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RESEARCH ARTICLE

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COVID-19 deaths in dental occupations and other healthcare occupations among U.S. decedents in 2020

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Abstract

Background: Early studies during the COVID-19 pandemic suggested dental occupations were among the highest risk for exposure to SARs-CoV-2 because of multiple factors increasing exposure, including close proximity to unmasked patients and performance of aerosol-generating procedures. However, to date, few studies have investigated COVID-19 deaths in United States dental occupations, and compared COVID-19 deaths among healthcare occupations.

Methods: We analyzed 2020 mortality data collected by the National Center for Health Statistics' National Vital Statistics System. Multivariable logistic regression was used to generate odds ratios (ORs) and 95% confidence intervals for COVID-19 as the underlying cause of death in relation to occupation in working-age decedents (≤65 years), after adjusting for age, sex, race/ethnicity, education, and medical conditions associated with severe COVID-19.

Results: Dental occupations did not have significantly higher risk for COVID-19 death when compared to all other occupations combined. Among healthcare occupations with frequent, direct patient- or client interactions, LPNs and LVNs, and speech and language pathologists had significantly elevated adjusted ORs for COVID-19 death when compared to dentists, dental hygienists, or dental assistants. Similarly, nurse practitioners had significantly higher ORs for COVID-19 mortality than dentists or dental hygienists, and approached significance when compared to dental assistants. Conversely, massage therapists and other health diagnosing and treating practitioners had significantly lower adjusted ORs for COVID-19 death compared with dental occupations.

Conclusion: Our study highlights potential differences in work-related transmission of SARs-CoV-2 and subsequent COVID-19 deaths in healthcare occupations, and furthers a previously limited understanding of COVID-19 deaths in healthcare occupations in 2020, before COVID-19 vaccine availability. Our results indicate that dental occupations were not among the highest, nor lowest risk, healthcare occupations for COVID-19 deaths in 2020, despite their known risks of direct exposure.

KEYWORDS

COVID-19, COVID-19 mortality, dental occupations, healthcare occupations

1 | INTRODUCTION

Previous studies during the COVID-19 pandemic suggested healthcare personnel were at increased risk for exposure to SARs-CoV-2, the virus that causes coronavirus disease 2019 (COVID-19),[1–3] and subsequent death from COVID-19.[4] Although dental personnel make up a small proportion of healthcare personnel, dental occupations were previously identified as among occupations with the highest risk for exposure to SARs-CoV-2 because of several unique factors including inability of patients to mask during dental procedures, close proximity to patients' nasal and oral regions, and dental procedures that generate aerosols during routine dental practice.[2,5] Studies by Singhal et al. and Zhang in 2021 both identified dental occupations as those at the highest risk for exposure to disease or infection and concluded that dental personnel have a higher risk of exposure to SARS-CoV-2 and COVID-19 compared to other occupations.[2,5] Despite dental personnel being identified as higher risk for exposure to SARs-CoV-2 and subsequent COVID-19 infection, to the authors' knowledge, no previous study has evaluated differences in COVID-19 deaths among dental occupations and other occupations in 2020.

Our objectives were to use United States decedent data from 2020 to assess (1) COVID-19 deaths among dental occupations and (2) differences in COVID-19 deaths between (a) dental occupations and all other occupations combined and (b) dental occupations and other healthcare occupations. We utilized COVID-19 as the underlying cause of death to assess COVID-19 deaths among United States working-age decedents with dental occupations in 2020. We report odds ratios (ORs) for COVID-19 deaths after adjusting for age, sex, race/ethnicity, education, and medical conditions associated with severe COVID-19 as recorded by the National Center for Health Statistics' (NCHS) National Vital Statistics System (NVSS).

2 | METHODS

2.1 | Study population

We limited our mortality analyses to 2020 to keep to a time period before widespread availability of COVID-19 vaccines to the United States population because vaccination status affects mortality from COVID-19. We utilized publicly available mortality data from NVSS for all analyses. NVSS data includes death certificate information for all reported decedents in the United States annually. NVSS obtains death certificate information from the registration offices in all 50 states, New York City, the District of Columbia, and the United States territories.[6] Death certificates are completed by physicians, coroners, medical examiners, and funeral directors, and are filed with state vital statistics offices that transmit the files to NCHS' NVSS; more than 99% of deaths occurring in the United States are believed to be registered.[6] NIOSH and NVSS collaborate to code the industry and occupation data obtained from death certificates. Industry and occupation were collected from 46 states in 2020; four states (Iowa, Arizona, North Carolina, and Rhode Island) and the District of Columbia either had data that were inconsistent with other states' data due to differences in data collection or did not participate in the program in 2020.[7] Industry and occupation codes are derived from the decedent's usual occupation and kind of business/industry described on the death certificate. "Usual occupation" is obtained as the occupation the person did for most of his or her working life.[7] We restricted our data to working-age decedents ranging in age from 16 to 65 years old and occupations outside the home. We excluded decedents who (1) had any of the following occupations: own home/homemaker; volunteer, not for pay; retired; student attending a high school or college; cannot work, never worked, disabled, patient or inmate; unknown, refused, don't know, or missing; or (2) had any of the following industries: retired; housewife, volunteer, student, cannot work, never worked, disabled, patient or inmate; unknown, refused, don't know, or missing. This activity was reviewed by CDC, deemed research not involving human subjects, and was conducted consistent with applicable federal law and CDC policy.

2.2 | Demographic and COVID-19 variables

Demographic and COVID-19 variables included in our univariable and multivariable models included age, sex, race/ethnicity, education, and medical conditions associated with severe COVID-19. COVID-19 death was defined as COVID-19 as the underlying cause of death (ICD-10 code U07.1). Alternatively, COVID-19 death defined more broadly as COVID-19 listed anywhere on the death certificate was also included in a separate, sensitivity analysis. COVID-19 listed anywhere on the death certificate was defined as COVID-19 listed as (1) the underlying cause of death (that which initiated the chain of events that resulted in death), or (2) as a contributing factor. Age was categorized into the following groups: 16–24 (referent), 25–34, 35–44, 45–54, and 55–65. Education was categorized into the following groups: less than high school, some high school or completed high school, some college, completed college, completed graduate or professional degrees (referent), and unknown. Sex was categorized as male or female (referent). Race and ethnicity were categorized as Hispanic, Non-Hispanic White (referent), Non-Hispanic American Indian Alaskan Native (AIAN), Non-Hispanic Asian, Non-Hispanic Black, Non-Hispanic Multiple Race, Non-Hispanic Native Hawaiian or Other Pacific Islander (NHOPI), and unknown race and ethnicity. Medical conditions associated with a higher risk for severe COVID-19 included 31 conditions, listed anywhere on the death certificate (obtained from record-axis codes for each decedent; see Supporting Information S1: Table S1).[8]

2.3 | Occupational variables

Occupations were coded using 2010 Census Occupation Codes. Dental occupations included dentists, dental hygienists, and dental assistants. Other healthcare occupations included (1) chiropractors; (2) clinical laboratory technologists and technicians; (3) diagnostic

related technologists and technicians; (4) dietitians and nutritionists; (5) emergency medical technicians (EMTs) and paramedics; (6) health diagnosing and treating practitioners (all other); (7) health practitioner support technologists and technicians; (8) healthcare support workers (all other), including medical equipment preparers; (9) licensed practical and licensed vocational nurses (LPNs and LVNs); (10) massage therapists; (11) medical assistants; (12) medical records and health information technicians; (13) medical transcriptionists; (14) miscellaneous health technologists and technicians; (15) nurse anesthetists; (16) nurse practitioners (NPs); (17) nursing, psychiatric, and home health aides; (18) occupational therapists (OTs); (19) OT assistants and aides; (20) opticians, dispensing; (21) optometrists; (22) other healthcare practitioners and technical occupations, including audiologists and podiatrists; (23) pharmacists; (24) pharmacy aides; (25) phlebotomists; (26) physical therapists (PTs) and exercise physiologists; (27) physical therapy (PT) assistants and aides; (28) physician assistants (PAs); (29) physicians and surgeons; (30) radiation therapists; (31) recreational therapists; (32) registered nurses and nurse midwives; (33) respiratory therapists; (34) speech-language pathologists (SLPs); (35) therapists (all other); (36) veterinarians; and (37) veterinary assistants and laboratory animal caretakers. Healthcare occupations were grouped in results as healthcare practitioner; healthcare support; and healthcare therapists, technicians, and other specialists using the United States Bureau of Labor Statistics groupings for healthcare occupations.[9]

2.4 | Statistical methods

All analyses for demographic and COVID-19 data were conducted in SAS version 9.4 (SAS Institute Inc.) and R (version 1.4.1106, R Foundation for Statistical Computing). Univariable model analyses were conducted to analyze associations between COVID-19 as underlying cause of death (COVID-19 mortality) and usual occupation, age, sex, race/ethnicity, education, and medical conditions listed on the death certificate associated with higher risk for severe COVID-19.[8] Multivariable logistic regression was utilized to generate adjusted odds ratios (ORs) and 95% CIs for COVID-19 deaths in relation to occupational group, after adjusting for sex, age, race/ethnicity, education, and medical conditions associated with higher risk for severe COVID-19. Logistic models were run to compare (1) each dental occupation with all other occupations combined, and (2) each dental occupation with each healthcare occupation. The adjusted ORs were used to assess COVID-19 deaths by estimating the odds for COVID-19 as the underlying cause of death among an occupation relative to the odds for COVID-19 as the underlying cause of death among the referent occupation. In all models, dental occupations were dentist, dental hygienist, and dental assistant. In the model comparing each dental occupation with all other occupations combined, all other occupations combined was the reference group. In the three models comparing each of the dental occupations with all other individual healthcare occupations, the dental occupation (dentist, dental hygienist, or dental assistant) was selected as the reference group for ease of comparing each dental occupation with other healthcare occupations.

3 | RESULTS

3.1 | Demographics by occupational group

Decedent demographics by occupational group can be seen in Tables 1a–c. Among the 3,390,278 decedent records available in the NVSS mortality data for 2020, 636,036 met inclusion criteria of 16 to 65 years old at time of death with a usual occupation outside the home. Healthcare occupations were reported for 42,849 (6.7%) decedents. There were 317 dentists, 307 dental hygienists, and 754 dental assistants (Tables 1a and 1b). Twenty-four percent of dentists, 97% of dental hygienists, and 94% of dental assistants were female (Tables 1a and 1b). The median and age range for dentists was 60 (range: 23–65) (Table 1a), dental hygienists was 57 (range: 25–65), and dental assistants was 54 (19–65) (Table 1b).

3.2 | COVID-19 death by demographic factors

Univariable model estimates of ORs and 95% confidence intervals for demographic factors (age, education, race/ethnicity, and medical conditions listed on the death certificate) across all working age decedents are reported in Supporting Information S1: Table S1. ORs for COVID-19 death increased with increasing age category. All age groups had significantly higher ORs for COVID-19 death when compared with the youngest referent age category (16–24). Decedents with less than high school or completed college education levels had significantly higher ORs for COVID-19 death when compared with the highest education referent category (completed graduate or professional degrees). All race and ethnicity categories except the Non–Hispanic Multiple Race category had significantly elevated ORs for COVID-19 death when compared with the referent Non–Hispanic White category. Male sex had a significantly elevated OR for COVID-19 death compared with female sex. Among medical conditions, asthma, chronic kidney disease, dementia, diabetes mellitus (types 1 and 2), primary immunodeficiencies, interstitial lung disease, obesity, and pulmonary embolism were associated with significantly elevated ORs for COVID-19 death (Supporting Information S1: Table S1).

3.3 | COVID-19 death (COVID-19 as underlying cause of death) by occupational group

COVID-19 death by occupational group can be seen in Tables 1a–1c. Among working-age decedents, the following healthcare occupations had greater than 10% of decedents with COVID-19 as the underlying cause of death: LPNs and LVNs (11.0%); NPs (11.1%); miscellaneous health technicians (11.0%); nursing, psychiatric, and home health

TABLE 1a Demographic characteristics and number and percent dying from COVID-19 for decedents with healthcare practitioner occupations (n = 15,914).

	Chiropractors (n = 207)	Dentists (n = 317)	Health diagnosing and treating practitioners, all other (n = 110)	LPNs and LVNs (n = 2422)	Nurse anesthetists (n = 63)	NPs (n = 306)	Opticians (n = 195)	Optome-trists (n = 75)	Other healthcare practitioners and technical occupations (n = 203)	PAs (n = 204)	Physicians and surgeons (n = 1545)	RNs and nurse midwives (n = 10,113)	Veterinarians (n = 154)
COVID-19 underlying cause of death, n (%)	17 (8)	29 (9)	1 (1)	267 (11)	2 (3)	34 (11)	10 (5)	3 (4)	12 (6)	14 (7)	154 (10)	966 (10)	7 (5)
Age (Median, Range)	59 (27–65)	60 (23–65)	58 (20–65)	58 (20-65)	58 (34–65)	56 (27-65)	57 (20–65)	58 (20–65)	57 (19-65)	54 (23-65)	58 (20-65)	59 (20-65)	58 (24-65)
Sex, male, n (%)	166 (80)	242 (76)	46 (42)	264 (11)	32 (51)	57 (19)	72 (37)	40 (53)	150 (74)	97 (48)	997 (65)	1,317 (13)	85 (55)
Race and ethnicity, n (%)													
Hispanic	6 (3)	33 (10)	7 (6)	120 (5)	0 (0)	14 (5)	14 (7)	6 (8)	17 (8)	19 (9)	161 (10)	536 (5)	11 (7)
Non-hispanic AIAN	1 (0)	0 (0)	2 (2)	30 (1)	0 (0)	1 (0)	3 (2)	1 (1)	2 (1)	0 (0)	8 (1)	52 (1)	1 (1)
Non-hispanic Asian	4 (2)	44 (14)	17 (15)	53 (2)	2 (3)	15 (5)	6 (3)	6 (8)	4 (2)	8 (4)	194 (13)	476 (5)	5 (3)
Non-hispanic Black	7 (3)	10 (3)	3 (3)	487 (20)	6 (10)	42 (14)	17 (9)	6 (8)	29 (14)	26 (13)	159 (10)	1,848 (18)	3 (2)
Non-hispanic multiple race	1 (0)	1 (0)	6 (5)	15 (1)	0 (0)	1 (0)	1 (1)	1 (1)	0 (0)	2 (1)	11 (1)	68 (1)	2 (1)
Non-hispanic NHOPI	0 (0)	0 (0)	1 (1)	2 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	13 (0)	0 (0)
Non-hispanic white	188 (91)	229 (72)	73 (66)	1713 (71)	55 (87)	232 (76)	154 (79)	55 (73)	151 (74)	149 (73)	1,011 (65)	7,110 (70)	132 (86)
Unknown	0 (0)	0 (0)	1 (1)	2 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	10 (0)	0 (0)
Education, n (%)													
Less than high school	0 (0)	0 (0)	3 (3)	3 (0)	0 (0)	0 (0)	3 (2)	0 (0)	0 (0)	2 (1)	0 (0)	24 (0)	0 (0)
Some high school or completed high school	2 (1)	8 (3)	16 (15)	302 (12)	1 (2)	9 (3)	82 (42)	10 (13)	47 (23)	32 (16)	85 (6)	949 (9)	7 (5)

(Continues)

TABLE 1a (Continued)

	Chiropractors (n = 207)	Dentists (n = 317)	Health diagnosing and treating practitioners, all other (n = 110)	LPNs and LVNs (n = 2422)	Nurse anesthetists (n = 63)	NPs (n = 306)	Opticians (n = 195)	Optometrists (n = 75)	Other healthcare practitioners and technical occupations (n = 203)	PAs (n = 204)	Physicians and surgeons (n = 1545)	RNs and nurse midwives (n = 10,113)	Veterinarians (n = 154)
Some college	4 (2)	5 (2)	21 (19)	1858 (77)	6 (10)	18 (6)	80 (41)	13 (17)	37 (18)	55 (27)	111 (7)	3,957 (39)	9 (6)
Completed college	10 (5)	19 (6)	20 (18)	219 (9)	11 (17)	24 (8)	25 (13)	7 (9)	51 (25)	40 (20)	101 (7)	4,438 (44)	16 (10)
Completed graduate or professional degree	191 (92)	285 (90)	48 (44)	38 (2)	45 (71)	255 (83)	5 (3)	45 (60)	67 (33)	73 (36)	1242 (80)	717 (7)	122 (79)
Unknown	0 (0)	0 (0)	2 (2)	2 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	2 (1)	6 (0)	28 (0)	0 (0)

Abbreviations: AIAN, American Indian Alaskan Native; LPN, licensed practical nurses; LVN, licensed vocational nurses; NHOPI, Native Hawaiian or Other Pacific Islander; NPs, nurse practitioners; PAs indicates physician assistants.

aides (10.4%); OT assistants and aides (11.7%), pharmacists (10.8%); PTs and exercise physiologists (11.9%); and recreational therapists (16.7%). Among dental occupations, 9.1% of dentists (n = 29), 3.3% of dental hygienists (n = 10), and 6.9% of dental assistants (n = 52) had COVID-19 as the underlying cause of death (Tables 1a and 1b).

Adjusted ORs for COVID-19 death among dentists, dental hygienists, and dental assistants were not significantly different from all other occupations combined (dentists, $p = 0.58$; dental hygienists, $p = 0.19$; dental assistants, $p = 0.61$) (Table 2), after adjusting for age, sex, race/ethnicity, education, and medical conditions.

Among healthcare occupations, health diagnosing and treating practitioners (all other) and massage therapists had significantly lower adjusted ORs ($p < 0.05$) for COVID-19 death when compared with dentists (Figure 1) and dental assistants (Supporting Information S1: Figure S1). No healthcare occupations had significantly lower adjusted ORs for COVID-19 death when compared with dental hygienists; however, health diagnosing and treating practitioners had a lower adjusted OR (less than 1.0) and approached significance ($p = 0.053$) when compared with dental hygienists (Supporting Information S1: Figure S2).

Several healthcare occupations had significantly higher adjusted ORs for COVID-19 death when compared with dentists, dental hygienists, or dental assistants and included EMTs and paramedics, LPNs and LVNs, NPs, PTs and exercise physiologists, PT assistants and aides, recreational therapists, and SLPs. NPs had significantly higher adjusted ORs for COVID-19 death than dentists (Figure 1) and dental hygienists (Supporting Information S1: Figure S2), and the elevated adjusted OR for COVID-19 death among NPs also approached significance when compared with dental assistants ($p = 0.11$; Supporting Information S1: Figure S1). Multiple additional healthcare occupations had significantly higher adjusted ORs for COVID-19 death when compared to dental hygienists and included EMTs and paramedics, PTs and exercise physiologists, PT assistants and aides, and recreational therapists (Supporting Information S1: Figure S2).

3.4 | Sensitivity analyses (COVID-19 listed anywhere on the death certificate)

Results were similar in our sensitivity analyses of models with COVID-19 death more broadly defined as COVID-19 being listed anywhere on the death certificate. In our sensitivity analyses, using the broad definition of COVID-19 listed anywhere on the death certificate increased the number of COVID-19 decedents by two to four decedents for the dental occupations (Supporting Information S1: Table SII). Similar to results from the more narrow definition of COVID-19 as the underlying cause of death, no significant differences in adjusted ORs for COVID-19 listed anywhere in the death certificate were observed between dental occupations and all other occupations combined (dentist, $p = 0.33$; dental hygienist, $p = 0.25$; dental assistant, $p = 0.65$; Supporting Information S1: Table SIII). Results from logistic regression analyses of COVID-19 death among

TABLE 1b Demographic characteristics and number and percent dying from COVID-19 for decedents with healthcare support occupations (n = 18,989).

	Dental assistants (n = 754)	Dental hygienists (n = 307)	EMTs and paramedics (n = 1,053)	Healthcare support workers, all other, including medical equipment preparers (n = 465)	Medical assistants (n = 1521)	Medical transcriptionists (n = 306)	Nursing, psychiatric, and home health aides (n = 13,715)	OT assistants and aides (n = 60)	Phlebotomists (n = 568)	PT assistants and aides (n = 135)	Veterinary assistants and laboratory animal caretakers (n = 105)
COVID-19 uderlying cause of death, n (%)	52 (7)	10 (3)	102 (10)	43 (9)	116 (8)	17 (6)	1427 (10)	7 (12)	49 (9)	13 (10)	8 (8)
Age (Median, Range)	54 (19–65)	57 (25–65)	54 (20–65)	57 (17–65)	50 (18–65)	60 (19–65)	56 (16–65)	60 (22–65)	55 (19–65)	56 (21–65)	51 (18–65)
Sex, male, n (%)	44 (6)	10 (3)	702 (67)	152 (33)	170 (11)	13 (4)	1698 (12)	14 (23)	87 (15)	44 (33)	26 (25)
Race and ethnicity, n (%)											
Hispanic	124 (16)	18 (6)	64 (6)	27 (6)	296 (19)	11 (4)	1132 (8)	2 (3)	63 (11)	10 (7)	10 (10)
Non-hispanic AIAN	12 (2)	3 (1)	22 (2)	2 (0)	10 (1)	5 (2)	171 (1)	0 (0)	7 (1)	0 (0)	2 (2)
Non-hispanic Asian	22 (3)	6 (2)	7 (1)	22 (5)	33 (2)	3 (1)	221 (2)	1 (2)	8 (1)	5 (4)	1 (1)
Non-hispanic Black	78 (10)	20 (7)	101 (10)	181 (39)	336 (22)	22 (7)	5732 (42)	18 (30)	163 (29)	14 (10)	4 (4)
Non-hispanic multiple race	9 (1)	2 (1)	13 (1)	5 (1)	13 (1)	4 (1)	107 (1)	1 (2)	5 (1)	0 (0)	1 (1)
Non-hispanic NHOPI	2 (0)	0 (0)	0 (0)	0 (0)	4 (0)	0 (0)	21 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Non-hispanic white	507 (67)	258 (84)	845 (80)	226 (49)	829 (55)	261 (85)	6305 (46)	37 (62)	321 (57)	106 (79)	87 (83)
Unknown	0 (0)	0 (0)	1 (0)	2 (0)	0 (0)	0 (0)	26 (0)	1 (2)	1 (0)	0 (0)	0 (0)
Education, n (%)											
Less than high school	1 (0)	2 (1)	2 (0)	8 (2)	3 (0)	0 (0)	341 (2)	0 (0)	3 (1)	2 (1)	0 (0)
Some high school or completed high school	291 (39)	49 (16)	345 (33)	328 (71)	506 (33)	106 (35)	8750 (64)	15 (25)	193 (34)	26 (19)	67 (64)
Some college	419 (56)	164 (53)	584 (55)	101 (22)	906 (60)	171 (56)	4031 (29)	35 (58)	323 (57)	78 (58)	30 (29)

(Continues)

TABLE 1b (Continued)

	Dental assistants (*n* = 754)	Dental hygienists (*n* = 307)	EMTs and paramedics (*n* = 1,053)	Healthcare support workers, all other, including medical equipment preparers (*n* = 465)	Medical assistants (*n* = 1521)	Medical transcriptionists (*n* = 306)	Nursing, psychiatric, and home health aides (*n* = 13,715)	OT assistants and aides (*n* = 60)	Phlebotomists (*n* = 568)	PT assistants and aides (*n* = 135)	Veterinary assistants and laboratory animal caretakers (*n* = 105)
Completed college	38 (5)	87 (28)	104 (10)	25 (5)	79 (5)	24 (8)	442 (3)	9 (15)	42 (7)	24 (18)	5 (5)
Completed graduate or professional degree	3 (0)	5 (2)	15 (1)	1 (0)	24 (2)	3 (1)	84 (1)	1 (2)	5 (1)	5 (4)	3 (3)
Unknown	2 (0)	0 (0)	3 (0)	2 (0)	3 (0)	2 (1)	67 (0)	0 (0)	2 (0)	0 (0)	0 (0)

Abbreviations: AIAN, American Indian Alaskan Native; EMTs, emergency medical technicians; NHOPI, Native Hawaiian or Other Pacific Islander; OT, occupational therapy; PT, physical therapy.

healthcare occupations using either of the two definitions of COVID-19 death were similar. Health diagnosing and treating practitioners (all other), and massage therapists had significantly lower adjusted ORs for COVID-19 death, using either the narrow or broad definition for COVID-19 mortality, when compared with dentists or dental assistants (Supporting Information S1: Figures 1 and 2, Table SIV). LPNs and LVNs had significantly elevated adjusted ORs for COVID-19 death using either the narrow or broad definition when compared with any of the dental occupations. Similar to results for COVID-19 as the underlying cause of death, SLPs had significantly elevated adjusted ORs for COVID-19 being listed anywhere on a death certificate when compared with dental hygienists, and approached significance when compared with dentists and dental assistants ($p = 0.06$ and $p = 0.07$, respectively; Supporting Information S1: Table SIV). Additionally, multiple other healthcare occupations also had significantly elevated adjusted ORs for COVID-19 death (using either the narrow or broad definition for COVID-19 mortality), when compared with dental hygienists and included EMTs and paramedics, PTs and exercise physiologists, and PT assistants and aides (Supporting Information S1: Table SIV).

4 | DISCUSSION

A previous study using the same NVSS mortality data set from 2020 assessed COVID-19 death by usual occupation and observed that healthcare support and healthcare practitioners and technical occupations had higher proportionate mortality ratios (PMRs) than all other occupations combined; however, the authors did not report PMRs for individual healthcare occupations.[4] After adjusting for factors that are known to contribute to more severe outcomes from COVID-19, including age, sex, race/ethnicity, and medical conditions associated with higher risk for severe outcomes from COVID-19, we observed that COVID-19 deaths in 2020 varied by individual healthcare occupation.

Despite dental occupations having been previously identified as among the top occupations for risk of exposure to SARS-CoV-2,[2,5] we did not observe dental occupation decedents as having the highest proportion of COVID-19 deaths or significantly elevated adjusted ORs for COVID-19 death when compared with all other occupations combined. Multiple healthcare occupations had COVID-19 as the underlying cause of death listed for greater than 10% of decedents, and included: LPNs and LVNs; NPs; miscellaneous health technologists and technicians; nursing, psychiatric, and home health aides; OT assistants and aides; pharmacists; PTs and exercise physiologists; and recreational therapists. In comparison, 9.1% of dentist, 6.9% of dental assistant, and 3.3% of dental hygienist decedents were listed with COVID-19 as the underlying cause of death. Additionally, we observed that dental occupations were not among the top healthcare occupations for COVID-19 deaths. After accounting for factors that are known to contribute to more severe outcomes from COVID-19, several individual healthcare occupations were identified as having significantly elevated adjusted ORs for

TABLE 1c Demographic characteristics and number and percent dying from COVID-19 for decedents with occupations of healthcare therapists, technicians, and other specialists (n = 7,946).

	Clinical lab. tech. (n = 1012)	Diagnostic related tech. (n = 803)	Dietitian and nutritionist (n = 580)	Health practitioner support tech. (n = 2033)	Massage therapist (n = 504)	Medical records and health info. tech. (n = 307)	Misc. health tech. (n = 544)	OT (n = 189)	Pharmacist (n = 528)	Pharmacy aides (n = 79)	PT and exercise physio. (n = 303)	Radiation therapist (n = 32)	Recreation therapist (n = 54)	SLP (n = 200)	Respiratory therapist (n = 432)	Therapist, all other (n = 346)
COVID-19 underlying cause of death, n (%)	85 (8)	67 (8)	49 (8)	137 (7)	15 (3)	23 (7)	60 (11)	13 (7)	57 (11)	3 (4)	36 (12)	2 (6)	9 (17)	18 (9)	41 (9)	23 (7)
Age (Median, Range)	58 (18–65)	57 (20–65)	59 (18–65)	54 (17–5)	51 (21–65)	60 (25–65)	56 (19–65)	57 (24–65)	58 (23–65)	56 (21–65)	56 (23–65)	58 (31–65)	59 (25–65)	56 (23–65)	59 (23–65)	56 (20–65)
Sex, male, n (%)	354 (35)	331 (41)	88 (15)	542 (27)	120 (24)	44 (14)	261 (48)	32 (17)	292 (55)	23 (29)	127 (42)	11 (34)	17 (31)	13 (6)	198 (46)	111 (32)
Race and ethnicity, n (%)																
Hispanic	75 (7)	53 (7)	40 (7)	189 (9)	50 (10)	23 (7)	44 (8)	6 (3)	31 (6)	11 (14)	19 (6)	3 (9)	0 (0)	10 (5)	23 (5)	26 (8)
Non-hispanic AIAN	12 (1)	3 (0)	9 (2)	26 (1)	9 (2)	8 (3)	12 (2)	0 (0)	3 (1)	0 (0)	2 (1)	0 (0)	1 (2)	0 (0)	3 (1)	3 (1)
Non-hispanic Asian	57 (6)	20 (2)	9 (2)	54 (3)	35 (7)	9 (3)	20 (4)	12 (6)	56 (11)	4 (5)	33 (11)	0 (0)	1 (2)	3 (1)	10 (2)	8 (2)
Non-hispanic Black	233 (23)	98 (12)	230 (40)	435 (21)	49 (10)	83 (27)	184 (34)	13 (7)	66 (12)	7 (9)	31 (10)	4 (12)	16 (30)	16 (8)	61 (14)	53 (15)
Non-hispanic multiple race	5 (0)	6 (1)	2 (0)	16 (1)	6 (1)	1 (0)	3 (1)	1 (1)	2 (0)	3 (4)	4 (1)	2 (6)	0 (0)	0 (0)	3 (1)	5 (1)
Non-hispanic NHOPI	5 (0)	0 (0)	0 (0)	3 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	0 (0)
Non-hispanic white	623 (62)	622 (77)	289 (50)	1308 (64)	354 (70)	182 (59)	280 (51)	157 (83)	370 (70)	53 (67)	212 (70)	23 (72)	36 (67)	171 (86)	331 (77)	251 (73)
Unknown	2 (0)	1 (0)	(1 0)	(2 0)	0 (0)	1 (0)	1 (0)	0 (0)	0 (0)	0 (0)	2 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Education, n (%)																
Less than high school	0 (0)	2 (0)	10 (2)	8 (0)	8 (2)	0 (0)	5 (1)	0 (0)	3 (1)	0 (0)	2 (1)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)
Some high school or completed high school	285 (28)	128 (16)	289 (50)	794 (39)	164 (33)	131 (43)	227 (42)	4 (2)	34 (6)	48 (61)	19 (6)	1 (3)	9 (17)	3 (1)	29 (7)	45 (13)
Some college	410 (41)	458 (57)	132 (23)	973 (48)	240 (48)	131 (43)	223 (41)	38 (20)	32 (6)	25 (32)	54 (18)	10 (31)	13 (24)	6 (3)	247 (57)	50 (14)

(Continues)

TABLE 1c (Continued)

	Clinical lab. tech. (n = 1012)	Diagnostic related tech. (n = 803)	Dietitian and nutritionist (n = 580)	Health practitioner support tech. (n = 2033)	Massage therapist (n = 504)	Medical records and health info. tech. (n = 307)	Misc. health tech. (n = 544)	OT (n = 189)	Pharmacist (n = 528)	Pharmacy aides (n = 79)	PT and exercise physio. (n = 303)	Radiation therapist (n = 32)	Recreation therapist (n = 54)	SLP (n = 200)	Respiratory therapist (n = 432)	Therapist, all other (n = 346)
Completed college	273 (27)	182 (23)	87 (15)	217 (11)	72 (14)	32 (10)	66 (12)	87 (46)	186 (35)	5 (6)	128 (42)	16 (50)	30 (56)	24 (12)	124 (29)	64 (18)
Completed graduate or professional degree	40 (4)	31 (4)	57 (10)	30 (1)	17 (3)	10 (3)	20 (4)	59 (31)	272 (52)	1 (1)	100 (33)	5 (16)	2 (4)	167 (84)	30 (7)	186 (54)
Unknown	4 (0)	2 (0)	5 (1)	11 (1)	3 (1)	3 (1)	3 (1)	1 (1)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (0)	0 (0)

Abbreviations: AIAN, American Indian Alaskan Native; Clinical lab. tech., clinical laboratory technologists and technicians; Diagnostic related tech., diagnostic related technologists and technicians; Healthcare practitioner support tech., healthcare practitioner support technologists and technicians; Medical records and health info. tech., medical records and health information technicians; Misc. health tech., miscellaneous health technologists and technicians; NHOPI indicates Native Hawaiian or Other Pacific Islander; OT, occupational therapists; PT exercise physio., physical therapists and exercise physiologists; SLP, speech language pathologists.

TABLE 2 Adjusted estimates of ORs for COVID-19 as the underlying cause of death among dentists, dental hygienists, and dental assistants versus all other occupations combined.

Occupation	OR	95% CI	p-value
Dentists	1.12	0.74–1.70	0.58
Dental hygienists	0.64	0.33–1.24	0.19
Dental assistants	1.08	0.80–1.47	0.61

COVID-19 death when compared with dentists, dental hygienists, or dental assistants. LPNs and LVNs, and SLPs, had significantly elevated adjusted ORs relative to dentists, dental hygienists, or dental assistants for COVID-19 death. Additionally, NPs had significantly elevated adjusted ORs for COVID-19 death relative to dentists and dental hygienists.

Dental hygienist decedents were among occupations with some of the lowest proportion of COVID-19 deaths, with only 3.3% of dental hygienist decedents with COVID-19 as the underlying cause of death. Our results align with previous studies that have reported low prevalence of COVID-19 infection among dental hygienists in 2020.[10,11] One factor potentially contributing to lower SARs-CoV-2 infection and subsequent COVID-19 deaths among hygienists is the early infection control recommendations by the American Dental Association and the United States Centers for Disease Control and Prevention in April and May of 2020 which included the recommendation to use hand scaling when cleaning teeth rather than performing aerosol generating procedures (AGPs) with ultrasonic scalers, as a means to minimize aerosols.[12–14] The ability to defer AGPs with ultrasonic scalers could have contributed to lower SARs-CoV-2 infection risk and subsequent mortality among hygienists. In our study, multiple additional healthcare occupations (EMTs and paramedics, PTs and exercise physiologists, PT assistants and aides, and recreational therapists) had significantly elevated adjusted ORs for COVID-19 death when compared with dental hygienists, but not dentists and dental assistants. This difference within dental occupations is notable because dentists and dental assistants likely were not able to defer AGPs as often as hygienists were, given few low- or no-aerosol alternatives for dental procedures that require use of the high-speed handpiece; however, to our knowledge, no previous studies have assessed differences in frequency of AGPs performed by dentists, dental hygienists, or assisted by assistants in 2020, making it difficult to directly assess the role of AGPs, and their deferral, in the lower proportion and adjusted ORs for COVID-19 death among hygienists.

Exposure controls utilized by dental personnel could also potentially be contributing to lower ORs for COVID-19 death when compared with other healthcare occupations, despite dental personnel's close proximity to patient's oral pharyngeal region and frequently performed AGPs. Unlike healthcare occupations that must care for ill or seriously ill patients, dental occupations can screen and defer patient care with symptomatic patients, thus minimizing

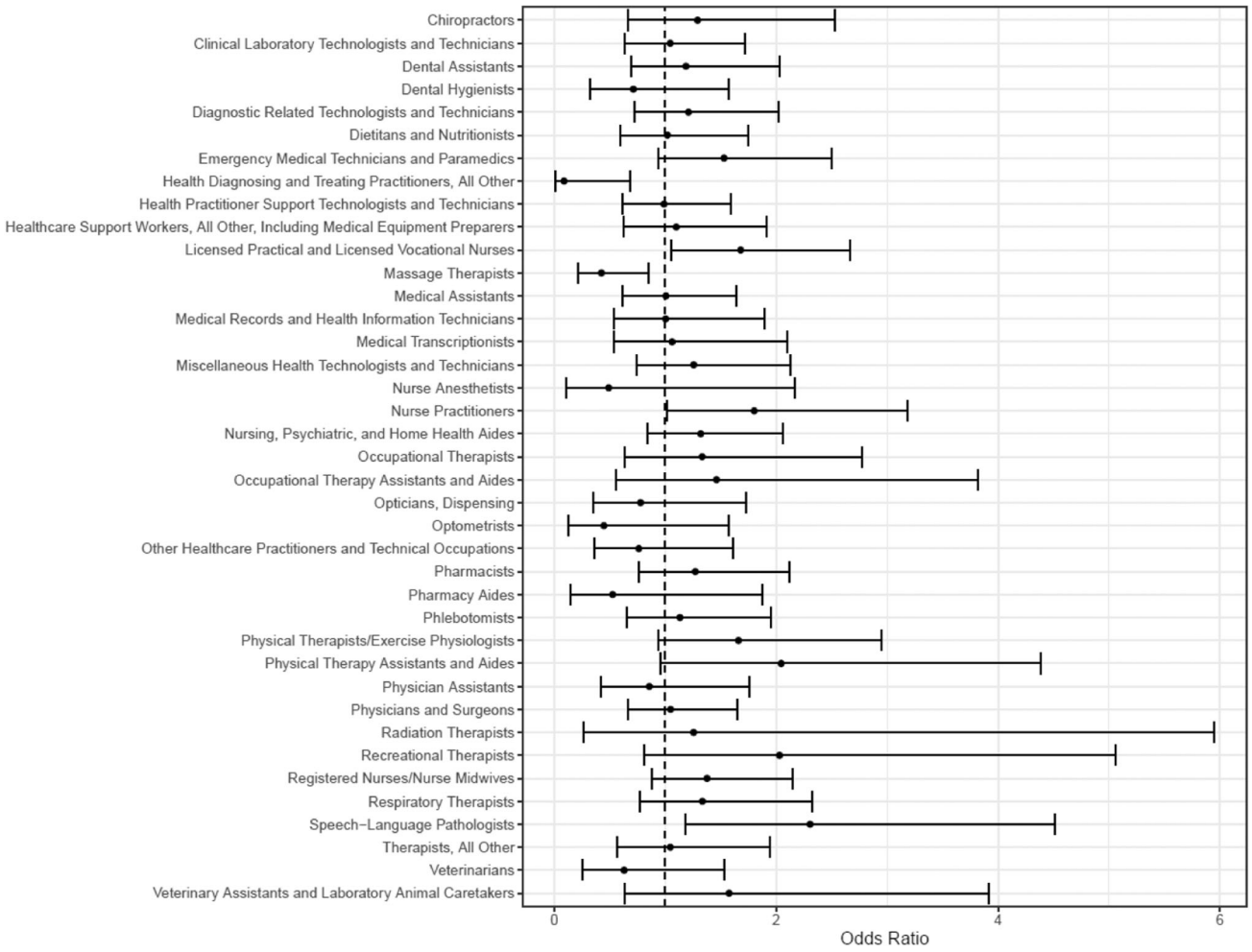

FIGURE 1 Adjusted ORs for COVID-19 as underlying cause of death by healthcare occupation with dentists as the referent category (indicated by the dashed line).

potential exposure to SARS-CoV-2. A previous study of infection control practices among United States dentists in 2020 observed that greater than 97% of dentist respondents reported screening patients for symptoms and checking patients' temperatures with a thermometer before treatment.[15] Additionally, dental personnel can utilize source controls such as high-volume evacuation (HVE) during AGPs which can remove aerosols at the source and has shown promise in lowering aerosols generated during AGPs.[16,17] HVE is commonly utilized by dental personnel during dental procedures that can generate aerosols to remove water generated by the high-speed handpiece and saliva generated by the patient during dental procedures. Use of HVE during AGPs could be contributing to lower adjusted ORs for COVID-19 death among dental occupations when compared with other healthcare occupations who might not have similarly effective source controls available to them during AGPs they might encounter. However, further study is needed to better understand ventilation source controls' effect on healthcare personnel's exposure to potentially infectious aerosol during AGPs. Additional studies are needed to evaluate (1) frequency of use of ventilation source controls and (2) potential differences in efficiency and of source controls available to different healthcare occupations to minimize aerosols generated during AGPs.

Although dental occupations were not among the occupations with the highest proportion for COVID-19 as the underlying cause of death and highest adjusted ORs for COVID-19 death, they were not among the lowest either. Our observation of two other healthcare occupations with direct patient-care duties or direct client interactions, specifically health diagnosing and treating practitioners (all other), and massage therapists, having lower adjusted ORs for COVID-19 death than dentists and dental assistants aligns with studies from early in the pandemic that highlighted dental personnel as high risk for exposure to SARs-CoV-2 given their close proximity to patients, inability of patients to wear a mask during procedures, and frequently performed AGPs.[2,5] Multiple factors could be contributing to the elevated COVID-19 death among dentists and dental assistants relative to these other occupations. Infection control guidance early in the pandemic encouraged dentists to minimize the occurrence of AGPs in dental settings; however, a previous study of dental practices early in the pandemic observed a majority of dentists reported they had provided emergency oral health care (91.1%) and

elective oral health care (80.1%) as of June 2020.[15] Additionally, a majority of dentists who had provided elective oral health (92.8%–97.3%) reported they had performed AGPs indicating that AGPs were still commonly encountered in dental practice even early in the pandemic when guidance recommended minimizing AGPs.[15,18] Further, infection control guidance for dental personnel providing oral health care during the pandemic recommended using an N95 or equivalent mask and basic clinical PPE when performing AGPs with asymptomatic patients; however, this was only reported as always being worn by a little over half of dentists who reported performing AGPs.[18] N95 respirators were limited early in the pandemic and a limited supply of N95 respirators could have contributed to lower compliance with N95 respirator use during AGPs. The inability to completely eliminate AGPs, combined with limited supplies of higher-level PPE could have contributed to several other healthcare occupations including those with direct patient-care duties such as health diagnosing and treating practitioners (all other) and direct client interactions, such as massage therapists, having lower adjusted ORs for COVID-19 death relative to dentists and dental assistants.

Among healthcare occupations with significantly elevated adjusted ORs for COVID-19 death when compared with dentists and dental hygienists, LPNs and LVNs, and NPs are occupations with duties that include providing basic nursing and first aid care, and they often provide care to ill or critically ill patients. Our observation of nursing occupations such as LPNs, LVNs, and NPs having elevated adjusted ORs for COVID-19 death aligns with previous studies of COVID-19 infection risk among healthcare occupations in 2020. Previous studies observed nursing occupations to have higher prevalence of COVID-19 infection or seroprevalence in 2020.[19,20] Oda et al. discuss how high-risk job duties of nursing staff, such as extended close physical contact with patients, AGPs, and interactions with patients who may be extremely ill and infectious, potentially contributed to nursing occupations' higher occupational risk of COVID-19 infection.[20] Increased proximity to and frequency of interaction with ill patients potentially contributed to multiple nursing occupations having elevated adjusted ORs for COVID-19 death and could potentially explain why LPNs and LVNs, and NPs had significantly elevated adjusted ORs for COVID-19 death when compared with dentists and dental hygienists.

SLPs also had significantly elevated adjusted ORs for COVID-19 death when compared with dentists, dental assistants, or dental hygienists. SLPs also have frequent, direct contact with patients, and can perform procedures with patients that generate aerosols including assessments for dysphagia, instrumental assessment of voice via endoscopy, assessment and management of laryngectomy, assessment and management of tracheostomies, and noninvasive ventilation.[21] Kearney et al. administered a survey to SLPs in the United States and Canada from May–June 2020, including SLPs who were likely to perform AGPs. Among the SLPs they surveyed, 90% reported continuing to perform endoscopy procedures in May–June of 2020, albeit often at lower frequency than before the COVID-19 pandemic began. Despite performing procedures that can generate aerosols, few studies to date assessed occupational risk for SARs-CoV-2 infection among SLPs specifically. Eyre et al. assessed occupational risks of SARs-CoV-2 to healthcare workers in 2020 and observed that the occupational group including SLPs (physical, occupational, and speech language therapists) were among the top two healthcare occupational groups for highest COVID-19 infection rates.[22] In contrast, another study by Barrett et al. assessed SARs-CoV-2 infections among 3,904 hospital workers in New Jersey in 2020 and they reported lower SARs-CoV-2 infections among the therapist occupational group (7.1% among physical, occupational, and speech therapists). However, these results are difficult to interpret for SLPs specifically, because SLPs were combined with other therapists in their analyses. In our study, SLPs had significantly elevated adjusted ORs for COVID-19 death when compared with dental occupations, and had similar adjusted ORs for COVID-19 death to other occupations with direct patient-care tasks such as LVNs and LPNs, and NPs.

Additional healthcare occupations with significantly elevated adjusted ORs for COVID death when compared with dental hygienists specifically included EMTs and paramedics, PTs and exercise physiologists, PT assistants and aides, and recreational therapists. Elevated adjusted ORs for COVID-19 death observed among PT occupations when compared with dental hygienists aligns with previous studies of seroprevalence for SARs-CoV-2 infection among healthcare workers in 2020. Akinbami et al. reported that PTs were among the top two healthcare occupations with highest seroprevalence for SARs-CoV-2 infection among healthcare, first response and public safety personnel tested in Michigan in May–June 2020.[23] Similarly, the elevated adjusted ORs for COVID-19 death observed among EMTs and paramedics when compared with dental hygienists aligns with previous studies that evaluated seroprevalence for SARs-CoV-2 infections among healthcare workers in Minnesota in 2020–2021[24] and first responders and public safety personnel in New York City in 2020.[25] Wiggen et al. reported that relative to physicians, EMTs and paramedics had significantly higher ORs for a seropositive sample.[24] Similarly, Sami et al. observed that among first responders and public safety personnel, EMTs and paramedics were among the top two occupations for highest SARs-CoV-2 infection prevalence.[25] EMTs and paramedics often perform emergency care including procedures with high risk for exposure such as airway management in relatively small, variably ventilated spaces such as ambulances.[26] Ventilation of indoor spaces is considered an important determinant in the transmission of SARs-CoV-2 and, in combination with AGPs performed by EMTs and paramedics, could be a factor contributing to the higher seroprevalence reported for EMTs and paramedics in previous studies, and elevated adjusted ORs for COVID-19 death observed among EMTs and paramedics when compared with dental hygienists in our study.

Our study is subject to several limitations. First, COVID-19 death estimates here combine the risk of both COVID-19 infection and death from COVID-19, making it difficult to infer conclusions about independent risk for infection at work and subsequent death. Additionally, we relied on death certificate data when adjusting for potential confounders that have previously been associated with higher risk for COVID-19 infection and mortality, such as race and

ethnicity and education.[27,28] However, we were not able to account for other factors associated with higher risk for COVID-19 infection and subsequent death not listed on the death certificate, including nonoccupational factors such as housing density or use of public transportation. Second, we relied on the occupation and industry information listed on the death certificate which is the usual occupation and industry reported for the decedent. We sought to minimize this limitation by restricting our analyses to working-age decedents (decedents 16 to 65 years). Third, there is the potential for misclassification of causes of death on death certificates,[29] and our analysis of COVID-19 deaths could have been affected if COVID-19 was the underlying cause of death but was not reported as the underlying cause of death and was listed elsewhere on the death certificate. However, results from our sensitivity analyses were consistent with our main analyses of COVID-19 as the underlying cause of death, indicating that any effect from this potential misclassification was small and did not substantially alter results for COVID-19 death. Additionally, we were limited to medical conditions listed on the death certificate when adjusting for medical conditions associated with severe COVID-19. Lastly, some occupations had few decedents with COVID-19 listed as the underlying cause of death and the small numbers in some occupations contributed to wider confidence intervals and potentially limited our ability to detect significant differences.

5 | CONCLUSION

Similar to previous studies, we observed that COVID-19 deaths varied by occupation in 2020. Our results highlight potential differences in work-related COVID-19 deaths among healthcare occupations in 2020. Multiple healthcare occupations with frequent, direct patient- or client- interactions had significantly elevated adjusted ORs for COVID-19 death when compared with dentists, dental assistants, or dental hygienists. Although dentists and dental assistants were not among the top healthcare occupations for COVID-19 death, they were not among the lowest healthcare occupations for COVID-19 death either; two other healthcare occupations with frequent, direct patient- or client- interactions had significantly lower adjusted ORs for COVID-19 death when compared with dentists and dental assistants. Alternatively, no other healthcare occupation had significantly lower adjusted ORs for COVID-19 death when compared to dental hygienists. Our results indicate that despite previous studies identifying dental professions as among the top occupations for exposure to SARs-CoV-2, there was no evidence that dental occupations had the highest adjusted ORs for COVID-19 death when compared to other occupations, in 2020.

AUTHOR CONTRIBUTIONS

Brie Hawley Blackley, Ethan D. Fechter-Leggett, Fotinos Panagakos, Tammy Chipps, and Jean M. Cox-Ganser conceptualized the study. Brie Hawley Blackley, Ethan D. Fechter-Leggett, and Jean M. Cox-Ganser designed the study. Brie Hawley Blackley, Ethan D. Fechter-Leggett, Talia Alexander, and Jean M. Cox-Ganser participated in the analysis and interpretation of data for the work. All authors assisted in drafting the work or revising it critically for important intellectual content and agree to be accountable for all aspects of the work in ensuring that questions related to accuracy or integrity of any part of the work are appropriately investigated and resolved.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

John Meyer declares that he has no conflict of interest in the review and publication decision regarding this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in Mortality Multiple Cause Files U.S. Data 2020 at https://www.cdc.gov/nchs/nvss/mortality_public_use_data.htm. These data were derived from the following resources available in the public domain: - NCHS Vital Statistics Online Data Portal, https://www.cdc.gov/nchs/nvss/mortality_public_use_data.htm.

ETHICS APPROVAL STATEMENT

This activity was reviewed by CDC, deemed research not involving human subjects, and was conducted consistent with applicable federal law and CDC policy.

DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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