

Health survey of employees regularly using 3D printers

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Background	3D printers emit potentially hazardous ultrafine particles and volatile organic compounds. Workers using 3D printing technologies may be at risk of respiratory illness from occupational exposure.
Aims	To assess whether 3D printing is associated with health effects in occupational users.
Methods	This was a preliminary survey. Workers in 17 companies using 3D printing, including commercial prototyping businesses, educational institutions and public libraries, in the Greater Toronto Area, Canada, were asked to complete survey questionnaires concerning demographic, occupational and health information. Associations between self-reported health history variables and occupational characteristics were examined by chi-square and Fisher's exact tests.
Results	Among 46 surveyed workers, 27 (59% of participants) reported having respiratory symptoms at least once per week in the past year. Working more than 40 h per week with 3D printers was significantly associated with having been given a respiratory-related diagnosis (asthma or allergic rhinitis) ($P < 0.05$). We observed a wide variation in occupational hygiene practices in the 17 printing workplaces that we surveyed.
Conclusions	Our finding of frequently reported respiratory symptoms suggests a need for additional studies on exposed workers in this field.
Key words	3D printing; asthma; respiratory; ultrafine particles; volatile organic compounds.

Introduction

The term 3D printing encompasses various technologies that share a layer-by-layer basis of product fabrication using 3D computer-aided design. Its popularity has been led by the advent of inexpensive, consumer-grade printers, most of which use fused deposition modelling, a technology that involves melting and extrusion of filaments to form the product [1]. The heating of materials at temperatures $>200^{\circ}\text{C}$ [2] could expose users to hazardous aerosols and thermal decomposition products. Recently, there have been studies examining the emission of ultrafine particles (UFPs) ($<100\text{-nm}$ diameter) and volatile organic compounds (VOCs) from 3D printer operation [2–4]. UFPs are thought to exert unique respiratory, allergic and cardiovascular toxicities [5]. There has been a case report of hypersensitivity pneumonitis associated with nylon powder used in 3D printing [6] and a case report of asthma associated with 3D printing [7], as well as two cases of contact dermatitis [8]. This study was a pilot investigation that aimed to evaluate

any links between occupational 3D printing use and detrimental health outcomes.

Methods

Workers who were directly involved in the maintenance and use of 3D printers or regularly exposed to their operation were surveyed. A questionnaire capturing demographic, occupational and health history (Supplementary data available at *Occupational Medicine* Online) was offered in person to consenting individuals at sites using 3D printing that had been identified by online searching in the Greater Toronto Area.

Data collection occurred from May to June 2016. Informed consent was obtained verbally and in writing. The study protocol was granted ethical approval by an academic hospital in Toronto and administrative approval by a public university in Canada.

Analyses were performed using IBM SPSS 22. Proportions were compared by chi-square or Fisher's exact tests to determine if occupational characteristics were associated with participants' health histories.

Results

We approached 24 locations, of which 17 (71%) consented to participate, three (13%) expressed an interest but did not follow up and four (17%) declined to participate. From the surveyed locations, 46 completed questionnaires by employees were obtained (100% of workers

present on visit days). There were approximately seven employees not present on the survey dates who did not participate. All participants had reported exposures to 3D printers in their work.

Of the 46 workers, 80% were male with a median age of 26 years (interquartile range 24–30 years). Demographic and occupational characteristics of study participants are

Table 1. Demographic and occupational characteristics of study participants

	<i>n</i> (%) or median (IQR)
Demographic characteristics (<i>n</i> = 46)	
Gender	
Male	37 (80)
Female	9 (20)
Age	26 (24–30)
Educational background	
Elementary school	1 (2)
High school	6 (13)
College/trades degree	4 (9)
Bachelor's degree	27 (59)
Graduate/professional degree	8 (17)
Smoking	
Current smoker	6 (13)
Quit more than 1 year	5 (11)
Never smoked	35 (76)
Occupational characteristics (<i>n</i> = 46)	
Worksite category	
Commercial prototyping service	36 (78)
Educational institution	7 (15)
Public library	3 (7)
Years in current position in 3D printing company (<i>n</i> = 45) ^a	
<1	19 (41)
1 to < 3	17 (37)
3–5	2 (4)
>5	7 (15)
Hours worked per week with 3D printers	
<20	19 (41)
20–40	18 (39)
>40	9 (20)
Tasks responsible for in workplace	
Loading/pouring raw powder materials in printers	17 (37)
Direct handling of precursor materials with bare hands	25 (54)
Cleaning/maintaining ventilation equipment	12 (26)
Cleaning/maintaining floors and surfaces in studio	30 (65)
Applying glazes/coats/paints to finished prints	16 (35)
Cleaning/maintenance of printers	34 (74)
Creating 3D prints	37 (80)
Drafting and design of prints	28 (61)
Sanding/smoothing finished parts	27 (59)
Disposal of raw materials/paints/glaze	27 (59)
Other (including paperwork, handling of printing materials, client consultation, gluing, soldering)	12 (26)
Personal protective equipment used	
Respirator or mask	16 (35)
Eye protection	15 (33)
Gloves or skin protection	17 (37)
Other	11 (24)
None	24 (52)

IQR, interquartile range.

^aOne missing value.

shown in Table 1. Current cigarette smokers comprised 13% of the surveyed participants, and 24% of participants were previous smokers. Most surveyed workers (78%) were employed at commercial prototyping businesses. In total, seven commercial prototyping businesses, seven educational institutions (universities and colleges) and three public libraries were surveyed. Polylactic acid (PLA) (45%), acrylonitrile butadiene styrene (ABS) (19%) and nylon (16%) were the most commonly used printing materials reported by employees with knowledge of these materials. Fifty-two per cent of participants reported not using any form of personal protective equipment (PPE).

Table 2 shows recent symptoms and previous diagnoses. Respiratory symptoms were the most common among participants (59%): symptoms of nasal congestion (26%); rhinorrhoea (20%); cough (20%); and itchiness of the nose, throat or eyes (20%) were the most often reported. Twenty per cent reported cutaneous symptoms, particularly dry skin or pruritus of the hands. Some participants reported alleviation of their symptoms while away from work, but no significant trends were observed. Asthma was the most frequent previous diagnosis, reported by 10 (22%) participants. When symptoms or diagnoses were assessed in relation to hours worked per week, having a previous respiratory diagnosis, including asthma or allergic rhinitis, was significantly associated with working >40 h per week with 3D printers compared with working 40 h or less per week (56 versus 16% $P < 0.05$). There was no evidence of an association between use of any specific materials, polymers or printing technologies with respondents' health histories.

We observed marked differences in the 17 occupational printing sites we visited, especially for commercial prototyping businesses. Some operated as professional, large-scale manufacturers with workplace safety protocols, such as using enclosed, ventilated printing environments and PPE. In contrast, there were prototyping services using basic printing equipment fulfilling orders for small businesses and hobbyists. Often, prototyping services incorporated other methods of manufacturing; we encountered workers whose duties included welding, soldering, laser cutting and sanding.

Discussion

Our pilot study found that respiratory symptoms were often reported by workers using 3D printing. Fifty-nine per cent reported respiratory symptoms, 20% cutaneous symptoms and 17% headaches occurring more than once per week in the past year. We noted that individuals working for >40 h per week with 3D printing were more likely to report a previous respiratory-related diagnosis including asthma or allergic rhinitis.

Table 2. Symptoms and past diagnoses of study participants

	<i>n</i> (%)
Symptoms experienced more than once per week in the past year	
Any symptoms	30 (65)
Respiratory symptoms	27 (59) ^a
Upper respiratory symptoms	17 (37)
Rhinorrhoea	9 (20)
Itchy nose/throat/eyes	9 (20)
Nasal congestion	12 (26)
Sneezing	1 (2)
Lower respiratory symptoms	14 (30)
Shortness of breath	7 (15)
Cough	9 (20)
Wheeze	3 (7)
Chest tightness	4 (9)
Headaches	8 (17)
Cutaneous	9 (20)
Dry/cracked skin on hands	9 (20)
Blistered, itchy, red, bleeding and/or swollen skin on hands	3 (7)
Previous physician diagnoses	
Any respiratory or cutaneous diagnosis	14 (30)
Respiratory	11 (24) ^b
Asthma	10 (22)
Allergic rhinitis	1 (2)
Cutaneous	3 (7)
Hives/urticaria	1 (2)
Allergic contact dermatitis	1 (2)
Irritant contact dermatitis	1 (2)
Atopic dermatitis/eczema	1 (2)

^aWe specifically excluded symptoms for one case of apparent respiratory infection and one case of seasonal allergies.

^bThe proportion of workers reporting a respiratory diagnosis was increased in those working >40 h per week compared with those working <40 h per week ($P < 0.05$).

Little has been published about respiratory disease associated with 3D printing. However, there have recently been case reports of a worker who developed asthma while using ABS filaments with 3D printing [7] and of a worker who developed hypersensitivity pneumonitis while exposed to 3D printing using nylon filaments [6]. 3D printing is associated with emission of VOCs, including styrene [2], a possible respiratory sensitizer and carcinogen, from ABS; methyl methacrylate [3], a respiratory and dermal sensitizer and respiratory irritant, from PLA; and caprolactam [2,4], a potential inducer of contact dermatitis, from nylon [9].

We noted marked differences in the exposure environments and control measures in various 3D printing environments. Short *et al.* have published a guide reviewing chemical hazards and environmental concerns in rapid prototyping environments and current occupational safety guidelines [10]. From our assessment of 3D printing workplaces, there are no standardized safety guidelines that are widely implemented in this setting.

Weaknesses of our study include a small sample size and cross-sectional design. Additionally, our study lacked a non-exposed control group, and we developed our own (non-validated) questionnaire to assess health effects in this work sector. Larger prospective studies would be helpful in the future.

We observed that some 3D printing workers reported respiratory symptoms, but there has been little published evidence supporting a causal association. While our survey is the first examining potential health effects associated with 3D printing exposure, further studies in this nascent field are needed.

Key points

- 3D printing generates ultrafine particles and volatile organic compounds that may have adverse effects on workers.
- In this study, 3D printing users reported respiratory symptoms including upper and lower respiratory tract symptoms.
- Working >40 h per week with 3D printers was significantly associated with a previous respiratory-related diagnosis, including asthma or allergic rhinitis.

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Conflicts of interest

None declared.

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3D Printing Study – Questionnaire

ID Number: _____

Date Completed: _____

Worksite Number: _____

Demographic Information

Please indicate your age: _____

Please indicate your gender:

☐ Male ☐ Female ☐ Other _____ ☐ Prefer Not To Say

What best describes your educational background (check one):

- | | |
|---|--|
| ☐ Completed elementary school | ☐ Completed high school |
| ☐ Completed college/trades degree | ☐ Completed bachelor's degree |
| ☐ Completed graduate/professional degree | |

Work and Exposure History

Please state your job title (if you are a student or casual user and not an employee please indicate this):

If you are an employee please indicate how many years have you worked in your current position at this company (check one):

☐ <1 year ☐ 1-3 years ☐ 3-5 years ☐ >5 years

Please indicate how many years have you used or worked directly with 3D printers (check one):

- ☐ <1 year ☐ 1-3 years ☐ 3-5 years ☐ >5 years

How many hours do you work per week with 3D printers typically (check one):

- ☐ <20 hours ☐ 20-40 hours ☐ >40 hours

Check any of the following tasks you are responsible for (check all that apply to you):

- | | |
|---|---|
| ☐ Loading/pouring raw powder materials in printers | ☐ Cleaning/maintenance of printers |
| ☐ Direct handling of precursor materials with bare hands | ☐ Creating 3D prints |
| ☐ Cleaning/maintenance of ventilation equipment | ☐ Drafting and design of prints |
| ☐ Cleaning/maintaining floors and surfaces in studio | ☐ Sanding/smoothing finished parts |
| ☐ Applying glazes/coats/paints to finished prints | ☐ Disposal of raw materials/paints/glaze |
| ☐ Other tasks – please specify: _____ | |

Of the above tasks, please list the top 3 that you participate in and hours spent per day at each:

#1 task: _____	Hours spent: _____
#2 task: _____	Hours spent: _____
#3 task: _____	Hours spent: _____

Check any of the following materials that you work with directly (i.e. handled by you specifically):

- ☐ Glues ☐ Paints ☐ Printing polymers ☐ Solvents ☐ Dyes ☐ Others (specify) _____

Check any of the following types of protective equipment that you use when working with 3D printers:

- ☐ Respirator or mask ☐ Eye protection ☐ Gloves or skin protection ☐ Other (specify): _____ ☐ I do not use any of this equipment

Symptom/health history

Have you experienced any acute illnesses or injuries that occurred in your current workplace (for students/casual users, injuries/illnesses when working with 3D printers)?

- ☐ Yes ☐ No ☐ Unsure

If yes, please describe:

Check any of the following symptoms that you have experienced more than once/week in the past year:

- | | |
|---|--|
| ☐ Shortness of breath | ☐ Runny nose |
| ☐ Cough | ☐ Itchy nose/throat/eyes |
| ☐ Wheeze | ☐ Nasal congestion |
| ☐ Chest tightness | ☐ Chest pain at rest |
| ☐ Chest pain when active | ☐ Headaches |
| ☐ Dry/cracked skin on hands | ☐ Dry/cracked skin on face |
| ☐ Blistered, itchy, red, bleeding and/or swollen skin on hands | ☐ Blistered, itchy, red, bleeding and/or swollen skin on face |
| ☐ Foul smells | ☐ Foul tastes |
| ☐ Other tasks – please specify: _____ | |

If you have any of the above symptoms, please state how many days per week each of these symptoms have occurred:

Symptom	Days per week

(For employees) For each of the above symptoms, please indicate whether these have changed when away from work on weekends or on vacation, and if so how:

Symptom	How this changes away from work

Check any of the following diagnoses that a physician has given you in the past:

- | | | | |
|--|---|--|--|
| ☐ Asthma | ☐ Chronic Bronchitis | ☐ Allergic Contact Dermatitis | ☐ Heart Disease |
| ☐ Angioedema | ☐ Emphysema | ☐ Irritant Contact Dermatitis | ☐ Hypertension |
| ☐ Hives/
Urticaria | ☐ Allergic Rhinitis | ☐ Atopic Dermatitis/Eczema | ☐ Other Lung Disease: _____ |

For any of the above diagnoses, please list any medications or treatments you have tried or are currently taking to improve symptoms or prevent disease:

For any of the above diagnoses, please indicate which if any started AFTER you began working with/using 3-D printing:

For any of the above diagnoses, please indicate which if any worsen AFTER you are working with/using 3-D printing (if this happens, how soon does it happen?):

Please check any of the following diagnoses that someone in your immediate family has (e.g. brothers, sisters, parents):

- | | | | |
|--|---|--|---|
| ☐ Asthma | ☐ Chronic Bronchitis | ☐ Allergic Contact Dermatitis | ☐ Heart Disease |
| ☐ Angioedema | ☐ Emphysema | ☐ Irritant Contact Dermatitis | ☐ Hypertension |
| ☐ Hives/
Urticaria | ☐ Allergic Rhinitis | ☐ Atopic Dermatitis/Eczema | ☐ Other Lung Disease |

Please indicate if you a cigarette smoker:

- | | |
|--|--|
| ☐ Yes, I smoke current | ☐ No, I quit more than one year ago |
| ☐ No, I quit in the past year | ☐ I never smoked |

If you are a current smoker, or quit in the past year, please indicate the highest number of cigarettes you've smoked per day:
