Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Risk for dental healthcare professionals during the COVID-19 global pandemic: An evidence-based assessment

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ABSTRACT

Objectives: Heightened anxiety among dental healthcare professionals (DHPs) during the COVID-19 pandemic stems from uncertainties about the effectiveness of personal protective equipment (PPE) against dental aerosols and risk levels of asymptomatic patients. Our objective was to assess the risks for DHPs providing dental care during the pandemic based on available scientific evidence.

Methods: We reviewed the best available evidence and estimated the annualized risk ($p = d_a s(1 - 1\text{-}p_0 p_1(1\text{-}e)^{yn}$) for a DHP during the COVID-19 pandemic based on the following basic parameters: p_0, the prevalence of asymptomatic patients in the local population; p_1, the probability that a DHP gets infected by an asymptomatic patient; e, the effectiveness of the PPE; s, the probability of becoming symptomatic after getting infected from asymptomatic patient; d_a, the probability of dying from the disease in age group a; n, number of patients seen per day; and y, number of days worked per year.

Results: With the assumption that DHPs work fulltime and wear a N95 mask, the annualized probability for a DHP to acquire COVID-19 infection in a dental office, become symptomatic, and die from the infection is estimated at 1:13,000 (0.008 %) in a medium sized city in the US at the peak of the pandemic. The risk estimate is highly age-dependent. Risk to DHPs under the age of 70 is negligible when prevalence of asymptomatic cases is low in the local community.

Conclusions: Risk of COVID-19 transmission in dental office is very low based on available evidence on effectiveness of PPE and prevalence of asymptomatic patients. Face shields and pre-procedure oral rinses may further reduce the risks.

Clinical significance: DHPs should follow guidelines on pre-appointment protocols and on PPE use during dental treatments to keep the risk low.

Providing dental care during infectious disease outbreaks carries inherent risks to dental healthcare providers (DHPs) due to spatters and aerosols generated during dental treatments [1]. The HIV/AIDS pandemic in the 1980s caused great anxiety in DHPs for fear of the spread of a deadly bloodborne infectious disease in dental offices, which accelerated the adoption of universal precaution that emphasizes efficient sterilization, hand hygiene and use of personal protective equipment (PPE) during the provision of dental care [2,3]. Basic PPE that includes facemasks, gloves, isolation gowns or coats, and eye protection goggles has been widely adopted in dental offices and contributed to a much safer environment for DHPs and their patients than ever before [4]. Widespread and consistent use of PPE by DHPs may have played a significant role in minimizing the risks of exposure to SARS-CoV-2 in dental offices during the current global pandemic. As of today, there are no confirmed cases of COVID-19 transmission or mortality associated with dental care for DHPs and their patients, while many physicians and nurses have fallen victims of COVID-19 worldwide [5,6]. However, absence of detrimental outcomes in DHPs does not negate the presence of potential risks for disease transmission in dental offices during an evolving respiratory disease pandemic. COVID-19 brings unique challenges to dentistry as a profession and has prompted DHPs worldwide to reassess and modify their daily practice routine to mitigate the potential risks from an elusive and invisible enemy [7–11]. Dental professional organizations and regulatory agencies have also acted rapidly and provided guidance on measures to protect DHPs and their patients during the pandemic that included postponing elective treatments, prescreening patients for contact history and symptoms, increasing level of PPE, improving spatter and aerosol controls, and strengthening post-

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treatment disinfection and sterilization protocols [12,13]. Despite such unprecedented efforts in risk reduction, DHPs remain anxious and continue to search for opportunities for practice improvement [7,8,14,15].

As a community safety net for oral health, dental urgent care services in the authors' institution have not only continued but expanded to accommodate the increased demands due to extended closures of local dental offices following national and state guidelines and regulations during the COVID-19 pandemic. We have provided urgent care services to more than 5000 patients from mid-March when American Dental Association (ADA) issued its urgent care only guidance, to early June when New York state announced reopening of dental practices for non-urgent care. From this experience we recognized that heightened anxiety from DHPs stems mainly from two aspects: shortage and uncertain effectiveness of current PPE against the SARS-CoV-2 virus, and unknown risk level of transmission from a patient who might be infected with the virus but remain asymptomatic.

Considering that the primary route of transmission for COVID-19 is from respiratory droplets, and potentially from spatters or aerosols generated during dental treatments, risks of COVID-19 transmission from asymptomatic patients to DHPs are dependent on several factors: effectiveness of PPE, specifically the N95 masks in preventing virus transmission, prevalence of asymptomatic cases in the local community, rate of transmission from asymptomatic patients to healthcare providers in close contact, probability for an infection acquired from an asymptomatic patient become symptomatic, and age-adjusted infection fatality rate of symptomatic COVID-19 patients. We reviewed currently available evidence pertaining to above factors and attempt to estimate the probability of DHPs may be affected by COVID-19 during the pandemic.

1. Methods

During the pandemic, we continued to provide dental emergency and urgent care services when dental offices in the community are mostly closed following U.S. Center for Disease Control and Prevention (CDC) and ADA guidance and state orders. To understand the potential impact of COVID-19 on dental care and oral health and assess the risks to DHPs from the disease while providing essential services to the community, we periodically searched and reviewed published literature in PubMed and Google Scholar using various combinations of keywords, including SARS CoV-2, COVID-19, Dental, Dentist, Dentistry, Droplets, Aerosols, Healthcare Workers, Symptomatic, Asymptomatic, Saliva, PPE, N95 Masks, Face Shields, and Infection Fatality Rate. We also searched manuscripts in pre-publication stage but listed in bioRxiv, medRxiv and SSRN preprint platform to keep up with the most up to date information. In addition, we payed attention to news media and used Google search to complement the information from academic journals. Our literature review focused on the following areas: prevalence of asymptomatic COVID-19 patients in the community, probability and potential outcomes from transmission from asymptomatic patients, effectiveness of PPE (N95 masks), and the infection fatality rate of COVID-19.

We estimated the probabilities for a DHP to get infected by an asymptomatic patient in a dental office, become symptomatic and die from the infection based on the best available published data and the local data on disease prevalence using the following basic parameters:

p_0, the prevalence of asymptomatic patients in the local population (for example, the population in the Greater Rochester Metropolitan area);

p_1, the probability that a DHP (without PPE) gets infected after contacting an asymptomatic patient;

e, the effectiveness of the PPE;

s, the probability of becoming symptomatic after getting infected from asymptomatic patient;

d_a, the probability of dying from the disease in age group a.

Table 1 lists formulas used to calculate the risks of different events if the DHP sees n patients per day, and works y day per year

2. Results

2.1. Evidence synthesis

2.1.1. Effectiveness of N95 masks

a Experimental evidence

N95 masks or respirators are comprised of four layers: an outer layer constructed of hydrophobic non-woven polypropylene that is moisture resistant, followed by two filter layers of melt-blown non-woven polypropylene that capture particles of various sizes through inertial impaction, interception, diffusion and electrostatic attraction [16], plus an inner layer that is also made of the moisture resistant non-woven polypropylene material [17]. The "N95" rating is based on the performance of these filter layers and denotes that the mask can collect at least 95 % of the challenge aerosols that are 0.3 μm in median diameter [16]. The N95 masks have been extensively tested in the laboratories in the context of particle and virus filtrations simulating clinical and infectious disease conditions. Comprehensive reviews of these experimental evidence indicate that all the N95 masks tested could achieve greater than 99 % efficiency in preventing the penetration of particles ranging in sizes from 20 nm to 20 μm and of viral particles 30 nm–35 nm in diameters [18,19]. Recent studies have focused not only on particle filtration efficiency but also on the removal of viable viruses responsible for infectious respiratory diseases when using a N95 mask [17,20]. N95 masks were found to have greater than 99 % efficiency in removal viable viruses from 20 nm (human rhinovirus) to 110 nm (human influenza A) in sizes [17]. A study from the US Department of Health and Human Services and the National Institute of Occupational Safety and Health (NIOSH) found that N95 masks could remove at least 99 % of viable H1N1 viruses carried in artificial saliva aerosols (median diameter 0.8 μm) at a continuous flow rate of 85 L per minute, and at least 96 % of the viruses under extreme conditions at air flow rate of 175 L per minute [20]. This study concluded that properly fitted N95 masks could effectively reduce the risk of inhalation of the H1N1 viruses by healthcare providers. Another finding from this study is that the filtration efficiency of N95 masks is primarily dependent on the size but not the type or origin of the particles [20], which is important information for the current COVID-19 pandemic as the SARS-CoV-2, at about 125 nm in diameter [21], is larger than the H1N1, also a RNA virus. N95 masks should have at least the same removal efficiency against viable SARS CoV-2.

b Clinical evidence

Clinical studies assessing the effectiveness of N95 masks in preventing viral respiratory disease transmission in healthcare workers have largely replicated the findings of the experimental studies [22,23]. The infection rate was only 0.1 % among more than 2000 healthcare workers who wore N95 masks and treated patients with coronavirus infections in hospital settings during a 4-week period [22]. A recent systematic review sponsored by the WHO synthesized data on SARS, MERS and COVID-19 and found that wearing a mask (surgical or N95) could significantly reduce the risk of coronavirus infection (Adjusted OR = 0.15, 95 % CI 0.07 – 0.34) in 10 observational studies involving both healthcare or non-healthcare settings [24]. As COVID-19 has a significant different transmission profile from that of SARS and MERS [25], and surgical masks may perform differently from N95 masks, this type of pooled data and analysis may not help us to understand the utility of N95 masks in healthcare settings in the current COVID-19 pandemic. Including those cited in the above systematic review, we reviewed several observational studies that reported rates of infection

Table 1
Formulas for daily and annul risk calculations.

Event	Daily risk	Annual risk
Contacting at least one asymptomatic patient	$1\text{-}(1\text{-}p_0)^n$	$1\text{-}(1\text{-}p_0)^{yn}$
Getting infected without PPE	$1\text{-}(1\text{-}p_0p_1)^n$	$1\text{-}(1\text{-}p_0p_1)^{yn}$
Getting infected with PPE	$1\text{-}[1\text{-}p_0p_1(1\text{-}e)]^n$	$1\text{-}[1\text{-}p_0p_1(1\text{-}e)]^{yn}$
Becoming symptomatic with PPE	$s\{1\text{-}[1\text{-}p_0p_1(1\text{-}e)]^n\}$	$s\{1\text{-}[1\text{-}p_0p_1(1\text{-}e)]^{yn}\}$
Dying from the disease in age group a	$d_as\{1\text{-}[1\text{-}p_0p_1(1\text{-}e)]^n\}$	$d_as\{1\text{-}[1\text{-}p_0p_1(1\text{-}e)]^{yn}\}$

in healthcare workers (either with or without wearing N95 masks) in close contact with COVID-19 patients in hospital settings [26–29]. Collectively, these studies reported COVID-19 infections in 132 of 4670 (2.83 %) healthcare workers who did not wear N95 masks, mostly during early stages of the pandemic and before the diagnosis was confirmed in the patients they were caring, and in 1 of 1636 (0.06 %) healthcare workers who did wear N95 masks as a part of the enhanced precaution. The combined secondary attack rate of 2.1 % among healthcare workers in these studies is significantly higher than that reported in non-hospital settings in healthcare and community (0.45 %), but much lower than that among household members (10.5 %) [30,31].

2.1.2. Prevalence of asymptomatic cases in the local community

Prevalence of asymptomatic COVID-19 cases in the local community is the most important metrics for assessing the risk of dental office exposure as these patients are covert and cannot be identified through routine screening without testing the SARS CoV-2 RNA. If one of the asymptomatic patients in the community visits a dental clinic, DHPs may become exposed unknowingly.

The prevalence of asymptomatic COVID-19 cases is dynamic in an evolving pandemic and will certainly change over time, and it will be higher in areas where the cases are surging than in areas declining. Accurate estimate of asymptomatic patients in a community depends on population-based tests or random sampling tests. Nation-wide random sampling in Iceland from mid-March to early April tested a total of 13,080 individuals and found that 43 (0.33 %) of them were positive for SARS-CoV-2 but did not have any symptoms at the time of the test [32]. A review article published in *Annals of Internal Medicine* on June 3, 2020 summarized state-wide testing data from Indiana and city-wide testing data from San Francisco and reported that the prevalence of asymptomatic cases was 0.76 % (35/4611) and 0.94 % (39/4160), respectively [33]. Two consecutive city-wide tests involving 80 % of the local population were conducted in the town of Vo in northern Italy during the height of the pandemic lockdown, and found that the prevalence of asymptomatic COVID-19 cases was 1.1 % (30/2812) in the first series and 0.6 % (13/2343) in the second series at a later stage of the pandemic [34]. Prevalence rate of asymptomatic cases apparently decreased with the pandemic gradually winding down. At the end of May 2020, the city of Wuhan tested 9.9 millions of its 11 million residents and found only 300 (0.003 %) cases who were asymptomatic but tested positive for the SARS-CoV-2 viral RNA [35]. Another city-wide population testing found 19 (0.003 %) asymptomatic infections out of 658,772 people tested from June 1–7 in the city of Mudanjiang in northeast China [36].

Till June 15, 2020, a total of 259 (1.4 %) patients, who were not tested before and had no symptoms, have been found to be positive for the SARS CoV-2 RNA among 18,281 asymptomatic individuals tested at the University of Rochester Medical Center in Rochester, New York. These may include patients who may develop symptoms in a later date and are best described as a combination of pre-symptomatic and asymptomatic individuals. The prevalence rate is significantly higher in this patient population than in random population samples reviewed above.

2.1.3. Transmission from asymptomatic patients to close contacts

Whether asymptomatic patients could transmit the disease remains an issue of debate. Several studies reported family clusters originated from an index asymptomatic patient [37–40], while others did not find evidence of disease transmission from asymptomatic patients to close contacts [41–43]. Contact tracing during the height of pandemic have identified infected patients among close contacts with asymptomatic patients, especially when living in the same households [26,34]. But contact tracing of close contacts to an asymptomatic COVID-19 patient found no SARS CoV-2 infection among the 35 fellow patients, 196 family members and 224 hospital staffs [44]. In city-wide testing in Wuhan, contact tracing of the 300 asymptomatic patients found no infections among the 1174 close contacts, suggesting the infection may not be spreading to others from an asymptomatic patient, at least at a late stage of the pandemic.

Because there is no reported case of healthcare worker affected by an asymptomatic COVID-19 patient, it is difficult to accurately assess the risk for DHPs to contract the disease from an asymptomatic patient who visits a dental office. We may use data on the transmissibility of asymptomatic patients in households to assess the potential risk of transmission from asymptomatic patients in dental offices, with the understanding that the true risk of transmission in healthcare settings should be much lower [5,26,31]. Transmissibility of COVID-19 was found to be largely related to symptom severity, with the transmission rate (or attack rate) being 0.8 % for asymptomatic patients, 3.5 % for mild, 5.7 % for moderate and 4.5 % for severe symptoms [45]. Chen et.al traced 2147 close contacts of 187 patients (157 symptomatic and 30 asymptomatic) and compared the infectivity between symptomatic and asymptomatic cases [26]. A total of 132 individuals, 110 symptomatic and 22 asymptomatic, were confirmed to have been infected among the 2147 close contacts in households, community and healthcare settings. Of the 132 patients, 126 were from the 2001 close contacts with the 157 symptomatic patients, and 6 were from the 146 close contacts with the 30 asymptomatic patients, which signifies a transmission rate of 6.30 % from symptomatic patients and 4.11 % from asymptomatic patients, respectively. Most (94 %) of the secondary cases occurred among family and friends, followed by community close contacts (6%), and no infection occurred among the healthcare workers in close contacts with the symptomatic or asymptomatic cases. Another group of researchers conducted a secondary analysis of the same data and quantified the transmissibility of symptomatic and asymptomatic patients with the reproduction number R, defined as the ratio between the case count in the first generation divided by those in the second generation [46]. They found that the R number was 0.78 for symptomatic patients and 0.20 for the asymptomatic ones (RR = 3.9, 95 % CI 1.5–11.8), which indicates the infectivity of asymptomatic cases is 74 % lower than the symptomatic patients. In addition, these studies show that asymptomatic cases are more likely to produce asymptomatic cases since 50 % of the new cases transmitted from the asymptomatic primary cases were asymptomatic, compared to only 15 % asymptomatic new cases transmitted from the symptomatic primary cases [26,46]. In other words, the probability for a patient who acquires the COVID-19 infection from an asymptomatic patient to become symptomatic is likely 50 %, while the probability for an infection acquired from a symptomatic patient to become symptomatic is much higher at 85 % [46]. The finding that infection acquired from an asymptomatic patient is likely

also asymptomatic is further substantiated by contact tracing report in Vo, Italy, where close contacts with asymptomatic patients yielded one new symptomatic case and 3 new asymptomatic cases [34].

2.1.4. Infection fatality rate of COVID-19 patients

It is difficult to accurately assess the fatality rate of COVID-19 while the disease is still evolving. Case fatality rate (CFR), measured as a ratio between the number of deaths and the number of reported cases with confirmed diagnosis of COVID-19, is most conveniently used in media reports to signify the deadliness of the disease. CFR is often used at earlier stages of the pandemic when testing was mainly performed in hospitalized patients and not readily available in the community. Infection fatality rate (IFR), defined as the ratio between the number of deaths and the number of cases with COVID-19 infection in a population, is often considered as a more accurate representation of fatality associated with the disease. Reliable estimate of IFR is dependent on widespread testing in the population, which is only available at late stages of the pandemic. Serologic tests in a population would allow the use of seroprevalence data to estimate the cumulative incidence of SARS-CoV-2 infection [47]. Based on population seroprevalence data from 23 studies published as of June 7, 2020, median IFR of COVID-19 is estimated to be 0.26 % (range 0.02 %–0.86 %) [48]. The median IFR for individuals younger than 70 is 0.05 % (range 0.00 %–0.26 %). As most of the seroprevalence data was from the pandemic epicenters where the death burden is the highest, IFR from areas away from the epicenters is likely significantly lower [48]. A comprehensive analysis based on testing capacity and proportions of asymptomatic cases from 139 countries determined that global IFR of COVID-19 is 1.04 % (95 % CI 0.77 %, 1.38 %) [49]. As COVID-19 related death is not likely to occur in asymptomatic cases, IFR in symptomatic cases (IFR-S) may provide a more accurate estimate on the likelihood of death for a patient who developed symptoms. The IFR-S is estimated to be 1.3 % (95 % CI 0.6 %, 2.1 %) based on available national data on cumulative deaths in symptomatic COVID-19 patients in the United States [50].

It is important to point out that the above IFR estimates are based on population of all ages. As we know that death related to COVID-19 mostly occur in older patients with underlying systemic diseases, the IFR in younger age groups should be much lower. For example, age-dependent IFRs are 0.01 % in the 30 − 39 age group, 0.04 % in 40 − 49, 0.17 in 50 − 59, 0.70 in 60 − 69, 2.53 in 70 − 79, 7.12 in 80 − 89, and 17.5 % in the 90 and older groups in Lombardy region in Italy [51].

2.2. Estimate of risks associated with seeing patients in dental offices

Based on evidence reviewed above, important parameters associated with risks of disease spread in dental offices are summarized in Table 2:

Based on data summarized in Table 2 and using formulas listed in Table 1, daily risks for a dentist to acquire COVID-19 infection from an asymptomatic patient, become symptomatic, and die from the infection are calculated and presented in Table 3. The annualized risk estimate is dependent on the numbers of patients seen per day and days worked in a year. We estimate that dentist in training may see 6–8 patients per day, and a working dentist may see 8–10 patient per day on average in an eight-hour work day. Assuming that the prevalence of asymptomatic cases (1.4 %) and infection fatality rate (1.3 %) are constant throughout the year, and that a dentist sees 10 patients per day and works 212 eight-hour days for about 1,700 h per year [52], we can calculate annualized risk estimates in different age groups using age-adjusted infection fatality rates [51] (Table 4). The probability for a dentist to acquire COVID-19 infection from an asymptomatic patient, become symptomatic, and die from the infection in all age groups is estimated to be 1:13,000 in a year. The risk estimate is highly age-dependent, at about 1:1.7 million in the 30 − 39 age group but 1:1,000 in the 90 or older group.

To demonstrate the effect of uncertainties associated with the prevalence rate and transmissibility of asymptomatic cases on the risk estimates for DHPs, we conducted a range of sensitivity analysis based on potential variabilities of these two parameters (Supplemental Materials). Using lower bounds of 0.003 % for prevalence rate, 4.11 % for transmission rate, and upper bounds of 2.8 % for prevalence rate, and 6.30 % for transmission rate, the overall risk estimates ranged from negligible (1:6 millions) in areas where the pandemic is under control, to 0.02 % (1:4,330) in areas where the disease continues to spread widely in the community (Supplemental Tables 1–4).

3. Discussion

Based on available data about prevalence of asymptomatic COVID-19 cases in the community, transmissibility of asymptomatic COVID-19 cases, effectiveness of PPE (N95 masks), and the IFR of symptomatic COVID-19 cases in the US, we estimate that the annual risk for a DHP to contract COVID-19 from asymptomatic patients and dying from the disease is at approximately 1:13,000, or 0.008 % on average in all age groups. To put this number in perspective, the annual risk for an individual to be involved in a motor vehicle accident and dying from the injury in the US is higher at approximately 1:8,000 [53]. Risk from COVID-19 to DHPs in older age groups is significantly higher than in the younger ones. But the annual risk estimate in the oldest age group remains low at about 0.1 % based on available data, which indicates that a dentist older than 90 years of age may still have a 99.9 % probability to avoid dying from COVID-19 acquired from a dental office even if he or she continues to work fulltime. Risks are much lower in the younger age groups, approaching zero in those under the age of 40 years.

We recognize that the parameter values used in this analysis are mostly from data in medical settings treating severely ill patients, and may result in a significant overestimate of the true risks in dental settings where only asymptomatic patients are likely encountered. With the pandemic still evolving, these estimates should be treated with caution and adjusted based on local data where the DHPs work. Prevalence of asymptomatic cases in the community should decrease

Table 2
Parameters values used in the risk calculations.

Parameter	Value
Prevalence of asymptomatic cases in the community[a]	1.40 %
Transmission rate from asymptomatic cases in the community[20, 50]	4.11 %
Transmission rate from symptomatic cases in the community [20, 50]	6.30 %
Transmission rate from symptomatic cases in healthcare settings without PPE[20, 29, 31 − 33]	2.83 %
Transmission rate from symptomatic cases in healthcare settings with PPE[20, 29, 31 − 33]	0.061 %
Transmission rate from asymptomatic cases in healthcare settings with PPE [24, 26 − 28][20, 50]	0.0398 %
Proportion of infections acquired from symptomatic cases becomes symptomatic[20, 50]	85 %
Proportion of infections acquired from asymptomatic cases becomes symptomatic[20, 50]	50 %
Infection fatality rate (global, includes asymptomatic) [53]	1.04 %
Infection fatality rate (US, symptomatic only) [48]	1.30 %

[a] unpublished data from University of Rochester Medical Center in Rochester, New York.

Table 3
Daily risks for dental healthcare professionals seeing patients in a dental office.

	Number of patients per day		
	n = 6	n = 8	n = 10
Probability of contacting at least one asymptomatic patient	8.11×10^{-2}	10.67×10^{-2}	13.15×10^{-2}
Probability of getting infected without PPE	3.45×10^{-3}	4.59×10^{-3}	5.74×10^{-3}
Probability of getting infected with PPE	33.43×10^{-6}	44.57×10^{-6}	55.71×10^{-6}
Probability of becoming symptomatic after getting infected	16.71×10^{-6}	22.28×10^{-6}	27.86×10^{-6}
Probability of dying after getting infected and becoming symptomatic	21.73×10^{-8}	28.97×10^{-8}	36.21×10^{-8}

Table 4
Age-adjusted probabilities of dying from COVID-19 when seeing 10 patients per day in a dental office (assuming 212 8 -h work days per year).

Age group	IFR (%)[a]	Daily		Annual	
Overall	1.3	36.21×10^{-8}	1:2,762,000	76.32×10^{-6}	1:13,000
30 – 39	0.01	0.28×10^{-8}	1:357,143,000	0.59×10^{-6}	1:1,695,000
40 – 49	0.04	1.11×10^{-8}	1:90,090,000	2.35×10^{-6}	1:426,000
50 – 59	0.17	4.74×10^{-8}	1:21,097,000	9.98×10^{-6}	1:100,000
60 – 69	0.70	19.50×10^{-8}	1:5,128,000	41.10×10^{-6}	1:24,000
70 – 79	2.53	70.48×10^{-8}	1:1,419,000	148.53×10^{-6}	1:7000
80 – 89	7.12	198.33×10^{-8}	1:504,000	418.01×10^{-6}	1:2500
> =90	17.50	487.48×10^{-8}	1:205,000	1027.41×10^{-6}	1:1000

[a] overall infection fatality rate based on national data in the US in symptomatic cases(54); age adjusted infection fatality rate based on population data in the region of Lombardy, Italy(55).

drastically at later stages of the pandemic. Using formulas listed in Table 1, the risk estimate should be adjusted when new data are available.

Several other factors that may affect the risk estimate are not included in the calculations. COVID-19 patients who have underlying health conditions, such as diabetes, cardiovascular diseases, chronic lung diseases, were found to have six times higher risk of hospitalizations and 12 times higher risk of deaths [54]. Therefore, the true risk for DHPs who have these conditions may be significantly higher than the above risk estimate. Risk may also be higher in individuals who appear healthy but have predisposing genetic makeups that may increase the susceptibility to poor clinical outcomes [55,56].

Availability and effectiveness of PPE is an important determinant of risks posed to healthcare professionals. We only included effectiveness data associated with the use of N95 masks in our analysis. We contend that the risk may decrease further if PPE in addition to N95 masks is used. For example, face shields may add extra protection to DHPs as they may isolate the facial area and mucous membranes of eyes, nose and mouth from splashes and spatter of body fluids and from aerosols generated during treatment procedures [57]. It has been shown that dentist's face is often contaminated during dental treatments [58]. A study conducted in the NIOSH laboratory concluded that face shields were very effective for respiratory protection [59], which has prompted some experts to recommend the use of face shields in the community to minimize the spread of COVID-19 as it may be more effective than some face masks in reducing virus exposures [31]. Therefore, face shields should be included as part of the standard PPE in dental practices that generate spatters and aerosols.

DHPs may face increased risks during a viral respiratory disease outbreak because they work in close proximity to the patient's mouth performing procedures that generate droplets and aerosols potentially laden with viable viruses. In theory, DHPs could inhale these droplets and aerosols and become infected with the virus. However, there is no evidence that any DHP has contracted the disease in such a manner. The risk for virus transmission from droplets and aerosols to DHPs is determined by the presence of viable viruses in the patient's saliva. Information on saliva viral load and viability in COVID-19 patients, especially in asymptomatic patients, are scarce. In two widely cited studies that reported constant detections (90 % of cases) of SARS CoV-2 viral RNA in human saliva in hospitalized COVID-19 patients, the saliva was collected by asking the patient to cough out saliva from their throat [60,61], which may best reflect a mixture of secretions from upper and lower respiratory tracts with saliva. In a study that collected saliva directly from the salivary gland duct openings, SARS CoV-2 RNA was detected in only 4 out of the 13 (31 %) patients who had a positive oropharyngeal swabs [62]. The authors stated that salivary glands may only be affected in some patients who had severe viral infections as 3 out of the 4 patients who had a positive saliva test were on ventilators in the intensive care unit. This study indicates that viruses in the saliva may not be directly discharged from the salivary glands until late stages of the disease. Viruses shed from both the nasopharynx and the lung can nonetheless enter oral cavity and increase the sensitivity of saliva tests for SARS-CoV-2, especially in patients with severe or very severe conditions [63,64]. However, it is not clear if SARS CoV-2 is present in the saliva of asymptomatic patients. In a study that collected saliva and nasopharyngeal samples every 3 days for a period of 2 weeks in 98 asymptomatic healthcare workers, 2 individuals were found to be positive for the SARS CoV-2 RNA in saliva, which were not confirmed by nasopharyngeal swabs [64].

Viral load in sputum or saliva determines the probabilities for coughing or dental aerosols to contain the SARS CoV-2 viruses. The mean number of SARS CoV-2 RNA copies in sputum was reported to be 7.0×10^6/mL in hospitalized COVID-19 patients [65]. Based on this data, it was estimated that the probability for sputum coughing droplets 50 μm in diameter to contain one copy of viral RNA is at about 37 %, and much lower for smaller aerosols 10 μm and 3 μm in diameters at 0.37 % and 0.01 %, respectively [66]. SARS CoV-2 RNA copies in human saliva were reported to be in the range of 9.9×10^2 to 1.2×10^8/mL, with a median of 3.3×10^6/mL [60,67]. These data indicate that the probability for undiluted saliva droplets and aerosols that are 50 μm, 10 μm and 3 μm in diameters to contain any viral RNA is lower, at about 21.5 %, 0.17 % and 0.0047 %, respectively. As saliva pool is rapidly removed using high and low volume suctions, saliva remnants in the oral cavity may be diluted tens or hundreds of times by copious coolants from the handpieces and ultrasonic scalers during treatments, the chance for dental aerosols below 5 μm in size to contain any viral RNA at all is extremely low. This information suggests that it might be most productive for DHPs to focus on the prevention and elimination of larger dental droplets that are more likely to contain viruses, which further substantiates the importance of N95 masks and

face shields in dental offices. It is important to point out that the presence of viral RNA is not equal to the existence of viable viruses that can cause infection. It is the presence of viable viruses in saliva that causes concerns for dental office transmission of COVID-19. SARS CoV-2 RNA may be detectable in throat swabs for 22 days, but viable viruses could only be isolated in the first 7 days after symptom onset [65]. In the only study that reported viral culture findings of human saliva, viable viruses were only found in 3 out the 5 hospitalized patients with positive SARS CoV-2 RNA tests [60]. Data on SARS CoV-2 viral load and viral culture in human saliva are lacking for adult asymptomatic patients. SARS CoV-2 RNA was found in the saliva in 2 of the 3 asymptomatic children at an average of 5.5 $\log_{10}$ copies/mL [68], which is 10 times lower than that reported in the saliva of symptomatic patients [60].

Human saliva is considered first-line of defense against viral infections as it contains large amounts of antiviral proteins, peptides and micro-RNAs that may contribute to the destruction of SARS CoV-2 [69]. It has been shown that human saliva has strong innate antiviral activity against the H1N1 influenza virus [70,71]. Considering the fragility of the coronaviruses, their survivability may be low in human saliva, which may explain the absence of viable viruses in the saliva of some COVID-19 patients. Antimicrobial oral rinses may further reduce the risk of viruses in human saliva. SARS CoV-2 is sensitive to common disinfectants and antimicrobials such as povidone iodine and hydrogen peroxide that are commonly formulated as mouth rinses [8,72]. There is preliminary evidence that povidone iodine and chlorhexidine mouth rinses could rapidly eliminate or inactivate SARS CoV-2 [67,73]. Therefore, pre-procedural rinses with these products should further diminish the probability for dental droplets or aerosols to contain viable viruses.

Another factor that may affect potential COVID-19 transmission is the length of close contact between DHPs and their patients. COVID-19 transmissions, especially from asymptomatic patients, most likely happen in households where close contacts occur throughout the day [26,34]. A recent study collected respiratory droplets and aerosols from 111 symptomatic patients with confirmed diagnoses of respiratory viral infections, and detected no viral nucleic acids in the respiratory droplets or aerosols from a majority of the patients with coronavirus and influenza virus infections despite frequent coughs during the 30-minute sample collection period [74]. The authors concluded that even for respiratory viral infections that are known to primarily transmit through aerosols, 30 min of close contact without masks might be too short for the virus transmission to occur in many cases. In a study that examined the surfaces of N95 masks, eye protective goggles and shoe fronts of 30 healthcare workers after a short period close contacts with hospitalized COVID-19 patients, no SARS CoV-2 RNA was found in all the 90 samples [75]. In contact tracing of 224 hospital staffs who had close contact with an asymptomatic patient for at least one hour in the hospital, no virus transmission was detected by nucleic acid tests [44]. These findings indicate that the risk of disease transmission might be small from a relatively brief contact with a COVID-19 patient in dental offices in an outpatient setting. Our internal data also indicate that COVID-19 among DHPs is more likely to occur at home from household or community contacts than at work from patient contacts. In this regard, the risk for DHPs to acquire the infection from an asymptomatic colleague might be significantly higher than from a dental patient as it might be difficult to avoid prolonged contacts with coworkers in dental offices. It is therefore important to consistently use appropriate PPE and practice physical distancing at work during the pandemic.

In summary, current clinical and scientific evidence indicate that the inherent risk for DHPs to contract COVID-19 in dental offices through close contacts with dental patients is extremely low. Such low risk is determined by the effectiveness of PPEs including N95 masks and face shields, low prevalence of asymptomatic patients in the community, low transmissibility of both symptomatic and asymptomatic patients in healthcare settings, less severe outcomes of COVID-19 in individuals with no underlying conditions, relatively low viral load of SARS CoV-2 in human saliva even in the severely ill patients, extremely low probability for dental aerosols to contain viable viruses, readily available viricidal oral rinses that could rapidly inactivate viable viruses, and relatively brief period of contact with dental patients in an outpatient dental setting. We recognize that the risk probability estimate is contingent on several factors where uncertainties remain while the pandemic is still evolving. Our efforts in gathering the best available evidence around the risks of COVID-19 to DHPs are primarily meant to acknowledge uncertainty as an important challenge to dental professionals during the pandemic, and hopefully to mitigate the anxiety associated with the uncertainty as we resume vital services to our patients. Though currently there is no objective evidence that demonstrate an increased risk in providing dental care during the COVID-19 pandemic, there remain many unknowns and knowledge gaps regarding the potential risks a raspatory infectious disease poses to DHPs. We should take the COVID-19 pandemic as an opportunity to continuously improve our abilities to provide safe and effective services to our patients while protecting ourselves from work-related risks, which is especially important in the context of frequent infectious disease outbreaks on a global scale. To this end, dental professionals are actively exploring engineering control measures for droplet and aerosol removals in addition to the high and low volume suction devices that already have highly established efficiencies. We are confident that we can overcome the challenges from the pandemic and bring our profession to a new height in quality and safety.

CRediT authorship contribution statement

Yanfang Ren: Conceptualization, Methodology, Writing - original draft. **Changyong Feng:** Methodology, Formal analysis, Writing - review & editing. **Linda Rasubala:** Conceptualization, Writing - review & editing. **Hans Malmstrom:** Conceptualization, Writing - review & editing. **Eli Eliav:** Conceptualization, Writing - review & editing.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jdent.2020.103434.

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