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# Comparison of bougie-guided cricothyrotomy and traditional cricothyrotomy techniques in an obese 3D-printed surgical airway manikin: a randomized controlled study

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## Abstract

**Background** Obesity is one of the conditions that may require invasive airway management. The effectiveness of invasive airway techniques in obesity is not fully understood, and there is no routinely recommended technique. This study aimed to compare the first attempt success rate, procedure time, and difficulty of traditional surgical cricothyrotomy and bougie-guided cricothyrotomy on a 3D-printed surgical airway manikin made obese using simple techniques.

**Methods** The study was designed as a prospective randomized controlled study. The obese simulation was created with a 3D-printed surgical airway manikin and sponge layers. Bougie-guided cricothyrotomy and traditional cricothyrotomy techniques were taught to emergency residents, and they were asked to practice the technique on the designed manikin. The duration of the procedure for both techniques, the number of attempts, the success rate, and the difficulty scores of the techniques were recorded.

**Results** A total of 24 residents were included in the study. As the first technique, 13 residents used bougie-guided cricothyrotomy. A total of 23 (95.8%) were successful with both techniques. In the traditional surgical cricothyrotomy, 7 (31.8%) residents were successful on the first attempt, while in the bougie-guided cricothyrotomy, 15 (68.2%) residents were successful on the first attempt ($p=0.020$). In residents with less than 2 years of seniority, the mean difficulty score of the bougie-guided cricothyrotomy was lower ($p=0.024$).

**Conclusions** The success rate of the bougie-guided cricothyrotomy in the first attempt was higher than that of the traditional surgical technique. There was no statistically significant difference between the overall success rates and procedure times of both methods. The level of difficulty of the bougie-guided cricothyrotomy was found to be easier, especially for residents with less than two years of seniority.

**Presentations** The manuscript has been presented 9th EurAsian Congress on Emergency Medicine (oral presentation) at the 9–12 November, 2023, Antalya, Turkey, and won the best oral abstract award at this congress.

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**Keywords** Cricothyrotomy, Airway management, Difficult airway, Obese simulation, Simulation training, Surgical airway

## Introduction

Invasive airway management involves establishing an opening into the trachea to provide oxygenation and ventilation [1]. It may be necessary to use it in cases of predicted difficult airways or emergencies [2]. During unexpected difficult airway emergencies (cannot intubate—cannot oxygenate scenario), recommended invasive methods include surgical cricothyroidotomy, surgical tracheostomy, needle cricothyroidotomy, and large bore cannula cricothyroidotomy [3]. Approximately 1% of emergency airway management requires cricothyrotomy, and improper and delayed procedures can result in death [4, 5].

The American Society of Anesthesiologists has recommended in its 2022 guidelines that invasive airway management should be performed by trained personnel as soon as possible [3]. Therefore, it is important to provide training in these infrequently performed procedures in both emergency and anesthesia departments. Due to the lack of patient-based experience, manikin and animal studies are prominent in this area.

Numerous studies in the literature have compared different cricothyrotomy techniques [6]. However, there is still no consensus on the preferred method for invasive airway management [7]. The 4th National Audit Project of Major Complications of Airway Management in the United Kingdom reported that surgical techniques were more successful than needle cannula techniques [8]. A retrospective analysis of the two most commonly performed surgical methods, bougie-guided and traditional surgical cricothyrotomy, showed no significant differences in success or complications [9].

Obesity, one of the causes of a difficult airway, is one of the leading conditions requiring invasive airway intervention. However, obesity also complicates cricothyrotomy. Anatomical landmarks are difficult to palpate, and the increased distance between the skin and the cricothyroid membrane makes tube placement difficult [10]. The effectiveness of invasive airway techniques in obesity is unknown, and there is no routinely recommended technique [10].

This study aimed to compare the first attempt success rates of traditional surgical cricothyrotomy and bougie-guided cricothyrotomy on a three-dimensional (3D) printed surgical airway manikin made obese with simple techniques. The secondary objective was to compare the procedure time and difficulty of these surgical airway techniques.

## Methods

### Study design and population

This was a prospective, randomized, controlled, and cross-over study comparing two methods of cricothyrotomy in an obese surgical airway manikin. The study was performed in Gazi University Hospital, Ankara, Türkiye after approval by the Gazi University Ethics Committee (Date: 21.03.2023, Number: E.615448).

The study included emergency medicine residents at a university hospital. Emergency medicine residents who did not want to participate in the study, were not actively working at the time of the study and had previously performed a surgical airway were excluded.

### Sample size

Our two-sided hypothesis is that there is a difference in the first-attempt success rates of surgical airway techniques. Alpha was accepted as 0.05, and power as 80%. The ratio of the two groups was 1. A difference of 35% between the two groups was accepted as significant [11]. The sample size was calculated as 24 using G*Power version 3.1.9.4.

### Study protocol

Before the start of the study, the residents received 45 min of didactic training in surgical airway management. Traditional surgical cricothyrotomy and bougie-guided cricothyrotomy techniques were demonstrated on a manikin by an emergency medicine specialist experienced in surgical airway and working as an instructor. The steps and materials used for both methods are shown in Tables 1 and 2.

The 3D-printed surgical airway manikin was obtained from the drawing at www.thingverse.com (Fig. 1). To form the cricothyroid membrane, 5×5×0.1 cm electrical tape was used. Then, to make the cricothyroid membrane impalpable, layers of 22-density 10×10×3 cm sponge, 10×10×2 cm visco sponge, diluted artificial blood in 2×2 inch bags, and 20×15×0.1 cm adhesive foam paper were formed on the manikin from bottom to top (Figs. 2 and 3). When the layers were assembled and fixed on the manikin, a thickness of 4 cm was reached between the skin and the cricothyroid membrane.

After the 3D-printed manikin was made suitable for obese surgical airway simulation, it was placed on the stretcher and secured. The techniques were written on two different pieces of paper and placed in envelopes for randomization. The resident performing the procedure determined the first technique by selecting an envelope. Each resident performed both techniques.

**Table 1** Materials and procedure steps of the traditional surgical cricothyrotomy technique

| |
|---|
| **Materials**: |
| Scalpel with No. 11 blade, Trousseau dilator, curved hemostat, tracheal hook, and No. 5 tracheostomy tube |
| **Steps**: |
| 1. Standing next to the patient, stabilize the larynx with thumb and index finger of the non-dominant hand and identify the cricothyroid membrane |
| 2. Using a No. 11 blade, make a 2.5 cm midline incision over the cricothyroid membrane |
| 3. Dissect through the subcutaneous tissue to the cricothyroid membrane using the curved hemostat |
| 4. Make an incision into the trachea using the scalpel |
| 5. Extend the incision laterally in both directions |
| 6. Insert a tracheal hook on the caudal side of the larynx |
| 7. Vertically open the membrane using a Trousseau dilator |
| 8. Insert a No. 5 tracheostomy tube |
| 9. Remove the inner cannula and insert the adapter |

**Table 2** Materials and procedure steps of the bougie-guided cricothyrotomy technique

| |
|---|
| **Materials**: |
| Scalpel with No. 11 blade, tracheal hook, 70-cm gum elastic bougie, and 6.0 endotracheal tube |
| **Steps**: |
| 1. Standing next to the patient, stabilize the larynx with the thumb and middle finger of the non-dominant hand and identify the cricothyroid membrane |
| 2. If the anatomy is palpable, use a No. 11 scalpel blade to make a transverse stab incision through the skin and cricothyroid membrane. If the anatomy is not palpable, begin with a vertical midline incision before incising the cricothyroid membrane |
| 3. Place a tracheal hook at the inferior margin of the incision and pull the trachea upward |
| 4. Insert the bougie through the incision |
| 5. Pass the 6.0 endotracheal tube over the bougie and into the trachea. |

After completing the first technique, the resident performed the other technique. Each technique was given 180 s of procedure time for one attempt. Three attempts were allowed for each technique. Before the procedure, the participants were given five minutes to familiarize themselves with the manikin. The procedures began when the resident said, "I am ready." During the procedures, a number 5 cuff tracheostomy tube was used for the traditional surgical cricothyrotomy, and a 6.0 cuff endotracheal tube was used for the bougie-guided cricothyrotomy. The procedure was considered successful if the balloon representing the manikin's lung was inflated during artificial manual (Ambu) bag ventilation. If the procedure took longer than 180 s, it was stopped, and the next attempt was started. The procedure was considered unsuccessful if all three attempts for a technique failed.

### Measurements

The procedures were supervised and analyzed by two researchers. Age, gender, seniority, first method, procedure times for both methods, number of attempts, and success rate of the participants were recorded. During the procedure, the total procedure time from the time the practitioner said, "I'm ready" until the manikin was ventilated with an ambu bag was recorded with a chronometer.

At the end of the procedure, the participants were asked to rate both methods on a scale of 0–100 in terms of difficulty. A score of 0 was considered no difficulty, and 100 was considered extremely difficult.

### Analysis

The statistical analysis was performed using SPSS version 22 (SPSS Inc., Chicago, IL, USA). Frequency, mean, and standard deviation values were reported for the data. Normality was tested with the Shapiro–Wilk test. Categorical variables were statistically analyzed using Pearson's chi-square and Fisher's exact tests. Comparisons of numerical variables between two independent groups were analyzed using the Student's t-test, as the normal distribution condition was met. A p-value of less than 0.05 was considered statistically significant.

## Results

A total of 24 residents were included in the study. The mean age of the residents was 28.08±2.26 years, and 10 of them were female (41.7%). There were 14 residents (58.3%) with less than two years of seniority. Thirteen residents used bougie-guided cricothyrotomy as their first technique, while 11 residents used traditional surgical cricothyrotomy as their first technique.

In the traditional surgical cricothyrotomy method, 7 (31.8%) residents were successful in the first attempt, while in the bougie-guided cricothyrotomy method, 15 (68.2%) residents were successful in the first attempt (Table 3). There was a statistically significant difference between the success rates of both methods at the first attempt ($p=0.020$). For residents with less than two years of seniority, there was a statistically significant difference between the success rates of both methods at the first attempt (28.6% vs. 71.4%, $p=0.023$). For residents with more than two years of seniority, there was no statistically significant difference between the success rates of either method at the first attempt (37.5% vs. 62.5%, $p=0.363$). A total of 23 (95.8%) residents were successful in both methods, and there was no statistically significant difference between the success rates ($p=0.755$).

The mean procedure times of successful attempts for traditional surgical cricothyrotomy and bougie-guided cricothyrotomy are shown in Table 4. There was

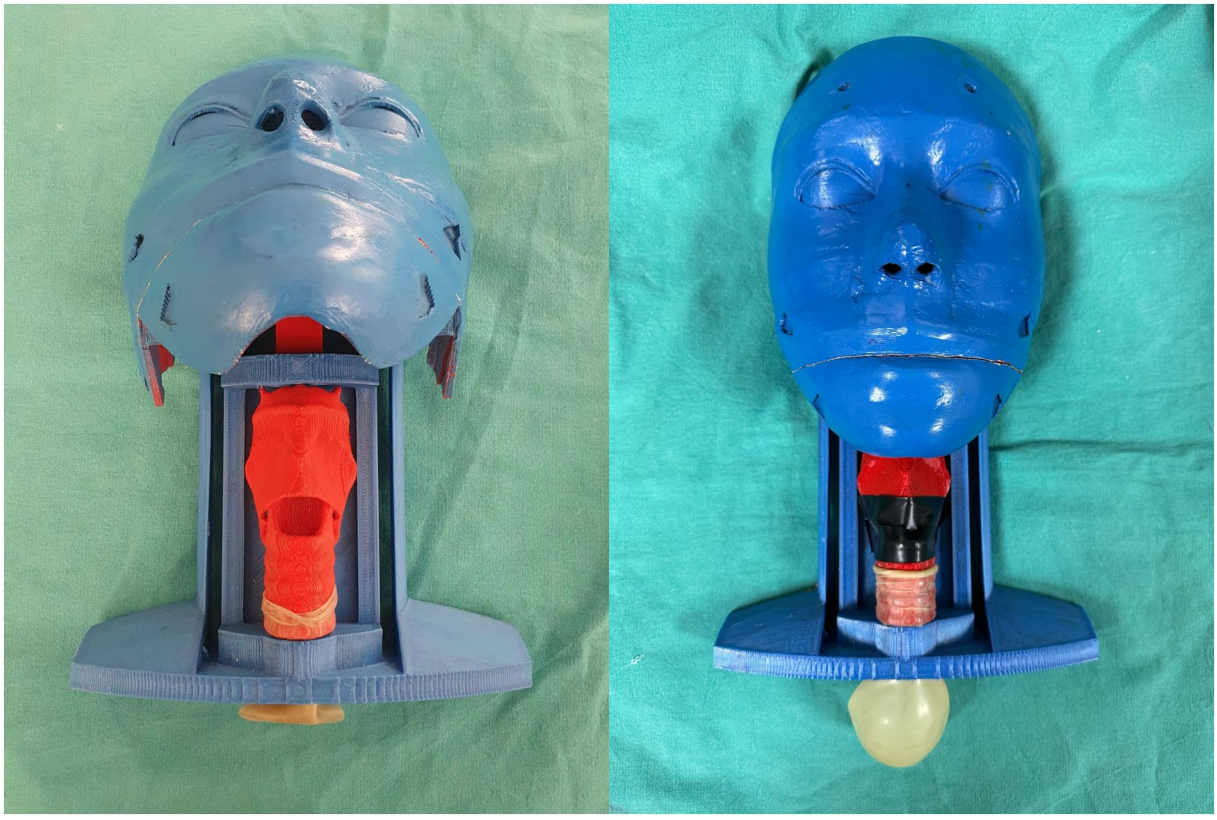

**Fig. 1** 3D printed manikin created with cricothyroid membrane with electrical tape

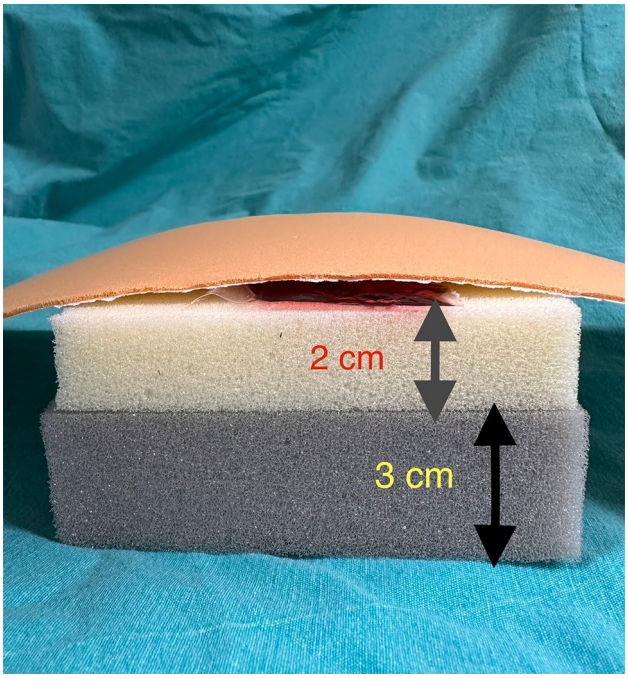


**Fig. 2** Layers consisting of 22-density 10×10×3 cm sponge, 10×10×2 cm visco sponge, diluted artificial blood in 2×2 inch bags, and 20×15×0.1 cm adhesive foam paper from bottom to top to create an obese manikin

**Fig. 3** 3D printed manikin with layers for obese simulation

no statistically significant difference in procedure time between the two techniques.

For residents with less than two years of seniority, the mean difficulty score for the traditional surgical cricothyrotomy method was 68.21±11.02, and the mean difficulty score for the bougie-guided cricothyrotomy method was

**Table 3** The number of successful attempts at traditional surgical cricothyrotomy and bougie-guided cricothyrotomy according to the seniority of the residents

| | Traditional surgical cricothyrotomy *N* = 24 (%) | Bougie-guided cricothyrotomy *N* = 24 (%) |
|---|---|---|
| **1st attempt** | | |
| Less than 2 years of seniority | 4 (28.6) | 10 (71.4) |
| More than 2 years of seniority | 3 (37.5) | 5 (62.5) |
| Total | 7 (31.8) | 15 (68.2) |
| **2nd attempt** | | |
| Less than 2 years of seniority | 6 (66.7) | 3 (33.3) |
| More than 2 years of seniority | 6 (75) | 2 (25) |
| Total | 12 (70.6) | 5 (29.4) |
| **3rd attempt*** | | |
| Less than 2 years of seniority | 4 (80) | 1 (20) |
| More than 2 years of seniority | 1 (25) | 3 (75) |
| Total | 5 (55.6) | 4 (44.4) |

* Of those who attempted 3 attempts, one failed both methods

**Table 4** Comparison of the total procedure time and difficulty scores of traditional surgical cricothyrotomy and bougie-guided cricothyrotomy

| | Traditional surgical cricothyrotomy (Mean ± SD) | Bougie-guided cricothyrotomy (Mean ± SD) | *P* value |
|---|---|---|---|
| **Total procedure time (seconds)** | | | |
| Less than 2 years of seniority | 118.86 ± 42.54 | 132.31 ± 36.82 | 0.379 |
| More than 2 years of seniority | 106.70 ± 31.39 | 113.22 ± 39.38 | 0.710 |
| Total | 114 ± 38,27 | 125,37 ± 38,01 | 0.328 |
| **Difficulty score*** | | | |
| Less than 2 years of seniority | 68.21 ± 11.02 | 57.14 ± 13.25 | 0.024 |
| More than 2 years of seniority | 56.44 ± 28.24 | 50.00 ± 23.58 | 0.606 |
| Total | 63.60 ± 19.90 | 54,34 ± 17,85 | 0.104 |

* 0 was considered no difficulty, and 100 was considered extremely difficult

57.14±13.25 ($p$=0.024). For residents with more than two years of seniority, there was no statistically significant difference between the two techniques (Table 4).

## Discussion

In our study on a unique manikin simulation, the success rate of the bougie-guided cricothyrotomy method in the first attempt was higher than that of the traditional surgical method. It was found that there was no statistically significant difference between the overall success rates and procedure times of both methods. The level of difficulty of the bougie-guided cricothyrotomy method was found to be easier, especially for residents with less than two years of seniority.

This study is the first to compare bougie-guided cricothyrotomy and traditional cricothyrotomy in an obese surgical airway manikin created with 3D modeling. Studies comparing the measurements of commonly used airway manikins to normal human anatomy have found that the manikins do not replicate human anatomy exactly [12, 13]. However, these studies compared measurements of the upper airway. The limitation of manikins in surgical airway training is more related to their ability to mimic human tissues such as skin and membranes. In a study on cricothyrotomy training, it was found that the use of a high-fidelity manikin and a handmade low-fidelity model had the same effect as a cadaver in terms of skill acquisition [14]. It was an advantage that the manikin created with the 3D printer we used in the study was lower in cost than the higher-fidelity manikins.

When obese airway models are examined, mostly animal studies and studies in which obesity was induced with meat on a manikin are observed [10, 15]. A study comparing a meat-modified obese neck, and a synthetic obese neck showed that the use of a synthetic obese neck may be useful for training and studies [16]. In this study, a 36 mm sponge and silicone layer were used for the synthetic model. In our study, we selected sponges that were considered appropriate for mimicking subcutaneous tissue and used foam paper as the skin layer. This resulted in cost, hygiene, and time advantages over the use of actual meat.

Studies in the literature comparing bougie-guided cricothyrotomy with traditional cricothyrotomy are animal- and manikin-based. Only one of these studies compared the two techniques in an obese simulation [10]. Driver et al. reported that the success rate in the first trial in an obese animal simulation was 50% for traditional cricothyrotomy and 60% for bougie-guided cricothyrotomy [10]. In Hill et al.'s study on sheep, the success rate for traditional cricothyrotomy was 72.7%, and for bougie-guided cricothyrotomy, it was 90% [17]. In another study by Quick et al. on a simulation manikin, a bougie-guided cricothyrotomy was 100% successful in the first attempt, while the traditional method was 75% successful [18]. The success rate of bougie-guided cricothyrotomy in the first attempt was also higher in our study; the success rate of traditional cricothyrotomy in the first attempt was 31.8%, while that of bougie-guided cricothyrotomy was 68.2%.

In studies comparing the bougie-guided method with other methods, it was observed that the bougie-guided method was performed more quickly. In an animal model study, the bougie-guided method was performed in an average of 67 s, while traditional methods took 149 s [17]. In a manikin-based study, the procedure times were similarly found to be 52.1 and 87.3 s, respectively [18]. In the obese animal simulation, traditional cricothyrotomy took an average of 183 s, while bougie-guided cricothyrotomy

was completed in an average of 118 s [10]. In a manikin study comparing synthetic and meat-modified obese necks, only a bougie-guided method was performed, and the median time to ventilation for synthetic obese manikin was 159 s [16]. In another study comparing the bougie-guided method with the cannula-to-melker technique, the bougie-guided method was found to be significantly faster (45.2 and 101.3 s, respectively) [19]. In our study, the mean time was 114 s for the traditional surgical method and 125 s for the bougie-guided method ($p=0.328$). Although more time was required, the bougie-guided method had a higher success rate in the first attempt. Failure at first attempt may have contributed to reducing procedure time by providing experience for subsequent attempts.

We think that traditional cricothyrotomy has a lower success rate on the first attempt due to the difficulty of practitioners in guiding the tracheostomy tube and malposition. In the post-procedure difficulty assessment of emergency residents, residents with less than two years of experience rated the bougie method as statistically significantly easier than the traditional method. Hill et al. also showed that practitioners, the majority of whom were medical students, rated the bougie-guided method as easier than the traditional method [17]. Considering the success rates and this scoring, the bougie method may be a more suitable option for emergency department physicians.

### Limitations

Although the use of animals and manikins is widespread in surgical airway training and research, the results obtained in real patients may vary since the 3D airway manikin used in the study may not be an exact match for human airway anatomy. Additionally, the sponges used for the obese manikin simulation may not have provided the same sensation as the subcutaneous tissue and muscles during application. Comparing our manikin to obese cadavers or high-fidelity manikin models could have allowed us to assess its realism. It should also be noted that the stress experienced during the procedure in manikin studies may not be equivalent to the stress encountered in real patient care. The study may yield different results with different participant groups (anesthesiologists, paramedics, etc.). Finally, we did not measure how practitioners would perform on a non-obese manikin. This situation prevents us from comparing the same techniques between obese and non-obese scenarios.

## Conclusions

Technique selection is important when an emergency surgical airway is required. Our study suggests that bougie-guided cricothyrotomy may be a better choice than the traditional surgical approach in obese patients. However, the choice of technique should be based on training and experience. If there is one thing that can be said about the need for an emergency surgical airway, which is a rare situation, it is: "The best technique is the one you know best." For this reason, the use of a bougie and endotracheal tube may be preferable to the use of a tracheostomy tube when establishing a surgical airway in obese patients.

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**Author contributions**
SY: Conceptualization, methodology, Data curation, writing-original draft EA: Conceptualization, methodology, data curation, formal analysis, writing original draft AK: Conceptualization, methodology, writing-final draft, supervision AD: Conceptualization, methodology, writing-final draft, supervision. All authors read and approved the final manuscript.

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**Data availability**
The data that support the findings of this study are available from the corresponding author upon reasonable request.

## Declarations

**Ethics approval and consent to participate**
The study was conducted after approval by the Gazi University Ethics Committee (Date: 21.03.2023, Number: E.615448). Written informed consent was given by each participant before the study.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare no competing interests.

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