Thermophysical Properties of Thermosoftening Nasotracheal Tubes

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Thermosoftening treatment of polyvinyl chloride (PVC) nasotracheal tubes (NTTs) can reduce the incidence and amount of epistaxis during nasotracheal intubation. The optimal thermal setting for thermosoftening treatment of NTTs without burn injury was investigated. Two composite types of PVC NTTs were used. Following withdrawal of the PVC NTTs from a bottle of water at 45 or 60°C, the changes in the surface temperature of the NTTs were measured by infrared thermography. Hardness of the NTTs at 25, 30, 35, and 40°C was measured. The incidence of epistaxis during nasotracheal intubation using thermosoftened NTTs was evaluated retrospectively. The surface temperature of both PVC NTTs dipped in 45 and 60°C water decreased to below body temperature 30 seconds after withdrawing them from the bottles. Although thermosoftening treatment proportionally decreased the hardness of both types of NTTs, the degrees differed according to their composition. When avoiding impingement of the NTT on the posterior wall of the nasopharynx, the incidence of mild and moderate epistaxis was 2.3%. Flexibility of PVC NTTs could be obtained by thermosoftening treatment at 60°C without burn injury. Thermosoftening treatment of PVC NTTs may be useful to avoid epistaxis during nasotracheal intubation.

Key Words: Nasotracheal intubation; Polyvinyl chloride tracheal tube; Thermosoftening treatment; Epistaxis; Thermography.

Epistaxis has been reported as the most common complication of nasotracheal intubation. The incidence of epistaxis has been generally reported as ranging from 50 to 80%.^{1–5} During nasotracheal intubation, the tip of the tube advances through the narrow nasal passages, reaches the posterior nasopharyngeal wall, and changes direction downward to the oropharynx. Epistaxis usually occurs from damage to Kiesselbach's plexus in Little's area in the anterior part of the nasal septum.⁶ Although bruising of the mucosa overlying the turbinate and adjacent septum are common (>50%), postoperative rhinoscopy did not detect any significant injury in patients who had epistaxis.¹ Since the posterior wall of the nasopharynx, which has recesses and the pharyngeal tonsils, is an area

of loose tissue, impingement of the tip of a nasotracheal tube (NTT) on the posterior wall of the nasopharynx can lead to nasopharyngeal laceration or potentially more severe complications.^{7,8} Clinically relevant bleeding related to nasotracheal intubation has been reported in 27.5%⁹ and 52%⁴ of cases when evaluated by anesthesiologists providing intubation.

Among several approaches to minimizing the incidence of epistaxis and impingement, the efficacy of thermosoftening treatment of the polyvinyl chloride (PVC) NTT before nasotracheal intubation has been reported.^{3,4,10} In the clinical application of thermosoftening treatment for nasotracheal intubation, the tip of the NTT should be kept at a high temperature without burning the mucosa; however, the thermosoftened NTT cools promptly to the ambient temperature of the room and consequently becomes stiffer.⁴ The surface temperature and hardness of the NTT following thermosoftening treatment have not been investigated. The aim of this study was to determine the optimal temperature setting for thermosoftening treatment of PVC NTTs with respect to the surface temperature and the hardness of the NTTs. Furthermore, the clinical efficacy of thermosoftening treatment to

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minimize the incidence of epistaxis and impingement was evaluated retrospectively.

METHODS

The bench tests of this study were carried out in the laboratory of the Product Development Research Center (Daiken Medical Co Ltd, Osaka, Japan).

Changes in Surface Temperature of Tracheal Tubes After Dipping in Bottled Water at 45 or 60°C

Five samples each of 2 composite types of PVC NTTs with inner diameters (IDs) of 7.5 mm, Mallinckrodt Nasal RAE Endotracheal Tube with TaperGuard Cuff (Mallinckrodt tube, outer diameter [OD] 10.1 mm, wall thickness 1.3 mm, Covidien Japan, Inc, Tokyo, Japan) and Ivory PVC Portex North Polar Preformed Endotracheal Tube (Portex tube, OD 10.9 mm, wall thickness 1.7 mm, Smiths Medical Japan Ltd, Tokyo, Japan), were used. The portion of the NTT between the tip and 10 cm from the proximal end of the tube was dipped for 3 minutes in bottled water at 45 or 60°C (the upper heatproof temperature of the PVC NTTs is 60°C based on reference material provided by the manufacturers) and then left at room temperature (22–25°C) for 5 minutes. Changes in the surface temperature of the NTTs between the tip and 15 cm from the distal end were measured by infrared thermography using an infrared thermal camera (Thermo Shot F30, Nippon Avionics Co Ltd, Tokyo, Japan).

Changes in Flexibility of Tracheal Tubes Due to Thermosoftening

In the bench test, a testing machine (LSC-1/300-2, Tokyo Testing Machine, Aichi, Japan) was placed in the environmental test chamber (PR-3KPH, ESPEC Corp, Osaka, Japan) set at 25, 30, 35, and 40°C, with relative humidity of 20%. A digital force gauge (temperature measuring range 0–40°C; DS2-200N, Imada, Aichi, Japan) and a linear gauge sensor (LGF-150L, Mitutoyo, Kanagawa, Japan) were attached to the testing machine. The PVC NTTs laid on the table of the testing machine were compressed by an acrylic plate with length of 50 mm and width of 30 mm attached to the bottom face of the force gauge with descending speed of 10 mm/min. In this study, the pressure force at 3-mm reduction of the external minor axis of the NTT was measured, and the

pressure force per 1 mm (N/mm) was used as the index of hardness of the NTT.

Clinical Incidence of Epistaxis During Nasotracheal Intubation

This retrospective study was conducted with the approval of the Medical Ethics Committee of Kindai University Faculty of Medicine (Ref: 28-227). A total of 171 anesthesia records (PrimeGaia PRM-7500, Nihon Kohden Co, Tokyo, Japan) of 163 patients (>17 years, ASA class I or II; 91 males and 72 females, 55.5 ± 18.4 years, 162.4 ± 9.2 cm, and 59.0 ± 11.2 kg) who underwent elective oral and maxillofacial surgery in which nasotracheal intubation was performed by 3 anesthesiologists between January 2015 and December 2016 were obtained. Since we often experienced a bend of the Portex tube at nostril due to its soft tube material, we have mainly used the preformed Mallinckrodt tubes for nasotracheal intubation. No topical vasoconstrictor was applied for nasal preparation prior to tube insertion. A thermosoftened Mallinckrodt tube (ID 7.5 mm for men and ID 7.0 mm for women), which was dipped in bottled water at approximately 55 to 60°C heated in a 600-W microwave oven for 3 minutes, was used for intubation. Following the application of 8% lidocaine spray, the thermosoftened NTT lubricated with jelly was deliberately advanced through the right nostril into the nasopharynx. If the tip of the tube could not pass through the nasopharynx beyond a depth of approximately 7–8 cm from the nostril due to restricted movement of the tube, the procedure was re-attempted using the other nostril. Epistaxis and bleeding, defined as blood on the NTT only (mild epistaxis), blood pooling in the pharynx (moderate epistaxis), and blood in the pharynx sufficient to impede intubation (severe epistaxis),¹¹ were recorded immediately after intubation by the attending anesthesiologists, and the incidence of failed nasotracheal intubation via the right nostril due to impingement of the tube on the posterior wall of the nasopharynx was also retrospectively evaluated.

Statistical Analyses

All measurements and calculated values are described as means $\pm$ SDs. Value changes over time were compared using one-way repeated measures analysis of variance (ANOVA) followed by Bonferroni's multiple comparison test, and comparisons among groups were analyzed by two-way ANOVA followed by Bonferroni posthoc tests. Data were analyzed using Prism software 5.0

(Graph-Pad, San Diego, CA). A value of $p < 0.05$ was considered significant.

RESULTS

Changes in Surface Temperature of Tracheal Tubes After Dipping in Bottled Water at 45 or 60°C

The surface temperatures at 5 cm from the proximal ends of the 2 types of PVC NTTs, the Mallinckrodt tube and the Portex tube, immediately after withdrawal of the tube from the bottled water at 45°C were $32.5 \pm 0.6^\circ\text{C}$ and $34.4 \pm 0.6^\circ\text{C}$, respectively (Figures 1 and 2); the surface temperatures decreased to $27.9 \pm 0.2^\circ\text{C}$ and $30.9 \pm 0.5^\circ\text{C}$ 30 seconds later and $26.5 \pm 0.4^\circ\text{C}$ and $28.7 \pm 0.6^\circ\text{C}$ 1 minute later, respectively. On the other hand, the surface temperatures of the 2 types of NTTs dipped in bottled water at 60°C decreased to $41.7 \pm 5.0^\circ\text{C}$ and $42.9 \pm 2.4^\circ\text{C}$ immediately after withdrawal, $35.6 \pm 1.7^\circ\text{C}$ and $35.3 \pm 1.4^\circ\text{C}$ 30 seconds later, and $33.3 \pm 1.3^\circ\text{C}$ and $32.0 \pm 1.0^\circ\text{C}$ 1 minute later, respectively.

Changes in Flexibility of Tracheal Tubes Due to Thermosoftening

Although thermosoftening treatment proportionally decreased the hardness of both types of NTTs, the degrees differed according to their composition (Figure 3). The Portex tube showed more flexibility than the Mallinckrodt tube at every temperature setting. Although the Mallinckrodt tube was harder than the Portex tube at 25°C, 15.2 ± 0.3 N/mm versus 9.5 ± 0.3 N/mm, respectively, the thermosoftening treatment was more effective for the Mallinckrodt tube than for the Portex tube. NTT hardness decreased proportionally with increasing temperature: reduction rates (reduction in hardness/temperature) of the Mallinckrodt tube and the Portex tube were 0.5 N/mm/°C and 0.2 N/mm/°C, respectively, in the range of 25 to 40°C. Thus, the hardness at 45°C was estimated at approximately 6 N/mm with both types of NTTs.

Clinical Incidence of Epistaxis During Nasotracheal Intubation

The records showed 2 cases of blood on the NTT only (mild epistaxis) and 2 cases of small blood pooling in the pharynx (moderate epistaxis), for an incidence of 2.3%; no cases showed blood in the pharynx sufficient to impede intubation or persistence of nasal bleeding. The

NTT could not be passed into the oropharynx via the right nostril due to impingement on the posterior wall of the nasopharynx in 15% of patients ($n = 26$), following which they were successfully intubated via the left nostril. The ratio of nasotracheal intubation via the right nostril to the left nostril was 140:31; the incidence of impingement of the NTT on the posterior wall of the nasopharynx was 18.1%.

DISCUSSION

In the bench tests, the surface temperature of both composite types of PVC NTTs decreased to below body temperature immediately after withdrawal of the tube from the bottle at 45°C and 30 seconds after withdrawal of the tube from the bottle at 60°C. Although the degrees of flexibility differed according to tracheal tube composition, thermosoftening treatment proportionally decreased the hardness of both types of NTTs. In this retrospective clinical study, the insertion site of the NTTs was changed from the right nostril to the left nostril to avoid impingement on the posterior wall of the nasopharynx in 15% of the patients, and, consequently, the incidence of mild and moderate epistaxis was 2.3% in nasotracheal intubation following thermosoftening treatment at approximately 55 to 60°C.

Kim and colleagues⁴ reported the efficacy of thermosoftening treatment of NTTs; in comparison to the incidence of epistaxis during nasotracheal intubation at room temperature (25°C) (52%), thermosoftening treatment of NTTs at 35 and 45°C decreased the incidence to 36 and 22%, respectively. Although the flexibility of PVC NTTs increases in proportion to the increasing temperature of the NTT and may lead to less epistaxis, burn injuries of the nasal mucosa should be avoided in nasotracheal intubation. The severity of heated water injury depends on the temperature of the water and the exposure time. Human exposure to hot water at 60, 55, and 51°C can lead to first-degree burns within 3 seconds, 17 seconds, and 2 minutes, respectively, whereas second-degree burns by 60, 55, and 51°C hot water take about 5 seconds, 30 seconds, and 4.2 minutes, respectively.¹² Hence, for nasotracheal intubation without burn injury, the surface temperature of the NTT should be kept at less than 50°C. The results of this study indicated that the thermosoftened NTTs cooled rapidly at room temperature; the surface temperature of PVC NTTs dipped in 60°C bottled water dropped to less than 45°C immediately after withdrawal and to skin temperature within 30 seconds. Thus, thermosoftening treatment with 60°C could provide enough time to prepare the NTT to insert into the nostril while maintaining a high temperature without burn injury.

Figure 1. Using infrared thermography, the changes in the surface temperatures of the tracheal tube between the tip and 15 cm from the proximal end are measured following dipping into 60°C water for 3 minutes. Infrared thermographs show the changes in the surface temperature after 5 minutes of the Mallinckrodt Nasal RAE Tube (a) and the Portex North Polar Preformed Tube (b) after withdrawing the tube from 60°C water. Color bars represent the temperature scale ranging from 20 to 60°C.

Kim and colleagues⁴ indicated that the incidence of nasal damage assessed by otolaryngologists was reduced from 48% at 25°C to 14% at 45°C thermosoftening treatment, and that of impingement

of the NTTs on the posterior wall of the nasopharynx was also reduced from 46 to 30%. Since the posterior wall of the nasopharynx is an area of loose tissue, forceful insertion of the tube might be the

Figure 2. Dots indicate the mean surface temperature between the tip and 15 cm from the distal end measured by infrared thermography ($n = 5$). Each polygonal line shows the sequential values of the surface temperatures of the tubes at 30-second intervals for 5 minutes after withdrawing the tube from 45 or 60°C water. (a) Mallinckrodt Nasal RAE Endotracheal Tube; (b) Ivory PVC Portex North Polar Preformed Endotracheal Tube.

most common cause of nasopharyngeal laceration following impingement of the tube.⁷ Thus, bleeding at the posterior wall of the nasopharynx due to impingement of the NTT was not negligible. We previously reported that the presence of the fossa of Rosenmüller along the direction of insertion of the tip of the NTT via the right nostril might play a significant role in failed insertion due to impingement of the tube. We speculated that the probability of impingement on the recesses is smaller during nasotracheal intubation via the left nostril.⁸ When avoiding impingement of the NTT on the posterior wall of the nasopharynx, the present retrospective study using thermosoftening treatment of the NTTs at 55 to 60°C showed low incidences of epistaxis (2.3%) and impingement (15%) assessed clinically by attending anesthesiologists. Sufficient flexibility of NTTs by thermosoftening treatment according to temperature could significantly reduce the incidence of epistaxis and impingement.

Although the thermosoftening effect is evident in both composite types of PVC NTTs, the thermal characteristics of the NTTs differed between the types. The hardness of the Mallinckrodt tube was hard (15 N/mm) at room temperature, but the thermosoftening treatment reduced hardness by 40% at body temper-

Figure 3. The pressure force for a 1-mm reduction of the minor axis of the tracheal tube was used as the index of hardness of the tube. Blue circles and orange circles indicate Mallinckrodt Nasal RAE Endotracheal Tube and Ivory PVC Portex North Polar Preformed Endotracheal Tube, respectively. Dots and error bars indicate the means and SDs. $n = 5$; ** $p < 0.01$ versus hardness at 25°C (Bonferroni's Multiple Comparison Test).

ature and by 60% at 45°C. On the other hand, the hardness of the Portex tube was 60 and 80% of that of the Mallinckrodt tube at room temperature and body temperature, respectively, but the thermosoftening effect was less than that in the Mallinckrodt tube. While nasotracheal intubation using the Portex tube could be performed with a low risk of epistaxis without thermosoftening treatment, the Portex tube may have a risk of increasing airway resistance due to intranasal constriction or kinking of the NTT.

The present study has certain limitations. First, although 2 kinds of PVC materials of tracheal tubes with a single size were measured, their wall thicknesses differed. The thermal properties of tracheal tubes could vary depending on the composition and size of the tubes. Second, the incidence of epistaxis in the clinical evaluation was not compared between groups with and without thermosoftening treatment of the NTT. Since the efficacy of thermosoftening treatment of the NTT is evident, as described in previous reports,^{3,4,10} we only used thermosoftened NTTs for nasotracheal intubation for the benefit of patients. The results of this retrospective study clearly indicated that thermosoftening treatment at 60°C had superior efficacy compared to the reported incidence of epistaxis at a lower temperature. Third, we only evaluated the clinical efficacy of thermosoftening treatment of the Mallinckrodt tubes at 60°C. The clinical efficacy of thermosoftening treatment at 60°C of the Portex tubes, as well as the Parker Flex-Tip tracheal and other tubes, which are also commonly used for nasotracheal intubation, should be explored. Fourth, we did not assess the damage to mucosa in the nasal cavity and the posterior wall of the nasopharynx. Further exploration is needed.

The results of this study showed that flexibility of the PVC NTT could easily be obtained without burn injury by thermosoftening treatment at 60°C. Thermosoftening treatment of the PVC NTTs can effectively prevent epistaxis and impingement during nasotracheal intubation.

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