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ORIGINAL RESEARCH–GENERAL OTOLARYNGOLOGY

A simple method to predict pretracheal tissue thickness to prevent accidental decannulation in the obese

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ABSTRACT

OBJECTIVE: Accidental decannulation is the most common and serious complication associated with tracheostomy in obese patients. We lack a simple way to choose appropriate-size tracheostomy tubes in this patient subset. Our purpose was to 1) establish the range of trachea-to-skin soft tissue thickness (TTSSTT) in obese patients and 2) determine which easily obtained anthropometric measurements are most predictive of TTSSTT.

STUDY DESIGN: Case series with planned data collection.

SETTING: Tertiary care center.

SUBJECTS AND METHODS: Forty consenting patients with body mass index ranging from 30 to 70 were evaluated. These patients, from a bariatric clinic, underwent ultrasound (US) of the neck in predetermined sitting, supine, and neck-extended positions (as for tracheostomy). US was performed by a qualified radiologist. Standard anthropometric measurements of weight, height, arm, hip, waist, and neck sizes were performed. Multiple regression analysis was used to determine which anthropometric measurements best correlated with TTSSTT.

RESULTS: The TTSSTT, as measured by US in the supine position, ranged from 0.65 to 3.53 cm. Although the anthropometric measurement most predictive of TTSSTT was waist circumference, a combination of the more practical arm and neck circumferences resulted in an equivalent correlation ($r = 0.82$). The average root mean squared error was 0.4 cm. From the fitted regression equation, a table predicting TTSSTT from neck and arm circumference was prepared.

CONCLUSION: TTSSTT can be closely predicted using simple anthropometric tape measures. The predicted TTSSTT can be used to select appropriate tracheostomy tube size in obese patients. Use of this simple tool is expected to significantly reduce the incidence of accidental decannulation in obese patients.

In Canada and North America there is an increasing trend toward obesity in both children and adults.[1-5] Obesity is defined by the World Health Organization as a body mass index (BMI) > 30 as measured in kilograms/meters squared.[5] Morbid obesity is variably defined as a BMI > 40. Surgery in obese patients compared to nonobese patients is technically more difficult and associated with higher complication rates.

In particular, obese patients requiring tracheostomy are at an increased risk of complications[6-10] primarily related to potentially fatal airway events such as accidental decannulation and tracheostomy tube displacement. The most likely cause of these airway events is the increased pretracheal soft tissue thickness (PTSTT), which effectively reduces the intratracheal length of the tracheostomy tube. Agitation, straining, and coughing may all result in decannulation or displacement of the tube into the pretracheal soft tissues. Reinsertion of the tube may be difficult because of the thick pretracheal tissues, resulting in creation of a false passage.

Although commercially available extended-length tracheostomy tubes do exist, they vary in length, size, material, and presence/absence of a cuff or inner cannula. Currently, the sizing and length of these tubes are not standardized and are not based on any scientific data. It is often impractical for hospitals to carry all possible tracheostomy tube sizes "in case" they are needed because of such factors as cost, expiration dates, and availability. Consequently, these special tubes are almost never available at the time of the procedure and must be obtained through a special order. As a result, either a "standard"-length tracheostomy tube (too short) or endotracheal tube (too long), both suboptimal choices, must be used at the time of surgery.

Alternatively, if we could estimate preoperatively with adequate precision the PTSTT of a patient from his or her BMI and other anthropometric values, a small quantity of appropriately sized preselected tracheostomy tubes could be made available for insertion at the time of surgery; this would be expected to translate into a safer choice for the patient, with a reduced likelihood of accidental decannulation or tube misplacement.

Materials and Methods

With the permission of the Royal Victoria Hospital Research Ethics Board (Research Ethics Board McGill Uni-

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versity Health Care Center, Royal Victoria Hospital) and after obtaining written informed consent, 40 consecutive, eligible, and consenting patients from a bariatric clinic were actively enrolled in the study between July 1, 2008, and April 30, 2009.

Patients aged ≥ 18 years and having a BMI ≥ 30 were included in the study. Exclusion criteria included: preexisting laryngotracheal pathology, previous neck surgery, massive goiter, and abdominal or hip surgery. Routine otorhinolaryngologic physical examination and history were performed. Each eligible patient underwent ultrasound of the neck in predetermined sitting, supine, and neck-extended positions (as for tracheostomy) as well as anthropometric measurements.

Ultrasonography

Ultrasound (US), performed by a qualified radiologist, involved ultrasonography of the cricoid, subcricoid areas, and the second tracheal ring, in predetermined sitting, supine, and neck-extended positions. The patient was first placed in the supine position and a foam wedge pillow (as a shoulder roll) was used to place the head into extension (as for tracheostomy). After completion of US measurements in this position, the wedge was removed and the patient was repositioned into the neutral supine position. Following this measurement, the back of the bed was raised to a 90-degree position and US of the patient in the sitting position was performed. To avoid respiratory-induced changes in upper airway dimensions, subjects were instructed to take a slow inspiration at constant flow during the measurement period.

US measurements were performed using ATL Phillips HDI 5000 Ultrasound (Riverside, CA) with a linear probe (broadband linear array transducer 50-mm length, frequencies 5-12 MHz) placed on the midline of the anterior neck. Probe measurements were then performed in the sagittal plane. The locations of the true vocal folds were initially identified, and the probe was then moved caudally to visualize the cricoid. Once the cricoid was identified, the distance between the second tracheal ring located below the cricoid and the skin was measured.

Anthropometry

In total, six anthropometric items were measured: BMI, weight, neck circumference (NC), waist circumference (WC), arm circumference (AC), and hip circumference (HC). All measurements were performed by a single individual using standard techniques.[5]

The weight of the patient was measured by a digital bariatric scale (Scale-Tronix Bariatric Scale 5107, Scale-Tronix, White Plains, NY) to within 0.5 kg without heavy clothing, and height was measured barefoot by portable stadiometer (Scale-Tronix Height Gauge, Scale-Tronix) to within 1 cm.

The waist measurement was obtained using a bariatric tape measure (Myotape, Forest Hill, NY) at the end of a gentle expiration midway between the lowest rib and iliac crest with the patient standing. The HC was measured at the greater trochanter. Mid-arm thickness was measured at the midpoint of the biceps. Additionally, the measurement tape was also calibrated weekly to within 1 mm.

NC was measured with a measurement tape both in sitting and supine positions and with head in extension at the midway of the neck between the angle of the mandible to the jugular notch. In men with prominent thyroid notch, it was measured just below the prominence.

Data Management and Statistical Analysis

Patient data were entered into a spreadsheet and statistical analysis was carried out using the JMP v7.0.2 statistical package (JMP, Cary, NC).

BMI was calculated from the weight and height measurement and expressed in kg/m^2. Waist-to-hip ratio (WHR) was additionally calculated. For each US and anthropometric measure, we used the average of the three recorded measurements.

The data for 40 patients were summarized using arithmetic means with their associated standard deviations. Our primary analysis focused on neck PTSTT measured by US in the supine position as patients posttracheostomy will ultimately assume this natural position most of the time. Our choice of predictor variables was guided not only by statistical significance, but also by considerations of which variables were most easily obtainable and available at the time of performance of an urgent tracheostomy. To investigate the relationship between anthropometric measures and US of the neck in the supine position, we first examined the pairwise correlations using a scatterplot matrix. We then chose as our first anthropometric variable the one that was most significant in a simple linear regression, and used multiple regression to determine which additional anthropometric measurements significantly added to the prediction equation. Statistical significance was defined as a P value of 5 percent or lower. The performance of the prediction equation was measured by the root mean squared error (RMSE) and the multiple r squared.

A cross-validation (leave one out) approach was used to assess how the prediction equation would work in independent patients. Finally, we then used the best-fitting prediction equation to create a table of predicted values.

Results

Table 1 shows the anthropometric and demographic characteristics of the 40 patients. A majority of the subjects were female (~68%) and on average, the subjects tended to be middle-aged. All but two were Caucasian. Most patients displayed a large BMI and tended to be in the range of obese to morbidly obese (BMI ≥ 30 kg/m^2). WHR on average was 1.03 (SD: 0.09) for males and 0.92 (SD: 0.07) for females in our population (not shown in table).

The US measurements of PTSTT tended to be greater in the sitting position (2.29 cm; SD: 0.70 cm), followed by

Table 1
Anthropometric and demographic characteristics of patient population

Category	Mean	SD
Demographics		
Male: 13	N/A	N/A
Female: 27	N/A	N/A
Caucasian: 38	N/A	N/A
African American: 2	N/A	N/A
Age (yrs)	42	12
Ultrasound neck measures (cm)		
Extension	1.79	0.62
Supine	2.07	0.68
Sitting	2.29	0.70
Anthropometric measures		
Weight (kg)	136	42
Height (cm)	168	9
BMI (kg/m^2)	48	13
Neck circumference (cm)		
Neck extended	45.5	6.5
Neck supine	44	6.2
Neck sitting	42.6	4.8
Hip (cm)	139	25
Waist (cm)	134	26
Arm thickness (cm)	42.8	7.7
Ratio		
Waist/hip ratio	0.96	0.1

Data are arithmetic means ± SD.

supine (2.07 cm; SD: 0.68 cm) and extended (1.79 cm; SD: 0.62 cm) groups. The opposite was found in the anthropometric measurements of neck circumferences. NC measures tended to be greater in the extended position (45.5 cm; SD: 6.5 cm), followed by supine (44.0 cm; SD: 6.2 cm) and sitting (42.6 cm; SD: 4.8 cm) positions.

As depicted in Table 2, incremental increases in the ranges of ultrasound measurements from extended (0.56-3.03 cm) to supine (0.65-3.53 cm) and to sitting (0.70-3.89 cm) positions were observed.

Table 3 shows the Pearson univariate correlation coefficients between the anthropometric measurements and the US neck thickness measurements in supine position with the corresponding scatterplot matrix (Fig 1) for this US neck position and the various anthropometric measurements. All anthropometric measurements were significantly and positively correlated ($P < 0.001$) with the US neck of trachea-to-skin soft tissue thickness (TTSSTT). The strongest correlation was seen with WC (Table 3). Equivalent strengths of correlation were also seen with weight ($r = 0.76$), BMI ($r = 0.76$), and NC ($r = 0.76$), followed by HC ($r = 0.69$) and AC ($r = 0.66$). WHR ($r = 46$) showed the weakest correlation among the anthropometric measures in Table 3.

Thus, a simple regression analysis showed that WC produced a strong single-item prediction equation for the estimation of trachea-to-skin thickness of the neck in supine position ($r = 0.86$; $P < 0.0001$; RMSE = 0.3). A table of predicted neck thickness as a function of WC was subsequently created (Table 4).

Our primary analysis focused on whether anthropometric measurements correlated with US of the neck in the supine position as most patients posttracheostomy will likely spend much of their time in this natural position. Additionally, in order to accommodate situations where WC measurements were not feasible or practical, the combined use of arm and supine NC was utilized as in combination; they produced equivalent correlation.

The anthropometric measurement most predictive of TTSSTT was WC ($r = 0.86$; RMSE = 0.3; $P < 0.0001$). However, multiple regression analysis revealed that the combination of the more practical arm and NC in supine position resulted in an almost equivalent correlation (multiple $r = 0.82$; RMSE = 0.4; $P < 0.004$). On average, in the supine patient, it took less than one minute to accomplish a single measurement of combined arm and neck circumferences. We also derived 40 predictions, each one based on 39 patients, and measured how far each was from the one left out. The average amount the prediction was "off" was 0.46 cm, slightly larger than we obtained by testing the prediction equation on the exact same subjects it was derived from. An additional table of predicted neck thickness as a function of NC in supine position and AC was also created (Table 5).

Discussion

Surgery in morbidly obese patients, irrespective of the procedure, is technically more difficult, and is associated with higher complication rates. Currently, 18 percent of intensive care unit patients requiring tracheostomy are morbidly obese.[6] Tracheostomy in obese patients is also associated with an increased risk of complications.[6-10] Specifically, the risk of potentially fatal airway events such as obstruction, accidental decannulation, or tracheostomy tube displacement is significantly greater.[6-8] This is likely attributable to the increased thickness (depth) of the pretracheal tissues, and the relatively "short" length of most tracheostomy tubes.

For reasons related to practicality and cost, most hospitals keep a number of variably sized standard-length tracheostomy tubes. Although extended-length tracheostomy tubes are available, the large number of variables and characteristics (length, material, presence/absence of inner cannula, presence/absence of cuff) are such that keeping a

Table 2
Ranges for ultrasound neck measurements

Category	Range (cm)
Extended	0.56-3.03
Supine	0.65-3.53
Sitting	0.70-3.89

Table 3
Correlation coefficients between ultrasound neck thickness and anthropometric measurements

	Anthropometric measures						
Ultrasound of the neck	Wt	BMI	WC	WHR	Hip	NCS	AT
Sitting	0.70	0.71	0.77	0.38	0.63	0.65	0.63
Supine	0.76	0.76	0.86	0.46	0.69	0.76	0.66
Extended	0.78	0.80	0.88	0.46	0.71	0.77	0.71

Wt, weight; *BMI*, body mass index; *WC*, waist circumference; *WHR*, waist-to-hip ratio; *NCS*, neck circumference supine; *AT*, arm thickness.

sufficient variety to fit each individual patient is impractical, costly, and wasteful. Consequently, when an obese patient requires a tracheostomy, either a standard tube (too short) or endotracheal tube (too long) must be used. Subsequently an accurate means of determining TTSSTT would allow hospitals to keep a small inventory of well-selected extended-

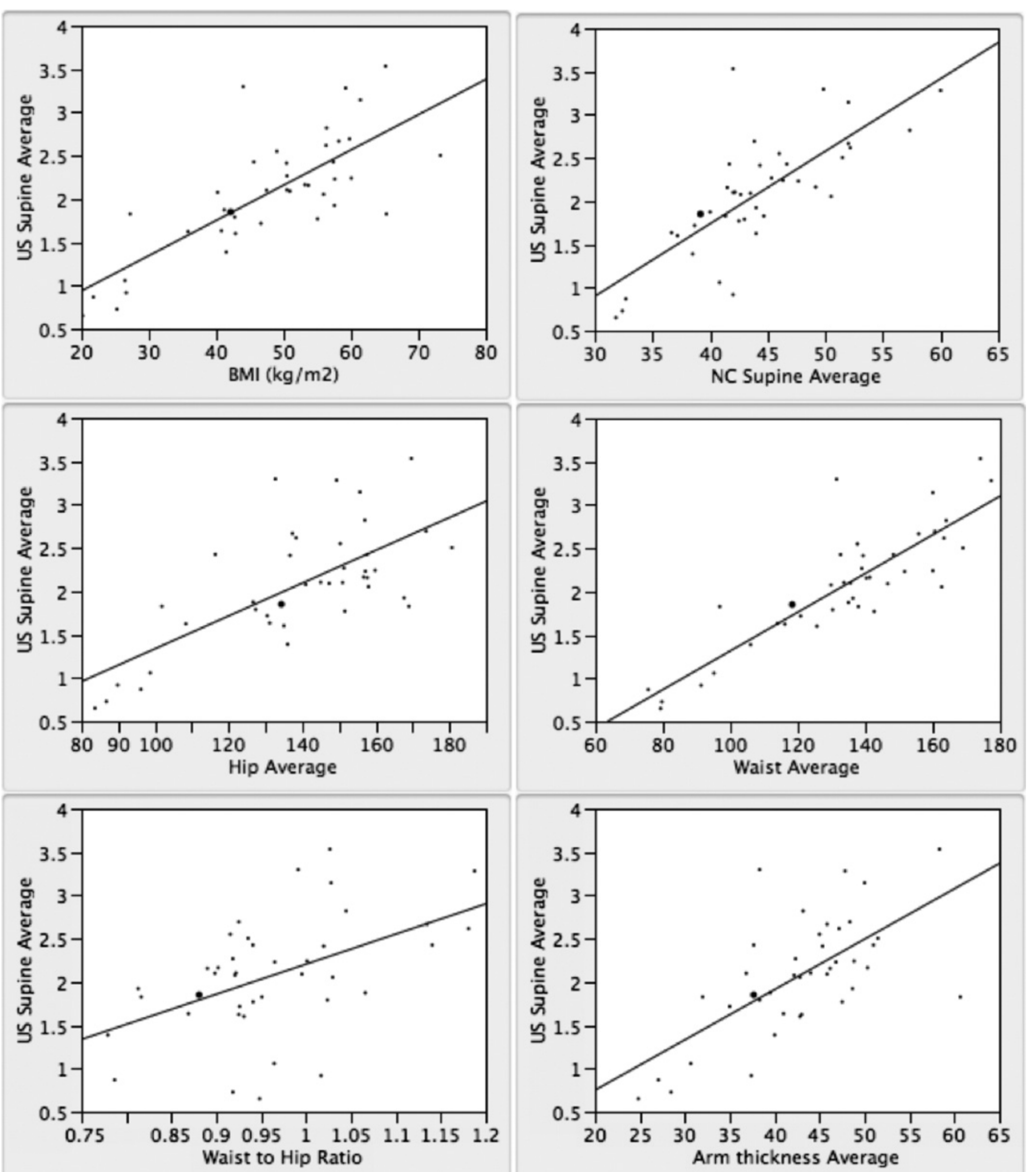

Figure 1 Scatterplot matrix based on ultrasound neck thickness measurements in supine position, indicating line of best fit and data points.

Table 4
Predicted neck thickness as a function of waist circumference

Waist circumference (cm)	60	80	100	120	140	160	180
Neck thickness (cm)	0.29	0.69	1.09	1.49	1.89	2.29	2.69

Root mean squared error (RMSE): 0.3 cm.

length tracheostomy tubes. These tubes would then be available for use at the time of surgery, thereby decreasing the risk of accidental decannulation or tracheostomy tube displacement into the pretracheal soft tissue.

In this study, PTSTT was measured by ultrasound. Ultrasonography has a long and well established safety record as a diagnostic method. It has been safely used in pregnancy as a means of establishing and following gestation[11] as well as to accurately evaluate airway structures and masses in the neck and thyroid.[12-14] This imaging modality was an ideal, noninvasive, painless, rapid, and accurate method of evaluating TTSSTT in our obese subjects. However, ultrasound is impractical for routine determination of PTSTT in every patient undergoing tracheostomy. This point is highlighted in the emergent airway situation whereby obtaining the ultrasound machine, obtaining a US technician to perform the procedure, and the time to perform the US would be difficult and time-consuming.

Similar challenges have faced clinicians in other areas who needed simple techniques to estimate, for example, body fat[10-16] or body surface area in order to determine the correct chemotherapy dose. In the latter, the investigators were able to use simply determined anthropometric measures to predict each patient's body surface area (BSA). By carefully measuring the BSA, height, and weight of a sample of patients, they developed a simple prediction equation that allowed others to estimate BSA without actually having to measure it each time.[9]

Our study also investigated the utility of anthropometry in the obese. Specifically, we examined whether standard anthropometric measures were correlated with PTSTT. This is analogous to how anthropometry has been used as a means of stratifying the general population at risk for being overweight or obese and thus being predisposed to risks such as hypertension, diabetes, coronary heart disease, and obstructive sleep apnea. Additionally, several studies have examined how standard anthropometric measures such as NC, BMI, WHR, and WC can reliably predict central obesity and obesity-associated risk factors.[15-20]

Similarly, our study utilized anthropometric measurements as a means of predicting PTSTT using simple tape measurements. PTSTT, as measured by US in the supine position, ranged from 0.65 to 3.53 cm. This study showed that although all anthropometric measurements were predictive of PTSTT, WC was most predictive of TTSSTT. However, a combination of the more practical arm and supine NC resulted in an almost equivalent correlation ($r = 0.82$) with an RMSE of 0.4 cm. From these fitted regression equations, tables predicting TTSSTT from waist as well as neck and arm circumference were produced.

From our investigation, we also realized that some commercially available extended-length tracheostomy tubes on the market may not be adequate to meet the needs of the obese patient population. Specifically, some extended-length tracheostomy tubes that are available with inner cannulas offer a maximal extended proximal length of approximately 3 cm (often only available in the largest-inner-diameter tracheostomy tube). In our sample, we have patients who have TTSSTT that are greater than 3 cm. Although there are tracheostomy tubes available that have adjustable proximal

Table 5
Predicted neck thickness (cm) as a function of waist circumference (cm) and arm circumference (cm)

	Waist circumference						
	30	35	40	45	50	55	60
Arm circumference							
20	0.5	0.8	1.1	1.4	1.7	2.1	2.4
25	0.6	0.9	1.3	1.6	1.9	2.2	2.5
30	0.8	1.1	1.4	1.7	2.0	2.4	2.7
35	0.9	1.2	1.6	1.9	2.2	2.5	2.8
40	1.1	1.4	1.7	2.0	2.3	2.7	3.0
45	1.2	1.5	1.9	2.2	2.5	2.8	3.1
50	1.4	1.7	2.0	2.3	2.6	3.0	3.3
55	1.5	1.8	2.2	2.5	2.8	3.1	3.4
60	1.7	2.0	2.3	2.6	2.9	3.3	3.6

Root mean squared error (RMSE): 0.4 cm.

and distal lengths,[21] they can have issues with flange malfunction, often do not have an inner cannula, are expensive, and are not easily obtainable. Finally, currently existing tracheostomy tubes with inner cannulas may not necessarily be appropriately sized to fit very morbidly obese patients.

One study describes defatting at the time of tracheostomy as a possible means of decreasing PTSTT in obese patients in order to fit standard-size tracheostomy tubes. The authors noted an associated increased morbidity in these procedures as they can be complicated by high rates of wound infection (i.e., abscess and cellulitis) and, less commonly, by tracheitis and tracheocutaneous fistulas.[22] Although this "last-ditch" alternative may be considered if extended-length tracheostomy tubes are not readily available, we believe that having the appropriate-size tracheostomy tube at the time of surgery would most certainly avert the morbidities of concurrent lipectomy and tracheostomy.

Our study is the first to use ultrasound to accurately measure TTSSTT in the obese with the mindset of selecting appropriate tracheostomy tube size. Some studies have accurately utilized this modality to measure trachea-to-skin distance in obese patients placed in the "sniffing position" in order to predict difficult laryngoscopies.[23,24] Similarly, we found that when carefully performed, US can be used as a noninvasive, quick, and accurate means of measuring TTSSTT in obese adults. Additionally, our study also demonstrated that simple, available, and easily obtainable anthropometric tape measurements were highly predictive of TTSSTT.

However, our study did have some limitations. A significant number of our patients were female (~68%). Body fat distribution among males and females are known to be different and although we feel that our prediction equation will still be accurate and predictive, it would be prudent to enroll further male subjects to ensure that our prediction equation and results remain constant. Additionally, the majority of our patients were Caucasian. We had two patients who were African American. Based on these numbers, we are not able to comment on whether ethnic differences exist for pretracheal thickness. However, examining TTSSTT in different ethnicities to see if differences do exist would certainly be an interesting area for future similar studies.

Although patients in our study did not undergo a tracheostomy, a previous pilot study showed that US and anthropometric predictive measurements strongly and accurately predicted TTSSTT, which were measured intraoperatively in a handful of morbidly obese patients requiring a tracheostomy. Appropriately sized tracheostomy tubes were chosen based on the anthropometric measures, and no incidents of accidental decannulation or obstruction were reported.

Some might consider that an average error of 4 mm is considerable uncertainty; however, this margin of error is balanced against the fact that it is achieved at virtually no cost, and that the prediction errors will be less than this in 68 percent (approximately two thirds) of patients.

Additionally, at present there does not appear to be a rapid and inexpensive method for predicting TTSSTT in the obese. Our rapid and useful equation allows us to predict TTSSTT with good accuracy in our patients and allows us to select an extended-length tracheostomy tube within 8 mm of the prediction equation, which takes into the account the possible 4-mm error. Thus, we strongly feel that the use of simple anthropometric tape measurements will give a much more accurate and rapid estimate of TTSSTT, especially in the emergent tracheostomy situation, where tape measures can be obtained in 30 seconds to permit rapid and appropriate selection of tracheotomy tube size.

In conclusion, our study demonstrates that TTSSTT can be closely predicted using simple anthropometric tape measures. Specifically, our study confirms the importance of WC in the standing position as a predictor of TTSSTT in the obese. However, the use of the more practical combination of arm and neck circumference in the supine position provided an equivalent correlation that can easily be performed, especially in an emergent situation. Thus, the predicted TTSSTT can be used to select appropriate tracheostomy tube size in obese patients. The use of this simple tool is expected to significantly reduce the incidence of accidental decannulation in obese patients.

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Author Contributions

Christopher Szeto, study design, analysis, conduct, and presentation; **Karen Kost,** study design, analysis, and drafting; **James A. Hanley,** study design, analysis, and drafting; **Ann Roy,** study conduct, analysis, and drafting; **Nicholas Christou,** study conduct, analysis, and drafting.

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