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ORIGINAL ARTICLE

Laryngotracheal separation using skin flap formation: a novel surgical procedure

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Abstract Laryngotracheal separation is often performed to prevent intractable aspiration for children with severe mental and physical disabilities. However, tracheo-innominate artery fistula after surgery can occur as a severe complication and cause fatal hemorrhage. We have therefore developed a novel procedure to prevent tracheo-innominate artery fistula. Surgery was performed by making an H-shaped incision and creating skin flaps. The trachea was not raised anteriorly and the skin flaps were sutured to the trachea. We performed this procedure on nine patients, and no major complications occurred in any case. This procedure can be expected to reduce the occurrence of tracheo-innominate artery fistula.

Keywords Laryngotracheal separation · Intractable aspiration · Tracheo-innominate artery fistula

Introduction

In recent years, laryngotracheal separation has often been performed to prevent intractable aspiration, a major problem for children with severe mental and physical disabilities. However, tracheo-innominate artery fistula has been reported as one severe complication of this procedure. Tracheo-innominate artery fistula causes massive hemorrhage and can be fatal. The frequency of this fistula in conventional laryngotracheal separation is relatively high compared with that in tracheotomy. In addition to thoracic deformities of children with severe mental and physical disabilities, one reason might be that the trachea is shifted closer to the skin during this procedure, compressing the trachea by the innominate artery. We report a novel surgical procedure of laryngotracheal separation using skin flap formation to avoid this shift of the trachea, with the aim of reducing the frequency of tracheo-innominate artery fistula.

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Patients and methods

Between August 2009 and March 2010, we performed the novel procedure of laryngotracheal separation on nine patients with severe mental and physical disabilities. Patient age ranged from 1 to 23 years, with an average of 9 years. Six were male and 3 were female, with 5 having an existing tracheotomy (Table 1).

We investigated the positional relationship at the innominate artery level by comparing preoperative and postoperative computed tomography (CT) images for ten cases of the conventional procedure and eight cases of the novel procedure. We also investigated the difference in operation time between 34 cases of the conventional procedure and 9 cases of the novel procedure.

Data were expressed as mean ± standard deviation. Results were compared by using Mann–Whitney's U test for paired analysis and using the Wilcoxon signed-ranks

Table 1 Clinical characteristics and outcomes of nine cases

Case	Sex	Age	Tracheotomy	Cranial side of skin flap	Tracheal tube	Complications
1	M	13	+	Subcutaneous	Removed	
2	M	2	+	Subcutaneous	Used for tracheomalacia	
3	F	6	−	Subcutaneous	Used for humidification	
4	M	23	+	Subcutaneous	Removed	Tracheocutaneous fistula
5	M	8	−	Below investing layer of cervical fascia	Removed	
6	F	17	−	Below investing layer of cervical fascia	Used for tracheomalacia	
7	M	5	−	Below investing layer of cervical fascia	Removed	
8	M	5	+	Below investing layer of cervical fascia	Used for humidification	
9	F	1	+	Below investing layer of cervical fascia	Used for humidification	

test for unpaired analysis. Results showing probability levels <0.05 were considered significant.

Surgical technique

An H-shaped skin incision was made and flaps on the cranial and caudad sides were created. The cranial-side flap was longer because a larger flap was required on that side (Fig. 1a). The width of the skin incision was approximately the same as that of the trachea or slightly larger. In order to preserve circulation to the skin flaps, the length:width ratio was kept as close as possible to 1:1, without exceeding 2:1 even when a long skin flap was required. In patients with a tracheotomy, the skin around the tracheotomy was hard and scar tissue had developed subcutaneously, so this was resected as it was unsuitable for skin flaps (Fig. 1b). The skin flap on the cranial side was created by detaching the layer above the anterior jugular vein and below the investing layer of cervical fascia, and the skin flap on the caudad side by subcutaneous detachment. A vertical incision was made in the center of the sternohyoid muscle, and the thyroid gland was dissected at the isthmus and adequate hemostasis performed. The anterior half-circumference of the trachea was detached cranially as far as the cricoid cartilage and caudally as far as the fourth or fifth tracheal ring, without detaching the posterior surface. Stay sutures of nylon thread were inserted on the left-hand and right-hand surfaces of the trachea. After a vertical incision had been made in the trachea, additional horizontal incisions were made half-way around the circumference of the trachea at the top point of this vertical incision and from 1/3 to 2/5 of the way around the circumference at its bottom point, opening up the anterior surface of the trachea like a set of double doors (Fig. 1c). The upper horizontal incision was made between the first and second tracheal rings. Because the horizontal incision could only be made at the top edge of the tracheotomy, however, an upper incision was made between the cricoid cartilage and the first tracheal ring in one case with high tracheotomy. An incision of the posterior wall was made to a distance of approximately 1/2–2/3 of its thickness from inside the trachea at the upper horizontal incision level. After the incised area had been opened to a width of approximately 2 mm, the cranial stump of tracheal membrane was then cauterized with an electric scalpel at a width of approximately 2–3 mm around the entire circumference, creating a rough surface to which the closure portion could easily adhere. In addition, incisions were made in the left and right sides of the first tracheal ring, and wedge resections were made in several places in the first tracheal cartilage and the cricoid cartilage by using an electric scalpel. After these had been pushed down dorsally with the fingers to fracture the cartilages, no strain was imposed on the sutures. Knotted sutures were inserted in the cranial edge of the incision in the posterior wall and the anterior wall with 3-0PDS and the oral stump was closed (Fig. 2). The tracheostomy was formed cranially and caudally by skin flaps and on the left and right by tracheal flaps. The cranial skin flap was sutured to the caudal edge of the incision in the

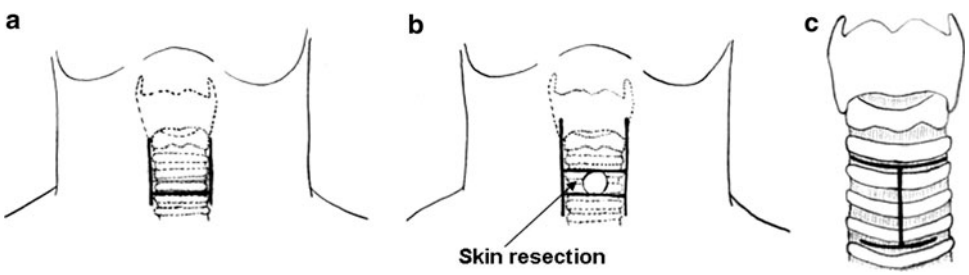

Fig. 1 **a** H-shaped skin incision without tracheotomy. **b** H-shaped skin incision with tracheotomy. **c** Incision in trachea: opening up the anterior surface of the trachea like a set of double doors

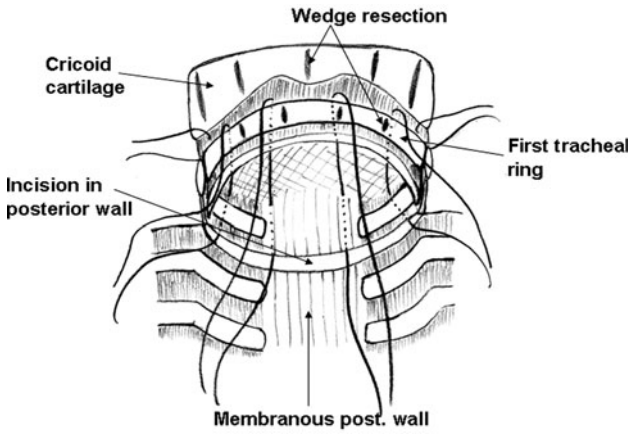

Fig. 2 Closure of oral trachea. The posterior wall was not detached. An incision was made in the posterior wall from inside the trachea. After the first tracheal cartilage and the cricoid cartilage were pushed down dorsally with the fingers, knotted sutures were inserted in the cranial edge of the incision in the posterior wall and the anterior wall with 3-0PDS

posterior wall of the trachea, the caudal skin flap to the anterior wall at the caudal edge of the tracheostomy, the left and right edges of the cranial skin flap to the cranial edge of the tracheal flap, and the skin on left and right to the left and right tracheal flaps (Fig. 3a). During this process, the cranial skin flap was pulled close to the incision in the tracheal posterior wall, and if it was under strong strain, the length of the skin flap was increased. As the skin of the neck extends easily, sufficient skin flaps could be obtained even in patients with high tracheotomies. As the cranial skin flap was long, the cranial tip was closed by a skin–skin suture (Fig. 3b).

Results

No major complications occurred in any of the nine cases. Transient tracheocutaneous fistula was observed in one patient, but this closed after 1 week without surgical intervention. Redness in the cranial skin flap was observed in the first four patients, but this improved in 1–2 weeks with the administration of antibiotics, and no infection was observed in the second five patients in whom the skin flap was formed by detaching the layer below the investing layer of cervical fascia. A tracheal tube was used postoperatively in five patients. In three of these, it was used for humidification, and the other two were patients with tracheomalacia from whom the tracheal tube could not be removed. In the other four cases, the tracheal tube was removed, and there was no tendency toward stenosis of the tracheostomy even 8 months after its removal.

Postoperative CT showed that the trachea was not raised anteriorly compared with its preoperative position (Fig. 4). There was no significant effect of the novel procedure on the length from the trachea to skin at the innominate artery level (LTSI) according to a comparison of preoperative and postoperative CT scans. In the conventional procedure, however, postoperative LTSI decreased significantly compared with preoperative LTSI ($p = 0.0034$). There was no significant difference in preoperative LTSI between the conventional and novel procedures (Fig. 5). We calculated the ratio of tracheal displacement (RTD) as the postoperative LTSI divided by the preoperative LTSI. There was a significant difference in RTD between the conventional procedure (0.86 ± 0.11) and the novel procedure (1.09 ± 0.14) ($p = 0.0015$). Operation time for the conventional procedure (109.1 ± 37.3 min) and the novel procedure (109.4 ± 26.2 min) was unaltered.

Discussion

Reported surgical procedures for preventing intractable aspiration of children with severe mental and physical disabilities include glottic closure [1] and supraglottic closure [2, 3] in addition to laryngotracheal separation, all of which have both advantages and disadvantages. In recent years, however, laryngotracheal separation has often been performed owing to its simplicity, as it does not require surgical operation on the larynx. Laryngotracheal separation was first reported by Lindeman, and both tracheoesophageal diversion [4] and laryngotracheal separation can be performed [5]. There is no consensus of opinion at different institutes concerning the relative advantages of

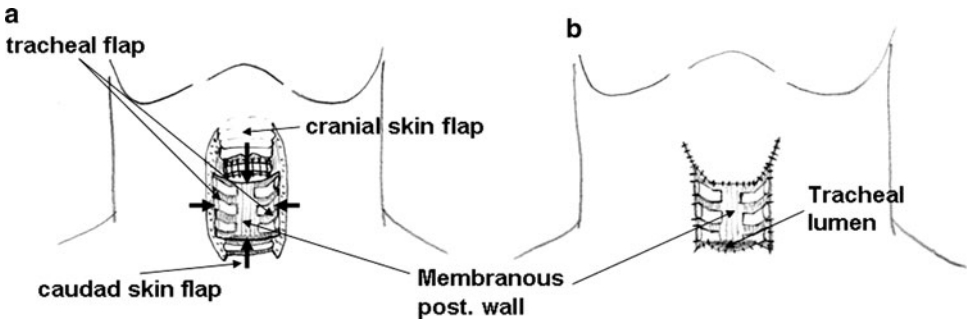

Fig. 3 **a** The tracheostomy was formed cranially and caudally by skin flaps and on the left and right by tracheal flaps. **b** As the cranial skin flap was long, the cranial tip was closed by skin–skin suture

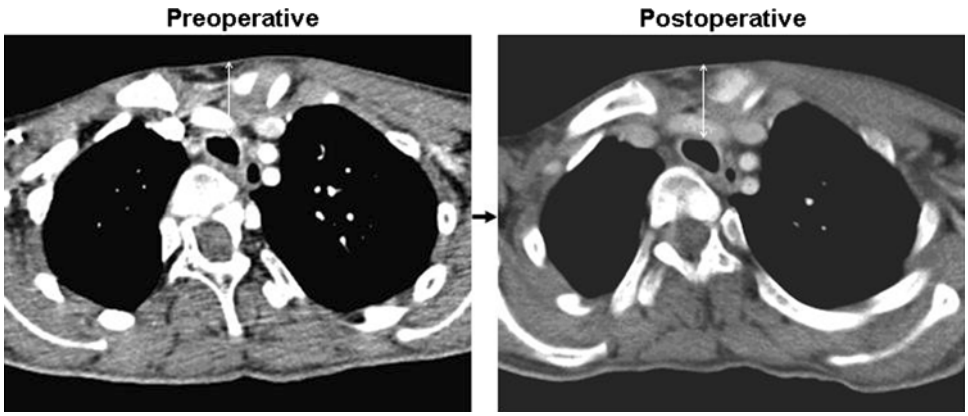

Fig. 4 There was no change in tracheal position between postoperative and preoperative CT scans as a result of the novel procedure

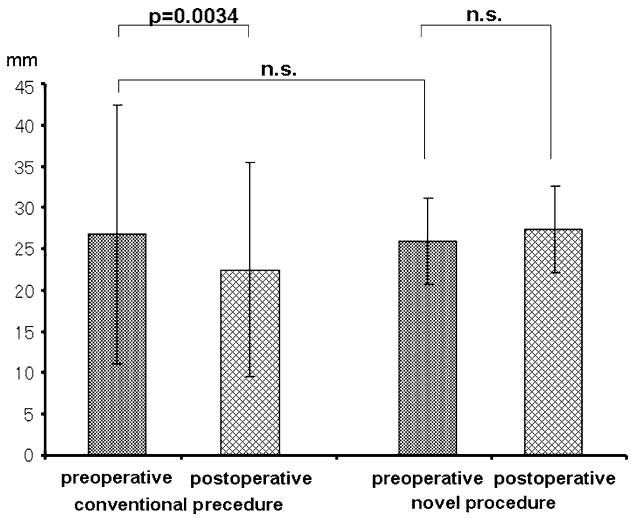

Fig. 5 Postoperative LTSI decreased significantly compared with preoperative LTSI in the conventional procedure ($p = 0.0034$). There was no significant difference between preoperative and postoperative LTSI as a result of the novel procedure. There was no significant difference in preoperative LTSI between the conventional and novel procedures

each procedure and which should be chosen [6, 7]. We had initially been performing tracheoesophageal diversion, but shifted to laryngotracheal separation owing to the ease of the procedure and the lack of major problems without tracheoesophageal anastomosis. Reported complications include infection, tracheocutaneous fistula, tracheostomal stenosis, granuloma, hemoptysis, and tracheo-innominate artery fistula [8–10], among which tracheo-innominate artery fistula can be fatal. We also experienced more numbers of tracheo-innominate artery fistula as cases of laryngotracheal separation increased. Before laryngotracheal separation, when we were managing such patients by tracheotomy only, tracheo-innominate artery fistula had been an extremely rare complication at our hospital, with only two cases in 30 years. However, during the 6-year period in which we performed laryngotracheal separation, this complication occurred in 4 out of 53 cases (7.5%), 1 of whom died as a result of hemorrhage. Innominate artery ligation was performed in five cases, including two in which it was carried out prophylactically. In addition to thoracic deformities of children with severe mental and physical disabilities, one reason might be the shift of the trachea closer to the skin, resulting in the trachea being compressed by the innominate artery.

The surgical procedure we report here was developed so as to avoid this shift of the trachea. Its advantages are as follows. (1) As the trachea is not raised anteriorly, there is little tracheal shift, meaning that the occurrence of tracheo-innominate artery fistula could be expected to become less frequent. (2) The formation of a rectangular tracheotomy by left and right tracheal flaps could make it harder for stenosis to occur, and enables tube removal in those patients that do not require a respirator. (3) As the posterior wall of the trachea is not detached, the risk of esophageal injury during surgery is low. The disadvantages of this method are as follows. (1) The risk of infection and frequency of tracheocutaneous fistula might increase, because the upper tracheal closure site is directly underneath the cranial skin flap. To date, there have been no cases of suture failure or severe infection such as abscess, but redness of the cranial skin flap was observed in some patients. Preoperative culture tests of respiratory tract secretions and the administration of sensitive antibiotics are therefore required. (2) Because not all layers of the posterior wall of the trachea are resected, the oral tracheal stump is difficult to flatten anterio-posteriorly, and closure might be difficult. Techniques such as performing wedge resection of the tracheal cartilage or cricoid cartilage are required in order to flatten the trachea anterio-posteriorly. It is also possible to dissect the posterior wall of the trachea completely until the soft tissues between the trachea and esophagus are exposed, closing them after the circumference of the oral stump has been detached. As this raises the posterior wall of the trachea somewhat, however, we have so far refrained from complete dissection, choosing to perform surgery with the fewest possible incisions. Although the follow up

period is still short, laryngotracheal separation using skin flap formation could avoid a shift of the trachea, and we therefore consider this procedure to be useful for reducing the frequency of tracheo-innominate artery fistula.

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