the chances of failure of mini-implant placement, saves time, and reduces the risk of infection [134]. Unfortunately, the invasive character of surgeries may impair the acceptance of this technology among patients and orthodontists. Hence, these most invasive applications are not very suitable as forerunners, reaching only level (4) of technological readiness.

Although rehabilitative robots for TMD (13%) and nano-/microrobots for remote monitoring of compliance of removable appliance wear (9%) came in the 4^{th} and 5^{th} places, they are showing a great premise in the orthodontic research, evidenced by the highest technological readiness level reached (9). Different rehabilitative robots for management of TMD have been proposed with well-established protocols, promoting active participation of the patient and accurately tracking the progress of a patient over time, by using progressive therapy routines with smooth continuous transitions between movements, increasing patient comfort [128, 130, 131].

In the same ways that technology research and development drove the space race and nuclear arm race, a race for nanorobots is occurring. The reasons behind this are that large corporations, such as General Electric and Siemens, have been recently working in the development and research of nanorobots [135]. Surgeons are getting involved and starting to propose ways to apply nanorobots for common medical procedures [136], and universities and research institutes

were granted funds by government agencies towards research developing nanodevices for medicine [137].

Nanorobots have been proposed earlier for the acceleration of tooth movement which is always a matter of great concern to both orthodontists and patients. This could be done through the induction of electrical or ultrasound waves which enhance cellular enzymatic phosphorylation activities and fibroblast growth factor release from a macrophage-like cell line (U937), accelerating tooth movement [37–41]. The idea of incorporating microrobotic sensor systems to control the 3D-force-moment of the orthodontic bracket was enormously promising in nature; however, the innovation is yet to test the telemetric energy and data transfer phase [42]. Nanorobots for remote monitoring of compliance is proven to be a safe, reliable, feasible, and more accurate objective evaluation of the compliance and effectiveness of treatment over their subjective alternatives of evaluations including questionnaires and patients reporting of wearing hours. Moreover, they provide the basis for more individualized wear time recommendations for patients with removable appliances, resulting in a more efficient, shorter, and less painful orthodontic therapy [44, 45, 105]. It has to be unequivocally acknowledged that robotic objective monitoring will be an important determinant of orthodontic care protocols in the future.

Research on educational robotics (6%) in university environments seems to be an appealing initiator to introduce robotics and take the first hurdle towards acceptance of robots among future orthodontists, as it has already reached a reasonable level of technological readiness (7). "Hanako," the SIMROID robotic patient, is a real contribution to the educational terrain. It is standing 165 cm tall. It comes with a metal skeleton and vinyl chloride-based gum pattern of the skin. It is imitating a human in its actions and expressions. It can verbally express pain, roll its eyes, blink, shake its head in pain, and perform movements of the jaw, tongue, elbow, and wrist. Furthermore, it can simulate a vomiting reflex with a uvula sensor and also simulate functions to induce bleeding and saliva flow. It provides emotional feedback to dentists especially pain and discomfort and also responds and reacts to questions and commands and finally rating and evaluating their treatment, thus helping the dental students to learn in a better way [20].

The least addressed domains were the automated aligner production robots and the assistive robots, accounting for only 1% both. Although a lot of research has focused, during the last decade, on the effectiveness and efficiency of the use of aligners in controlling tooth movement and treating different malocclusions reaching the highest level of technological readiness (9) [138, 139], very few of them tackled the importance of the role of robots in their fabrication and in the automated attachment fabrication [120]. Likewise, research in the field of assistive robotics, though not much with the lowest technological readiness level (3), seems to be promising to facilitate the introduction of this new robotic enabled era, since robots will help keep the records of the patients, manage the appointments, and assist the orthodontist without tiring.

As observed, the percentage of different domains as a reported outcome was not always positively correlated to the level of technological readiness reached. To be more specific, wire bending robots, TMD robots, and nanorobots gained both significant contribution as reported domains and also reached the highest levels of technological readiness [9], whereas diagnostic robots and surgical robots gained a high percentage as reported domains but lower levels of technological readiness (7 and 4, respectively). A patient robot was a moderately reported domain and at the same time reached a moderate level of readiness [7]. An assistive robot was both lowest as a reported outcome and in technological readiness level [3]. Despite the fact that automated robotic aligner production was one of the least reported domains, it reached the highest technological readiness [9], due to the growing market of aligner companies, as well as the remarkable increase in patients seeking more esthetic alternatives of appliances.

A reasonable explanation why robotics is still a field of low interest in dentistry may be the lack of expert knowledge to program and control those systems as a nonprofessional. Consequently, research in this domain still relies on efficient collaboration between engineers and dentists. This may rapidly change in the near future as the robotic community researches novel programming paradigms and interaction methodologies in order to make communication between robots and humans as intuitive as possible. Furthermore, the use of ML and AI methods to autonomously plan tasks and reason about the environment may further reduce the effort on the user side when using a robot.

A noteworthy point to mention is the tremendous effort that is required of orthodontists and dental assistants in order to learn to work with these advanced technologies. Older generations may be more used to familiar tools and are rather skeptical to adapt. However, new generations of orthodontists can be considered digital natives, and their experience might lead them to use digital tools more naturally. Moreover, in light of the expected developments in robotics, AI and ML, future generations may even be considered "robonatives" [140].

All the aforementioned robot applications presented in this review have an inherent potential to advance dentistry far beyond digitalization and into a new world where digitalization reaches out to manipulate our real world. However, the overall technological readiness is still low, and more effort and research are needed for optimum utilization of the real value of robotics. On the other hand, there are numerous approaches in the research community to explore the potentials and challenges of integrating robotics, AI and ML, into dentistry; thus, the speed of innovation in this novel field should increase in the upcoming years. Knowledge gaps identified could be core outcome sets (COS) for scholarly literature in the future (Table 3).

Our world is witnessing exceptional events over the past two years of the COVID-19 pandemic, a new era that will be a significant turning point in the world's history. Despite our accumulated experience in crisis management, this virus has been able to isolate us all in our homes. With the emerging robotic technology, orthodontists can easily practice orthodontics remotely with its numerous applications in the different domains in this life-threatening pandemic,

Table 3: Knowledge gaps identified which could be core outcome sets (COS) for scholarly literature in the future.

(1) Prospective human trials assessing biocompatibility, efficacy, efficiency, and cost benefit ratio of robotic systems
(2) Clinical audit of 4D printing applications
(3) Clinical audit of AI-based robotic training
(4) Tactile and motor movements of robotic arms
(5) Clinical efficacy of advanced wire bending mechanics
(6) Performance of human-computer interface to be tested in clinical situations
(7) Surface trackers guided robotic movements
(8) Orthodontic material evaluation for precision in material science

following the new norms of social distancing and reducing the human working hours, thus dramatically decreasing the risk of infection to the orthodontists as well as to the patients.

5. Orthodontic Applications of Robotics: Crystal Gazing into the Future!

(1) Larger scale, human clinical trials need to be done to test the feasibility, safety, accuracy, and usability of different robotic systems

(2) 4D printing of soft robotics can replicate natural physiomechanical changes over time leading the transition from static to dynamic, with precise controllability and unlimited reversible actuation [141]

(3) Machine learning methods and artificial intelligence are used to train robots to reliably perform their assigned tasks and even to be able to reason about current events and new information in order to adapt to new situations

(4) The flexibility and motor functions of robotic arms need further technical advancements to suit different individual clinical situations

(5) For arch wire bending robots, the research in the future needs to focus on the arch wire spring back and bending algorithm, adapting bending to more complicated clinical arch wires, as well as improvement of plier design for dexterous collision avoidance [86]

(6) Friendly human-computer interaction software is designed to provide humanization input and feedback for the operators

(7) Advanced self-conscious robot control by patients using surface EMG (sEMG) signal of the facial muscles is developed to guide the actuation of the robot [127]

(8) Further prospective studies with larger numbers of patients and longer follow-up periods are required to confirm the success and the evolution of OA compliance patterns over time [45]

(9) Orthodontic material testing is done by robots

6. Conclusions

The orthodontic specialty is moving forward towards a new era of data-driven and robot-assisted medicine. Robotics is by all means a breakthrough in the field of technology, and its evident applications in orthodontics are potentially immense. Noteworthy, with the incorporation of AI and ML to our day-to-day clinical practice, there are speedy improvements in precision and success of our treatments through the implementation of robots. Hence, it is very important for all clinicians to have basic knowledge and training with these technologies. However, the latest step changes in modern robot technology, ML and AI, have not yet been fully introduced to orthodontic research nor have they reached technological readiness and cost-efficiency to enter the dental market.

Arch wire bending robots, simulative robots for diagnosis, and surgical robots have been important areas of research in the last decade. Rehabilitative robots and nanorobots are quite promising and have been considerably reported in the orthodontic literature. On the other hand, assistive robots, patient robots, and automated aligner production robots need more scientific data to be gathered in the future.

In fact, the increased intuitiveness of the systems combined with broad educational efforts and introduction of affordable systems are key challenges that need to be overcome to truly introduce robotics to orthodontics.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare no conflict of interest.

Supplementary Materials

Supplement 1: studies included for the scoping review ($n = 87$). Supplement 2. studies excluded from the scoping review ($n = 46$) [7, 29, 30, 35, 37, 38, 43, 47, 48, 132, 133, 142–176]. *(Supplementary Materials)*

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