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Surgical Tactic with Development of New Algorithm for Selecting an Elimination Method of the Anterior Tracheal Wall Defects

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Abstract **Aim** of the study was to improve the treatment results of patients with persistent defects of the anterior wall of the trachea and soft tissues of the neck. **Material and methods.** 220 patients with cicatricial tracheal stenosis were treated at the Republican Specialized Scientific and Practical Medical Center for Surgery named after academician V. Vakhidov. 120 of them had defects in the anterior tracheal wall of various sizes. There were 89(74,2%) males and 31(25,8%) females. The patients' age ranged from 6 to 70 years (mean age was 30.19 ± 1.21 years). All patients were performed mandatory endoscopic and MSCT examinations. The patients were performed surgical treatment after a planned examination. **Results and discussion.** The literature data on reconstructive-plastic methods for eliminating open tracheal defects were summarized and analyzed in the article. The advantages and disadvantages of various plastic materials for closing extensive tracheal defects were given. Unresolved issues in the treatment of persistent extensive defects of the anterior tracheal wall, problems of terminology and clear distribution of defects were indicated. The authors presented an original classification of fenestrated tracheal defects and their own algorithm for choosing a method of closing a defect depending on its parameters up to complete restoration of the airway patency. **Conclusion.** The choice of the method for plastic elimination of the tracheal defect depends on the size, depth of the airway lumen and the condition of the donor skin in the area of operation.

Keywords Laryngotracheostomy, Persistent extensive defects, Trachea, Classification, Algorithm

1. Introduction

Despite the detailed methods of preventing of the airway walls injuries during prolonged mechanical ventilation, the number of patients with iatrogenic postresuscitation cicatricial tracheal stenosis (CTS) is not decreased. Moreover, there has been a tendency towards an increase in the proportion of patients with extended and multifocal lesions [1-3].

A complex of endoscopic, surgical measures, as well as methods of reconstructive and plastic surgery are used in the treatment of patients with CTS. When patients with critical and decompensated forms of CTS are admitted, the first stage is endoscopic methods of expanding and maintaining of the tracheal lumen in the narrowing area. In the case of plastic surgery of the tracheal lumen on a T-shaped stent after prolonged exposure, the question of how to eliminate an open defect arises in the future.

A great progress has been made in the treatment of patients with chronic tracheal stenosis recently. But the issues of plastic surgery and closure of the defect are still controversial and it is confirmed by the literature data analysis [4-7].

Circular tracheal resection (CTR) belongs to the category of complex reconstructive interventions, requires the coordinated work of thoracic surgeons, endoscopists and anesthesiologists-resuscitators and should be performed in specialized clinics. Simultaneous resection of the trachea with an end-to-end anastomosis and elimination of the tracheal anterior wall defect from the cervical approach can be performed only in the absence of evident neurological deficit, a non-extensive defect of the trachea with the presence of tracheomalacia, which does not allow to perform musculocutaneous plasty with local tissues. Plasty of extensive defects of the trachea cervical part involves the restoration of not only the soft tissue defect, but also the mucous lining and frame function of the trachea and it requires a sufficient supply of complete, hairless skin in the reconstruction zone [8-9]. The absence of such areas near the tracheal defect (sharp dystrophic or cicatricial changes) requires the use of tissues with skin taken from other areas of the patient's body (the formation of the Filatov's flap, the movement of fascial skin flaps on the vascular pedicle, autotransplantation of complex flaps on microvascular anastomoses) [10-11].

A large number of possible tissues and materials, as well

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as options for surgeries aimed at eliminating the defect of the cervical trachea have been proposed. The basic requirements for them are clearly formed: they must be of sufficient size, provide a frame function and the ability to evacuate secretions and also be resistant to infection [1,5,7,12-14]. Despite this, the problem is relevant and continues to be the subject of research and discussion of thoracic surgeons, plastic surgeons and otolaryngologists. The choice of a method for eliminating a tracheal defect depends on its size, the depth of the airway lumen and the state of the tissues surrounding the defect [8,11,14-15].

Aim of the study was to improve the treatment results of patients with persistent defects of the anterior wall of the trachea and soft tissues of the neck.

2. Material and Methods

220 patients with cicatricial tracheal stenosis were treated at the Republican Specialized Scientific and Practical Medical Center for Surgery (RSSPMCS) named after academician V. Vakhidov from March 2008 to December 2020. 120 of them had defects in the anterior tracheal wall of various sizes. There were 89(74,2%) males and 31(25,8%) females. The patients' age ranged from 6 to 70 years (mean age was 30.19 ± 1.21 years).

Goryainov D.A. (2014) referring to Grillo H.C., (2004) indicates that tracheal defects can be fenestrated and circular, small and large. Unfortunately, there are no other divisions of tracheal defects, especially the classification and clear definition of defects. In the absence of such, we took the liberty of developing our own working classification of tracheal defects.

Classification of tracheal defects (RSSPMCS named after academician V. Vakhidov)

I. By defect's structure

Fenestrated tracheal defects

A - Small (up to 1.5 cm^2)
B - Large (from 1.5 cm^2 to 5.0 cm^2)
C - Extensive (over 5.0 cm^2)

II. By the duration of the defect persistence

1. Persistent (are persisted after the tracheostomy removal for more than 2 months).
2. Unstable (are closed independently after the tracheostomy removal within 2 months).

III. By the appearence mechanism

1. Post-traumatic
2. Formed laryngotracheostomy

IV. According to the condition of tracheal walls near the defect

1) Morphologically restoration of multi-row epithelium with ciliated and goblet cells
2) Tracheomalacia and overgrowth of coarse-fibrous connective tissue (chronic tracheocannulars)
3) The presence of a tracheoesophageal fistula

V. By the height (depth) of the side walls of the defect

1) Less 13 mm
2) More 13 mm, but less 15 mm
3) 15 mm and more

All patients with an open tracheal defect (OTD) had tracheal stenosis of varying degrees before admission to the center. These patients had previously undergone plastic surgery of the tracheal lumen with the expansion of the stenotic area, removal of granulations and the installation of a T-shaped stent, commensurate with the location and length of the affected area. It should be noted that this is a difficult category of patients, each of whom has undergone a total of 3 to 11 operations. Before admission to our center 98 patients were performed tracheostomies. In 5 cases at intermediate stages of treatment, modified endotracheal tubes passed through the defect of the anterior tracheal wall, the so-called "clefts" were used. In 24 cases plastic surgery of the tracheal lumen was performed on a T-shaped stent, mainly by ENT doctors. 32 patients were referred from other hospitals of the country to close an existing OTD. 88 patients were hospitalized again for the final stage of a staged reconstructive plastic surgery (SRPS) - earlier in the Department of the lungs and mediastinum surgery they were performed stages of endoscopic coagulation, bougienage of tracheal stenosis followed by plastic surgery of the trachea with the formation of a lumen on the T-shaped stent. Therefore, when patients were admitted for OTD elimination they were of different sizes and depths. It was necessary to evaluate the parametric data of the defects of the anterior tracheal wall themselves to select the optimal tactics of surgical treatment for each specific patient. The high accuracy of measuring geometric relationships in comparison with bronchoscopy is an advantage of MSCT. MSCT allows to perform differential diagnostics between tracheomalacia and expiratory stenosis, external compression. It can be used as a criterion for the effectiveness of the surgical treatment of patients with tracheomalacia. The disadvantages of the method include radiation exposure, so its frequent repetition is not always justified. Three-dimensional models can be useful to improve the efficiency of X-ray diagnostic techniques and allow estimating the volume of surgical intervention when planning an operation (Fig. 1).

Unlike traditional endoscopy, virtual endoscopy allows to see both the inner and outer surfaces of the trachea on the monitor screen. The main advantages of MSCT: 1) the ability to accurately visualize the airway in a pathological process both in three planes and in the variant of volumetric reconstructions; 2) an objective assessment of the OTD parameters, the existing stenosis of the larynx and trachea above and below the defect; 3) the ability to assess the condition of the walls of the larynx and trachea, surrounding organs and tissues; 4) non-invasiveness.

Frontal and lateral projections obtained with MSCT allow obtaining accurate information about the diameter, length of narrowing, deformation of the cartilaginous semirings frame

and changes in peritracheal tissue, the size of the defect in the anterior wall of the trachea. All this helps to answer the main question facing the surgeon - how to eliminate OTD and completely restore the tracheal lumen (Fig. 2).

In patients with persistent OTD, with the size of the defect not exceeding 16 mm in width and up to 30 mm in height, musculocutaneous plasty was performed with the simultaneous elimination of the defect with local tissues. In the presence of OTD, but also with tracheomalacia, restenosis and defect of the anterior tracheal wall after laryngotracheoplasty, as well as the presence of tracheoesophageal fistula (TEF) in combination with cicatricial tracheal stenosis after ineffective attempts of elimination by endoscopic and surgical methods, CTR was performed in 5 cases. Thirteen patients had extensive defects in the anterior-lateral walls of the cervical trachea and subglottic larynx, as well as a deficiency of soft tissues of the neck around the stoma. The sizes of the defect in one case were 3x8 cm.

3. Results

Depending on the size and nature of the elimination of the anterior tracheal wall defect the patients were divided into two groups (Tab. 1).

Figure 1. 3-D reconstruction of the tracheobronchial tree of a patient with OTD

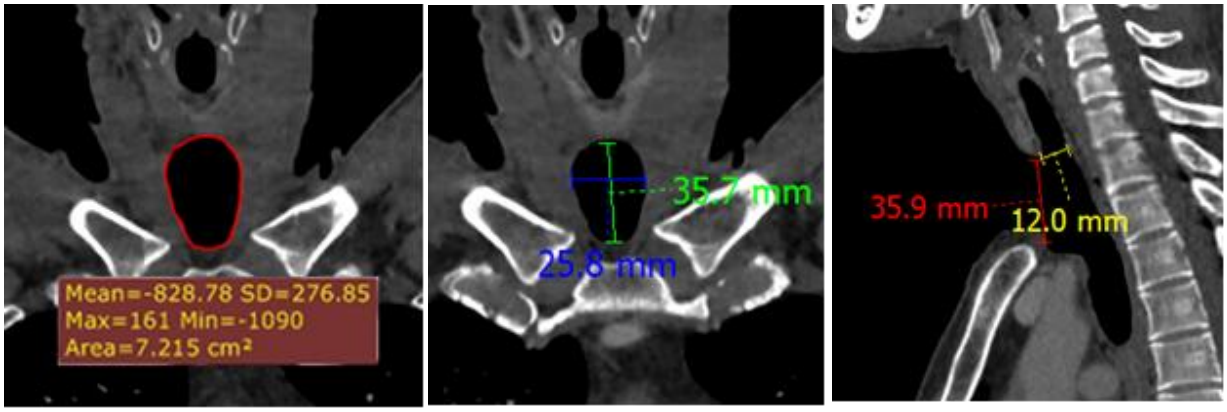

Figure 2. MSCT in frontal and lateral projections with measurement of the parameters of the OTD

Table 1. Comparison of OTD average parameters in groups

OTD parameres	General group	Group 1				Group 2
		1 A	1B	1C	1D	
	n=120	n=87	n=5	n=7	n=8	n=13
Width	15.91±0.33	15.70±0.21	13.8±0.96	9.71±1.64*	15.25±0.52	21.92±1.46*
Height	26.87±0.8	25.89±0.41	21.2±2.48	13.28±2.2*	24.62±1.07	44.15±3.79*
Depth	14.97±0.16	15.60±0.07	15.2±0.37	15.42±0.52	14.87±0.51	10.46±0.29*

Note: * - significant difference from the indicators of the general group and 1 A group ($p < 0.05$).

Each group has several subgroups. The first group: subgroup A - patients in whom the defect was closed by skin-muscle-skin plasty according to Bokstein in the modification of our Department (n=87). Subgroup B includes patients with circular tracheal resection with elimination of the defect (n=5). Subgroup C included patients in who after elimination of tracheal stenosis and decannulation, thrachea closed independently or after applying several sutures due to its small size up to 8-10 mm (n=7). Subgroup D - the rest of the patients were in the intermediate stages of treatment, chronic tracheocannulars (n=8). The second group consisted of 13 patients: the tracheal defect was eliminated using microsurgical techniques as the size of the defect was significantly larger and, according to our classification, was defined as persistent extensive defects. Subgroup A - implantation of prefabricated autocostal cartilages (n=5). Subgroup B - plasty with displaced flaps (n=8). Subgroup C - plastic surgery using a prefabricated fascial-cartilaginous flap on a vascular pedicle (n=2). The total number of patients in the group was 15, as in 2 cases plasty was used with prefabricated autocostal cartilage supplemented with rotational flaps due to complications associated with the prolapse of the cartilaginous skin flap into the tracheal lumen. Conducted morphological studies of biopsy specimens of the tracheal mucosa showed that over time the multi-row epithelium of the tracheal mucosa was restored. The multi-row epithelial lining with an accumulation of superficial prismatic cells has been determined after 5 months already. Moderate perinuclear edema and mitotic figures in the basal parts of the multilayered epithelium are noted in prismatic cells. Rather large vacuoles were detected in its own connective tissue layer of the mucosa. However, during this period, the appearance of prismatic cells with characteristic cilia, as well as goblet cells has not been noted yet.

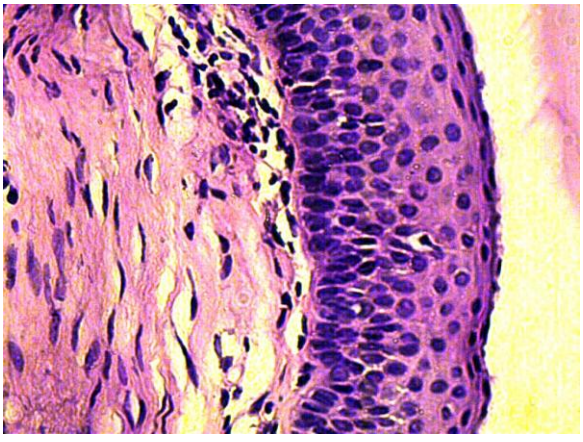

Figure 3. Multi-row epithelial lining with accumulation of superficial prismatic cells, moderate perinuclear edema and mitotic figures in the basal parts. 7 months. OTD. G-E. 10x40

7-10 months after the patient's stay with OTD a well-formed multi-row epithelial lining was noted, but without the presence of ciliated and goblet cells. There are quite a lot of blood vessels in the own connective tissue layer of the mucous membrane. There are figures of mitosis in the basal parts of the multilayered epithelium (Fig. 3).

In more distant terms (12-15 months from the beginning of the formed laryngotracheostomy) we observed an evident tendency for the appearance of ciliated and goblet cells in the surface layers of the multilayered epithelium. There were quite a few vessels in its own connective tissue layer and there were small accumulations of inflammatory infiltrates in the perivascular zones (Fig. 4).

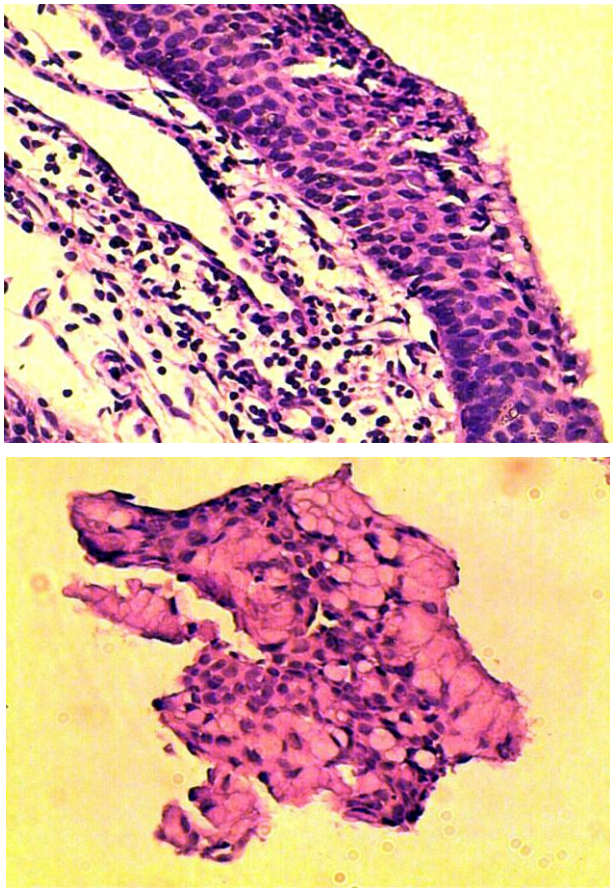

Figure 4. A) The multi-row epithelial lining with an accumulation of superficial prismatic cells. 12 months. OTD. B) Goblet cells of the epithelial lining. 15 months. OTD. G-E. 10x40

Analysis of biopsies, depending on the timing of the study shows that tracheal stenting with traditional therapy leads to a decrease in edema and inflammation of the tracheal walls. If at the beginning of surgical treatment at severe tracheal stenosis there is a sharp reduction in the epithelial lining of the mucous membrane with a significant proliferation of coarse connective tissue in the tracheal wall, then the multi-row epithelial lining is restored, and highly specialized ciliated and goblet cells appear.

Naturally, the OTD is closed only if the patient no longer needs the stoma for any purpose. If the stoma is still needed for suction of mucus, or if there is a possibility of immediate re-tracheostomy, then closure is meaningless. If granulation tissue surrounds the stoma, closure should also be avoided. The minimum dilation period is 5 months. In the presence of

severe tracheomalacia and the growth of coarse fibrous connective tissue in the tracheal wall, even after 10 months of stenting, OTD elimination should not be carried out due to the high risk of re-stenosis. In these cases it is necessary to prolong the T-shaped stenting of the trachea for 1-2 years. The final decision on the timing of closure of the laryngotracheostomy is based on the morphological study of biopsies of the lateral walls of the defect and trachea. In the case of chronic tracheocannulars, even in terms of more than 3-5 years, there is no restoration of the multi-row epithelium with highly specialized ciliated and goblet cells and a significant growth of coarse-fibrous connective tissue in the tracheal wall remains, which, according to our material, leads to restenosis in 87.5% of cases during the first 3 days with decannulation.

4. Discussion

We have developed our own algorithm for choosing a method for closing the defect depending on the size of the defect in the anterior tracheal wall. The application of this algorithm allows to use a differentiated choice of treatment tactics with the performance of a certain type of reconstructive plastic surgery for fully restoration of the airway patency. The choice of tracheal defect eliminating method depends on its size, the depth of the airway lumen and the state of the donor skin in the area of the defect. At small-sized defects skin-muscle-skin plasty (SMSP) according to Bokstein is performed in the modification of our clinics. CTR at OTD can be performed with limited stenosis without severe concomitant pathology, when there is tracheomalacia, restenosis, and the presence of a tracheo-esophageal fistula (TEF) in combination with cicatricial tracheal stenosis after ineffective attempts of elimination by endoscopic and surgical methods. A cartilaginous skin flap is used for large defect sizes which is prepared 1.5-2 months before the final operation. One of the main parameters in eliminating of a tracheal defect is the depth of the airway lumen - the distance from the anterior edge of the tracheostomy to the posterior wall of the trachea. When the depth of the lumen is less than 13 mm, the indications for plasty with autocostal cartilage are considered as a framework (Fig. 5).

At an evident cicatricial process around the defect (as a result of repeated surgical interventions) and the impossibility of using Bokstein's method in cases of persistent extensive defects in the anterior wall of the trachea and soft tissues of the neck, plastic surgery with skin-fascial displaced flaps is effective. When using a displaced flap to form a mucous lining in the area of a tracheal defect, it is advisable to use this flap as the first stage of biological training, which consists in separating it and re-fixing it with sutures to the maternal bed. The task of this stage is to enhance the axial blood circulation and increase the graft rate of the flap. The main stage is carried out 12-14 days after the first stage. The indication for the use of displaced flaps for plasty is a satisfactory depth (not less than 13 mm) and a defect size of not more than 20x45 mm.

A complex-compound prefabricated flap (delto-pectoral skin-fascial-cartilaginous flap) is recommended for use in the presence of a persistent extensive tracheal defect (more than 10 cm^2), evident cicatricial transformation of the surrounding soft tissues and a formed tracheal lumen at this level, without signs of airway restenosis, absence of inflammation and infection of tissues around the defect. Thanks to the optimization of tactics and the introduction of a modified 4-layer SMSP method we managed to reduce the number of complications from 28.8% to 13.04%. The most formidable is the prolapse of the flap into the tracheal lumen after SMSP in the early postoperative period clinically manifesting itself by progressive respiratory failure (Tab. 2).

Table 2. Evaluation of the significance of the complications rate depending on the plasty technique

Complications type	Three-layer SMSP (n=47)	Modified SMSP (n=46)
Re-stenosis	2 (3.84%)	0
Tracheal flap prolapse after SMSP	4 (7.69%)	2 (4.34%)
Partial suture failure	9 (17.3%)	4 (8.69%)
All complications	15 (28.8%)	6 (13.04%)*
Criterion name	Criterion value	Significance level
$\chi 2$ test	4.736	P=0.030
Fisher's exact test (two-sided)	0.04599	P<0.05
McNemar's test	11.364	P<0.001

* The decrease in the frequency of the trait is statistically significant, $p < 0.05$

In 13 patients there was a partial insufficiency of the postoperative suture, with the flow of air from the zone of the created musculocutaneous anterior wall without divergence of the internal sutures. In all cases, by conservative methods with the imposition of aseptic ointment dressings, the elimination of signs of inconsistency of the seams was achieved with the cessation of air flow during phonation and coughing with hermetic closure of the defect. T-shaped restorations were required in 6 cases of early OTD due to flap prolapse into the tracheal lumen and in 1 case 6 months after SMSP as a result of restenosis. Subsequently, these patients were performed repeated surgery, the choice of OTD closure depended on the size of the tracheal defect and the state of the surrounding tissues.

As a result of the application of an improved diagnostic and treatment algorithm, the introduction of 4-layer plastics of the OTD, we were able to reduce significantly the number of complications in the early postoperative period and to decrease the number of repeated interventions aimed at expanding the tracheal lumen from 25.5% to 6.5%.

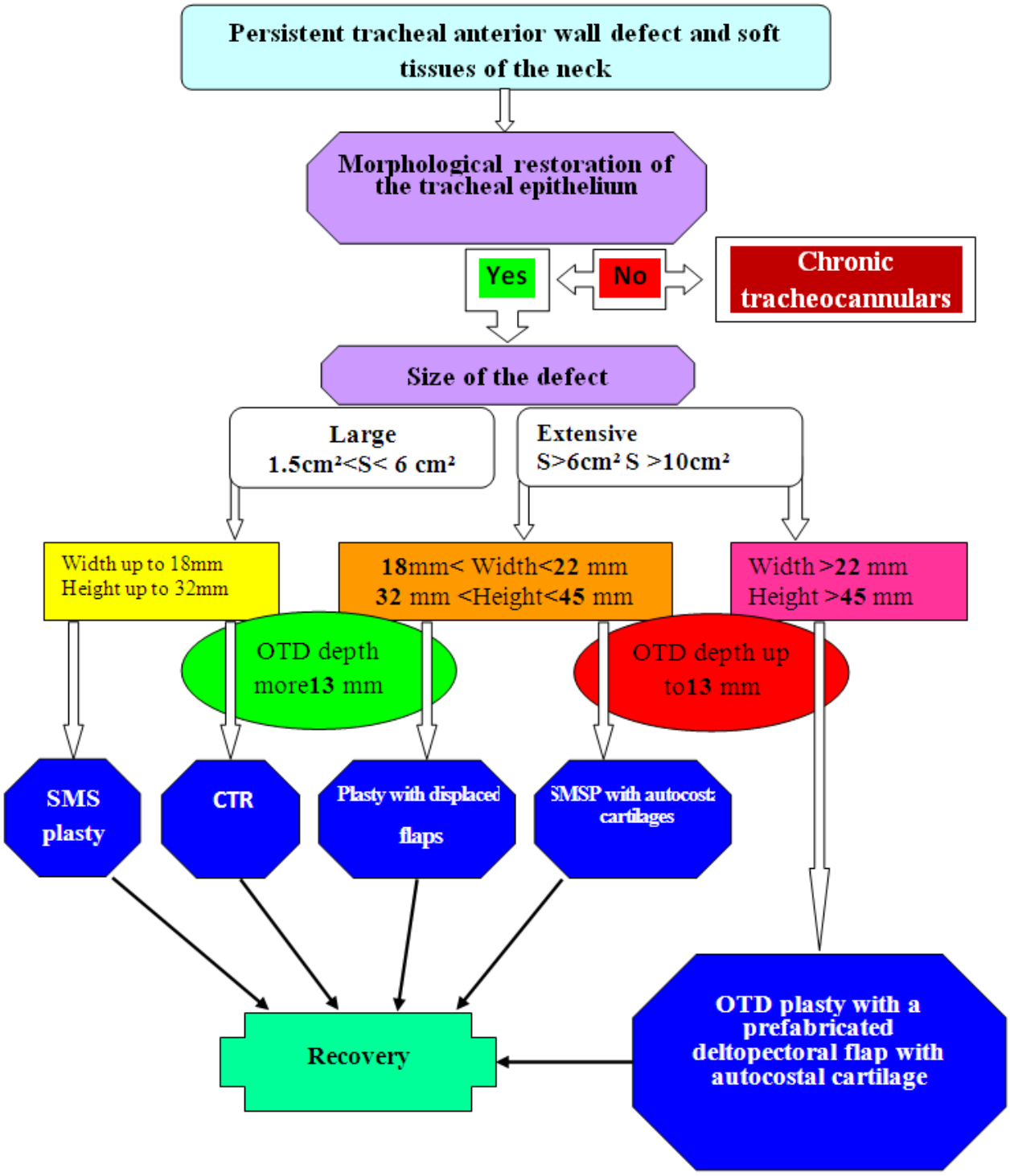

Figure 5. Algorithm of choosing a method for closing a defect depending on the size of the OTD

5. Conclusions

When determining the strategy of eliminating defects of the trachea and soft tissues of the neck, there are no and cannot be absolutely established dogmas. In each specific case we have to choose one or another reconstruction option. Even fundamentally similar interventions in technical aspects can differ significantly from each other. The choice of the plastic elimination method of the tracheal defect depends on the size, depth of the airway lumen and the condition of the donor skin in the area of surgery. The timing of OTD elimination depends on the restoration of the stratified epithelium with highly specialized ciliated and goblet cells. If there is a significant proliferation of coarse-fibrous connective tissue in the tracheal walls adjacent to the defect, there is a high risk of restenosis during the first days after decannulation, which requires prolongation of T-shaped stenting.

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