A comparison of methods used to secure pediatric endotracheal tubes using a live human dermal model

Une comparaison des méthodes utilisées pour fixer les tubes endotrachéaux pédiatriques à l'aide d'un modèle de derme humain vivant

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Abstract

Background Endotracheal intubation is a common lifesaving procedure. An *in situ* endotracheal tube (ETT) must be secured in position to avoid displacement and potentially life-threatening complications. Adhesive tapes form the most common intraoperative ETT stabilization methods. Limited published data are available to guide the clinical decision regarding ETT taping method. We performed an interventional study aiming to establish which of many commonly employed ETT tape/supplementary adhesive methods provides the most resistance to ETT distraction.

Methods An experiment was undertaken to measure the force required to distract an ETT secured to a live dermal

model with 24 different ETT securing methods comprising six types of tape alone and in combination with one of three supplementary adhesives. The primary measurement was the peak force (Newtons) required to distract a secured ETT 3 cm.

Results A total of 1,164 measurements were made. The mean force required to distract the ETT ranged from 7.8 to 21.8 Newtons. The combination of Cloth AdhesiveTM + Mastisol® had the greatest observed mean distraction force, as well as the greatest estimated lower and upper confidence limits.

Conclusions There are significant differences in force required to distract an ETT based on taping methods.

Résumé

Contexte L'intubation endotrachéale est une intervention critique courante. Le tube endotrachéal (TET) *in situ* doit être fixé en position adéquate pour éviter qu'il ne se déplace et provoque des complications potentiellement fatales. Les bandes adhésives sont la méthode de stabilisation peropératoire de TET la plus fréquemment utilisée. Il n'existe que peu de données publiées pour guider la décision clinique quant à la méthode de fixation du TET. Nous avons réalisé une étude interventionnelle visant à établir laquelle des nombreuses méthodes couramment employées de bandes adhésives ou de méthodes adhésives supplémentaires du TET procurait la meilleure protection contre un déplacement du TET.

Méthode Une expérience a été menée pour mesurer la force nécessaire à déplacer/déloger un TET fixée à un modèle de derme vivant avec 24 méthodes différentes de sécurisation du TET, comprenant six types de ruban

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adhésif seuls et en combinaison avec l'un de trois adhésifs supplémentaires. La mesure principale était la force maximale (en newton) nécessaire pour déplacer un TET sécurisée de 3 cm.

Résultats Au total, 1164 mesures ont été effectuées. La force moyenne requise pour déplacer le TET allait de 7,8 à 21,8 newtons. La combinaison du ruban Cloth Adhesive™ + Mastisol® a entraîné la plus grande force de déplacement moyenne observée, ainsi que les plus grandes limites inférieure et supérieure estimées des intervalles de confiance.

Conclusion Il existe des différences significatives dans la force nécessaire pour déplacer un TET en fonction des méthodes de fixation utilisées.

Keywords airway management · intubation, intratracheal · anesthesiology · intensive care · resuscitation

Endotracheal intubation is a common lifesaving procedure performed in the operating room, intensive care units (ICU), and emergency department. An endotracheal tube (ETT) must be secured in position to avoid accidental extubation or mainstem intubation, as both can be potentially life threatening. Despite the importance of ETT stabilization, unplanned extubation remains common in adult ICUs, with the rates in pediatric ICUs even higher.¹

Unplanned ETT displacement results, at least in part, from failure of stabilization. Various methods of ETT stabilization are used including tapes, ties, and purpose-built commercial devices.² The most commonly studied ETT stabilization methods include adhesive tapes or commercial devices.^{3–8} In the operating room, prone positioning and high turnover limits the use of bulky and costly commercial devices. There are limited published data comparing the most effective taping method in the intraoperative setting, and none using a live human dermal model. This research will help guide best practice for the important and frequently performed intraoperative endotracheal tube stabilization.

Methods

Design, setting, and ethical approval

Local research ethics board approval (University of Saskatchewan; Bio #15-83) was obtained prior to commencement of this prospective assessor blinded experimental study. Participant consent was obtained using a standardized consent procedure comprising both a

verbal and a written description of the study procedures. The investigation was conducted at facilities of the Saskatoon Health Authority from June to August of 2015, 2016, and 2019.

Participants and materials

There is no similar study from which to calculate sample size. A convenience sample of 50 volunteers per taping method was planned. The Canadian pediatric anesthesia community was informally polled regarding the most used ETT taping methods via the Canadian Pediatric Anesthesia Society listserv. The most reported taping methods, including various tapes with or without supplementary adhesives, formed the basis for our choice of studied ETT securing methods. The study tapes included were Elastoplast™, Transpore Clear™, Transpore Cloth™, Medipore™, Micropore™, and Cloth Adhesive™ (all products of 3M Maplewood, St Paul MN, USA). The supplementary adhesives were none, Cavilon™ (3M Maplewood, MN), USA, tincture of benzoin (Rougier, Ulm, Germany), and Mastisol® (Ferndale Laboratories, Ferndale, MI, USA). Each tape type was tested with and without each supplementary adhesive for a total 24 tested combinations.

Experimental protocol

Volunteers' left forearm and hand were immobilized in a custom experimental apparatus with the distraction device directly above the volunteer's second metacarpophalangeal joint (see Fig. 1). The radial aspect of the dorsal hand and left index finger centred over the metacarpal phalangeal joint was used as a live dermal model of a human upper lip. For all adhesive methods, we applied the various tapes using a modification of the Lillehei method, as it has been

Fig. 1 Experimental Setup. Annotations 1—Load Cell; 2—Turnbuckle (used to generate incremental force); 3—Pulleys; 4—Tie and wire; 5 - Vertical wire guide; 6 - Adjustable ETT distraction distance indicator

described as a standard taping method in previous studies.^{3,9,10} Specifically, two pieces of the experimental tape were 2.5 cm in width and 8 cm in length. Each length was split in half longitudinally to its midpoint. The unsplit side of the first of the two pieces of tape was applied to the skin in a longitudinal direction starting 4 cm proximal to the second metacarpophalangeal joint, with one of the split halves continued distally along the radial aspect of the second finger. The remaining split piece of tape was wrapped circumferentially around the distal aspect of a PVC ETT tube (4.5-mm internal diameter) (Portex®; Smith Medicals International limited, Hythe, Kent, UK). The second piece of tape was similarly applied, but in the opposite direction. The experimental adhesive, if any, was applied to both the volunteers' skin and ETT prior to application of the tape. The experiments were performed in random order first with all tapes without supplementary adhesives, then repeated with addition of each of the supplementary adhesives. The volunteers' skin was cleaned thoroughly between measurements with alcohol swabs to remove any residual adhesive, and then allowed to dry for approximately one minute.

Measurements

The proximal end of the ETT was connected to a load cell (RAS1 S-Beam Load Cell, Loadstar sensors, Fremont, CA, USA) via a steel wire and doubled #2 heavy silk surgical tie through a system of pulleys that connected to the custom-made incremental distraction device. An incremental force was slowly applied by manually turning a threaded turnbuckle that was located between the fixed load cell and ETT. The load cell output was digitized using an analogue to digital converter (DI-100U 16-bit load cell interface, Loadstar sensors, Fremont, CA, USA) (load range is 0–45.4 kg, accuracy of $\pm 0.1\%$, sampling rate 40 Hz) and recorded on a personal computer using the commercial software supplied with the load cell.

Force was vertically applied to the ETT until a reference point on the ETT was distracted by 3 cm over a period of approximately one minute. The 3-cm distraction distance was chosen as it represents the probable distance required to extubate a child likely to be intubated with a 4.5-mm inner diameter ETT ($\sim$ two years old) if the ETT tip was initially in the mid-tracheal position as the expected tracheal length in such a child is ~ 6 cm.¹¹ The data were analyzed to determine the peak force in Newtons (N) applied during ETT distraction.

To account for the force losses through the testing apparatus, the system was calibrated by adding incremental known weights to the experimental apparatus and recording the measured force. A calibration curve was created using the known and measured data. The testing

measurements were adjusted using the linear regression relationship of the calibration curve. To ensure we accounted for potential changing resistance of the testing apparatus over time, the testing system was calibrated for each testing period.

Statistical analysis

Statistical analysis was performed with IBM SPSS Statistics version 25.0 (Armonk, NY, USA). Calibrated raw data analyzed were the forces required to pull the ETT 3 cm vertically. Generalized Linear Model with two independent variables, taping method with six levels, and supplementary adhesive with four levels were used to determine difference in the force required to pull the ETT 3 cm vertically for the given taping method and supplementary adhesive. Standard errors were estimated using the robust method with clustering for the number of subjects. Significance of main effects and interaction were reported as well. To compensate for multiple comparisons among the 24 groups, $P < 0.001$ was treated as significant for post hoc comparisons of means and 99.9% confidence intervals (CIs) were reported for the marginal means.

In clinical practice, some clinicians routinely secure an ETT using tape alone (without any supplementary adhesive). For such a case, the difference of the means of the six groups when the ETT is secured with tape alone were compared using one-way ANOVA. As above, to account for multiple comparisons, a Bonferroni corrected $P < 0.001$ was considered significant for comparison of means and 99.9% CI were reported for the marginal means.

Results

A total of 1,164 study measurements were made, with 47 measurements per taping method in 12 studied methods and 50 measurements per method in the other 12. An administrative error led to the less than planned (47 vs 50) number of measurements in 12 of the studied methods. The mean forces required to extract the ETT 3 cm for all 24 tested taping/adhesive combinations ranged from 7.8 to 21.8 N and presented in Table 1 and Fig. 2. The combination of Cloth AdhesiveTM + Mastisol® had the greatest observed mean distraction force, as well as the greatest estimated lower and upper confidence limits.

Of the tapes without supplementary adhesive, Transpore ClearTM required more force ($P < 0.001$) to extract the ETT by 3 cm than the other studied tapes did except Transpore ClothTM (Tables 2 and 3). The supplementary adhesives generally increased the force required to extract the ETT (Table 4). There was a statistically significant taping method-by-supplementary adhesive interaction

Table 1 Summary of force (Newtons) required to distract the ETT 3 cm for all taping/supplementary adhesive methods

ETT securing method	Mean force* (SD)	99.9 % CI lower limit	99.9 % CI upper limit
Cloth Adhesive TM - Mastisol®	21.8 (3.6)	19.5	24.0
Transpore Clear TM - Cavidon TM	21.1 (3.2)	18.9	23.3
Transpore Clear TM - Mastisol®	19.4 (3.6)	17.2	21.5
Medipore TM - Mastisol®	19.2 (3.9)	17.0	21.5
Transpore Clear TM -None	17.9 (3.4)	15.7	20.1
Micropore TM - Mastisol®	17.7 (4.6)	15.4	20.0
Transpore Cloth TM - Mastisol®	17.5 (4.1)	15.2	19.7
Transpore Clear TM - Tincture of Benzoin	17.4 (3.6)	15.2	19.6
Transpore Cloth TM - Tincture of Benzoin	17.1 (4.2)	14.9	19.3
Medipore TM - Tincture of Benzoin	15.9 (4.2)	13.8	18.1
Cloth Adhesive TM - Tincture of Benzoin	15.7 (4.0)	13.5	17.9
Elastoplast TM - Mastisol®	15.5 (3.7)	13.3	17.7
Transpore Cloth TM -None	15.4 (6.1)	13.2	17.7
Transpore Cloth TM - Cavidon TM	15.1 (5.0)	12.9	17.4
Elastoplast TM - Cavidon TM	14.5 (4.7)	12.4	16.7
Micropore TM - Tincture of Benzoin	14.2 (3.9)	12.0	16.4
Micropore TM -None	14.0 (4.4)	11.8	16.3
Cloth Adhesive TM - Cavidon TM	13.8 (5.3)	11.5	16.0
Medipore TM -None	13.3 (8.3)	11.0	15.5
Micropore TM - Cavidon TM	13.1 (4.8)	10.9	15.4
Cloth Adhesive TM -None	13.0 (4.7)	10.7	15.2
Medipore TM - Cavidon TM	12.8 (5.1)	10.5	15.0
Elastoplast TM - Tincture of Benzoin	10.0 (4.3)	7.8	12.2
Elastoplast TM -None	7.8 (6.6)	5.6	9.9

*Marginal mean †Where lower CI of the better taping method > higher CI of the worse.

CI = confidence interval; ETT = endotracheal tube; SD = standard deviation.

($P < 0.001$), indicating the effect of supplementary adhesive is a function of each tape type (Fig. 2). This interaction makes a comparison of the mean additional force required to extract the ETT as a function of supplementary adhesive inappropriate.

Discussion

There are significant differences in force required to distract an ETT based on taping methods. This study shows that among the 24 tested combinations of commonly used tapes and supplementary adhesives used to secure an ETT from distraction, the combination of Cloth AdhesiveTM + Mastisol® had the greatest observed mean distraction force, as well as the greatest estimated lower and upper confidence limits. In isolation, Transpore ClearTM provided more resistance to ETT distraction compared with all other tapes except Transpore ClothTM. Interestingly, the interaction between taping and supplementary adhesive appears to be idiosyncratic,

meaning the knowledge of specific combinations is important. To give clinicians a sense of the forces involved in this experiment, 9.8 N of force is approximately equal to 1 kg. In comparison with a familiar object, this about the same as 1 litre of water. The mean forces measured in all tape and adhesive groups in this experiment [mean (SD) 16.0 (5.6) N; 99.9% CI, 15.4 to 16.5] are about half those of laryngoscopy.¹²

Our study had both limitations and strengths. A notable strength of this study is the number of taping methods studied. These taping methods encompass a large cross section of current intraoperative clinical practice as reflected from the input we received from anesthesiologists practicing in numerous institutions. A second strength is the standardized taping protocol and objective assessment method. Our experimental methodology limited the variance of the data set, making meaningful comparisons and conclusions more likely. A limitation of the study includes the use of the hand as a dermal model. The skin of the dorsal hand is likely different from that of the upper lip. In addition, the time of taping application before

Fig. 2 Box and whisker plot of force (Newtons) required to distract the ETT 3 cm, after securing with various tape and adhesive combinations. Tape type labels: Elastoplast™ (Elast), Transpore Clear™ (Transp clear), Transpore Cloth™ (Transp cloth), Medipore™ (Medipo), Micropore™ (Micro), Cloth Adhesive™ (Cloth A). Supplementary adhesives labels: None, Cavilon™ (Cav), tincture of benzoin (TB), and Mastiso® (Mas). The centre line within each box denotes the median value, while the box contains the 25th to 75th percentiles of each taping method. The whiskers indicate the 5th and 95th percentiles, and values beyond these upper and lower bounds are considered outliers, marked with dots.

Table 2 Summary of force (Newtons) required to distract the ETT 3 cm, expressed as a function of tape type. Each tape type is compared with the tape type immediately below

Tape type	Mean force* (SD)	99.9 % CI lower limit	99.9 % CI upper limit	P value
Transpore Clear TM	17.9 (4.8)	16.0	19.8	<0.001
Transpore Cloth TM	15.4 (3.7)	13.5	17.4	1.00
Cloth Adhesive TM	14.0 (3.6)	12.1	16.0	1.00
Micropore TM	13.3 (4.6)	11.3	15.3	1.00
Medipore TM	13.0 (3.9)	11.0	14.9	<0.001
Elastoplast TM	7.8 (3.6)	5.8	9.7	n/a

CI = confidence interval; SD = standard deviation.

distraction was brief. It is possible that the adherence qualities would change over time in unpredictable ways. Further, sweat and secretions often come into contact with the ETT securing tape (and supplementary adhesive if used) in the clinical setting; these factors were not replicated in our study. These limitations may weaken applicability of our results to the clinical environment.

Despite our best efforts, there are many other untested tapes (and commercial devices), tape application methods, and non-adhesive methods (including twill tape) used to secure an ETT, limiting our ability to form conclusions on all ETT securing practices. We did not conduct a clinical study, which would be considered to be unethical. As such, we have no clinical outcome measurements; we do not know if

Table 4 Summary of force (Newtons) required to distract the ETT 3 cm, expressed as a function of supplementary adhesive

Supplementary adhesive	Mean force* (SD)	99.9% CI lower limit	99.9% CI upper limit
Mastisol®	18.3 (6.4)	17.1	19.5
Cavilon TM	15.2 (4.9)	14.0	16.4
Tincture of Benzoin	15.1 (4.9)	13.9	16.3
None	13.4 (5.1)	12.2	14.6

*Marginal mean.

CI = confidence interval; ETT = endotracheal tube; SD = standard deviation.

using an ETT securing method requiring more force to distract the ETT improves patient outcomes or causes harm to fragile skin. The addition of a supplementary adhesive exposes the patient to more potential allergens. Nevertheless, both tincture of benzoin and Mastisol® are unusual causes of hypersensitivity, with Mastisol® reported to be less implicated in contact dermatitis than tincture of benzoin in other clinical studies.^{13,14}

The most important distinction between this and previous investigations of force required to distract an ETT is the use of a live dermal model. Previous study models have included polyvinylchloride pipe, mannequins, and cadavers, which are likely less similar to the live skin of the face than our model using the dorsum of the hand.^{3,7,15} Our results generally showed less force than previous studies (up to 165 N). This may reflect other

Table 3 Summary of multiple pairwise comparisons of marginal mean force (Newtons) required to distract the ETT 3 cm, when secured with tape alone

Taping method comparison	Mean force difference	99.9% CI lower limit	99.9% CI upper limit	P value
Transpore Clear TM - Transpore Cloth TM	2.4	-0.9	5.8	0.052
Transpore Clear TM - Micropore TM	3.8	0.5	7.2	<0.001
Transpore Clear TM - Medipore TM	4.6	1.3	8.0	<0.001
Transpore Clear TM - Cloth Adhesive TM	4.9	1.6	8.3	<0.001
Transpore Clear TM - Elastoplast TM	10.1	6.8	13.4	<0.001
Transpore Cloth TM - Micropore TM	1.4	-2.0	4.8	1.00
Transpore Cloth TM - Medipore TM	2.2	-1.2	5.6	0.16
Transpore Cloth TM - Cloth Adhesive TM	2.5	-0.9	5.9	0.05
Transpore Cloth TM - Elastoplast TM	7.7	4.3	11.0	<0.001
Micropore TM - Medipore TM	0.8	-2.6	4.2	1.00
Micropore TM - Cloth Adhesive TM	1.1	-2.3	4.5	1.00
Micropore TM - Elastoplast TM	6.3	2.9	9.6	<0.001
Medipore TM - Cloth Adhesive TM	0.3	-3.1	3.7	1.00
Medipore TM - Elastoplast TM	5.5	2.2	8.9	<0.01
Cloth Adhesive TM - Elastoplast TM	5.2	1.9	8.5	<0.01

CI = confidence interval; ETT = endotracheal tube.

methodological differences, including the distance of ETT distraction, amount and type of tape used, and the way the force was applied (constant *vs* tugging). Our group conducted a previous exploratory study using similar methodology but assessing a smaller number of taping methods and using a different measurement device.¹⁶ The results of the present study are generally about half those of the previous study, suggesting the measurement device is an important factor in reported study differences. Although our recorded measurements generally differ from those of previous reports, the relative difference and rank order among groups are likely to be valid.

The addition of supplementary adhesives is novel in the study of force required to distract an ETT, but has been studied for securing intravenous catheters.¹⁷ This study similarly showed that the use of supplemental adhesive, notably Mastisol®, improved the adherence of tape to intact skin. Further, Mastisol®, more so than tincture of benzoin, has been shown to significantly improve the adhesion of wound taping.¹⁸ This data adds to the external validity of our results.

Previous studies have examined the role of commercial devices in securing an ETT from dislodgement.^{3,4,6,7} We chose not to study commercial devices as our experience and a review of the literature suggests they are not commonly used in the intraoperative setting. Interestingly, these previous studies do not uniformly conclude that the studied commercial devices more resistance to ETT distraction than taping methods do. A larger body of literature is available examining methods of securing an ETT in an ICU population.^{2,5} The most recent of these studies was of high quality, but was designed to examine outcomes of primary importance to the ICU population, limiting extrapolation to the intraoperative setting.⁵

There are several implications of this study for clinicians. Unplanned extubation or ETT distraction is a serious complication. The choice of technique used to avoid this complication would ideally be driven by clinical data, which is currently lacking. Further, measuring extubation force in the clinical setting seems perilous and likely unethical. This situation leads clinicians to rely on laboratory experiments, even if these are not ideal. Despite the limitations of our study, we assume that the technique that requires the largest force to dislodge the endotracheal tube is likely superior, and thus a rational choice of common ETT securing techniques can be made from our data set. Finally, the choice to use Mastisol® compared with tincture of benzoin as a supplementary adhesive appears to be clear as it provides the most additional resistance to ETT distraction and is reported to be safer in terms of dermal complications.

Conclusions

Our data suggest the force required to distract an ETT varies by taping methods. When considering the methods examined, the combination of Cloth Adhesive™ and Mastisol® had the greatest observed mean distraction force, as well as the greatest estimated lower and upper confidence limits.

Author contributions The manuscript is the collaborative work of nine authors. William P. McKay and Jonathan J. Gamble conceptualized the study. Jayden Cowen, Andrew Peeling, Christopher Durr, Trevor Krysak, Rachel Guo, and Tanner Lange acquired the data. William P. McKay and Jagmeet S. Bajwa participated in data analysis. Jonathan J. Gamble wrote the initial draft and all nine authors revised the manuscript.

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