Innovation in respiratory therapy and the use of three-dimensional printing for tracheostomy management

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Respiratory therapy (RT) is a profession with a long history of clinical applications of advanced and emerging technologies (1,2). A cursory review of the previous two iterations of the national competency profile for Canadian respiratory therapists provides insight into the rapid evolution of our professional practice (3,4). Many changes in practice patterns were influenced, at least in part, by technological advances. It is not, therefore, unexpected that the rapid evolution of technologies currently being witnessed, both clinical and nonclinical, will invariably have an impact on RT practice. It is by adopting emerging technologies that the profession of RT will advance in innovative ways.

Early literature in organizational change observed that variability in hospital adoption of innovation could be accounted for, at least in part, by a variability in the development of structural mechanisms that provide access to knowledge about change (5). Fortunately, organizational structures that support sharing of knowledge about change, including this *Journal* and professional conferences, exist in RT. It is by developing a rich culture of using these venues for knowledge sharing that the innovative capital existing in RT can be fostered.

We may typically believe that innovation occurs as a result of an 'a-ha' moment. However, the knowledge-building literature suggests that the majority of new ideas adopted into practice result from collaborative processes that develop organically over a period of time (6,7). Taking a page from educational design researchers, it has been theorized that professional innovation can be spurred by "creating environments where ideas can connect" (8). The following example illustrates how a collaborative approach, along with an environment supportive of knowledge sharing, became useful in addressing a problem in RT practice through adopting three-dimensional (3D) printing technology.

ADOPTING 3D PRINTING TECHNOLOGY

Additive manufacturing, more commonly known as '3D printing,' has been used in the clinical sciences for planning complex surgeries and designing custom implants. The introduction of low-cost consumer-grade 3D printers enables this technology to be used for more routine procedures, although its application in RT has not been widely published. These 3D printers deposit 0.1 mm- to 0.3 mm-thick layers of hot acrylonitrile butadiene styrene or polylactic acid plastic. The resulting model (3D printout) is slowly built up layer by layer. An important feature of 3D printers is that they can produce complex objects. In addition, there are several software packages that import medical magnetic resonance or computed tomography (CT) images and enable the creation of models suitable for printing.

The use of medical imaging and 3D printing had previously been used for radiation therapy applications at CancerCare Manitoba. Additionally, the institution's medical devices department regularly modifies tracheostomy tubes and, thus, has developed a strong collaborative relationship with the respiratory therapists of the Long Term Ventilator Service (LTVS), Winnipeg Regional Health Authority (Manitoba). It was natural then that this unique collaboration may lead to an innovative approach to client care by applying 3D printing technology to RT practice.

A COLLABORATIVE APPROACH TO INNOVATIVE TRACHEOSTOMY MANAGEMENT

The LTVS provides RT services to long-term clients in the community who require support for medically complex needs. These needs frequently include tracheostomy airway management in clients who may or may not also require mechanical ventilation. There are several well-known long-term effects of tracheostomy, including dysphagia, inability to phonate, tracheal granuloma and tracheomalacia (9,10). Respiratory therapists at the LTVS use various methods of customizing tracheostomy tubes to mitigate anatomical or other therapeutic challenges, or to manage complications resulting from long-term use of the airway itself. Routine diagnostic techniques, such as bronchoscopy, broncheolar lavage, radiography and CT, have been used to diagnose and monitor these long-term effects.

Although a cornerstone of management, these diagnostic techniques have occasionally proven insufficient for identifying the etiology of symptoms related to long-term tracheostomy use that have appeared clinically. This has limited the ability of the respiratory therapists to determine appropriate clinical interventions such as tracheostomy type, position and need for customization. For example, occasionally complicated tracheal anatomy may make airway visualization highly challenging and, thus, limit the ability to determine a differential diagnosis in the presence of multiple long-term complications.

One approach that has been used to give a detailed and informative understanding of the etiology of client symptoms has been the use of 3D printing technology to reproduce the results of high-resolution CT scanning. The genesis of the idea to use 3D printing technology in cases such as these came as a result of collaborative review and a shared desire to design a solution for these clinical concerns. The existing relationship between the respiratory therapists of the LTVS and personnel in the Medical Devices Department at CancerCare Manitoba served as an important environmental factor, which facilitated the connection of ideas. Encouraging professionals to connect ideas and expertise with those of colleagues and others in this manner brought individuals together and supported a sense of collective cognitive responsibility (11). Through sharing in the responsibility for knowledge creation, both the individual goals of the respiratory therapist and the patient, as well as the collective goals of the organization were achieved in an innovative way. As a result, 3D printing was used as a means of assessing airway abnormalities and symptomology not explained by traditional diagnostic and assessment techniques.

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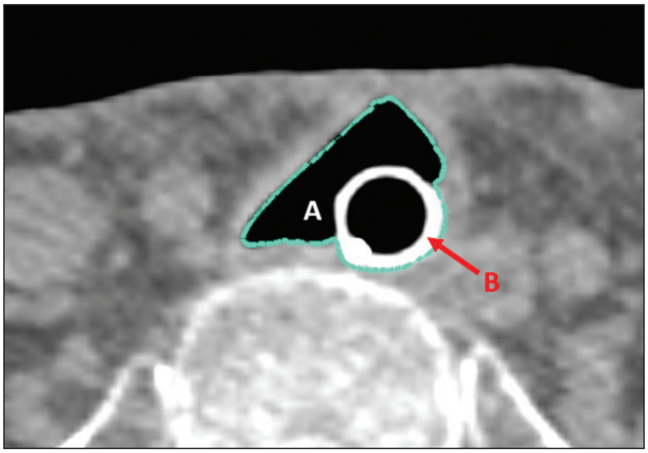

Figure 1) *Image acquired using high-resolution computed tomography showing a tracheal cross-section. Visible are the tracheal lumen (***A***) and tracheostomy tube (***B***) in situ. The contour (in cyan) was used to create a stereolithography (stl) file*

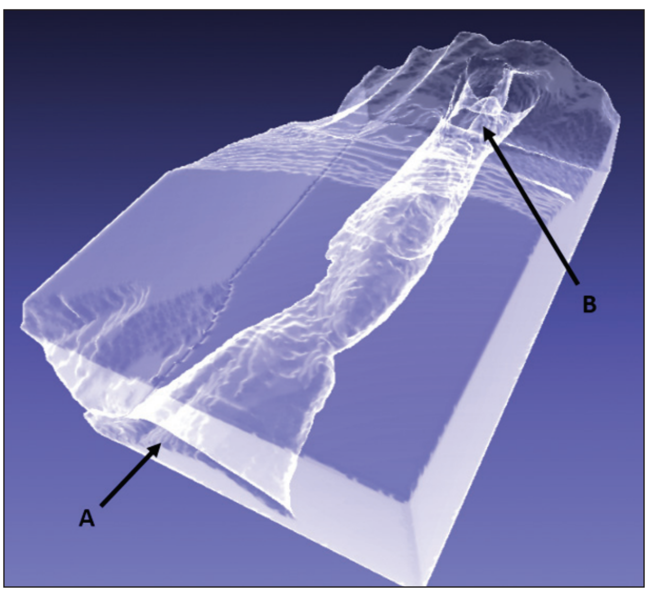

Figure 2) *Computer rendering of a stereolithography (stl) file developed from a high-resolution computed tomography scan, from which a positive model of the airway could be created using a three-dimensional printer.* **A** *Tracheal lumen.* **B** *Tracheal lumen and stoma*

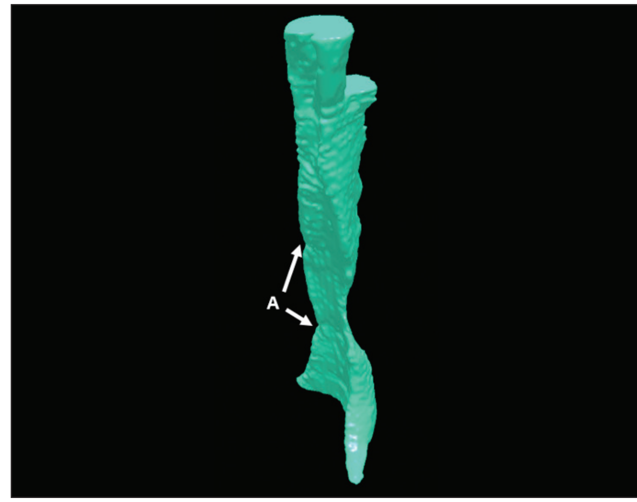

Figure 3) *Computer rendering of a stereolithography (stl) file developed from high-resolution computed tomography scan, from which a negative model of the tracheal lumen could be created using a three-dimensional printer.* **A** *Extensive anatomical abnormality*

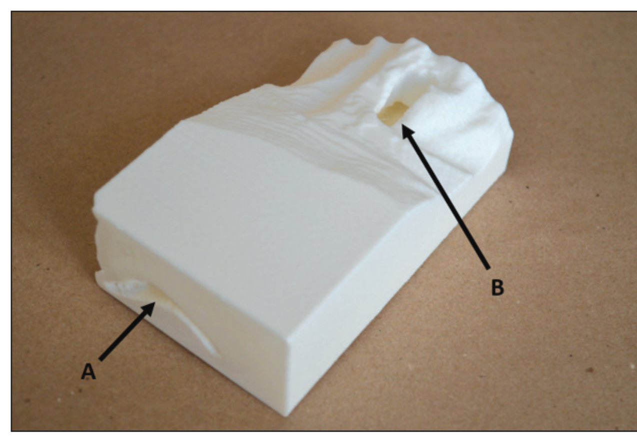

Figure 4) *Photograph of three-dimensional printed positive model of the airway. This model corresponds to the stereolithography data shown in Figure 2. The model is approximately 11.5 cm × 3.8 cm × 7 cm.* **A** *Tracheal lumen.* **B** *Tracheal lumen and stoma*

INNOVATION DESIGN CHALLENGES

In this example, a client underwent a high-resolution CT scan. The resulting images were then imported into 3D modelling software (3D Doctor V5, Able Software Corp, USA) in which the trachea was outlined. Although parts of this task were automated, several hours of manual work by the medical devices personnel was necessary. A significant challenge is that because a trachea tube was in place during the CT scan, it was subsequently necessary to remove it from each image manually (Figure 1). The resulting outline of the trachea was then exported as a stereolithography (stl) file from which tracheal models were printed using a consumer-grade fused-deposition printer (Solidoodle 3, Solidoodle LLC, USA and MakerGear M2, MakerGear LLC, USA) (Figures 2 and 3). Printing the tracheal models was relatively straightforward as either a positive that was a copy of the patient anatomy, or as a negative that revealed the lumen of the trachea.

The 3D printed model of the tracheal lumen simplified observation of its complex shape. Furthermore, the ability to physically fit the tracheostomy tube into the positive model enabled the team to better determine the most appropriate airway specification relative to the anatomical limitations and other complications. Figures 4, 5 and 6 demonstrate three different models of the trachea that were printed using the 3D printer. These models provided a profound visual aid in understanding the unexpectedly extensive anatomical abnormality of this symptomatic client. An additional strength of 3D printing is that the models may be sliced in any plane before printing, and producing additional copies is simple.

Although 3D printing technology holds much potential for use in RT and in tracheostomy management, one notable limitation of this approach is the lengthy process of outlining the trachea on the CT images. Although this step is partially automated, the presence of the trachea tube in the images complicates the process considerably.

CONCLUSION

The use of 3D printing technology to enhance clinical evaluation of clients with long-term tracheostomy provides an example of how innovative ideas lead to practical solutions using new technologies. The adoption of 3D printing in RT practice has not previously been reported in the literature. As is the case in many innovation-generating organizations, the roots of a new practice concept rest in sharing and synthesizing multiple perspectives, problem solving and collective

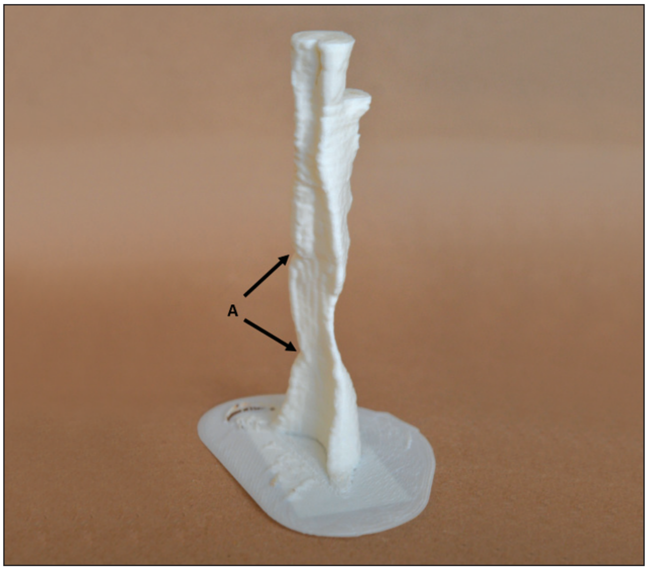

Figure 5) *Photograph of three-dimensional printed negative model of the tracheal lumen corresponding to the stereolithography data shown in Figure 3.* **A** *Extensive anatomical abnormality*

knowledge construction (12). Through dissemination of this idea, it is hoped that others will be prompted to share in further exploration and development of this particular idea, thus fostering new insights.

An interesting array of issues worthy of further inquiry have emerged from this innovation. To evaluate the possible scope of applicability of 3D printing in tracheostomy management, it would be valuable to quantify the prevalence and morphology of tracheal abnormalities in clients with long-term tracheostomy. Additionally, it would also be of great interest to determine whether routine assessment using 3D printing technology could impact client outcomes. Finally, we need to consider its application as a tool for professional and client education.

Beyond spurring interest and inquiry in this new assessment technique, it is also hoped that this discussion will promote wider awareness and use of the structural mechanisms available to respiratory therapists for sharing knowledge. Supporting an environment of information exchange and community knowledge generation will lead to enhancements in the support we provide to those with respiratory challenges.

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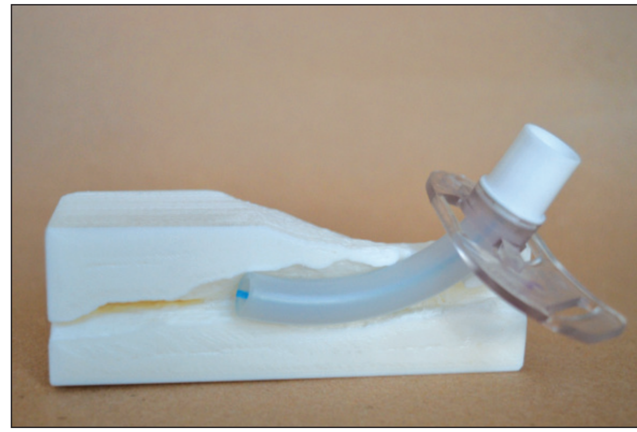

Figure 6) *Photograph of three-dimensional printed positive model sliced along the medial plane to enable visualization of the cross-section of the trachea, with a tracheostomy tube modified to fit anatomical abnormalities in situ*

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