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THESIS APPROVAL PAGE FOR MASTER OF SCIENCE IN ORAL BIOLOGY

Title of Thesis: The impact of COVID-19 PPE on the carbon footprint of the Naval Postgraduate Dental school (NPDS)

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Master of Science Degree
April 14, 2023

THESIS/MANUSCRIPT APPROVED: DATE:

KIM.JEFFREY.J.1553853377 Digitally signed by KIM.JEFFREY.J.1553853377 Date: 2023.06.07 16:27:46 -04'00' 6/7/23

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THE IMPACT OF COVID-19 PPE ON THE CARBON FOOTPRINT OF THE NAVAL POSTGRADUATE DENTAL SCHOOL

by

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A thesis submitted to the Faculty of the
Comprehensive Dentistry Graduate Program
Naval Postgraduate Dental School
Uniformed Services University of the Health Sciences
In partial fulfillment of the requirements for the degree of
Master of Science
in Oral Biology
June 2023

THESIS APPROVAL PAGE

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ACKNOWLEDGMENTS

Sabrina J. Sincere-Sombie, DDS, thanks the leadership and staff of the Naval Postgraduate Dental School at Walter Reed National Military Medical Center for their support in conducting this research. Special thanks to CDR Hernandez Feldpausch, Marina, DDS, MS Associate Investigator, and to Retired CAPT Luu, Thu Nhuan, Associate Investigator, for their mentorship. Sincere gratitude to LCDR Dickens, Noel Evan, DMD, PhD, Research Coordinator, and to Kim, Jeffrey J, DDS PhD, Research Coordinator, for their critical reviews and timely literature suggestions that made possible the quality research performed.

Sabrina J. Sincere-Sombie, DDS, also acknowledges the assistance received from the chief librarian at NPDS, Mrs. Ann Holman, and from ENS Deane, Jermin, IHO, MSc, GSP, ASHM, a former colleague now in Norfolk, VA, for both enriching the literature review.

DEDICATION

To my husband, Serge D. Sombie, and to our three children, Olivia, Christopher, and Nicolas.

DISCLAIMER

The views presented here are those of the author and are not to be construed as official or reflecting the views of the Uniformed Services University of the Health Sciences, the Department of Defense or the U.S. Government.

ABSTRACT

The Impact of COVID-19 PPE on the Carbon Footprint of the Naval Postgraduate Dental School (NPDS)

Sabrina J. Sincere-Sombie, DDS, 2023

Thesis directed by: Jeffrey J. Kim, DDS, PhD
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Introduction: Green dentistry aims at reducing the environmental impact of Greenhouse Gases (GHG) emissions generated in dental offices, specifically CO_2 emissions due to their effective heat-trapping property that affects public health and climate change. There is a knowledge gap in how much GHG dental offices produce and if COVID-19 affected the level of emissions.

Objective: The purpose of this study was to analyze the variation in carbon footprint from key Personal Protective Equipment (PPE) used at the Naval Post Graduate Dental School (NPDS) during the surge of the COVID-19 pandemic.

Methods: From the Corporate Dental System (CDS) web-based patient scheduler, we collected procedure codes of all aerosol-generated procedures (AGP) and non-aerosol generated procedures (NAGP), from September 2018 to August 2021, designating two 18-month periods as 'pre-COVID-19' and 'during pandemic outbreak' periods. By using life cycle assessment (LCA), we estimated the carbon footprint for the entire dental operation (September 2018 to August 2021) by applying the benchmark units of CO_2 equivalent (CO_2E) per selected PPE to NPDS procedure data.

Results: PPE used at NPDS contributed 17,557 kg of CO_2E pre-COVID-19 (18 months) and 17,655 kg of CO_2E during the pandemic outbreak (18 months), which led to 0.6% increase. In the pre-COVID-19 period, disposable gowns were the primary contributors to the overall disposable PPE carbon footprint (13,285 kg CO_2E). During the pandemic, shoe covers, and disposable gowns were the main contributors to the overall disposable PPE carbon footprint (approximately 6,000 kg CO_2E each).

Conclusions: Despite a decrease in the number of dental procedures delivered during the pandemic, there was a negligeable change in total PPE carbon footprint due to the increase in quantity and types of disposable PPE items used, during the COVID-19 pandemic compared to pre-COVID-19. Careful selection of PPE items can help dental providers be environmentally sustainable without compromising the safety of patients and providers.

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LIST OF ABBREVIATONS

ADA	American Dental Association
AGP	Aerosol-generating procedure
CDC	Center for Disease Control and Prevention
CH_4	Methane
CO_2	Carbon Dioxide
CO_2E	Carbon Dioxide equivalents
COVID-19	Coronavirus Disease 2019
GHG	Greenhouse Gas
HFC	Hydrofluorocarbon
IPAC	Infection Prevention and Control
Kg	Kilogram
LCA	Life Cycle Analysis or Life Cycle Assessment
N_2O	Nitrous oxide
N95	Non-Oil, 95% efficiency
NAGP	Non-aerosol generating procedure
NPDS	Naval Postgraduate Dental School
O_3	Ozone
PFC	Perfluorocarbon
PP	Non-woven Polypropylene
PPE	Personal Protective Equipment
SARS CoV2	Severe Acute Respiratory Syndrome Coronavirus 2
SF_6	Sulphur hexafluoride

CHAPTER 1: Introduction

STUDY BACKGROUND AND SIGNIFICANCE

Carbon footprint. Since the 1970s' the excess anthropogenic emission of CO_2 and other greenhouse gases at a critical rate have been contributing to global warming. That is of great concern for public health due to fostering risk multipliers such as heat-related mortality in the frail elderly population, and the spread of viral, bacterial, and vector-born infections (Cunha, M. F. and Pellino, G. (2022); K. Hariharan and R. Zeldin (2021)).

In 2005, the Kyoto Protocol under the 1992 United Nations Framework Convention on Climate Change, had identified six greenhouse gases: Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs); and Sulphur hexafluoride (SF_6) (Cunha, M. F., and Pellino, G., 2022). CO_2 molecules can vibrate in ways that simpler nitrogen and oxygen molecules cannot, which allows CO_2 molecules to capture the infrared photons. Conversely, gas molecules such as nitrogen (N_2) and oxygen (O_2), which make up more than 90% of Earth's atmosphere, do not absorb infrared photons. As UCAR Center for Science Education (2012) highlighted, "the property of the CO_2 to absorb and re-emit infrared radiation makes CO_2 effective at heat-trapping greenhouse gas."

Green dentistry, environmentally sustainable dentistry, aims at reducing the environmental impact of carbon footprint generated in dental offices. Carbon footprint is defined as "the sum of greenhouse gas emission generated throughout the supply chain of activities and products expressed in carbon dioxide equivalents (CO_2E)" (I. Steinbach,

2018). Carbon footprint assessments are crucial in monitoring and regulating products, resource usage, and practices from individuals and organizations that impact the ecosystem (S. S. Muthu, 2016).

Carbon footprint in dentistry. In 2013, the dental sector contributed to 3% of the 655 metric tons of CO_2E generated in the U.S. healthcare industry, which represented 10% of the U.S. total GHG emission as reported in Eckelman, M. J., & Sherman, J. (2016). The production of carbon footprints in dental clinics consists mostly of carbon dioxide, methane, and nitrous oxide (Pathak N., 2021). Personal protective equipment usage, patient travel, facility water, energy consumption, biomedical materials, imaging modalities, biomedical waste, and metallic waste are sources of GHGs emissions (B. Duane, R. Stancliffe, F.A. Miller, and Ali., 2020; and Nicolas Martin, 2021). Per U.S. Department of Labor, Occupational Safety and Health Administration, OSHA 3151-12R, 2004, Personal protective equipment (PPE) is an "equipment worn to minimize exposure to a variety of hazards - physical, electrical, heat, chemicals, biohazards, and airborne particulate matter." PPEs include gloves, face masks, protective eye wear, face shields, and protective clothing, to include reusable or disposable gowns, jackets, coats, bouffant hair covers, surgical caps, and shoe covers. (Centers for Disease Control and Prevention, 2016). Most disposable PPEs contain plastic elements (Khoo et al., 2021), which present high risks of contamination of the ecosystem. For example, disposable masks initially break down into micro and nano plastics, however complete biodegradation takes approximately 400 to 500 years (Lambden, 2020; J. Ashworth, 2022; Lambden, 2020) in P. Monolina, M.H. Chowdhury, and N. Haque, 2022).

Response to COVID-19 in dental offices. COVID-19 is a respiratory tract infection disease caused by the virus SARS-CoV-2, which has 2-14 days of incubation (CDC, 2023). Most people affected by COVID-19 have mild symptoms (*e.g.,* fever and cough); however, a subset of people can become severely ill, especially if presenting certain medical pre-conditions. SARS-CoV-2 spreads within 6 feet when an infected person exhales droplets and very small particles that contain the virus. These droplets and particles can be inhaled by other people or land on mucosal membranes (i.e., eyes, noses, or mouth). In some circumstances, the disease transmission can occur via contaminated surfaces that an infected individual has recently coughed or sneezed on (CDC, 2023).

In March 2020, it became apparent that treating patients especially in the context of aerosol-generating procedures (AGPs) while mitigating COVID-19 infection disease transmission is extremely challenging. Aerosol Generating Procedures (AGPs) are commonly defined as dental or medical procedures that result in the production of respirable airborne particles less than 5μm in diameter that could remain suspended in the air for extended periods (Proffitt, 2020; Tran K, Cimon K, Severn M, and Ali, 2012; CDC, 2022). On April 1, 2020, the American Dental Association (ADA) recommended postponing radiographs, oral examinations, aesthetic dental procedures, routine cleaning and preventive therapies, and orthodontic procedures that do not involve pain management. Urgent dental care procedures included extensive dental caries involving pain, uncontrolled intraoral bleeding, facial trauma, dental trauma, tooth fractures and biopsies of abnormal tissues (ADA, 2021).

PPEs in general were used more in quantity and changed more frequently during the pandemic, while dental clinics were authorized to only treat urgent cases and defer

elective care. Providers requested and were asked to use PPEs with higher-level protection (*i.e.,* a N95 mask instead of a surgical mask). With those sudden changes, it is not known how PPEs usage during the COVID-19 pandemic impacted greenhouse gas emissions in dental practices.

KNOWLEDGE GAP

Due to the COVID-19 pandemic, Naval Postgraduate Dental School (NPDS) undertook major logistical shifts in the volumes and types of PPEs used, to include face shields, shoe covers, and N95 masks. However, with that increased usage of PPEs, there is a knowledge gap on the effects of COVID-19 pandemic on carbon footprint in dental offices including Military Treatment Facilities (MTFs).

STUDY OBJECTIVES

The current study contributes to bridging the knowledge gap in PPEs' carbon footprint assessment and waste management strategy. The first objective is to analyze the variations in NPDS' PPE carbon footprint from pre-COVID-19 to during the COVID-19 outbreak. The second objective is to explore ways to mitigate the irreversible growth of NPDS' carbon footprint due to increased utilization of PPE in the operating room. The question is no longer what if, but which eco-friendly choices to adopt, especially in times of fast spreading pandemics.

CHAPTER 2: Materials and Methods

ASSESSMENT OF CARBON FOOTPRINT

The Life Cycle Analysis (LCA), also known as life cycle assessment, eco-balance, and cradle-to-grave analysis, is the common method of quantification of the carbon footprint. LCAs investigate, compile, and analyze all direct and indirect gas emissions and express them in tons [kilograms or grams] of CO_2 equivalent (CO_2E), a robust metric for comparison across products, industries, and regions (Duane, Stancliffe & Ali., 2020).

The two approaches to life cycle assessments are the "bottom-up" and the "top-bottom" approaches (Duane, Stancliffe & Ali.,2020). The "bottom-up" or "ground-up" analyses for a product/category or/and small-scale entities, look at actual materials and processes to estimate GHG emissions from production to disposal of a product. In the case of PPEs, this includes the extraction of resources, the production of basic raw materials (i.e., polypropylene fabric, polycarbonate, nitrile rubber, various metals), manufacturing, packaging/transport of PPE, use of PPE by providers and patients, and waste disposal of PPE. The "top-bottom" approach is for large-scale entities or economic sectors (*i.e.,* national/ international levels). That study relies on health care expenditures and economic input-output tables as a surrogate for embodied pollutants. International Organization for Standardization (ISO) standards, in particular ISO 14040 and 14044 assure the reproducibility of LCAs (Franchetti and Apul, 2013). Managing strategies of carbon footprint could involve internal processes (i.e., life cycle), external drivers (*e.g.,* leadership and research to foster change), and other factors (*e.g.,* feasibility study) as illustrated in Duane, Stancliffe & Ali., 2020(see *Figure 1)*.

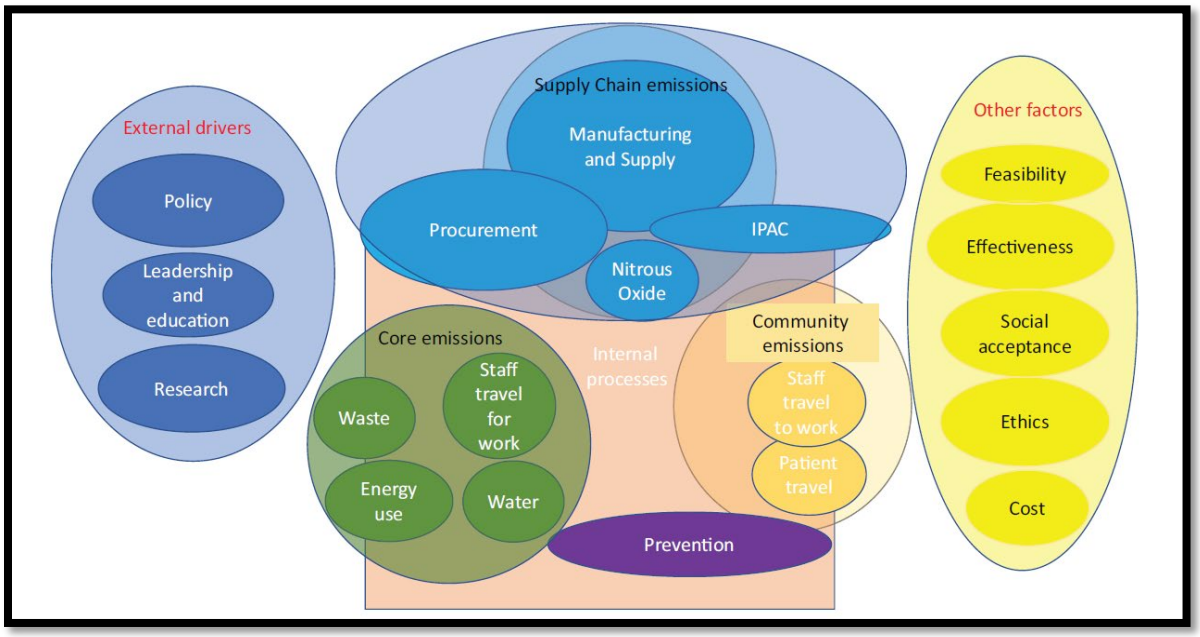


Figure 1. Multifaceted approaches to carbon footprint management

Management strategy of carbon footprint could involve: Internal processes, *i.e.,* life cycle with manufacturing, procurement, travels, water, energy, and waste disposal. Prevention could help "reduce" emissions. External drivers, *e.g.,* leadership, education, and research can foster "rethinking". Other factors, *e.g.,* feasibility, social acceptance, and ethics can assist in decision-making about alternate eco-friendly solutions (adapted from *Duane, Stancliffe & Ali. 2020*)

SELECTED RESEARCH SCOPE OF WORK

With limited resources and time, it is impractical to investigate all GHG emissions from raw materials to waste disposal for all PPE. Therefore, it was critical to identify key disposable PPEs used in treatment performed at NPDS to delineate the research scope of work. It was also critical to use available benchmark carbon footprint measurements from prior LCA studies.

STUDY DESIGN

This study design first consisted of quantifying aerosol generating procedures (AGP) and non-aerosol generating procedures (NAGP) performed at NPDS using Corporate Dental System (CDS) web-based scheduler software. The designated timeline covered a "pre-COVID" period of 18 months, and a "during-COVID" period of 18 months, both revolving around March 11, 2020, when the World Health Organization declared COVID-19 a pandemic (*i.e.,* study timeline from September 2018 to March 2020, and from March 2020 to August 2021).

Naval Postgraduate Dental School. With a building of 14,326 square feet, the NPDS encompasses 10 departments and 70 dental operatories. About 75 dentists and 81 auxiliary staff members deliver care to an average of 34 patients per day.

AGP vs. NAGP. PPE requirements are dependent upon the type of clinical treatment being delivered and whether the procedure is associated with generating aerosol particles. M.K. Virdi, K. Durman, and S. Deacon (2021) reported, "the main area of consensus [on AGDP] is that the use of high-speed handpieces, air-water syringes, and powered scalers creates the greatest amount of biological aerosol (secretions, saliva, and blood) and therefore poses the highest risk of transmission (…) There is less consensus that

other procedures, such as air abrasion, polishing of teeth, and the use of a surgical handpiece, constitute an AGDP." In most countries, "procedures that do not involve the use of rotatory instruments or induce the gag reflex can be considered non–aerosol generating"; however, only a few list NAGPs due to grey areas correlated to COVID-19 transmission risk (M.K. Virdi, K. Durman, and S. Deacon, 2021). Per ADA guidelines, procedures unlikely to be associated with the generation of aerosols include oral examination, post-op evaluation, periodontal screening, re-cementation of crown, hand scaling, impressions, intra-oral radiographs, and photographs, aesthetic dental procedures, routine cleaning, preventive therapies, and various orthodontic procedures.

Benchmark studies. This study evaluated the type of plastic materials contained in each key disposable PPE used across the spectrum of AGP and NAGP; however, literature reviews of prior studies life cycle assessments (LCA) helped quantify the amount of carbon footprint for each PPE.

Carbon footprint matrix. This study computed the benchmarked carbon footprint units, the number of PPEs used per procedure, and the number of procedures performed. The resulting matrix of CO_2E by PPE and by AGP/NAGP contributed to bridging the knowledge gap previously outlined.

Environmental Goals. Finally, the literature review offered ways to pivot towards implementing waste management strategies in PPE procurement/usage to pursue sustainable green dentistry.

CHAPTER 3: Results

PROCEDURES PERFORMED AT NPDS UNDER COVID-19

NPDS Dental procedures performed during the study timeline *(Table-1)*. Based on the daily data collected from the web-based scheduler, pre-Covid, NPDS performed a total of 25,891 dental procedures vs 12,707 procedures provided during COVID-19 surge (AGP and NAGP combined).

COVID-19 clearly caused a sharp decrease in the frequencies of AGP from 1,838 procedures (Dec-2019 to Feb-2020) to 487 procedures (Mar-May-2020) and 756 procedures (Jun-Aug-2020). The NAGP decreased from 2,109 procedures performed (Dec-2019 to Feb-2020) to respectively 422 procedures (Mar-May-2020) and 604 procedures (Jun-Aug-2020).

COVID-19 Timeline & procedures performed at NPDS *(Figure-2).* After reporting the first U.S. case of COVID-19 on January 21, 2020, the level of operation at NPDS clinic evolved in correlation with the guidelines from health authorities:

- March 16, 2020: ADA issued guidance to postpone elective procedures and only provide emergency care.
- March 31, 2020: the Department of the Navy postponed elective procedures at military dental facilities.
- July 5, 2020: NPDS staff and residents returned to work; and
- December 18, 2020: FDA issued EUA COVID-19 vaccine.

Breakdown of the dental procedures during COVID-19 *(Figure-3).* NPDS dental providers performed 65% less AGPs and 43% less NAGPs, when comparing the 18 months pre-COVID-19 to the 18 months during COVID-19.

Table-1. NPDS Dental procedures by departments performed during the study (Timeline Sep-2018 thru Aug-2021: summarized in intervals of 3 months).

Aerosol-generating procedures (AGP)

	Sep 18-Nov 18	Dec 18-Feb 19	Mar 19-May 19	Jun 19-Aug 19	Sep 19-Nov 19	Dec 19-Feb 20	Mar 20-May 20	Jun 20-Aug 20	Sep 20-Nov 20	Dec 20-Feb 21	Mar 21-May 2	Jun 21-Aug 21
Comp	320	301	336	423	307	274	88	187	240	185	262	268
OFP*	319	302	334	409	424	419	62	74	193	102	233	273
Endo	250	173	174	257	357	295	115	216	272	163	293	273
Max Fac Prosth	6	5	9	40	47	44	4	1	12	3	2	24
Oral Surgery	83	61	49	87	66	35	22	23	35	24	25	10
Ortho/pedo	96	38	57	77	113	76	27	10	78	39	81	64
Perio	169	169	187	244	329	357	98	158	383	262	345	358
Pros	119	157	170	114	120	111	22	52	85	56	80	70
Oral* Diagnosis	315	254	342	313	248	177	23	25	130	17	7	4
Faculty Practice	96	136	129	78	54	50	26	10	31	25	32	20
Total	**1,773**	**1,596**	**1,787**	**2,042**	**2,065**	**1,838**	**487**	**756**	**1,459**	**876**	**1,360**	**1,364**

Non-aerosol-generating procedures (NAGP)

	Sep 18-Nov 18	Dec 18-Feb 19	Mar 19-May 19	Jun 19-Aug 19	Sep 19-Nov 19	Dec 19-Feb 20	Mar 20-May 20	Jun 20-Aug 20	Sep 20-Nov 20	Dec 20-Feb 21	Mar 21-May 2	Jun 21-Aug 21
Comp	529	569	626	397	449	426	84	175	249	310	368	210
OFP*	0	0	0	0	0	0	0	0	0	0	0	0
Endo	368	343	403	312	246	199	45	81	151	72	45	103
Max Fac Pro	50	46	11	15	17	34	8	11	16	0	1	0
Oral Surgery	170	108	124	90	80	66	21	33	54	28	116	33
Ortho/pedo	174	92	149	130	272	219	44	53	155	139	223	254
Perio	597	524	646	432	475	449	74	139	308	199	262	207
Pros	407	319	515	550	529	470	92	106	327	307	451	422
Oral Diagnosis	0	0	0	0	0	0	0	0	0	0	0	0
Faculty Practice	543	357	335	287	285	246	54	6	78	59	141	91
Total	**2,838**	**2,358**	**2,809**	**2,213**	**2,353**	**2,109**	**422**	**604**	**1,338**	**1,114**	**1,607**	**1,320**

Note: Between March 2020 and the end of August 2020, the number of dental procedures performed at NPDS sharply decreased across all specialties due to the COVID-19 outbreak. The lowest records are in March-May 2020 with 487 aerosol-generating procedures and 422 non-aerosol generating procedures.

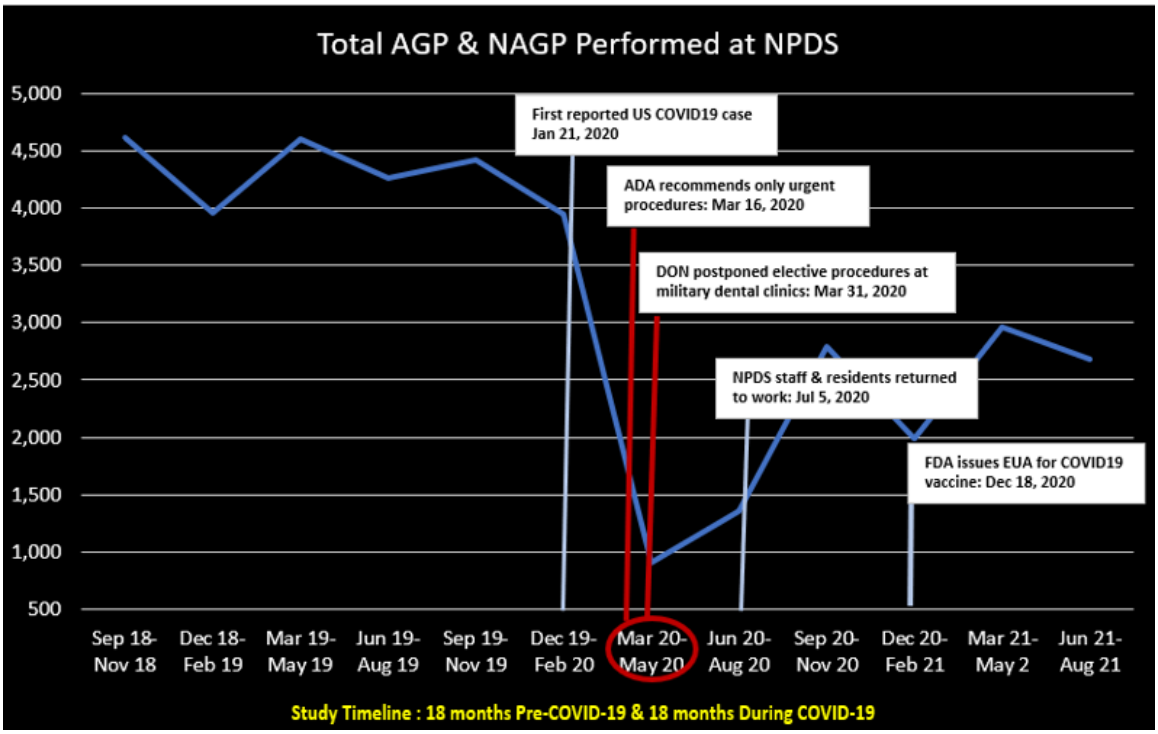
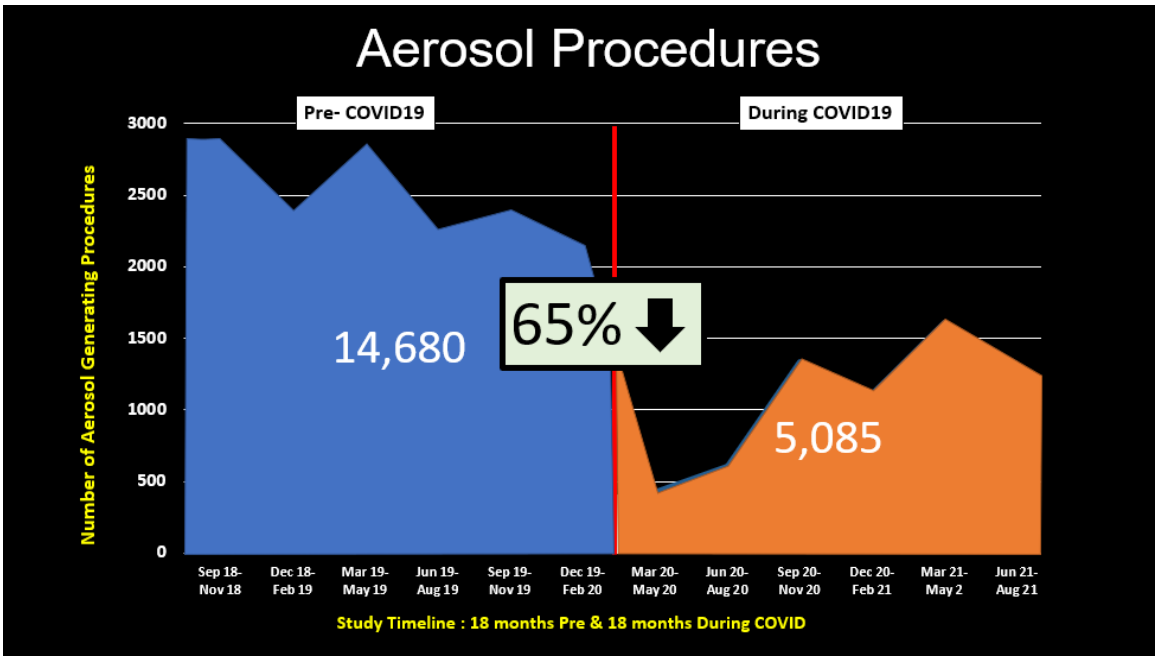


Figure 2. COVID-19 Timeline & procedures performed at NPDS.

The drop in the total dental procedures performed during COVID-19 surge correlates with the following key dates:

- January 21, 2020: First COVID-19 case reported in the U.S.
- March 16, 2020: ADA issued guidance to postpone elective procedures.
- March 31, 2020: DON postponed elective procedures at military dental treatment facilities.
- July 5, 2020: NPDS staff and residents returned to work.
- December 18, 2020: FDA issued EUA COVID-19 vaccine.



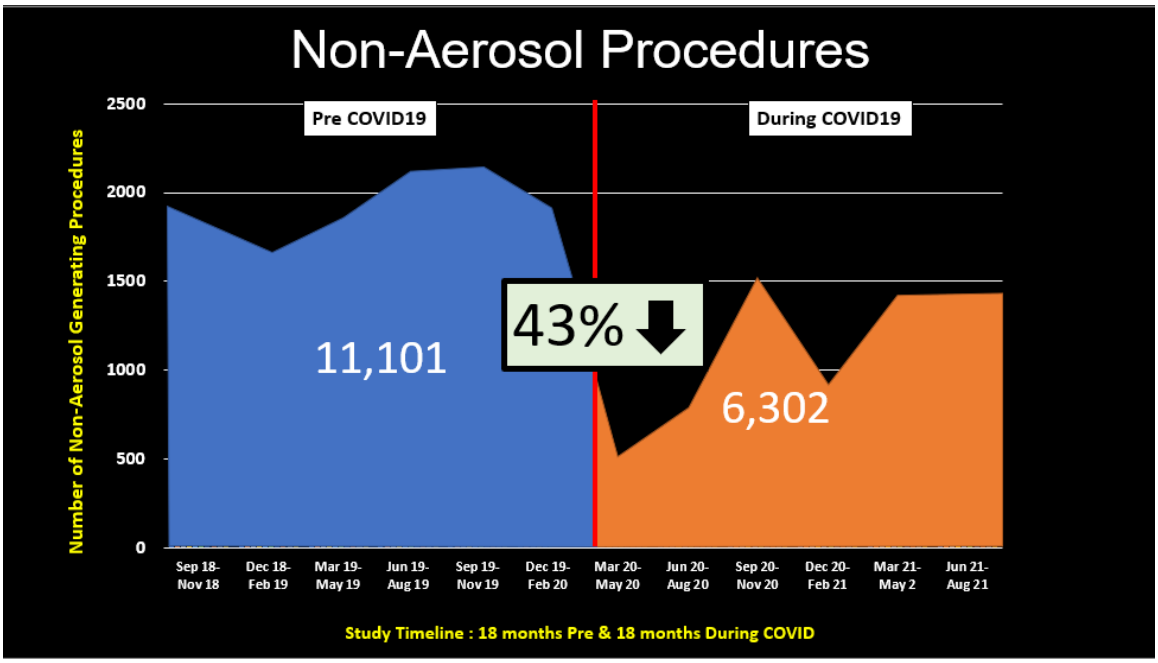


Figure 3. Comparative decline in levels of operation due to COVID-19, AGP vs NAGP performed at NPDS.

The cumulative number of dental procedures performed decreases by 65% for aerosol-generating procedures (AGP) and by 43% for non-aerosol generating procedures (NAGP) when comparing 18 months pre-COVID-19 to the 18 months during COVID-19 surge.

CHANGES IN PPE USED DURING THE COVID-19 SURGE

Disposable PPE recommended to mitigate COVID (Figure-4). The eight disposable PPE recommended across NPDS clinic were bouffant hair caps, face shields, N95 respirators, shoe covers, fluid resistant masks, nitrile gloves, surgical gloves, and isolation gowns. The first four PPE were essential to provide additional protection.

Chemical components in disposable PPE (Table-2). The disposable PPE reviewed are made of polymer derivatives: polypropylene, non-woven polypropylene, polyethylene terephthalate/polyester, synthetic rubber, and polyisoprene.

BENCHMARKED PPE CARBON FOOTPRINT UNITS

Figure-5 illustrates the carbon footprints gathered from Rizan, C., Ramasubbu, D., Wilmott, S., and Ali (2023) for the eight PPE items surveyed. The units are listed in grams (g) of CO_2E as follows: 301g for the bouffant/PP hair cover; 350g for the face shield; 32g for the fluid resistant mask; 50g for the high-grade medical mask/N95 respirator; 52g for the nitrile gloves; 572g for the surgical gloves; 905g for the isolation gown; and 920g for the shoe covers.

BASELINE PPE CARBON FOOTPRINT: PRE-COVID VS. DURING-COVID

Figure-6 depicts a marginal increase of 0.6% in total PPE carbon footprint from pre-COVID-19 to during COVID-19 for all procedures combined (AGP and NAGP) (from 17,557 $kgCO_2E$ to 17,655 $kgCO_2E$).

Figure-7 breakdowns the baseline finding as follows: pre-COVID-19, gowns were the culprit pollutant with over 12,500kg of CO_2E; and during COVID-19, shoe covers, and gowns contributed the most to the disposable PPE carbon-footprint with approximately 6,000kg of CO_2E each.

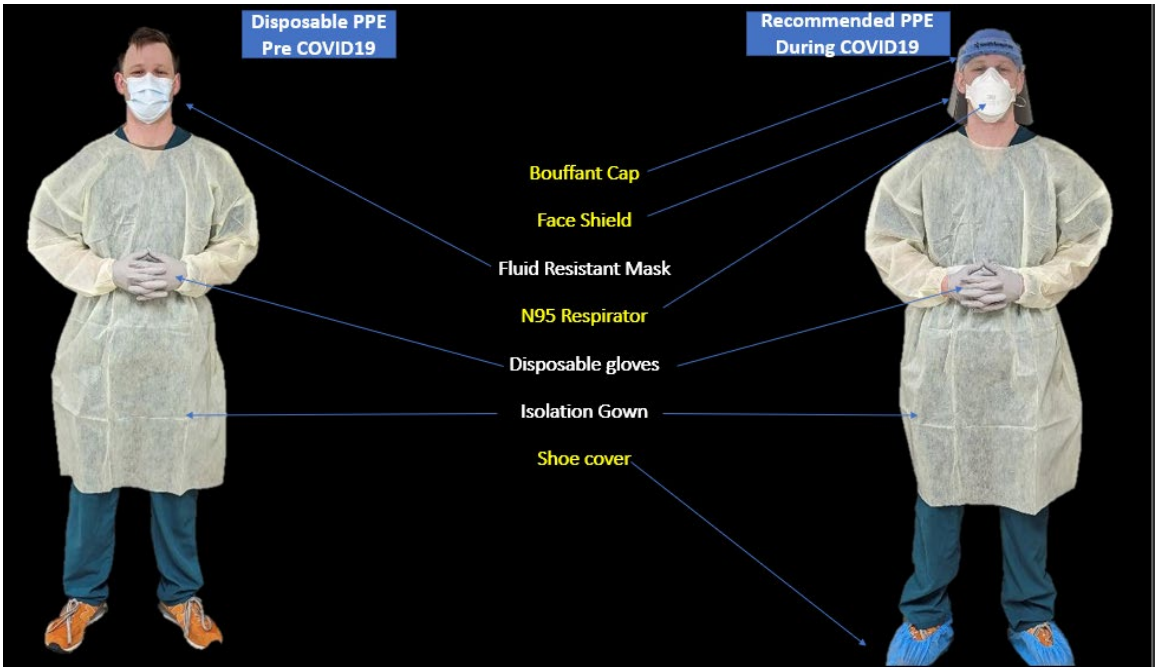


Figure 4. Changes in main disposable PPE used during COVID-19 surge.

Newly recommended disposable PPE items during COVID-19 pandemic surge: bouffant caps, face shields, N95 respirator masks, and shoe covers.

Table-2. Chemical components identified in selected disposable PPE

PPE item	Organic Component
Bouffant hair cap:	Non-woven Polypropylene (PP)
Face shield:	Polyethylene Terephthalate/Polyester (PET)
Fluid resistant mask:	Polypropylene (PP)
High grade medical mask/ N95 respirator:	Polypropylene (PP)
Nitrile gloves:	Synthetic rubber
Surgical gloves:	Polyisoprene
Isolation gown:	Non-woven Polypropylene (PP)
Shoe covers:	Non-woven Polypropylene (PP)

Note: The types of plastic materials contained in the eight selected PPE items surveyed are organic polymers: polypropylene, non-woven polypropylene, polyethylene terephthalate/polyester, synthetic rubber, and polyisoprene.

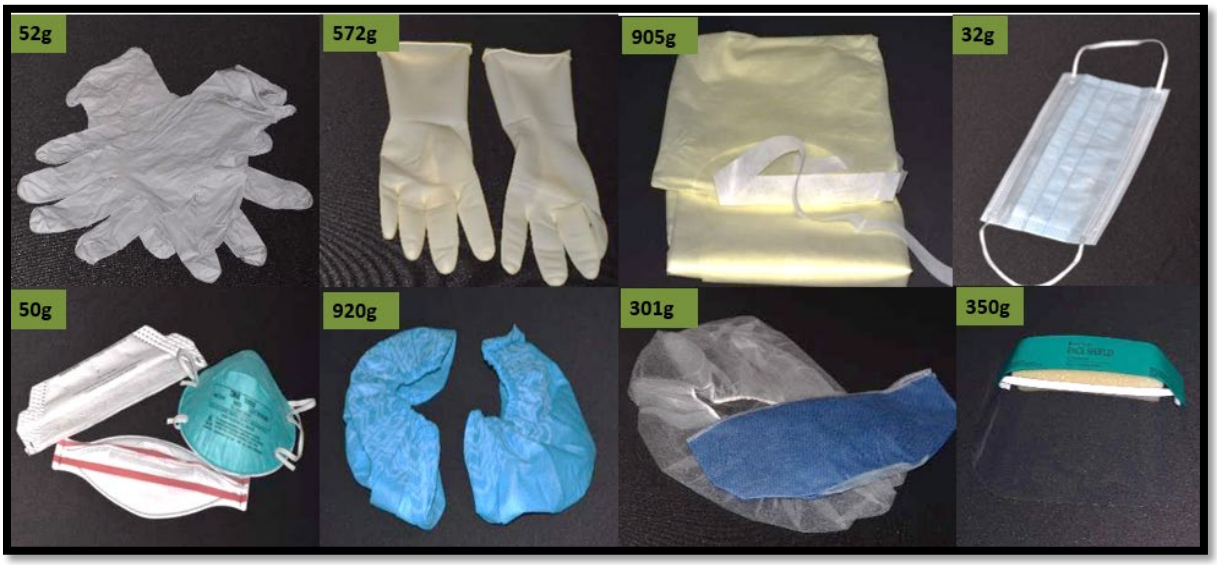


Figure 5. Benchmark PPE Carbon footprint units in grams (g) of CO_2E

Carbon footprint unit for each of the additional PPE items recommended at NPDS based on findings from Rizan, C., Ramasubbu, D., Wilmott, S., and Ali. (2022):

- 50g CO_2E for a N95 respirator mask
- 920g CO_2E for a pair of shoe covers
- 301g CO_2E for a bouffant cap (PP hair cover)
- 350g CO_2E for a face shield.

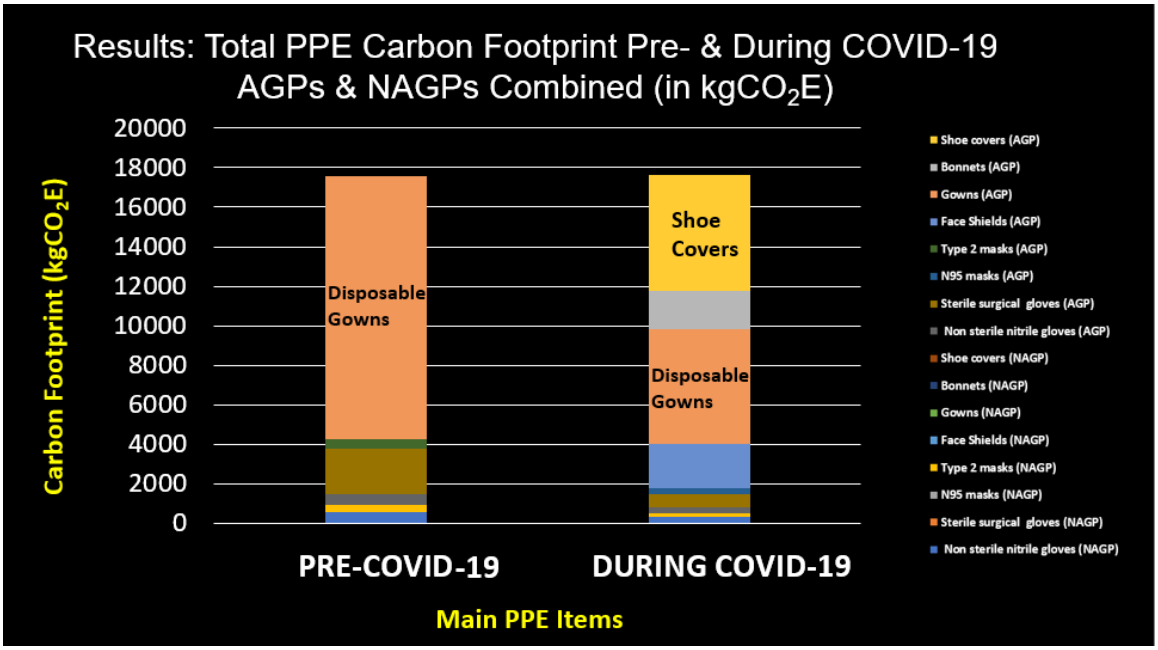
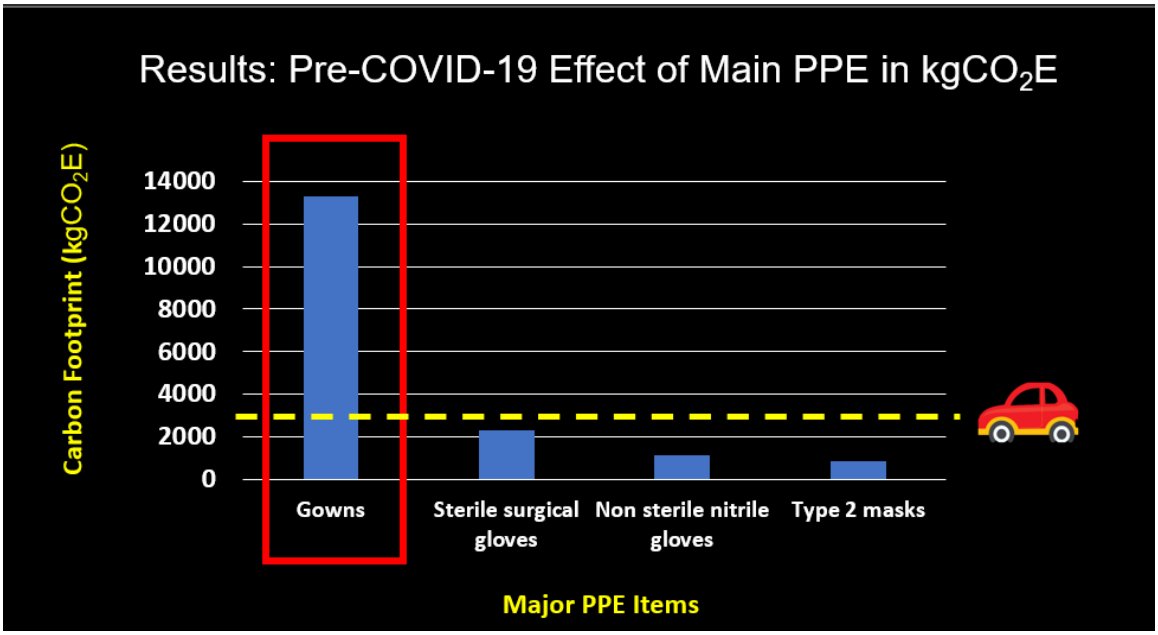


Figure 6. Total PPE carbon footprint pre-COVID-19 vs during-COVID-19 at NPDS

Total carbon footprint from disposable PPE increases 0.6% during COVID-19 (from 17,755 $kgCO_2E$ to almost 17,655 $kgCO_2E$. The change from the pre-COVID-19 total PPE carbon footprint is negligeable.



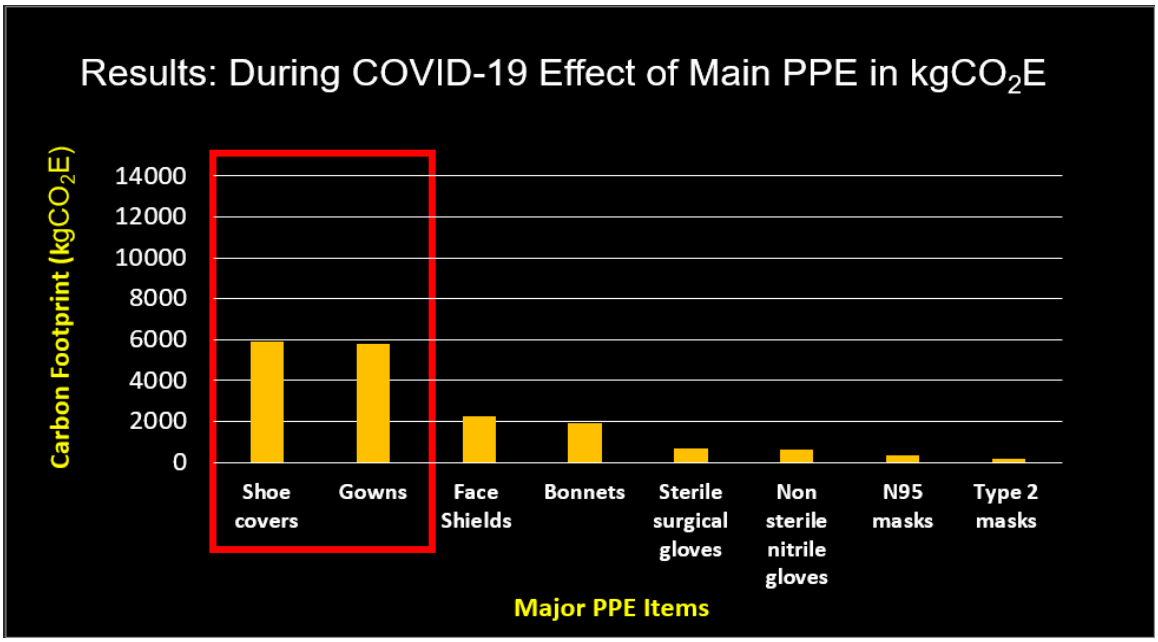


Figure 7. Breakdown of carbon footprints by key disposable PPE item at NPDS Pre-COVID vs during-COVID

Pre-COVID-19, with 12,500kg CO_2E, gowns are the main contributor to the total carbon footprint from disposable PPE. During the COVID-19 surge, gowns and shoe covers are the top PPE pollutant with 6,000kg CO_2E each.

CHAPTER 4: Discussion

IMPACT OF COVID-19 ON CLINIC LEVEL OF OPERATIONS

Overall, the data collected for NPDS clinics were consistent with prior studies that had analyzed the economic impact of the COVID-19 pandemic in the U.S. The strict public health guidelines led NPDS to treat 65% less AGPs and 43% less NAGPs compared to pre-COVID-19. Civilian dental offices also experienced an average 66.5% reduction in AGPs. The timeline of NPDS level of operation is consistent with forecast of the U.S. dental economy, which indicated a return to 60%-80% pre-pandemic levels of operation by the end of the 2nd Quarter of 2021.

SUSTAINED GROWTH IN PPE CARBON FOOTPRINT

During the COVID-19 outbreak, oral healthcare providers at NPDS delivered patient care under extraordinary circumstances. The providers asked for the best available PPE to protect themselves and urgent care patients. The disposable PPE recommended for more protection against COVID-19 encompassed hair covers (301g CO_2E), shoe covers (920g CO_2E), face shields (350g CO_2E), and N95 respirator (50g CO_2E). These PPEs were not typical items used prior to the COVID-19 pandemic and have high CO_2E values. Comparatively, a typical passenger car generates 1,000g of CO_2E over 4.5 miles.

An increase in quantity and types of PPEs contributed to a higher overall CO_2E contribution (+0.6%) despite NPDS clinics treating less patients. During COVID-19, shoe covers, and gowns contributed the most to the disposable PPE carbon-footprint with approximately 6,000kg of CO_2E each, that is twice as much as driving a typical passenger

car for 10,000 miles a year. The findings indicate a positive correlation between the cut in NPDS clinic operations and the drop in gown carbon footprint.

Furthermore, most disposable PPE items are made of a combination of plastic materials which are not easily recyclable. Plastic waste continue to threaten the quality of air, land, and water. In fact, as a side effect to the global response to COVID-19, 1.56 billion disposable masks ended up in oceans, out of the 52 billion masks that the world produced in 2020 (OceansAsia, 2020).

5-R Principles of Waste Management

It is imperative to promote sustainable dentistry without compromising the safety of patients and providers by implementing 5-R waste management principles: Reduce, Reuse, Recycle, Rethink/research/redesign, and Re-educate dental professionals (Kagoma et al., 2012; Energy Justice Network, 2014).

Leadership could foster innovations in PPE procurement choices, utilization practices, and waste management. “Rethink” means re-evaluating the benefit of shoe covers to protect patients and providers from respiratory infection. Studies have shown that the use of shoe covers has little scientific evidence in preventing the transmission of COVID-19 or other outbreaks (Khunti, K., Chan, X. H., Ross., L. et al., 2020). In our clinics, it is estimated that the overall CO_2E can be reduced by 33% by not using shoe covers as part of PPE. Using reusable polyester gowns instead of single-use gowns can also reduce CO_2E while cutting the related costs by 50% and providing comparable capacity to reduce microbial cross-transmission and liquid penetration (Baker, N., Bromley-Dulfano, R., Chan, J. et al, 2020).

Implementing monitoring tools such as patient-reported surveys, productivity reports, and cost-saving reports could help assess alternate eco-friendly solutions, such as washable shoes, biodegradable PPE, and pre- or post- treatment tele-dentistry (i.e., teleconsulting). This parallels the elements previously introduced in the multifaceted approaches to carbon footprint management strategy (see pages 4-5).

FUTURE IMPLICATIONS

Supporting sustainable changes in disposable PPE usage would be valuable because recent studies indicate that severe pandemics will become prevalent in the future. According to S.M. Eldred (2023), the World Health Organization monitors a list of viruses and bacteria, some with a pandemic risk potential that could be more severe than COVID-19 (Eldred, S.M., 2023).

In addition, ADA is likely to advocate keeping dental offices open during future pandemics because its study reported in June 2021 found that dentists had experienced "exceptionally low incidences of COVID-19 despite several regional and national spikes". The cumulative infection rate was 2.6% of the U.S. dentists surveyed over a 6-month period, primarily due to strict adherence to regulatory safety protocols while providing urgent care. Therefore, in correlation to the increased levels of clinical operations, the need for more PPE items of high quality would potentially generate more carbon footprint and more pollution (landfill, air, and oceans).

In prospective, this study predicted that disposable PPE procured and used at NPDS would cause 47% more greenhouse gas emissions in a scenario where the number of dental procedures only decrease by 10% during a future pandemic outbreak. So, the

result in terms of environmental impact would be significantly more alarming than the findings during the surge of the COVID-19 pandemic.

CHAPTER 5: Conclusions

The mitigation of the COVID-19 pandemic surge resulted in 56% decline in dental procedures at NPDS. Conversely, the eight main disposable PPE items used across dental treatments caused overall a negligeable increase in total carbon footprint (+0.6%). However, this overshadows more intensive use of higher protective PPE items, which have higher carbon footprint per unit. If dental offices were to remain open in a future pandemic, then the resultant increase in carbon footprint would critically impact the local and global environments. Therefore, leadership and providers should be more pro-active in pursuing green dentistry goals.

This study recommends adopting the 5-R waste management principles: reduce, reuse, recycle, rethink/redesign/research, and re-educate dental professionals. Interesting areas of research that go beyond the limited scope of this study could incorporate the review of non-disposable PPE items, the categorization of aerosol-generating procedures, or/and the investigation of other crucial elements of the life cycle assessment, such as water, energy, and waste disposal.

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