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ORIGINAL RESEARCH

The Impact of COVID-19 on Dental Clinic Transmission: Leveraging Internet of Things Technology

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Background: This study focused on the risk posed by pre-symptomatic and asymptomatic carriers in dental clinics during the period (February-June 2022) when Covid-19 transmission was highest and aimed to investigate the effectiveness of infection control protocols in the prevention of SARS-CoV-2 transmission. It also evaluated the potential of wearable sensors as part of the Internet of Things (IoT) to prevent cross-infection.

Material and Methods: Swab samples were collected from surfaces and air filters in dental clinics and analyzed using RT-PCR both before and after disinfection processes. Clinicians also used IoT-enabled wearable sensors and completed surveys (n=100) evaluating the impact of these technologies on infection control practices. The sensors monitored clinicians' movements and patient interactions to assess cross-infection risks.

Results: All RT-PCR tests returned negative results, indicating that no SARS-CoV-2 was detected on the sampled surfaces or air filters. Surveys revealed that 70% of resident clinicians trusted the effectiveness of wearable sensors in infection control. The technology was particularly well received among younger clinicians and was found to be effective in strengthening contact tracing, control measures, and awareness.

Conclusion: Strict infection control measures have contributed to preventing Covid-19 infections in dental clinics, although asymptomatic cases may still be present. These findings highlight the importance of adopting advanced technologies such as wearable sensors to support current infection control measures. With further studies, the scalability and integration of IoT technologies into routine infection control practices in diverse healthcare settings can be better understood, enhancing infection control potential and significantly contributing to the safety of healthcare workers and patients.

Keywords: COVID-19, dental clinics, infection control, wearable sensors, asymptomatic transmission, RT-PCR

Introduction

On March 11, 2020, the World Health Organization (WHO) declared the coronavirus disease (COVID-19) pandemic caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The pathogen responsible for the pandemic, SARS-CoV-2, is highly contagious compared to other coronaviruses, such as SARS-CoV, which caused relatively fewer outbreaks in a limited number of countries in 2003–2004.[1] The high infectivity of SARS-CoV-2 can be attributed to its relatively high reproduction number (RO) ranging from 2 to 6.75, its relatively long prodromal period, and the presence of asymptomatic carriers.[2,3]

The main route of transmission for SARS-CoV-2 is through aerosol/droplet diffusion, and it can also spread through contact with contaminated surfaces. In dental clinic settings, especially when procedures generating large volumes of

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saliva aerosols are used, airborne transmission of SARS-CoV-2 from pre-symptomatic and asymptomatic individuals is likely. This highlights the risk of cross-infection in dental clinics. The reason for this is the lack of an international protocol or guideline to follow during a pandemic.[4] To address this gap, dental guidelines for controlling SARS-CoV-2 transmission have been implemented in our country and dental clinics. During the study period, the following measures were implemented in Turkey:

- Curfews were enforced at specific hours and on weekends.
- Individuals over 65 and under 20 had movement restrictions at certain hours.
- Intercity travel was only permitted with special authorization.
- Indoor venues (restaurants, cafes, etc) were closed except for takeaway services.
- Schools switched to remote learning with limited in-person education.
- Hospital visitations were restricted, and non-COVID-19 healthcare services were provided under specific measures.

Dental boards and some associations have recommended temporary closure of dental offices, while others have suggested limiting dental care to urgent cases and reducing the number of routine dental check-ups and follow-up visits.[5] During the outbreak in China, despite widespread community infection with COVID-19, the need for emergency dental care only decreased by 8%.[6] There will always be a need for emergency dental practices in the community.

Several potential scenarios for COVID-19 transmission have been described. Transmission through respiratory activities such as speaking, coughing, and sneezing, as well as contact with droplets and aerosols produced during clinical procedures, is expected, similar to other respiratory infections.[7] Larger droplets (> 60 μm) can contribute to viral transmission to nearby individuals, while long-distance transmission is possible with smaller droplets (≤ 60 μm) containing suspended viral particles.[8] Dental healthcare professionals, including dentists, are at high risk of direct exposure to this virus as they may be exposed to airborne particles and aerosols generated during dental procedures, making them a high-risk group for infection.[9]

Asymptomatic infections are possible, and transmission can occur before the onset of symptoms (pre-symptomatic). In this case, healthcare workers, including dentists, may unknowingly provide care to patients infected with COVID-19 who have not yet been diagnosed.[10] The virus can survive and remain infectious in aerosols for up to 3 hours and on stainless steel and plastic surfaces for 5.6 and 6.8 hours, respectively.[11] During this period, admitting another patient to the same environment can lead to cross-infection risk. Therefore, dentists must be cautious and develop preventive strategies to protect themselves and their patients from COVID-19 infection (cross-infection) in addition to implementing classical, routine, and standard protective measures such as patient placement, hand hygiene, ventilation, surface disinfection, instrument sterilization, personal protective equipment, and aerosol-generating procedures.[12] Furthermore, dentists should not let their guard down and should be aware of the presence of various infectious threats that may challenge the existing infection control regimen and the risk of disease recurrence.[1,13]

Considering current and potential future outbreaks and pandemics, the issue of transmission through asymptomatic and pre-symptomatic individuals in dentistry necessitates exploration and evaluation of additional preventive protocols alongside standard ones.[7] However, to date, there is no significant evidence showing whether naturally recovered COVID-19 patients are protected against re-exposure to SARS-CoV-2. If they are susceptible to reinfection, recovered patients could potentially serve as reservoirs for continuous viral spread. An important concern regarding SARS-CoV-2 infection is the potential for transmission within the community by asymptomatic individuals,[14] in the event of reinfection. The risk of reinfection and subsequent transmission may be high in asymptomatic cases; therefore, health authorities need to be cautious and fully prepared. Estimating the prevalence of transmission from asymptomatic individuals in the community is of utmost importance since prolonged delay in diagnosis can significantly increase the infectiousness.

Additional preventive protocols are needed in dentistry to address transmission risks from asymptomatic individuals. Modern technologies, such as the Internet of Things (IoT), offer significant potential for enhancing infection control measures. IoT-enabled wearable sensors can monitor clinicians' movements and assess cross-infection risks by tracking patient interactions and environmental conditions. For example, digital technologies like "Safe Steps" can facilitate

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retrospective contact tracing and monitor asymptomatic cases effectively. This study serves as a preliminary investigation into IoT's potential in infection control, focusing on contact tracing and airborne transmission prevention in dental settings.

Moreover, embracing and investing in more modern technologies, such as the Internet of Things (IoT) applied in medicine, may be necessary to facilitate reporting, enable faster data distribution and analysis in accordance with sensitive epidemiological principles. IoT encompasses connected medical devices and software applications that provide comprehensive healthcare services. In the medical field, IoT opens up a world of possibilities as ordinary medical devices become invaluable sources of additional data when connected to the internet. It can provide extra information about symptoms, enable remote care, track medication orders, and utilize wearable devices to transmit this information.[15–17] The use of artificial intelligence methods has the potential to expedite the process of finding actionable insights and ultimately contribute to a better global response.

This study serves as a preliminary study to assess the prevalence of transmission among physicians, patients, and healthcare staff at a time when asymptomatic and/or pre-symptomatic individuals are highly present in the Turkish population. The hypothesis of this study is that IoT technology, combined with strict infection control measures, can prevent SARS-CoV-2 cross-infection in dental clinics. Furthermore, molecular techniques like RT-qPCR will provide a robust framework for evaluating transmission risks. It is hypothesized that COVID-19 cross-infection from asymptomatic individuals can be prevented through the use of IoT technology by clinicians in addition to infection protection methods, and the results of this cross-infection control can be assessed using molecular techniques.

Materials and Methods

Ethical Considerations

This study was performed according to the principles of the Declaration of Helsinki of the World Medical Association. Our study is an observational research that does not involve any invasive interventions and is limited to environmental sample analysis and anonymized survey data. Regarding the application made to the research ethics committee of Marmara University Faculty of Dentistry (31/01/2022), the Medical Device Agency, which works under the Ministry of Health (16/12/2021), was contacted and in line with the response, it was stated that there was no need for Clinical Research Ethics Committee approval (No. 1/2022). Informed consent was obtained from all participants.

Sample Collection

This study was conducted at the Endodontics Department of Marmara University Faculty of Dentistry (Figure 1) in the student clinic and four different private dental practices. All clinics were located in the same city with similar baseline SARS-CoV-2 incidences, minimizing potential confounding factors. Swab samples were collected twice a day, from five different areas (air filter, dental reflector (Figure 2), unit control panel (Figure 3), dentist's face shield (Figure 4), and the surface of the reflector handle facing the patient (Figure 5)) using an swab sample method after routine disinfection in the morning (negative control) and before routine disinfection in the evening after the last patient examination (test). The aerator, air-water syringe, saliva ejector handle, and X-ray device were excluded from the study since they are not routinely used for every patient. The swab samples collected during the period (February-June 2022) from each clinic were taken to the laboratory for molecular testing on the same day and stored at +4°C during this time. The limited number of samples was due to cost constraints. Reducing the waiting time for the test not only prevents sample loss but also facilitates informing the at-risk group in case of a positive result. Before starting patient admission in the clinic in the morning, swab samples (negative control) were taken from the mentioned areas, along with a virus transport medium-moistened swab, including a virus filter sample,[18] and pooled in a single tube. At the end of the day, after patient admission, swab samples were taken again from each of these five areas, each time (morning and evening) pooled in separate tubes. As a result, two tubes were obtained at the end of the day. The study was conducted in five clinics over periods of 10 days each, resulting in a total of 100 swab samples (50 pool samples in the morning and 50 pool samples in the evening). The samples were taken by the same person, and necessary protective equipment (bonnet, N95 mask, and gown) was used.

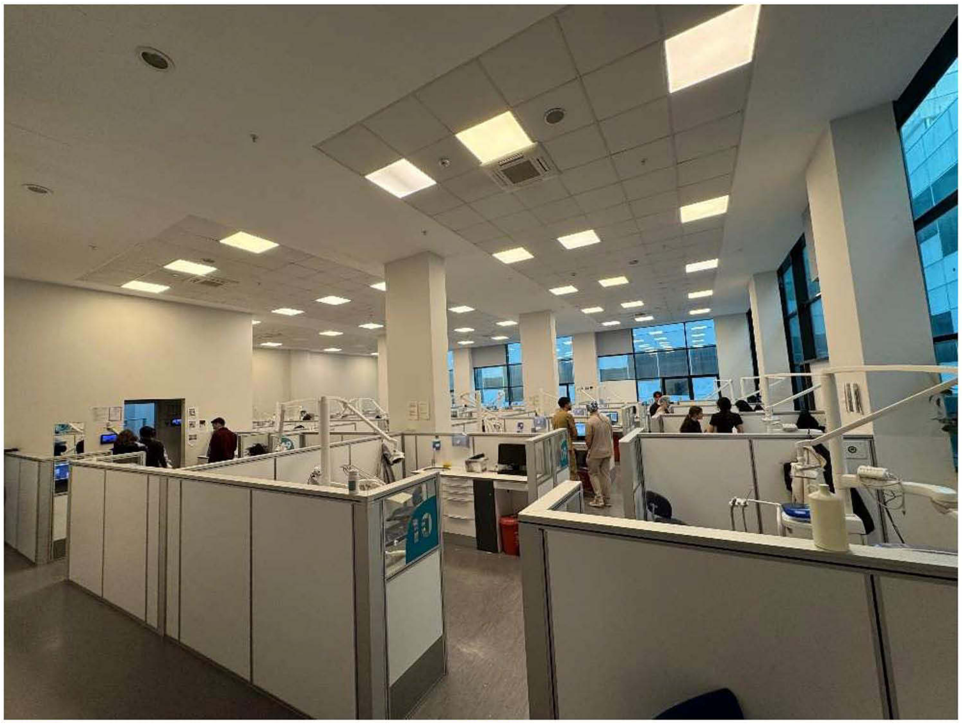

Figure 1 Dental clinic.

The protective-preventive measures and protection protocol implemented in the clinic were recorded by filling out a questionnaire form. As per the protocol, individuals known to be infected were not admitted to the clinic, and no procedures were performed on them. Treatment was postponed until after recovery (Appendix 1. Clinic Survey Form).

At the Marmara University Faculty of Dentistry Endodontic intern clinic, there are 28 dental units, and four auxiliary staff members' work. On average, 56 patients are admitted daily. A HEPA filter device is used for ventilation. After each patient, the units are disinfected with an alcohol-based medical device surface disinfectant (BioRad Clean Spray). The clinic is disinfected three times a day (at 9:15, 12:00, and 14:15) with a hypochlorous acid (HOCl) solution using an ultra-low volume (MMT ULV) device. At the end of each day, the units and clinic surfaces are disinfected with 0.05% sodium hypochlorite (NaOCl).

Other included clinics in the study have different numbers of dental units (2 to 7), staff members (2 to 16), and average patient numbers (15 to 45 days). Each clinic follows infection control measures, but they may have different disinfection protocols. There may be differences in the use of air purifiers, gargling, UV disinfection, and hypochlorous/ oxygenated water spray for air disinfection. Additionally, there may be variations in the ventilation periods left between patients and the treatment periods allocated to patients. To identify these differences, a short questionnaire form was filled out for each clinic to determine their specific protocols (Appendix 1. Clinic Survey Form).

Ventilation Device

In this study, General Filter Havak company designed VENTI-DENT and GEFI PURUFIER-35 devices were used to purify the ambient air from the virus. Both devices are air purification devices with a 3-stage filtration system. They are equipped with pre-filters for large particles, GFH System active carbon filters to capture odors and gases, and H14 class HEPA (High-Efficiency Particulate Air) filters that can capture micro-particles (viruses and bacteria) at a rate of at least 99.995% according to EN1822 standard. These devices are specifically designed for dentists to filter aerosols and particles emitted from the patient's oral area during operations at a rate of 99.995%. Micro-particles produced according to the EN1822 standard were taken using an elution from the H14 class HEPA filters, and swabs were placed into the virus carrier medium. The swabs were then kept at +4°C until they were delivered to the molecular laboratory along with

Figure 2 Dental Reflector.

other samples from the same clinic. Molecular results were determined daily for each clinic, reducing the waiting time for the samples.

Real-Time Reverse Transcription-Polymerase Chain Reaction (RT-qPCR)

The methods applied in this study, along with the mentioned control methods, included real-time reverse transcription-polymerase chain reaction (RT-qPCR) with RNA polymerase RNA-dependent targeting specific to detect the presence of SARS-CoV-2 in samples taken before and after patient admission. The cycle threshold values, which represent the number of cycles required for the fluorescent signal to cross the threshold in RT-qPCR, indicate the quantitative viral load; lower values represent higher viral load.[18]

In summary, samples were collected from each clinic room from five different areas before and after disinfection. Subsequently, clinical data, symptoms, and whether the disease was present were monitored for 10 days and compared with the RT-qPCR results. The collected swab samples were transported to the laboratory in vNAT Transfer Tubes with stratospheres containing ice packs. The swab samples collected in vNAT Transfer Tubes underwent viral inactivation within 5 minutes of merging with swab samples, ensuring the safety of laboratory workers and allowing direct progression to the RT-qPCR reaction process without the need for additional isolation/extraction steps. The samples were processed using the Biorad CFX96 Touch qPCR Device in a 96-well plate format. The Bio-Speedy® SARS-CoV-2 Variant Plus Kit (Cat: BS-SY-WCOR-402-100) was used for four-channel multiplex reactions, including internal control in the HEX channel to test whether the sample was correctly taken or preserved. The presence of SARS-CoV-2 viral RNA was tested in the FAM channel using two genes (N - Nucleocapsid gene and ORF1ab gene). The ROX channel was used to test the E484K mutation commonly seen on the Spike protein in the later stages of the study, and the CY5 channel was used to test the B.1.1.7 variant, also known as the UK variant, which has become dominant due to its rapid transmission. For each run, one positive control and one negative control were used, and the shape of the sigmoidal

Figure 3 Unit Control Panel.

curves obtained from the test results was examined for result evaluation. For this purpose, a cross-sectional study design was used with RT-qPCR pool testing.

Internet of Things Technology (IoT) - Use of Wearable Product

In collaboration with Boni Global and Turkey Metal Industry Employers' Union (MESS), the social distance tracking product "Safe Steps" was produced. Safe Steps is a wearable device (Figure 6) that records the interactions individuals have throughout the day and tracks the contact tracing structure through a management panel platform. The device aims to make social distancing compliance easier for individuals by monitoring close proximity between users and providing warnings when there is a risk of transmission. The use of IoT was conducted within this 10-day period, during which the device recorded risky interactions, making it easier to create contact tracing graphs. The wearable devices can be carried in various forms such as clips, yoyos, or neck lanyards, and when the 1.8-meter social distance with another person is breached, it provides audio, vibration, and light alerts. The interaction records are stored in the device's memory and transmitted to a server via a gateway. Subsequently, interaction data is matched with personal data on the management panel, reflecting past interactions for each user with accurate information on individuals, dates, and durations. The panel allows for risk monitoring, filtering interaction dates and durations to identify contact persons' risk status effectively.

The product also includes an additional feature, the social distance success score. The daily interactions of individuals are evaluated using an algorithm with different coefficients, such as interaction duration, the number of people involved, and how many days ago the interaction occurred, to create a personal social distance success score. This score is dynamically updated and shown to both the research team (management panel administrators), aiming to increase awareness of the product through gamification. The score also helps management to conduct more accurate risk analyses at both individual and team levels, supporting decision-making processes.

Figure 4 Protective face shield.

The past interaction records and contact tracing were done only through the management panel and were accessible only to authorized users. Occupational health and safety (OSH), IT, HR, etc., managers were authorized by the business manager to access the management panel and view the data. Product users (individuals carrying the devices) cannot directly access the interaction records. Instead, these users can download a special mobile application called "Safe Steps Device Manager" from Android or iOS markets to view their personal social distance success score and the device's battery status.[19]

The study tracked and retrospectively monitored social distance interactions between healthcare workers and patients in the clinic. As a result, information on when, at what time, and for how long an interaction occurred between healthcare workers and patients was accessible. Contact tracing personnel were able to conduct contact tracing using not only self-reporting but also the most accurate interaction data collected through the devices. Additionally, users were alerted during interactions in real-time, enabling both immediate and retrospective prevention and protection measures.

To ensure information accuracy throughout the entire screening process, including sample collection, nucleic acid testing, result reporting, isolation of positive cases, contact tracing, and tracking of positive cases' contacts, the Safe Steps management panel platform was used. All screening information was strictly kept confidential and not disclosed or used for any purposes other than clinical and public health management. Personal information of asymptomatic positive cases could be disclosed only for medical isolation and the identification of close contacts to medical institutions and public health centers. Additionally, an official provided training to the research team and clinic doctors at the beginning of the study on the use of Safe Steps for contact tracing. After introducing the product, clinicians who agreed to use it were asked to fill out a Google survey.

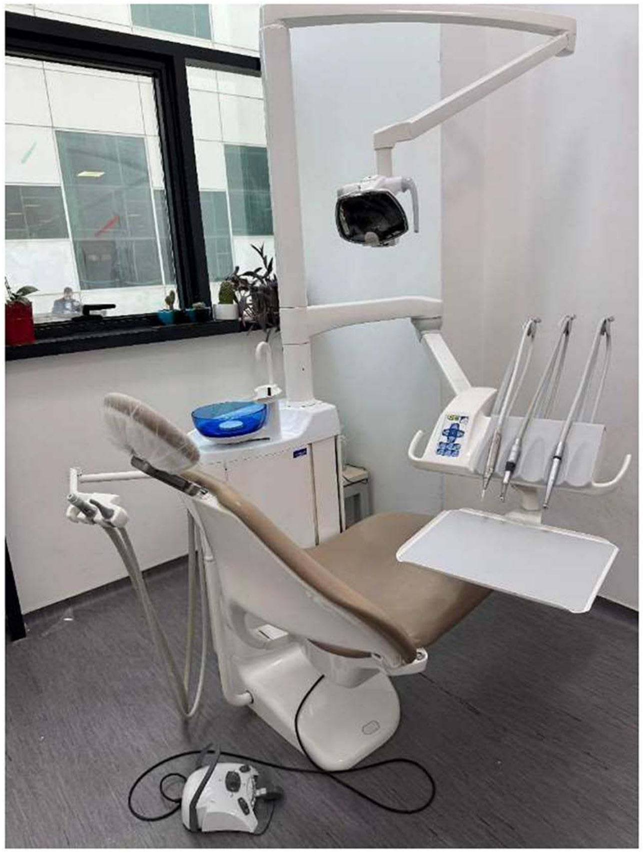

Figure 5 The surface of the reflector handle facing the patient.

Figure 6 Safe Steps sensors designed for wearable devices.

Statistical Analysis

When planning this study, it was anticipated that positive test results would be detected as a result of the implementation of the methods mentioned above in dental clinics. Based on these positive test results, it was envisioned that the prevalence of asymptomatic transmission in dental clinics within the Turkish population would be determined through

"Maximum Likelihood Estimation" and "Conjugate Bayes Estimation". Subsequently, it was contemplated that this study could be repeated over time and could complement cumulative prevalence estimates obtained from seroepidemiological studies or other surveillance systems. It was assumed that the identified point prevalence could also be utilized to feed into SEIR (Susceptible-Exposed-Infected-Recovered) models of the epidemic, refine predictions of epidemic progression, and evaluate the impact of control measures. However, no positive test results were found in any of the clinics as a result of the tests conducted, and the following methods could not be implemented. Nevertheless, to serve as an example for other studies where positive test results could be obtained, the relevant methods are outlined below.

The analysis can be conducted using the "PooledPrevalence" package in the R program (https://github.com/EU-ECDC/PooledPrevalence). Two different pooled test methods that allow for gradual improvement in estimates will be used.[20]

Explanation of Symbols Used in the Methods:

- *p*: Estimated Covid-19 prevalence
- *ptest*: Probability of a PCR test on a pool of being positive
- *w*: Number of pools tested in a study
- *k*: Number of positive pools in a study
- *s*: Pool size (number of individual samples in a pool)

Maximum Likelihood Estimation

This method is widely used, but it cannot be used when there are no positive pools. In such cases, assuming $k = 0.5$ allows obtaining results even though it may have an upward effect on the prevalence calculation.

The estimated prevalence probability (p) is calculated through the following formula: p

The 95% confidence interval (CI) is calculated using the following formula:

In the equations, the logit function is given by the general formula, and the inverse of the logit function (logit^{-1}) is calculated using the formula.

Conjugate Bayesian Estimation

Bayesian Conjugate Estimation allows making robust estimations in cases where zero positive pools exist. The model produces the posterior probability distribution of prevalence given a test result. The observed likelihood of *k* positive pools follows a binomial distribution. The observed posterior probability of p test can be estimated using the conjugate Bayesian theorem with parameters α and β. Then, the typical quantiles include the median ($q = 50\%$) and the 95% Credibility Interval (95%CrI) represented by $q = 2.5\%$ and $q = 97.5\%$:

Here, qBeta (q, x, y) denotes a function that retrieves the *q* quantile from the posterior conjugate Beta distribution with parameters $x = \alpha + k$ and $y = \beta + w - k$

Results

Summarizing the results according to the information obtained from the surveys: All users (100%) stated that they used the product related to the Internet of Things technology for the first time. All users (100%) mentioned that they had no prior knowledge about the product. 78% of the users expressed positive feedback about the product after using it. 70% of the users believed that the product provided sufficient alerts for contact tracing. 75% of the users reported that the use of the product motivated them to adhere to disinfection-sterilization conditions. 70% of the users indicated that using the product led to an increase in handwashing and glove-changing frequency. 79% of the users said they would use the product again in the future. Approximately 70% of the survey participants were female, and around 67% of them were between the ages of 25 and 30 (Tables 1 and 2).

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Table 1 Disinfectant Usage and Clinic Characteristics and Results

Category	Dental Units	Staff	Patients/ Day	Ventilation	Disinfection Protocols	IoT Sensor Using	RT-PCR Results
Endodontic Clinic (25–30 ages)	28	4	56	HEPA filter, intensive protocols	Alcohol-based, ULV hypochlorous acid, sodium hypochlorite	Yes	Negative
Other Clinics (45–65 ages)	2–7	2–16	15–45	Variable: HEPA filter, UV, hypochlorous spray	Variable: alcohol-based, UV, hydrogen peroxide	No	Negative

Table 2 Survey Results Summary for the Covid-19 Cross-Infection Study

Category	Percentage (%)
First Time Usage	100
No Prior Knowledge	100
Positive Feedbeck	78
Sufficient Alerts for Contact Tracking	70
Motivated for Disinfection	75
Increased Hand Hygiene Frequency	70
Willingness to Reuse	79

Notes: The following table summarizes the responses provided by the survey participants. These insights are part of a study evaluating the effects of IoT technology in dental clinics. Additionally, approximately 70% of the participants were women, and 67% were aged between 25 and 30 years.

Discussion

The COVID-19 pandemic has placed a significant burden on healthcare systems due to its high rates of illness and death. Additionally, the implementation of physical distancing measures has exerted substantial pressure on societies, both economically and socially. As a healthcare profession, dentistry involves close contact between patients, dentists, and healthcare workers, which increases the risk of transmission. The potential for transmission from asymptomatic individuals can lead to cross-infections in clinics, adding to the concern.

Okba et al,[21] reported that serum antibody levels against SARS-CoV-2 were higher in severe COVID-19 patients compared to those with asymptomatic to mild symptoms. Studies have also shown a rapid decline in anti-SARS-CoV-2 antibody responses in asymptomatic COVID-19 patients.[22–24]

COVID-19 is primarily transmitted through droplet spread, which can reach everyone within a 1-meter distance. Therefore, global social and technological measures have been implemented to halt the virus's spread and prevent the resurgence of infections. One of the technological measures adopted in many countries is contact tracing based on Internet of Things (IoT) technology.

The importance of distance tracking in controlling cross-infections of COVID-19 is indisputable, especially in high-risk areas like dentistry. Infection control measures are frequently updated and supported by the latest technologies. Nanotechnology, a sub-application of which includes sensors, is expected to become more widespread in these areas. However, the adoption of such devices in clinics will depend on their recognition and acceptance by clinicians, which may require more studies.

Therefore, in this study, the "Safe Steps" product was used for contact tracing in the context of the contact tracing process. This product was used for the first time in the healthcare field, with the aim of performing a risk analysis of individuals frequently in contact with others. However, all pool samples obtained yielded negative COVID-19 results. The data from the relevant date and clinic records were retrospectively tracked in terms of patient-doctor-personnel interactions. In case of a positive result, individuals who had longer interaction times or had contact with more people would be notified in advance for symptom assessment. The quarantine of high-risk individuals would be ensured to avoid disruption in the work continuity of other individuals and patient care in the clinic. Despite the negative results, the data from the conducted surveys suggest that during this period, the use of IoT technology, especially among young individuals, is effective in raising awareness and building confidence in preventing infection. Thus, IoT technology holds promise as an early preventive measure and a suitable technique for reducing the transmission rate in the healthcare field. However, there might be concerns regarding its usage, especially among other clinicians (eg, middle-aged and older professionals). On the other hand, the results of the survey, indicating positive attitudes towards using the device among young individuals, in a country where the majority of the population consists of young people, may suggest an opportunity for the widespread adoption of IoT devices in clinics.

This study contributes to awareness in this field. Considering the sensitivity during the period, the participation of a large number of individuals in the study was not possible, as the use of IoT devices was left to the discretion and desires of the clinicians. Clinicians who refused to use it thus formed the control group. The survey results highlight that 78% of young individuals preferred to use the devices, demonstrating their awareness and potential effectiveness in infection control.

In the follow-up period, which is crucial for tracking transmission, a 10-day period was considered, and samples were collected during this time. Clinicians were also instructed to be vigilant during the subsequent 10 days and inform the researchers of any signs of infection. The study covered a period when COVID-19 prevalence and transmission rates were high, and the hypothesis was that the use of IoT devices by clinicians during the COVID-19 transmission period could have positive potential effects on infection control, in addition to the infection control measures already in place.

Asymptomatic transmission can shape through different mutations and may require different tracking measures depending on the population, which could lead to diagnostic challenges. Therefore, the study used a molecular kit targeting mutation regions. The kit allowed detection of the Covid N gene and Orff1ab gene, as well as targeting the B.1.1.7 lineage and E484K mutation, if present.

The aim of the study was to assess the potential effects of clinicians using IoT technology through wearable devices in preventing cross-infection and enabling early diagnosis during the most prevalent period of COVID-19 transmission in dental clinics. The study also targeted demonstrating the presence of the effective SARS-CoV-2 virus on inanimate surfaces using RT-qPCR.

However, the RT-PCR results were negative in all groups. Looking at the study results, it may be considered that the outcomes are independent of the experiences of clinicians in the clinics. Although experienced clinicians (elderly ones) did not use the devices during the sample collection, all intern clinicians used them. However, there was no significant difference in the results, which indicates that, in addition to all effective infection control measures implemented during this period, this study reflected the cross-infection risk situation in the environments of both inexperienced and experienced clinicians, depending on whether they used IoT technology. At the same time, the assumption that the strict adherence to necessary infection control measures might not be neglected among young clinicians due to the use of this technology is also plausible.

The reluctance of some clinicians, particularly older professionals, to adopt IoT devices can be explained by factors identified in prior study on perceptions of smart home systems among the elderly. These factors include usability complexity, discomfort in daily routines, and insufficient awareness of the benefits of IoT technologies.

As highlighted in the referenced study,[25] older individuals often perceive IoT devices as overly complex and challenging to integrate into their daily activities. This perception of complexity may similarly apply to older clinicians, particularly when these technologies disrupt their established workflows or require significant effort to learn and adapt to. Additionally, the discomfort caused by unfamiliar technology further exacerbates resistance to adoption. Another critical barrier is the lack of awareness regarding the practical benefits of IoT devices. Initial resistance among elderly participants was mitigated after they gained a comprehensive understanding of the system's benefits, leading to greater willingness to adopt it.[25] A similar approach may benefit older clinicians by implementing targeted educational initiatives or practical demonstrations that emphasize the usability and advantages of IoT devices in their professional practice. To address these issues, further qualitative studies could explore specific challenges faced by older clinicians in adopting IoT devices, such as their concerns regarding usability, privacy, and integration into existing routines. By improving awareness and addressing these barriers through user-friendly IoT designs and tailored educational programs, adoption rates among older clinicians can be improved, ultimately enhancing healthcare delivery and efficiency.

During the COVID-19 pandemic, the high demand for SARS-CoV-2 RT-qPCR tests led researchers to consider pooled testing strategies.[26] These strategies involve testing multiple samples pooled together, and if the test results are negative, it is stated that the pooled samples do not have COVID-19. Pooled testing becomes even more important when test availability is limited and when the outbreak is spreading.[27] In dental clinics, where asymptomatic individuals can play a role in transmission and due to limited testing availability, pooled testing was found to be more cost-effective.[28] In this study, considering the possibility of asymptomatic patients and dentists, the pooled testing method was applied to equipment with a higher probability of close contact. If the result was positive, follow-up data obtained through the wearable tracking system would be used to trace individuals who had close contact. However, all our results were negative. This can be attributed to the rigorous implementation of disinfection methods and clinicians' continuous awareness through the IoT tracking system, leading to shortened contact durations and adherence to personal protective measures.

COVID-19 virus spreads through various-sized droplets expelled from the mouth during respiration, and especially in dry air, the viability of viruses as aerosols can be prolonged. Aerosols, including the smallest ones, can remain suspended in the air for 15 minutes to 3 hours, allowing for human-to-human transmission.[29] To purify indoor air from aerosolized viruses, general ventilation, and providing independent fresh air to the environment are generally employed. When this is not possible, the air in the environment is filtered through HEPA filters to eliminate virus-containing particles.[30] In this study, samples were collected from surfaces with potential high aerosol contact and from air filters to evaluate the effectiveness of removing aerosols from the environment using the VENTI-DENT and GEFI PURUFIER-35 devices designed by General Filter Havak.

Some studies have reported finding evidence of the virus during the post-recovery period of patients,[31,32] and some virus structures have been demonstrated in saliva even on the 29th day following recovery. Considering these findings, it was ensured that patients within this scope were not included in this study, and their appointments were postponed for 1 month after recovery.[33,34]

During this study, our clinicians were informed about the updated additional practices based on the findings of previous studies. Antimicrobial mouth rinsing before surgery can reduce the number of microbes in the oral cavity,[13,35] and this practice was applied before starting treatments during this period. Procedures that might induce coughing were avoided or performed carefully whenever possible. The use of a three-way syringe, which could generate aerosols, was minimized. Intraoral radiography is the most common radiographic technique in dental imaging; however, due to its potential to induce saliva secretion and coughing, extraoral dental radiographs, such as panoramic radiography and cone-beam computed tomography (CBCT), emerged as more suitable alternatives than periapical radiographs during the COVID-19 pandemic.[13] Studies have shown that human coronaviruses like Severe Acute Respiratory Syndrome (SARS) coronavirus can survive on inanimate surfaces such as metal, glass, or plastic for up to 9 years. However, they can be effectively inactivated with 62–71% ethanol, 0.5% hydrogen peroxide, or 0.1% sodium hypochlorite surface disinfection procedures within 1 minute. Other biocidal agents such as 0.05–0.2% benzalkonium chloride or 0.02% chlorhexidine digluconate have been reported to be less effective. Taking all this information into account, decontamination protocols were evaluated and selected for dental clinics, and they were meticulously followed during application.

Among dental procedures, it has been reported that the highest aerosol generation occurs during restorative and periodontal procedures. However, there is insufficient information about the amount of aerosols generated during endodontic treatments.[36] Endodontic procedures involving cavity preparation using air-driven handpieces and micromotors,[36] ultrasonic devices, and irrigation syringes used during preparation and irrigation can produce aerosols.[37] Endodontic motors and rotary files, which are used in almost every stage of root canal treatment, also generate aerosols containing infected blood, saliva, and mucous secretions.[38] At the University Faculty of Dentistry, student clinics follow a multidisciplinary-integrated approach, and although the Endodontics student clinic primarily treats endodontic patients, it also provides periodontal, restorative, and prosthodontic treatments.

Additionally, patient profiles may vary in private clinics. In private clinics, all patients seeking treatment are served, and not just one specific branch. This diversity can result in variations in the type of procedures performed. In the same clinic, there may be procedures with low aerosol production, such as orthodontic and initial examinations, as well as procedures with high aerosol production, such as periodontology, prosthodontics, endodontics, pediatric dentistry, surgery, and restorative procedures. This was done to create a mixed pool of procedures and increase the likelihood of encountering the pathogen.

As is known, tests that enable the diagnosis of coronavirus play a crucial role in combating the COVID-19 pandemic. However, due to the limitations in test capacity and the high cost of diagnosis, along with studies showing that tests can yield false-positive or false-negative results, especially in early diagnosis, it can be assumed that this aspect might be compromised. In this study, we opted for a modified test protocol where a set of probes is pooled due to economic reasons and difficulties in obtaining test kits. Studies have shown that this approach increases COVID testing capacity.[39,40]

While a positive result of nucleic acid testing indicates the presence of viral RNA, the relatively low viral load in asymptomatic infected individuals, inadequate sample collection, and limited accuracy of the test technology[41] can be addressed by using the Bio-Speedy® SARS-CoV-2 Variant Plus Kit, which offers high sensitivity and specificity values.

This study has some limitations. If patients have symptoms, they might be more diligent in providing information during follow-up. Additionally, conducting the study during a period of peak disease activity might have influenced the more stringent infection control measures implemented due to temporary concerns and fears, and this might not have fully reflected the potential of IoT device usage. However, the potential impact of this decision on the use or non-use of IoT devices should also take into account the potential occurrence of similar outbreaks in the future.

At this point, it is unclear whether the absence of COVID-19 transmission on surfaces and filters in our study is due to the low prevalence of asymptomatic/pre-symptomatic individuals in our population, methodological limitations such as a small sample size, or the stringent implementation of control measures and/or the impact of IoT technology usage.

This study can be considered as the first study that includes clinician attitudes towards the use of IoT technology in cross-infection control in dental clinics. However, when evaluating this study, it should not be forgotten that the possibility of the device serving as a deterrent and motivator for usage during that period. As part of our interest in the effects of nanotechnology on cross-infection control in clinics, this device was investigated in conjunction with other measures. However, even after the pandemic, it has the potential to be preferred by young clinicians due to its ability to create intrinsic motivation, confidence, convenience, and reminders in the implementation of control measures.

Moreover, the implementation of IoT-based sensors in dental clinics for infection control presents a cost-effective solution, even in resource-limited settings.[42] These sensors enable early detection of infections by monitoring environmental parameters, thereby reducing treatment costs. Additionally, optimizing the use of resources such as water, energy, and disinfectants supports sustainability. Remote monitoring and data analytics provide effective tools for predicting cross-infection risks and enabling timely interventions. Developing low-cost devices and applying financial incentives through public-private partnerships can enhance accessibility on a broader scale. However, effective adoption of these technologies requires clinician training and awareness initiatives. Integrating IoT technologies into health practices can deliver long-term economic benefits while improving patient safety and clinical efficiency.

Nonetheless, the use of IoT devices in dental applications comes with certain technical challenges and limitations. Technical issues include connectivity problems, difficulties in system integration, and inconsistencies in sensor accuracy. In resource-limited settings, the requirement for stable internet connections can pose a significant barrier. Additionally, the lack of user-friendly interfaces in IoT devices can hinder their adoption by clinicians.[43] Usability challenges such as complex device interfaces and insufficient training further exacerbate this issue. Moreover, data privacy and security concerns regarding the information collected by IoT devices are a major challenge. Risks of data misuse or unauthorized access can deter clinicians from adopting these technologies. To address these limitations, the development of user-friendly designs, the adoption of encryption protocols to enhance data security, and the implementation of targeted training programs are recommended. Effectively managing these technical and ethical limitations is crucial to realizing the potential benefits of IoT in dental practices.

Conclusion

This non-therapeutic study highlights the positive views of intern clinicians on the effectiveness of IoT usage in cross-infection control, supported by negative RT-PCR results obtained during the COVID-19 pandemic. By utilizing a wearable device and a smartphone-based tracking application, our study anticipated the potential widespread future use of this technology in dental clinics. The data obtained from this study may accelerate the realization of this potential and encourage further research on this topic. However, our study has certain limitations. For instance, the small sample size limits the generalizability of our findings. Acknowledging these limitations is essential to encourage further research to validate our results. Future studies should focus on comprehensive comparisons between clinics that adopt IoT technologies and those relying solely on traditional methods.

Furthermore, addressing potential barriers to the adoption of IoT technologies such as cost, clinician training, and privacy concerns is crucial. Developing strategies to overcome these challenges will expedite the integration of IoT technologies into healthcare services. Therefore, there is an urgent need for new studies to better understand the scalability and integration of IoT technologies into routine infection control practices in diverse healthcare settings, which remains a critical and necessary aspect of clinical practice.

Data Sharing Statement

The data utilized to underpin the discoveries of this investigation can be accessed from the corresponding author upon request.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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