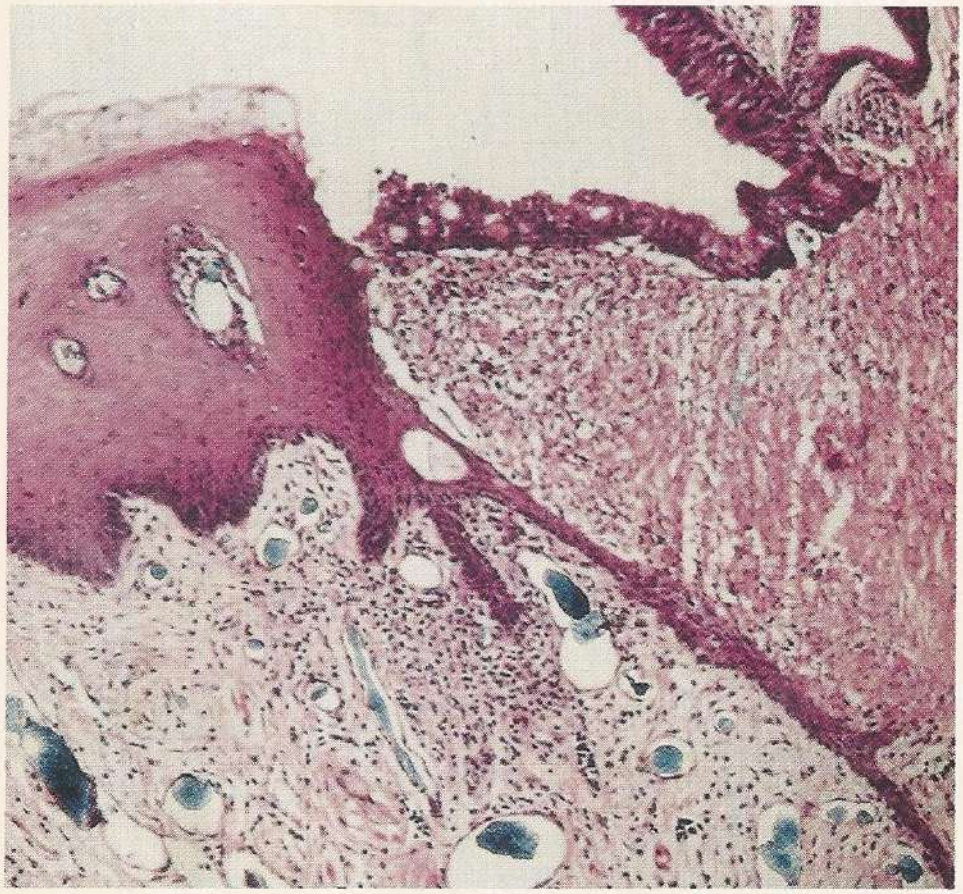

Experimental Laryngotracheal Reconstruction

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Experimental Laryngotracheal Reconstruction

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Delaere P.R., Boeckx W.D., Ostyn F., Tyberghein J. (1990) : Laryngoplasty with vascularized and non-vascularized auricular mucochondrial grafts. Orl J Otorhinolaryngol Relat Spec 52:107-110.

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Introduction

"The theme throughout is the perpetual battle of beauty versus blood supply. Herein lies the drama."

(D. Ralph Millard jr., 1957)

The larynx has three important functions : it conducts the air needed for ventilation, it generates the voice, it functions as a sphincter to protect the airway during swallowing and creates a seal for airtight postural effort.

These functions are in danger in different diseases :

1. Pathology of neuromuscular functions with loss of motoric or sensory innervation.
2. Fixation of the cricoarytenoid joints with subsequent impossibility to adjust the glottic opening and closure when needed, i.e. during respiration, speaking and swallowing.
3. Loss of anatomical substance - such as after trauma and removal of neoplasms.
4. Loss of cross section due to laryngotracheal stenosis.
   - After severe blunt laryngotracheal injuries, especially if poorly managed or if not treated early (Delaere et al. 1990, Verwoerd et al. 1991).
   - Complications of intubation with pressure by a stiff and unpliable endotracheal tube. This causes continuous pressure on a localized area of the mucosa often exceeding the arterial pressure. This causes disruption of blood flow and subsequent ischemic necrosis. Formation of granulation tissue and ulcerations are followed by dense scarring, usually seen after cartilage exposure. Perichondri-

tis may be present. This enlarges the region of stenosis by submucosal fibrosis and cartilaginous thickening (Andrews 1971, Cotton 1978, Stauffer et al. 1981, Whited 1984).

The first two diseases are beyond the scope of this study. Several options are available in solving the loss of substance and loss of cross section :

1. Conservative treatment in light cases such as direct suture and CO_2 evaporation (Koufman et al. 1981, Dedo et al. 1984, Ossoff et al. 1985, Shapshay et al. 1987).
2. Resection of a laryngeal or tracheal compartment and bridging the defect with an end-to-end anastomosis (Maassen et al. 1985, Pearson et al. 1986, Grillo et al. 1988). This works well if there is sufficient vascularization at the suture line. The outcome is less satisfactory if the blood supply is impaired after previous radiotherapeutic treatment (Muira et al. 1966, Salassa et al. 1977).
3. The marjority of the severe cases however need reconstruction with adding regional or distal tissue to the laryngotracheal tract (Rethi 1956, Biller et al. 1981).

The prerequisites for optimal reconstruction can be deduced from methods established in other areas. In the last years, it became clear that function after reconstruction is best served when well vascularized tissue is used with physical characteristics similar to those of the resected tissue. Microvascular surgery has revolutionized the possibilities in reaching this objective.

The following requirements can be formulated when applying this principle for laryngotracheal wall reconstruction :

1. The reconstruction technique should be supported by **a solid framework** (Toohill 1979) of bone, cartilage or other supportive tissue : the airway operates with both positive and negative pressure. An external skeleton is required to withstand the negative pressure of active inspiration. If one wall of the airway is weak of fails, inspiration causes collapse and obstruction results.
2. It should have **an epithelialized surface** without subcutaneous tissue, that narrows the laryngeal or tracheal lumen. Adjacent respiratory epithelium migrates only over a short distance if there is no internal lining. Granulation tissue will be formed on the uncovered area.
3. The technique should provide **a good blood supply**, nourishing the internal lining and the framework.

An introductory chapter deals with the literature on laryngotracheal wall reconstruction. From this overview one learns that the main problem with most methods of reconstruction is the blood supply. Especially large defects are difficult to repair such as after resection of transglottic tumors. This makes total laryngectomy usually mandatory more due to lack of reliable reconstruction techniques than to oncologic reasons.

Theoretically, the components of laryngotracheal reconstruction, i.e. support and lining, could be brought together, nourished by a vascular transferable bed. A fascial, vascular transferable bed which might be useful for this purpose is clinically available since 1983 (Brent et al. 1983).

The aim of this study is to explore the usefulness of this theoretical concept for laryngotracheal reconstruction in an experimental animal model.

Two different vascular connective tissue flaps are tested in the second chapter. The vascular characteristics needed for carrying the support and lining were analysed. From these results, an improved experimental model has been developed.

With this improved model, partial laryngeal defects were reconstructed. The importance of providing a mucosal lining, the peculiarities of wound healing inside the larynx and the possibility of reconstruction of the posterior glottic bulk are examined in the third chapter.

The same improved model was used to create a tracheal tube, supported by cartilage. This is discussed in chapter 4.

In summary, this study addresses the following questions :

1. Does graft vascularization play an important role in the outcome of laryngotracheal reconstruction.
2. Does vascularized connective tissue provide a suitable transferable bed for laryngotracheal reconstruction.
3. Does the type of connective tissue (fascial, perichondrial) of the vascularized flap have any influence.
4. Which is the better supporting tissue : autogenous or allogenous cartilage.
5. Does an internal mucosal lining of the larynx prevent contracture due to scar tissue formation.
6. Does this composite reconstruction concept allow for repair of the posterior glottic bulk.
7. Which is the blood supply needed for separated autogenous cartilage grafts.

Chapter 1

Results of Full-thickness Laryngotracheal Wall Reconstruction : Survey of the Literature

1.1. Introduction

Reconstruction of the larynx and/or tracheal wall is a challenging problem. The ideal reconstructive technique should involve a firm framework to maintain a patent airway. The reconstruction should have an epithelialized surface without narrowing the lumen and the graft should have a good blood supply. The controversies and the different approaches in the field of laryngotracheal reconstruction are due to difficulties in achieving these requirement. There are no grafts available in the human body outside the larynx which provide an all-in-one technique. Even free flap donor sites are restricted to anatomically priviliged blocks of tissue that are reliably perfused by well defined and surgically accessible large vascular pedicles. Hence, most of the proposed techniques are lacking one of more reconstruction requirements with subsequent effects on function.

In this chapter, an analysis is made of the reported success rates analysed against the theoretical requirements for laryngotracheal reconstruction.

1.2. Clinical Laryngotracheal Reconstruction : Techniques and Results

The reported methods all involve partial reconstruction of the airway wall. There are no reports of successful circumferential tracheal reconstructions. The techniques may be classified into the following groups related to their degree of vascularization : non vascularized free, trough principle, muscle pedicle, advancement with preserved

blood supply and vascular pedicle. The most frequently cited papers within the different groups have been reviewed. Reports with a mixture of different techniques are excluded.

1.2.1. Non-vascularized free grafts

Cartilage grafts : Costal cartilage (Cotton et al. 1981, Zalzal et al. 1986, 1988), auricular cartilage with or without skin (Morgenstein 1972) and nasal septal cartilage with attached respiratory mucosa (Toohill 1976, 1981) have been used as grafts to augment or reconstruct the anterior tracheal or laryngeal wall.

Free cartilage grafts have low metabolic requirements and become incorporated in the surrounding tissues. Costal cartilage grafts work well in the correction of subglottic stenosis in children (Cotton et al. 1984) : only small amounts are needed to produce lumen augmentation and mucosal regeneration occurs with minimal scarring because of the small surface area (usually 3 to 6 mm width).

More difficult to explain is the possible extra advantage of the compound mucochondral and chondrocutaneous grafts. The advantage of the respiratory mucous lining of a nasal septal graft has been emphasized (Toohill 1982, Duncavage et al. 1989). The mechanisms of survival of compound chondral grafts are easier to observe in other areas : free cartilage-mucosal grafts are used in eyelid reconstruction and cartilage-skin grafts in nasal ala defect reconstruction. A composite graft of this sort differs from an ordinary free skin graft in its mode of revascularization. In the usual free skin graft capillary revascularization occurs over the whole dermal surface in contact with the graft bed and the bulk of this is its deep surface.
In the composite graft, the area of revascularized contact between graft and bed is confined to the dermal margins. In the favourable situation this relatively small vascular contact is still sufficiently effective and revascularization is sufficiently rapid to allow survival of the entire graft skin and cartilage. Meticulous suturing is essential to maintain dermal contact. Good vascularity of the bed and a small defect between 1 and 1,5 cm in length are important. For nasal reconstruction, a proportion of failures must be expected even when all circumstances are favourable (Mc Gregor 1986).
The additional advantage of a lining on free cartilage grafts is questionable in laryngotracheal reconstruction where suturing is technically

more difficult, reconstruction dimensions are larger and more scarring of the surrounding tissues is encountered.

Bone grafts : Free grafts of the hyoid bone were first used by Looper in 1938 to repair laryngeal stenosis (Looper 1938, Alonso et al. 1976). It is extremely unlikely that free bone grafts become revascularized when placed in the laryngotracheal framework. Progressive resorption and granulation tissue formation can be expected (Delaere et al. 1990).

The success rate of free grafts in most of the papers in the literature is 71 % in a total of 35 patients (Table 1.1.).

Table 1.1. : List of reconstructive techniques within the group of 'free grafts'.

Free graft	External support	Internal lining	Stages	Stent type	Stent time	Decannulation	Success rate
1. Costochondral (Cotton et al. 1981)	costal cartilage	-	1	Montgomery	4M	8M	9/12
2. Auricular cartilage (Morgenstein 1972)	auricular cartilage	-	1	-	-	-	1/1
3. Nasal septum (Toohill 1981, Duncavage et al. 1989)	septal cartilage	(nasal mucosa)	1	-	-	4W	10/16
4. Hyoid arch (Alonso et al. 1976)	hyoid bone	-	1	Portex	8W	11W	5/6
	* Reconstruction Requirements			mean : 6 W		mean : 15W	25/35 = 71 %
	35+	16(+); 19-					

* + : present; - : absent; (+) : present with critical survival

1.2.2. *Trough principle* (Fig. 1.1)

This is a staged reconstruction first published in the American literature (Fairchild 1927). A trough is formed allowing the cervical skin to attach laterally to each side of the vertically incised stenotic segment (Boyce et al. 1967, Biller et al. 1986). A semirigid anterior wall is created after implantation of supporting material adjacent to the involved segment and subsequent hinged rotation of the embedded implant. Cervical skin is subsequently advanced over the reconstructed segment. The skin paddle for internal lining is interrupted together with the rotation stage of the reconstruction after which the flap has to rely on the newly formed vascular connections between the wall of the airway and the previously attached skin (Fig. 1.1B).

The success rate is 79 % in a total of 34 cases. The support material used has been marlex mesh (Biller et al. 1981), proplast (Lindholm et al. 1987) or nasal cartilage (Krizek et al. 1972) (Table 1.2.). The disadvantages of this technique are the multiple stages (from 2 to 8) and the length of time until final closure (from 3 to 36 months).

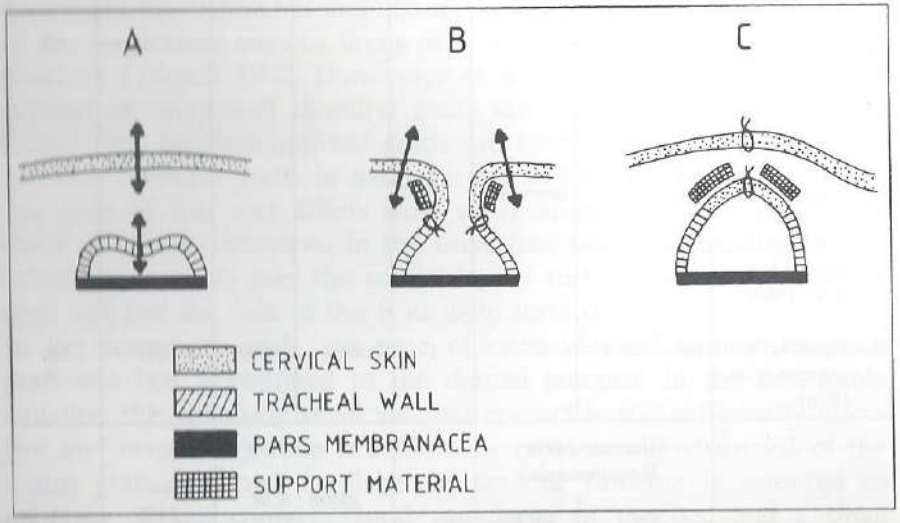


Fig. 1.1. : Staged reconstruction

A. Incision of stenotic segment and overlying skin.
B. Cervical skin is sutured to each side of the incised stenotic segment with formation of a 'trough'. Implantation of supporting material.
C. Final stage after several weeks with creation of a semirigid anterior wall.

Table 1.2. : List of reconstructive techniques 'Multiple Staged'

External support	Internal lining	Stages	Stent type	Stent time	Decannulation	Success rate
1. Marlex mesh (Biller et al. 1981)	cercival skin	3-6	-	-	an average period of 6 months	23/30
2. Proplast (Lindholm et al. 1987)	buccal mucosa	3	-	-	between first and last operation	3/3
3. Nasal cartilage (Krizek et al. 1972)	nasal mucosa	2	-	-		1/1
* Reconstruction Requirements: 34+	34+			mean : 0	mean : 6M	27/34 = 79%

* + : present

1.2.3. *Grafts vascularized by a muscle pedicle* (Fig. 1.2)

The strap muscles or the sternocleidomastoid muscle have been used as a carrier for skin, thyroid cartilage, clavicular periosteum or bone.

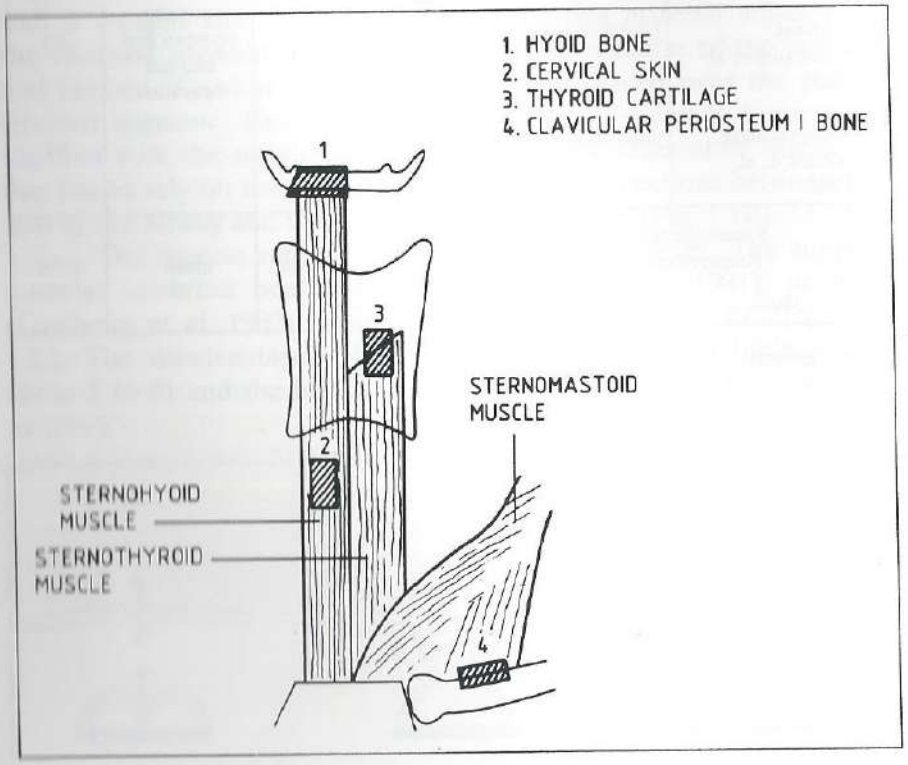


Fig. 1.2 : Grafts vascularized by a muscle pedicle : hyoid bone, overlying skin, thyroid cartilage and clavicular bone or periosteum may be pedicled on the strap muscles (sternohyoid, sternothyroid) or sternocleidomastoid muscle.

A portion of the hyoid bone can be pedicled on the sternohyoid muscle with the intention of diminishing reabsorption by preserving a vascular supply (Finnegan et al. 1975, Ward et al. 1977, Thawley et al. 1981, Burnstein et al. 1986). A muscle-pedicled thyroid cartilage flap may be used in the same way for subglottic and upper tracheal defects (Fry et al. 1985). The rotating door flap, a bipedicled sternohyoid flap rotated through 180° on its longitudinal axis, can bring an overlying

skin paddle inside for airway repair (Eliachar et al. 1989). Providing vascularization by way of small muscle insertions is however dubious. The arterial blood flow of the infrahyoid muscles is segmental from the superior and inferior thyroid arteries with external diameters of 0,5 mm (Eliachar et al. 1984). Because of this segmental vasculature of the strapmuscles, only flaps of a rotational nature can possibly survive.

Clavicular periosteum can be used on a sternocleidomastoid muscle flap for laryngotracheal wall defects (Tovi et al. 1983). A superiorly based muscolocutaneous sternocleidomastoid flap has been described for wedge enhancement of the airway lumen (Eliachar et al. 1981). One half of the clavicular circumference attached to the sternocleidomastoid has even be used for tracheal wall reconstruction with a buccal graft for internal lining (Schuller et al. 1988).

The sternocleidomastoid muscle does not have a localized vascular hilum but is supplied segmentally by identifiable vessels originating from the occipital artery, superior thyroid artery and thyrocervical trunk. There is no doubt that the overlying skin, clavicle or periosteum can be transferred viably. The blood supply of the upper half of the sternocleidomastoid should however not be disturbed (Siemssen et al. 1978).

The success rate in the literature is 79 % of a total of 78 patients (Table 1.3).

Table 1.3. List of previous reported techniques within the group of 'Muscle pedicle', 'Advancement flap' and 'Vascular pedicle'

	External support	Internal lining	Stages	Stent type	Stent time	Decannulation	Success rate
Muscle pedicle							
1. *Hyoid-sternohyoid* (Finnegan et al. 1975, Ward et al. 1977, Thawley et al. 1981)	hyoid bone	-	1	-	-	6M	33/46
2. *Rotary door*							
2.1. thyroid (Fry et al. (1985)	thyroid cartilage	-	1	T-tube	7M	-	3/4
2.2. sternohyoid (Eliachar et al. 1989)	-	cervical skin	1	T-tube + stent	6W	5M	10/20
3. *Sternocleidomastoid*							
3.1. myoperiosteal (Tovi et al. 1983)	-	-	1	silastic sponge	1W	-	3/3
3.2. myoosseus (Schuller et al. 1988)	clavicular bone	buccal mucosa	1	T-tube	3M	-	1/3
3.3. myocutaneous (Eliachar et al. 1981)	-	cervical skin	1	T-tube + stent	6W	10W	2/2
	* Reconstruction requirements 53+; 25-	48+; 30-		mean : 3,5 W		mean : 21 W	62/78 79 %
Advancement epiglottoplasty (Tucker et al. 1989)	epiglottic cartilage	epiglottic mucosa	1	-	-	3W	47/48
	48+	48+		mean : 0		mean : 3 W	97 %
Vascular pedicle iliac bone (Kambic et al. 1986)	iliac bone	skin graft	2	-	-	-	4/4
	4+	4+		mean : 0		mean : 0	100 %

1.2.4. Advancement flap

The epiglottis can be used as an advancement flap after release of the hyo- and glossoepiglottic ligaments with preservation of the vallecular blood supply for repair of frontal thyroid defects (Tucker et al. 1979, 1989, Sobol et al. 1981).
The success of the technique after full-course radiotherapy is proof of the reliable blood supply of the epiglottis (Tucker et al. 1989, Delaere et al. 1990) (cfr. addendum clinical case reports).

A success rate of 97 % of a total of 48 patients (26 of whom received preoperative radiotherapy) is reported (Table 1.3). The disadvantages are the temporary derangement of swallowing and the restricted area which can be reconstructed, namely, the frontal thyroid cartilage.

1.2.5. Microvascular anastomosis

The only clinical reported use of a microvascular reconstruction is the skin covered iliac crest graft to resolve subglottic stenosis (Kambic et al. 1986). In spite of the small series, it is worthwhile mentioning the technique because of the new blood supply brought into the reconstructed area. Four patients were successfully treated (Table 1.3).

1.3. Experimental Laryngotracheal Reconstruction : additional information

Information concerning circumferential tracheal reconstruction can be obtained only from experimental studies. There have been attempts to reconstruct a defect with silicone rubber (Neville et al. 1979) and microporous teflon (Bottema 1982). The main problem of these avascular materials is the absence of an epithelialized lining resulting in granulation tissue formation and stenosis at the suture lines. In an experimental study in rabbits, the re-epithelialization which took place from the marginal respiratory mucosa was never more than 0,5 cm (Bottema 1982).

When repairing defects with tracheal allografts avascular necrosis with graft expulsion can be expected. In the last few years, autogenous materials such as free revascularized bowel segments (Letang et al. 1990) and esophageal interposition (Kato et al. 1990) have been tried to repair tracheal segments. These techniques show an inherent absence of structural support but their well vascularized mucosal layer is responsible for the observation that the anastomoses healed fully without granulation tissue formation.

Fortunately, the problem of circumferential tracheal reconstruction can be solved in most patients by tracheal resection and end-to-end anastomosis if the affected segment is less than 5 cm in length (Mulliken et al. 1968, Grillo 1990).

1.4. Discussion

1.4.1. It is difficult to compare the results of different techniques, used for different defects and mostly with insufficient information about the reconstructed surface area. The only reported successful outcome is decannulation with the time interval since the operation. Bearing in mind the above difficulties the following conclusion can be drawn :

(1) The success rate is directly proportional to the presence of the reconstruction requirements. The degree of vascularization is the most significant factor in the outcome of the reconstruction ($P = 0{,}0019$) (Fig. 1.3).

(2) The number of different techniques is evidence for the lack of uniform success with any of them. All have their successes for partial reconstruction. No reliable technique can be used for circumferential tracheal reconstruction

(3) It has become clear that providing a technique with a well vascularized mucosal layer is the best way of preventing granulation tissue formation in circumferential reconstruction.

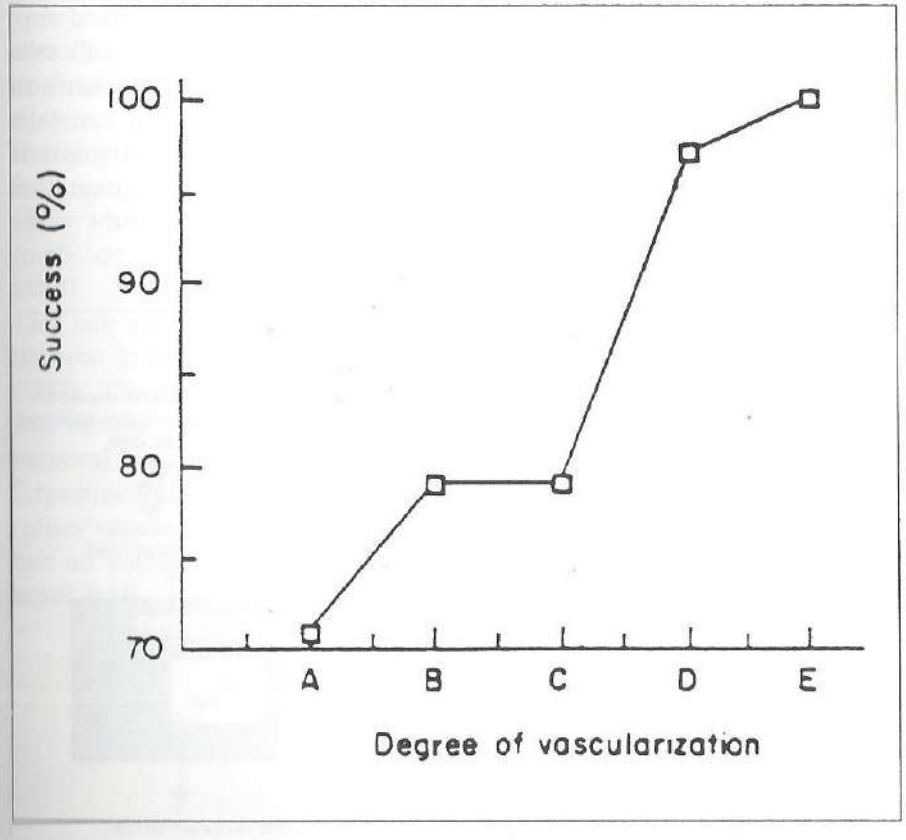


Fig. 1.3 : Success rate versus degree of vascularization.
A : free grafts; B : trough principle; C : muscle pedicle; D : advancement;
E : vessel pedicle; □ : percentage success

1.4.2. Mechanisms contributing to success or failure (Fig. 1.4)

Airway wound healing mechanisms do not differ from other more accessible areas. Full-thickness mucosal or skin defects heal by secondary intention with granulation and scar tissue formation due to the capillary outgrowth from the uncovered vascularized surface (Mc Gregor 1986).

Epithelial coverage by peripheral respiratory mucosal ingrowth will be seen only over a very small defect. Usually the vascularized surface should be provided with epithelial coverage (mucosa or skin)

as extralaryngeal donor sites lack the combination of vascularized supporting tissue and a suitable epithelial lining. The free graft will take only if immobilized over the vascularized bed by the same mechanisms of capillary outgrowth. Wound healing by primary intention can take place, improving the chance of successful reconstruction. A mucosal graft is preferable for airway lining to prevent crusting, desquamation and hair growth.

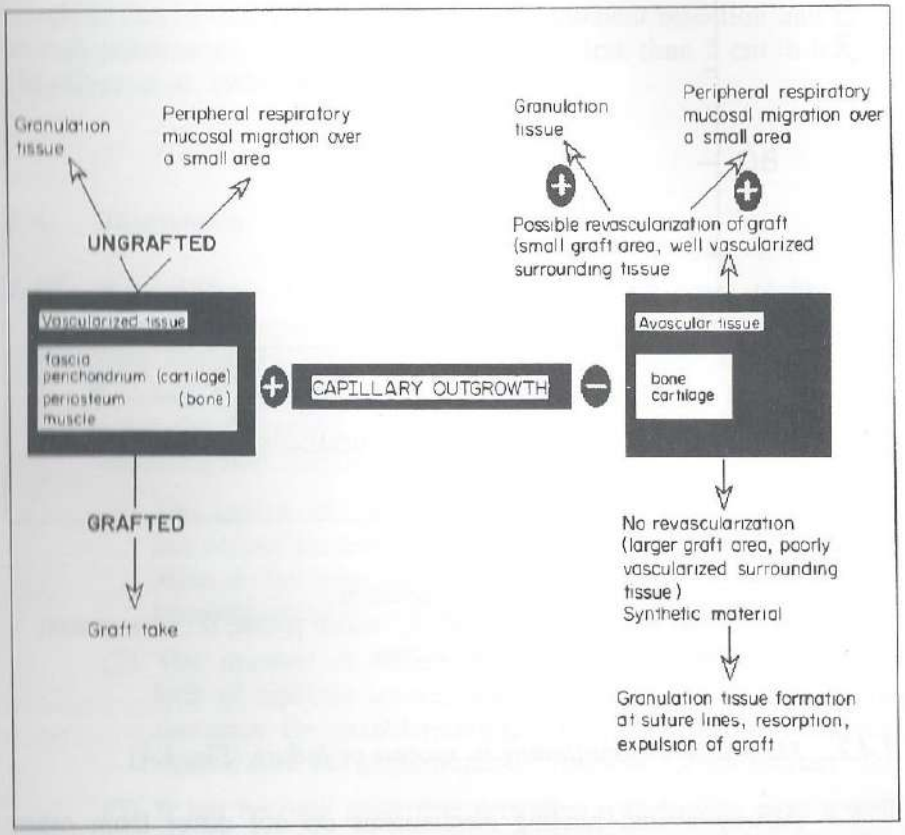


Fig. 1.4 : Capillary outgrowth as the essential biological process for graft take inside the larynx and trachea.

Avascular autogenous tissues will stay avascular or will become revascularized. The former will lead to granulation tissue formation beginning at the suture lines, progressive resorption and eventual extrusion.

If the graft becomes revascularized, it will be partially epithelialized from peripheral mucosal ingrowth. Graft revascularization is more likely when the graft is cartilaginous with low metabolic requirements, small, or has a good vascularized surrounding tissue (Pashley et al. 1984).

This can explain the success of costal cartilage grafting in the subglottic area in children (Cotton et al. 1981, Zalzal et al. 1986, Gray et al. 1987). The larger the reconstructed surface area, the more extensive will be the granulation reaction centrally with a constant peripheral mucosal ingrowth of unknown capacity.

Experimental studies teach us that respiratory mucosal migration is rather small (Bottema 1982). It is unlikely that a mucosal or skin layer has an advantage when it is attached to a free avascular cartilage or bone graft.

1.4.3. Effects of intraluminal stenting

There is much controversy in the literature concerning the type and duration of stenting (Goode et al. 1977, Schuller 1980, Smith 1987, Zalzal 1988). There are two possible roles of a stent in laryngotracheal reconstruction.

1.4.3.1. Supporting a free skin or mucosal graft

The function of the stent is to assure close, immobile contact between the graft and bed so that the graft becomes reattached and obtains a fresh blood supply. Standard laryngeal stents and stents with external fixation, which do not move with the airway wall on swallowing and respiration, cannot fulfil this role (Thomas et al. 1975). Soft well fitting laryngeal stents which are self retaining or fixed to the airway wall have to be used for this purpose (Eliachar et al. 1987). It has become clear from animal studies that the internally fixed stent has no adverse effects because of the absence of movement (Cotton et al. 1990). The stent supporting the graft can be removed after 2 weeks.

1.4.3.2. Maintaining a lumen and preventing scar contracture

A laryngeal stent or keel can be successfully used as an interposition material to prevent the reformation of an anterior or posterior web until mucosal recovery has taken place. The rationale and mechanism of long-term stenting to counteract scar contracture is less clear (Schuller et al. 1988). Usually there is something wrong with a reconstruction technique if long-term stenting is advocated. It may be true that the success of a laryngotracheal repair using a long-term stent occurs in spite of the stent rather than because of it (Olson 1979).

1.5. Conclusion

New techniques for full-thickness airway wall repair have to be evaluated in the knowledge of the theoretical requirements, of which a reliable blood supply is the most important.
Grafts with reanastomosis of a vessel pedicle should be developed in the future to avoid the disadvantages of multistage techniques and to extend reconstuctive possibilities (Delaere et al. 1992).

Research should be concentrated on improvement of reconstructive techniques because organ transplantation is not at the moment a realistic proposition.

Chapter 2

Experimental Transferable Bed

2.1. Introduction

2.1.1. Development of experimental model

Free vascular fascial flaps have been used in a variety of ways since 1980. The temporal (Brent et al. 1983, 1985), subscapularis (Kim et al. 1987), radial forearm (Ismail 1989) and lateral arm (Yousif et al. 1990) donor sites are most frequently used. Gradually it was established that these vascularized connective tissue flaps have characteristics not available in other tissues. Free fascial flaps provide neovascularity without adding bulk and are therefore particularly suited to serve as a microvascular transfer of a recipient bed carrying and epithelial lining. These qualities make it useful to apply a mucosal lining at the inner surface of a reconstructed larynx or trachea.

A free fascial flap may be designed to reconstruct a patch laryngeal defect or a circumferential tracheal defect. Also it may at the same time transport material for external support (Fig. 2.1).

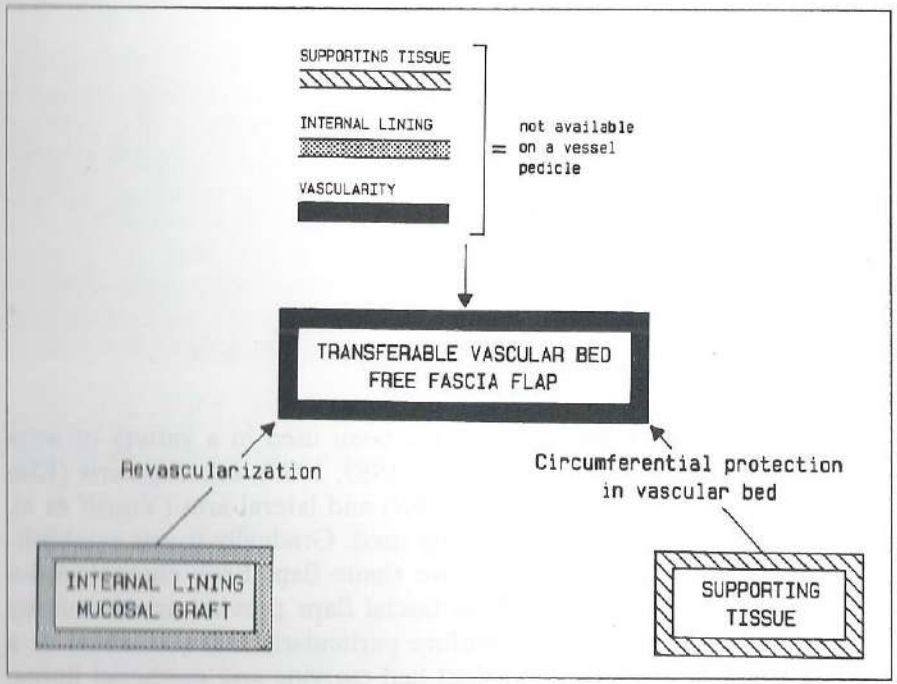


Fig. 2.1. : Concept of theoretic, laryngotracheal reconstruction with free fascial flaps.

It was our purpose to find an animal, vessel perfused connective tissue flap similar to the free human fascial flap. The free rabbit auricular perichondrial flap, was described previously for other purposes (Donski et al. 1980). It contains a rich vascularity and is nourished by a central vascular pedicle. This thin, pliable connective tissue sheet containing the vascularization can be transferred by microvascular techniques to the neck and was initially used in our experimental model (Fig. 2.2).

The vascular characteristics of this flap are examined with laser doppler flowmetry and injection studies to test the reliability of the vascular transferable bed in laryngotracheal repair.

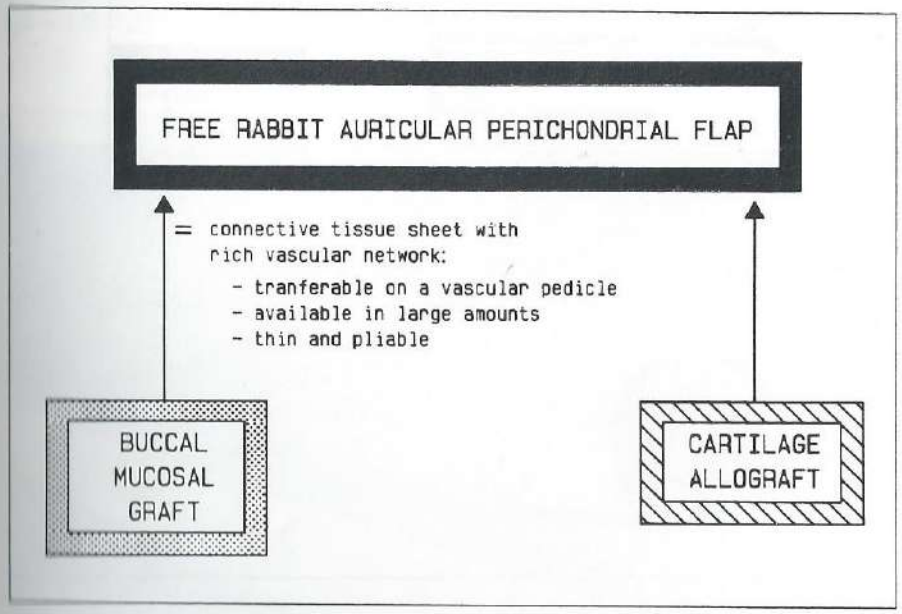


Fig. 2.2 : Concept of experimental laryngotracheal reconstruction with the free perichondrial flap.

2.1.2. *Construction of an Airway Wall*

The laryngeal patch may be constructed by rotating the vascularized fascia 180°. In this way, the supporting material is circumferentially covered and protected within a vascular bed (Fig. 2.3).

A tracheal tube may be created by rotating the fascia over 360° in order to bring the mucosal graft internally and to enclose a tracheal cartilage allograft (Fig. 2.3).

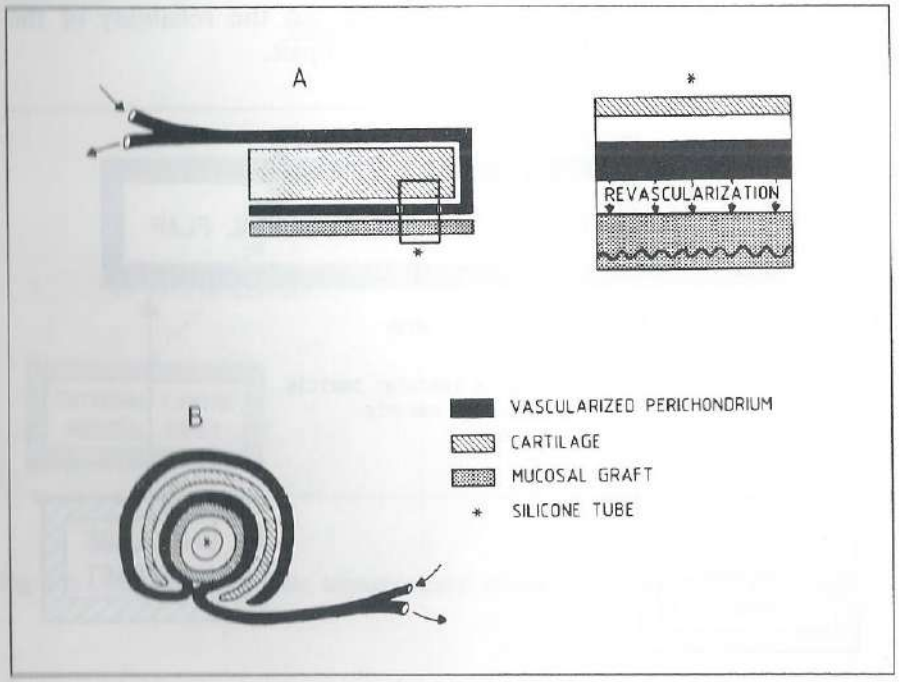


Fig. 2.3 : Concept of laryngotracheal wall construction.
A. The laryngeal patch is created by 180° rotation of the vascularized bed. The full-thickness mucosal graft will become revascularized by capillary outgrowth from the vascularized connective tissue flap (quadrangular detail-asterisk).
B. Circumferential tracheal construction with vascularized bed rotated over 360°.

Essential for success is a sufficient blood supply at the distal end of the flap even after 180° or 360° rotation to guarantee a complete ingrowth of the mucosal graft.

2.2. Materials and Methods

Surgical technique-flap preparation

The animals were anaesthetized with intravenous pentobarbital plus inhalation of halothane, nitrous oxide and oxygen. The dorsal auricular skin was removed, leaving the underlying vascular structures intact. Along the auricular skin defect, the soft tissues were incised including the perichondrium. The perichondrial flap, measuring 5 x 12 cm, was detached from the cartilage by a periosteal elevator. The central auricular artery and vein were dissected as a vascular pedicle for the flap (Fig. 2.4). The arteries measured 0,9 - 1,2 mm, the veins 1,0 - 1,8 mm.

Fig. 2.4 : Dissected perichondrial flap on its vascular pedicle. Axial perfusion by central auricular artery and vein (arrow).
(Flap length : 12 cm; flap width : 5 cm)

2.2.1. *Laser Doppler (L.D.) Flowmetry*

LDF provides a dynamic measure of blood flow as a voltage output that is proportional to the number and velocity of red blood cells in a measurement volume (normally 1 mm^3) (Shepherd et al. 1987).

LDF is based on the principle that monochromatic light scatters back from the microvascular bed, gaining a frequency (doppler) shift, which is proportional to the volume and velocities of circulating red blood cells (Kvietys et al. 1985, Pietilä et al. 1985, 1987). This principle is applied by directing a continuous laser beam to the tissue via an optic fiber, which then receives and carries the backscattered light to a photodetector. Emitted and backscattered light are continuously compared by a microprocessor to estimate blood flow in the tissue (Lindberg et al. 1989). This weighed (normalized) light is analyzed and converted to a voltage. The penetration depth for the laser light has been estimated to be about 1 mm in human skin (Bonner et al. 1981) (Fig. 2.5).

A Periflux PF_3 (Perimed, Stockholm, Sweden) was used for blood flow evaluation. The probe P_{436} was connected to a LDF measuring unit (model BPM_{403a}, TD) capable of generating a 5mW 780nm laser beam and analyzing the light scattering back from the tissue. To overcome movement artefacts meticulous stability and complete hemostasis in the surgical area is essential. The flap was divided in three equal areas : proximal, middle and distal areas of the vascular pedicle. The mean perfusion unit value for each area was calculated by averaging all the individual perfusion units that were collected during the first minute after stabilizing the probe. The measurements were made in the center of the ear by positioning the probe at the three discrete measurement sites.

Relative values were calculated from the mean perfusion unit values. Body temperature was maintained at 37,5°C with a heating pad. Measurements were performed with a constant flap temperature of 35°C and controlled by the temperature setting of the PF_3 laser-Doppler flowmeter.

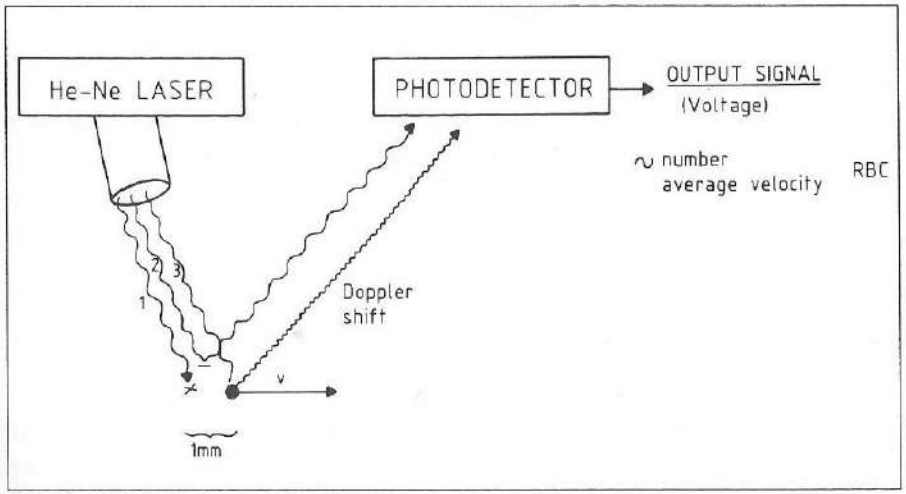


Fig. 2.5 : Blood flow assessment with laser doppler flowmetry.
Light (780 nm) is emitted by a helium-neon laser tube and transferred to the measuring site via a flexible optical light conductor, which also serves to transmit the back-scattered light to a photodetector. The light is diffusely scattered and partly absorbed (1) within the illuminated tissue volume.
Light, hitting static structures, will be unchanged (2).
Frequency shifts occur when light is scattered by moving red celles (3).
The doppler shifted light forms an output signal which is proportional to the flux (number of cells x their average velocity) of the illuminated red blood cells (RBC) and is converted to a voltage.
The equipment is commercially available.

2.2.2. *Vascular Pattern : India ink-Gelatin 10 %*

The vascular system of the perichondrial flap could further be visualized by washing out the flap with heparinized saline and perfusing it with India ink diluted 1:1 with 10 % gelatin. The flap is then excised, pinned onto cardboard, fixed in 10 % formal saline, cleared in cedar wood oil, and examined with a transmission light microscope.

We examined the distal blood supply of the flap and the influence of 180° to 360° rotation. Flap vascularization with preserved vascular pedicle was examined in 10 animals (**Group A**). Measurements were done after dissection of the flap in the neutral position and after rota-

tion of the distal end over 180° and 360° (over a tube) with the rotation point at 8 cm.

We examined flap vascularization with a preserved vascular pedicle and 360° flap rotation after a follow-up period of four weeks in five animals (**Group B**). A perichondrial flap measuring 12 x 5 cm was taken, with preservation of the vascular pedicle. The distal end was rotated over 360° (rotation point at 8 cm from vascular pedicle) over a silicone tube (diameter 0,7 cm). The ear donor site was closed over the flap. Measurements were done 4 weeks postoperatively after reopening the ear.

We examined flap vascularization after microvascular transfer and 360° rotation after a follow-up period of four weeks in five animals (**Group C**). The perichondrial flap was dissected and brought to the neck with reanastomosis of the central auricular vessels to the neck vessels (auricular artery end-to-side to common carotid artery, auricular vein end-to-end to external jugular vein; nylon 11.0). The distal end was rotated over 360° over a silicone tube. Measurements were done 4 weeks postoperatively after reopening the neck.

2.2.3. *Behavior of the Free Mucosal Graft and the Cartilage Allograft*

Five laryngeal patches and five tracheal tubes were preformed at the donor ear site. The perichondrial flap was dissected on its vascular pedicle.

The laryngeal patch was created by turning the distal end over 180° with interposition of a thyroid cartilage allograft. The cartilage allograft was preserved for a period of 2 to 4 weeks in Merthiolate. A full-thickness buccal mucosal graft measuring 1 to 1,25 cm was applied at the distal perichondrium with 9.0 nylon and fibrin glue (Fig. 2.3). Two mucosal grafts were taken for the neotrachea formation and applied one beside the other. The mucosal patch measuring 1,5 cm x 2 cm with its underlying perichondrium was circumferentially sutured around a silicone tube with diameter of 0,8 cm. A tracheal cartilage allograft with a length of 1,5 cm was then brought over the reconstruction and sutured to the perichondrium with nylon 8.0. The distal perichondrial remnant was sutured over the cartilage allograft. In this way a tracheal segment was preformed with a length of 1,5 cm (Fig. 2.3). The external ear was closed around the preformed reconstruction. Treatment and care of the rabbits followed the rules of the American Psychological Society. Ambi-pen (penicillin G suspension, 30.000 U/100 mg) was administered for prophylaxis.

After a follow-up period of 6 weeks, the ear was reopened. The vascular pedicle was dissected free and the central auricular artery was injected with India ink diluted 1:1 with 10 % gelatin. The rabbits were painlessly killed for histologic evaluation of the reconstruction site. All biopsy specimen were routinely processed and stained with hematoxylin and eosin.

2.3. Results

2.3.1. *Vascular Characteristics of the Perichondrial Flap*

In **Group A** studied for flap vascularization with a preserved vascular pedicle, measurements were done at 4, 8 and 12 cm (Fig. 2.6).

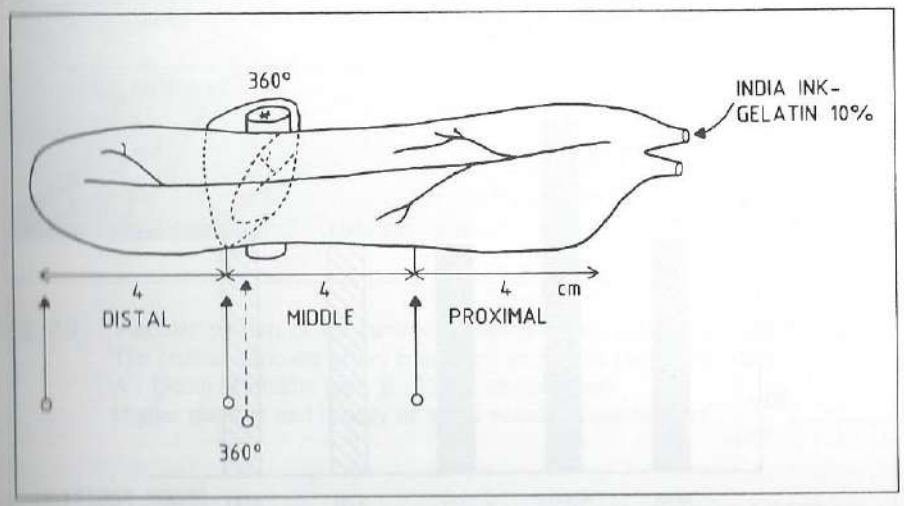


Fig. 2.6 : Perichondrial flap with three flap areas : proximal, middle and distal from vascular pedicle. Measurements distally were done before and after rotation of the distal flap area over 180° and 360°.
O : probe position in the different flap areas. The vascular system of the flap was visualized after India ink-gelatin 10 % injection.

The LDF registration, mean perfusion units, and relative values within each flap area are presented in Fig. 2.7 and Fig. 2.8.

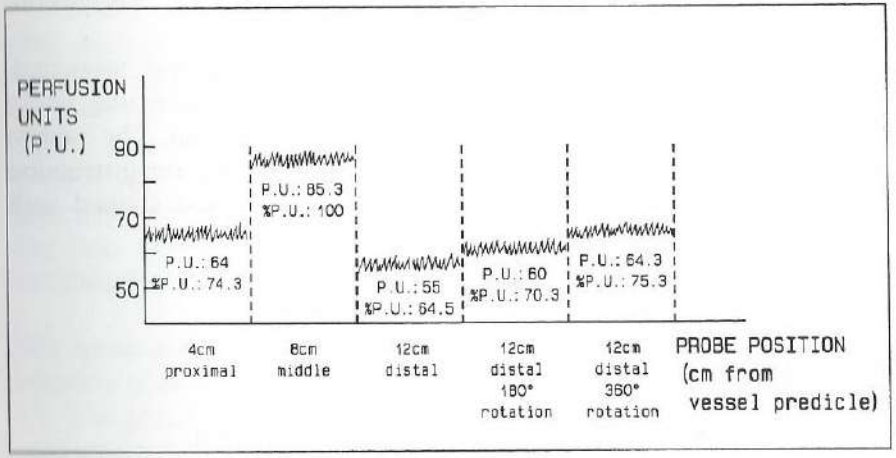


Fig. 2.7 : Recorded blood flow in rabbit number 1 with the probe placed in the 3 different flap areas. The distal registration is performed before and after rotation over 180° and 360°. Absolute perfusion units can not be compared between registrations at different moments or in different animals. Therefore, a relative value (% P.U.) is calculated from the P.U. values.

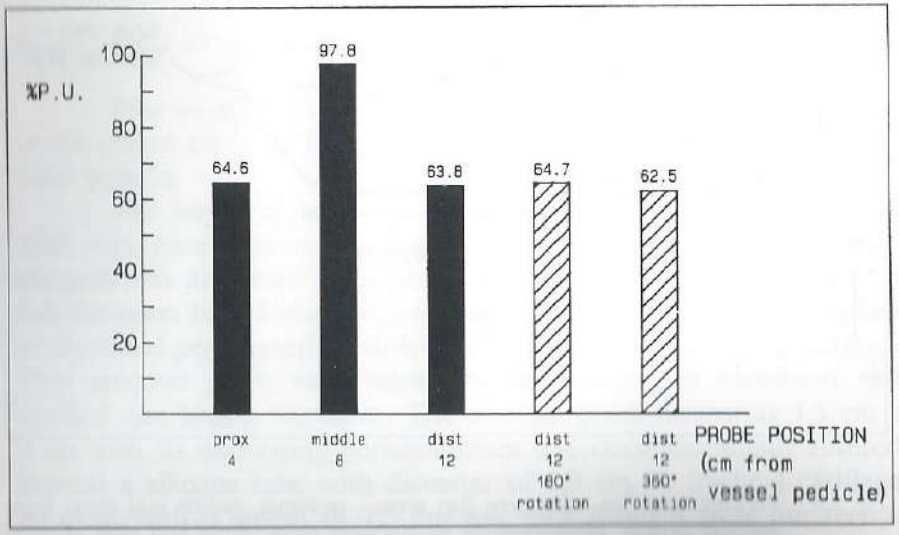


Fig. 2.8 : Mean relative perfusion units (% P.U.) for each flap area. Values are significantly higher in the middle part of the flap. There is no influence of rotation on the LDF values distally (▨).

There were no statistically significant differences between the proximal and distal values at 0°, 180° and 360° rotation. The middle part of the flap had the largest perfusion unit values ($P < 0,05$). This can be explained by the higher number of small blood vessels per surface area in the middle part of the flap, as can be seen after India ink-gelatin injection (Fig. 2.9).

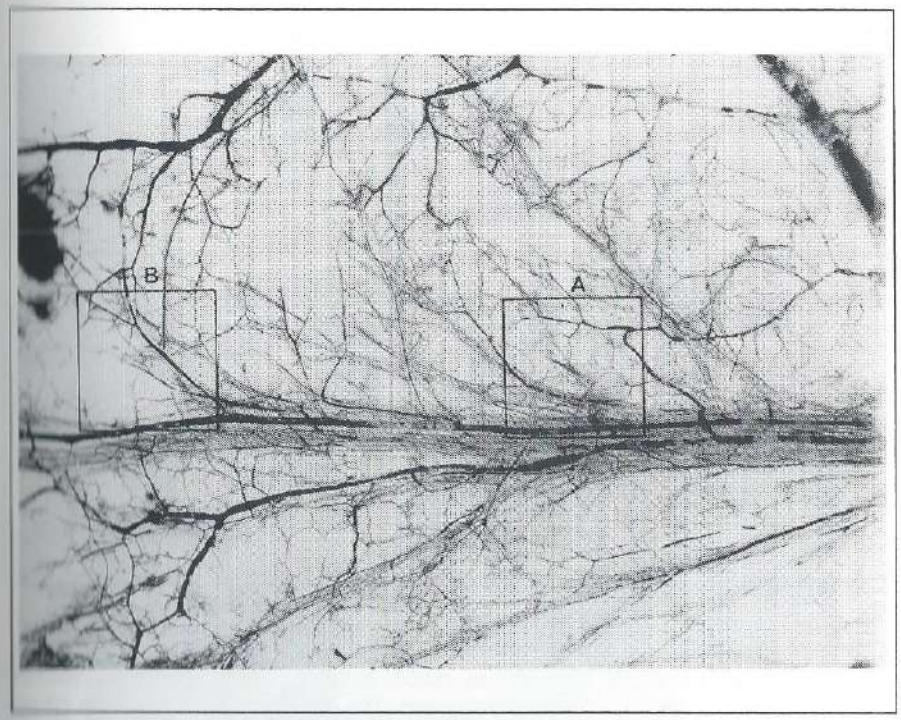


Fig. 2.9 : Vascular pattern of the perichondrium flap with preserved vascular pedicle. The central auricular artery is injected with India ink-gelatin 10 %.
A : Detail of middle part; B : Detail of distal part.
Higher number and density of blood vessels in middle part.

Group B (group with preserved vascular pedicle and 360° rotation after a follow-up of 4 weeks) : a constant observation was the tendency toward shrinkage of the dissected perichondrial flap. After 4 weeks, the mean flap length was reduced to 9 cm, and the width to 4 cm. The flap could easily be stripped from the cartilage after division of the adhesions. Measurements were done at 3 cm (proximal), 6 cm

(middle) and 9 cm (distal) in the center of the flap. No statistical differences were found among the perfusion values in the different flap areas (Fig. 2.10, Fig. 2.11).

The vascular pattern displayed a capillary outgrowth within the flap and even in the neighbourhood of the flap (neovascularity) (Fig. 2.12). There was no difference in vessel distribution between the different flap areas.

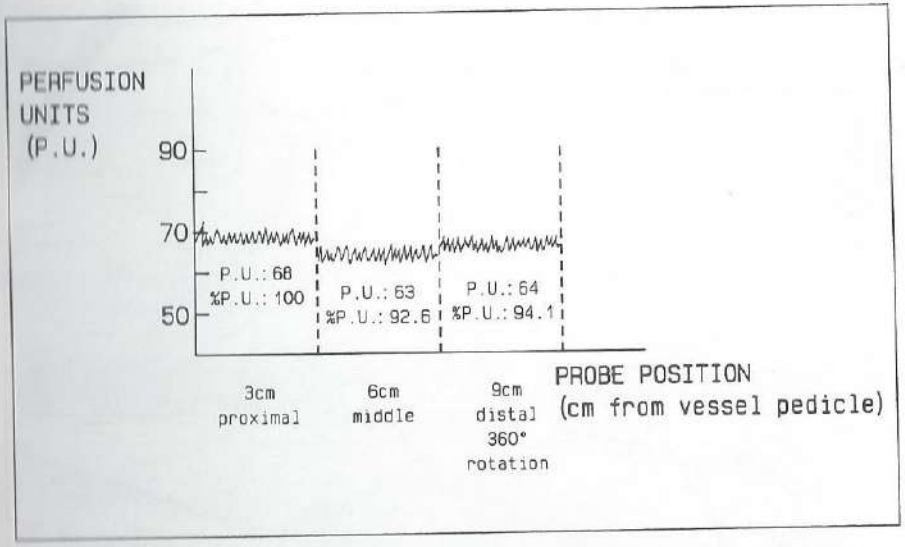


Fig. 2.10 : LDF recordings obtained in rabbit number 1 with preserved vascular pedicle, 360° rotation after follow-up. The probe was placed at 3 cm (proximal area), at 6 cm (middle area) and at 9 cm (distal area; 360° rotated) from the vessel pedicle of the flap. Relative values (% P.U.) were calculated from the perfusion units (P.U.).

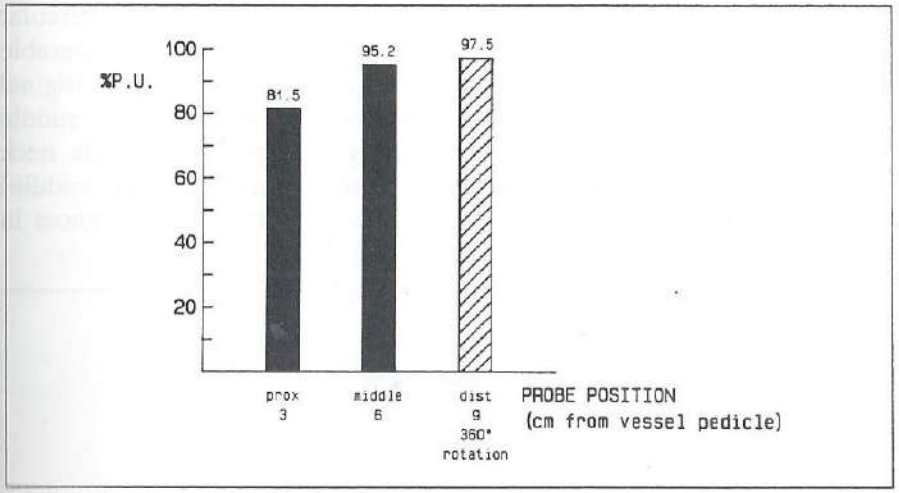


Fig. 2.11 : Mean relative perfusion units (% P.U.) for each flap area after follow-up (360° rotation). Group with preserved vascular pedicle. No significant differences between the flap areas.

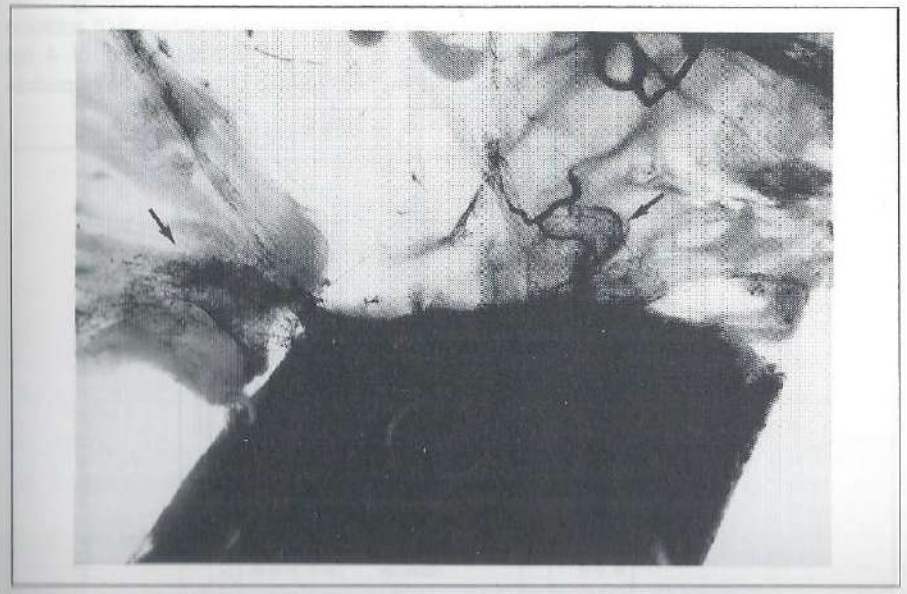


Fig. 2.12 : Vascular pattern of perichondriumflap after follow-up (India ink-gelatin 10 % injection of central auricular artery). Outgrowth of capillary networks in the connective tissue surrounding the original flap is visible (arrow).

Group C examined for flap vascularization after microvascular transfer and 360° rotation after a follow-up of 4 weeks : a considerable shrinkage of the flaps took place, to approximately half the original size. The most involved flap segments were the proximal and middle parts, which were not fixed and were lying on top of the mobile neck muscles. Measurements were done at 2 cm (proximal), 4 cm (middle) and 6 cm (distal) in the center of the flap. No statistical differences in perfusion values were found (Fig. 2.13, Fig. 2.14).

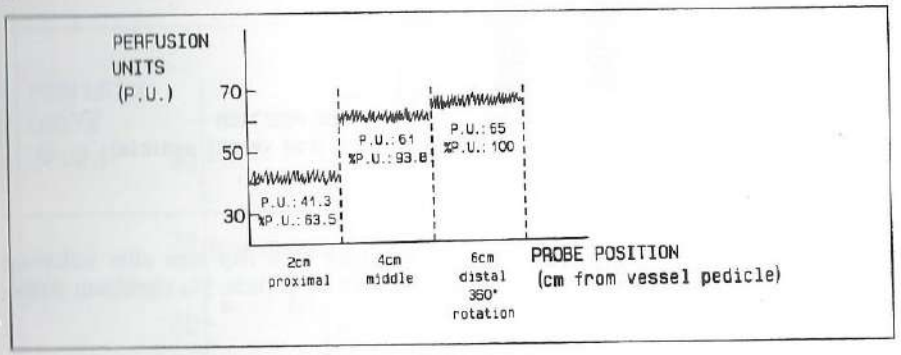


Fig. 2.13 : Recorded blood flow in rabbit 6 after microvascular transfer, 360° rotation after follow-up. The probe was placed at 2 cm (proximal area), at 4 cm (middle area) and at 6 cm (distal area, 360° rotated) from the vessel pedicle of the flap.

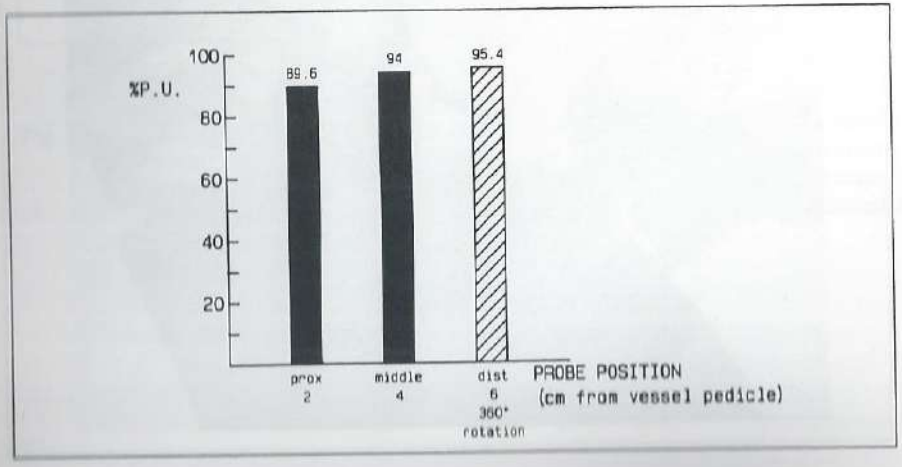


Fig. 2.14 : Mean relative perfusion units (% P.U.) for each flap area after follow-up (360° rotation). Group with microvascular transfer. No significant differences between the flap areas.

Table 2.1. : List of LDF values (P.U. and % P.U.) for the flap areas measured in group A, B, C.

GROUP A	Rabbit 1		Rabbit 2		Rabbit 3		Rabbit 4		Rabbit 5		Rabbit 6		Rabbit 7		Rabbit 8		Rabbit 9		Rabbit 10	
Probe positions	P.U.	% P.U.	P.U.	% P.U.	P.U.	% P.U.	P.U.	% P.U.	P.U.	% P.U.	P.U.	% P.U.	P.U.	% P.U.	P.U.	% P.U.	P.U.	% P.U.	P.U.	% P.U.
prox. 4 cm	64	74.3	100	71.8	33.3	34.2	82.3	76.9	59	53.6	49.3	36.4	187.3	85	91.3	63.8	65	77.3	83	72.6
middle 8 cm	83.3	100	139.3	100	97.3	100	107	100	85.7	77.9	135.3	100	220.3	100	143	100	84	100	114.3	100
dist. 12 cm	55	64.5	74	53.1	50.7	52.1	86.3	80.7	93.3	84.8	113.3	83.5	129	58.6	81.6	57	45.7	54.4	56.7	49.6
dist. 12 cm / 180°	60	70.3	80	57.4	61	62.7	78.7	73.6	110	100	68.3	50.5	85.3	38.7	96.7	67.6	57	67.9	66.7	58.4
dist. 12 cm / 360°	64.3	75.5	85	61	53.7	55.2	66	61.7	103.3	93.9	95.7	70.7	68	30.9	89	62.2	54	64.2	57	49.9

Mean values A		
	P.U.	% P.U.
prox. 4	81.5	64.6
middle 8	121.2	97.8
dist. 12	78.6	63.8
dist. 12 / 180°	76.4	64.7
dist. 12 / 360°	73.6	62.5

GROUP B	Mean values B		
		P.U.	% P.U.
prox. 3 cm	prox. 3 cm	48.1	81.5
middle 6 cm	middle 6 cm	55.4	95.2
dist. 9 cm / 360°	dist. 9 cm / 360°	56.3	97.5

prox. 3 cm	68	100	51.3	88.4	22.3	53	44.3	66.1	57.7	100	41.3	63.5	76	84.4	51.7	100	64	100	57	100
middle 6 cm	63	92.6	56	96.6	37	88	67	100	54	98.7	61	93.8	90	100	49	94.8	63	98.4	47.3	83
dist. 9 cm / 360°	64	94.1	58	100	42	100	63.3	94.5	54	98.7	65	100	84	93.3	50	96.7	61.7	96.4	51.7	90.7

GROUP C	Mean values C		
		P.U.	% P.U.
prox. 2 cm	prox. 2 cm	58	89.6
middle 4 cm	middle 4 cm	62.1	94
dist. 6 cm / 360°	dist. 6 cm / 360°	62.5	95.4

2.3.2. *Behavior of the Free Mucosal Graft and the Cartilage Allograft* (Fig. 2.15, Fig. 2.16)

The full-thickness mucosal graft was constant and complete viable in both the patch and tube reconstructions. Less successful was the cartilage-preserved (Merthiolate 1:4,000 aqueous solution) allograft. In the majority of cases, areas of cell death were visible within the allograft, with early signs of resorption and loss of the supportive strength after a follow-up of 6 weeks. An inflammatory reaction was visible around the cartilage allograft.

Patchy new cartilage formation was visible from the perichondrium in a cobblestonelike pattern. At other places, these patches coalesced and formed a more compact plate.

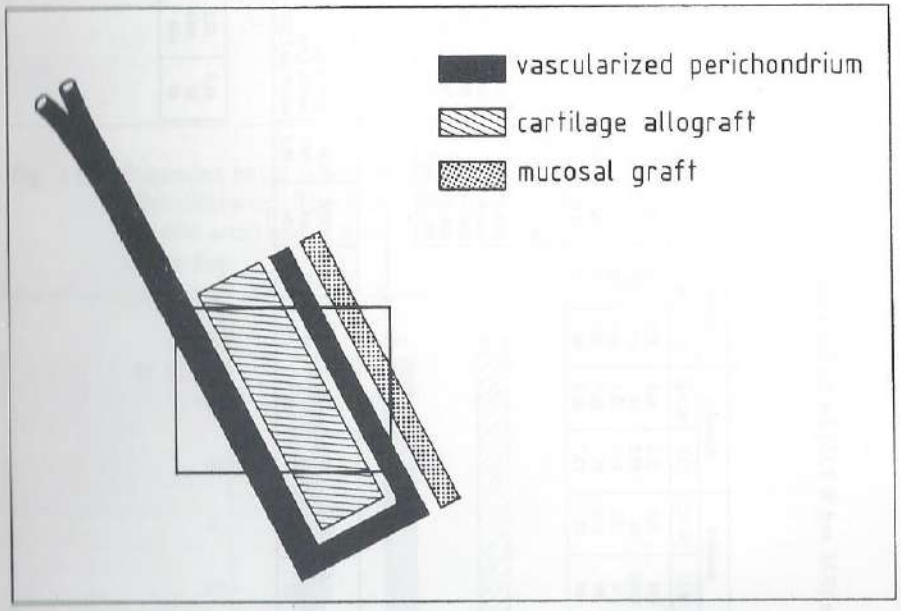


Fig. 2.15 : The reconstruction components (perichondrium, cartilage allograft, mucosal graft) of the preformed laryngeal patch after 6 weeks follow-up.
A : Outlining of the quadrangular detail for histological examination (Fig. 2.15 B)

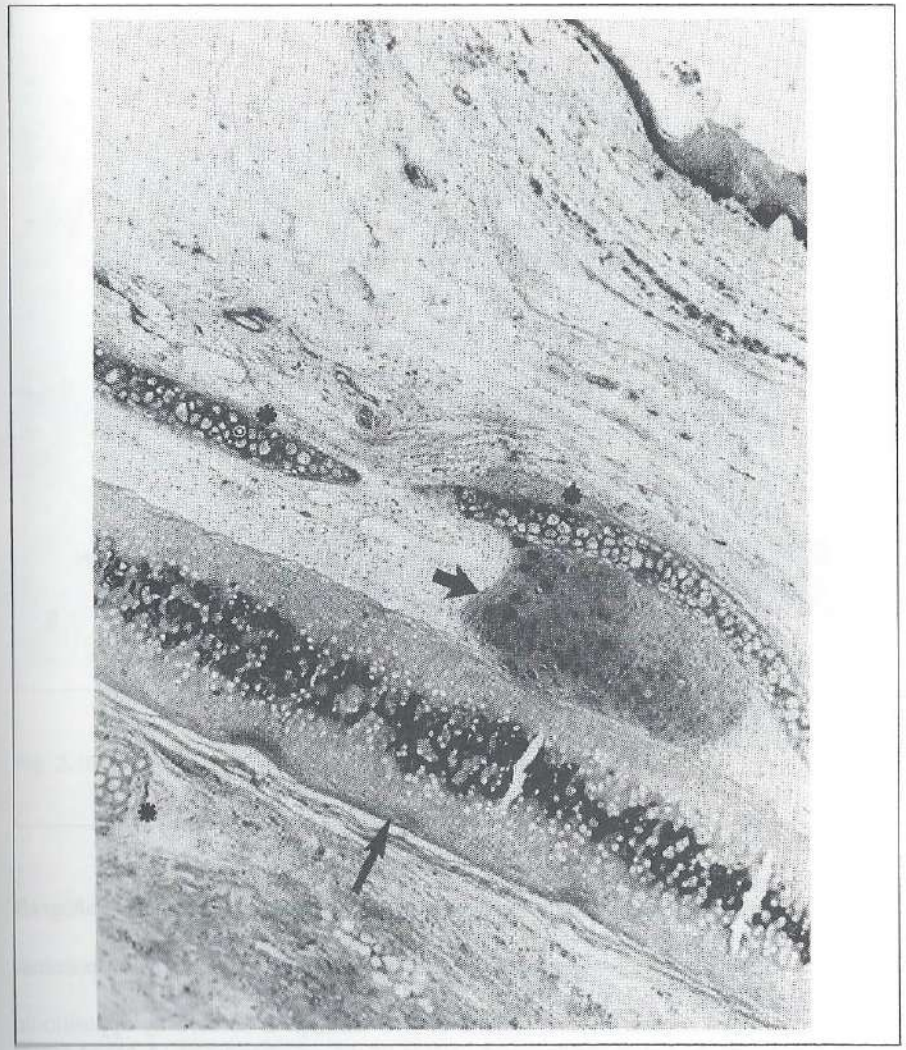


Fig. 2.15 B : Photomicrograph of the quadrangular detail (H.E. original x 20).
Top right : full-thickness buccal mucosal graft.
Cartilaginous support : long arrow shows cartilage allograft with few chondrocytes within chondral lacunae and more eosinophilic ground substance.
In contrast, vital cartilage (short arrow), which is a small piece of ear cartilage autograft taken, by chance, at the lower surface of the perichondrium with dissection of the flap.
Asterisk : areas of new cartilage formation.

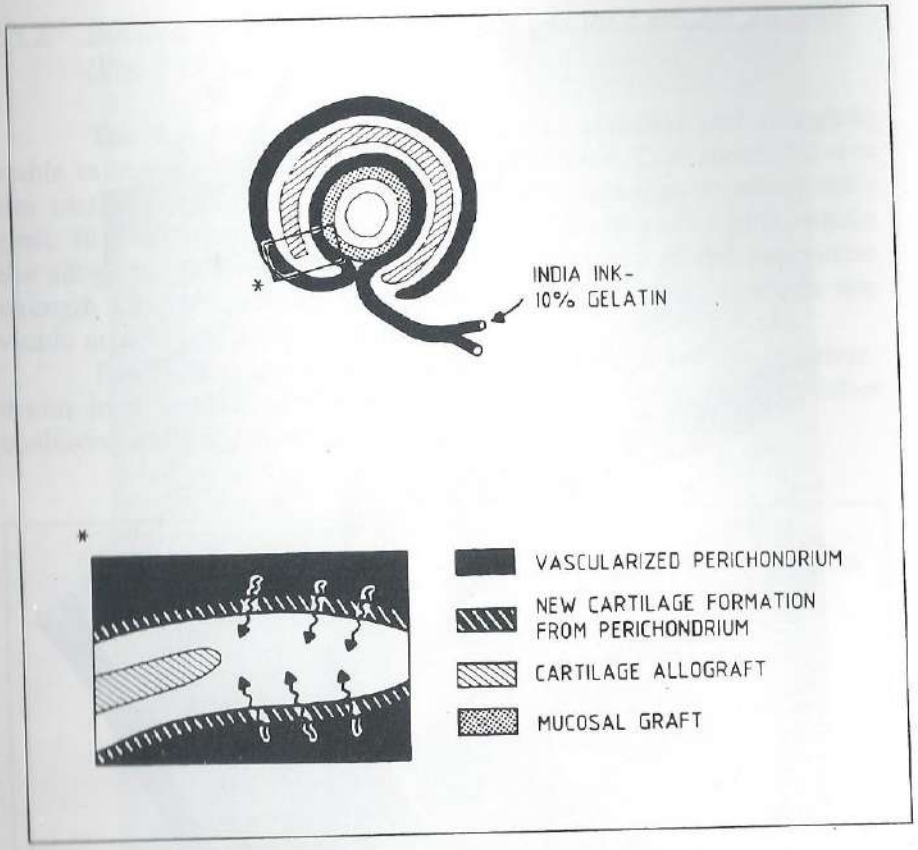


Fig. 2.16 : Preformed tracheal tube : vascularized perichondrium and cartilage allograft after 6 weeks follow-up.
A : Outlining of the quadrangular detail (asterisk) for histological examination (Fig. 2.16 B).
* Quadrangular detail : a plate of new cartilage is formed by appositional growth from the cartilaginous surface of the perichondrium. A blood vessel outgrowth originates from both the cartilaginous (vascular bed for cartilage graft) and the cutaneous (revascularization of mucosal graft) perichondrial surface. Arrow indicates neovascularity from cartilaginous perichondrial surface.

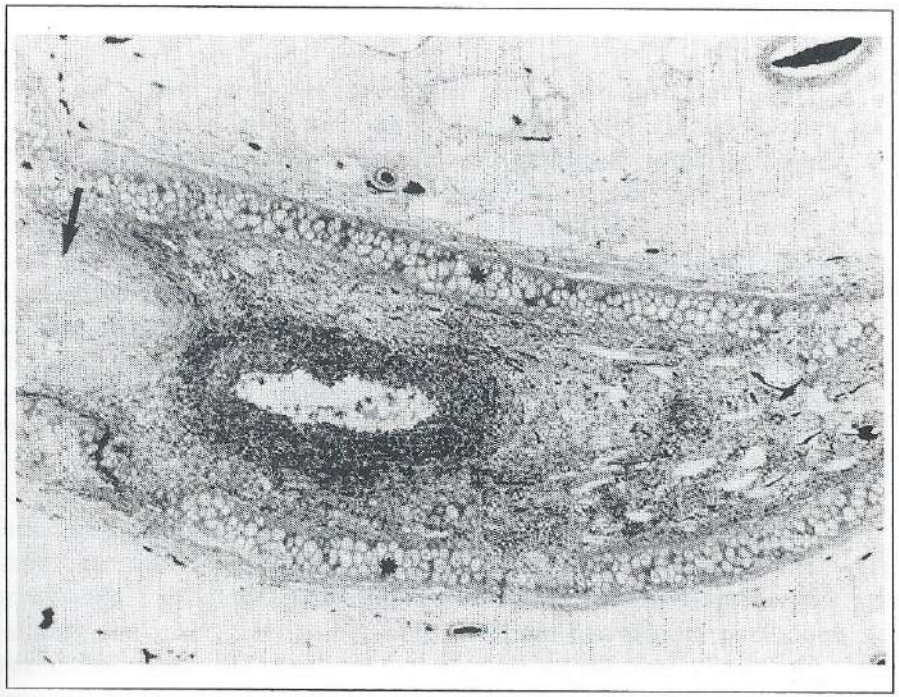


Fig. 2.16 B : Photomicrograph of the quadrangular detail of Fig. 2.16 A (H.E. original x 40).
Double row of new cartilage formation surrounding the end of the necrotic cartilage allograft (arrow).
An inflammatory reaction is visible around the allograft with India ink injected blood vessels which are new vascular formations from the original perichondrium.
Asterisk : areas of new cartilage formation.

2.4. Discussion

The thin, pliable nature and vascular characteristics of free vascularized connective tissue flaps seems most suitable for laryngotracheal reconstruction. Rotating the flap over 180° or 360° had no deleterious effect on distal vascularization. A well-vascularized surface is the best guarantee for take of the internal lining membrane. A full-thickness mucosal graft containing the entire thickness of the dermis is used for internal lining. To survive permanently, the graft has to become reattached and obtain a fresh blood supply from its new habitat. For take of the thick buccal graft, conditions have to be near-ideal : a rich blood supply of the graft bed, ensured by the distal perichondrium. Of importance, however, is the nature of the connective tissue holding the blood vessels together.

Perichondrium has a natural tendency for shrinkage to about 2/3 - 1/2 its original size if separated from the cartilage. The underlying tissue plays a role in the degree of shrinkage, which is higher with an underlying mobile and elastic wall. The loss of flap surface area is less when new adhesions can be formed between flap tissue and cartilage. This tendency of perichondrium flaps makes them unfit for use in repair of the laryngotracheal wall.

The long-term success of a cartilage graft depends on living chondrocytes that service and maintain the graft's bulk. Cartilage grafts preserved in Merthiolate undergo a progressive resorption with loss of external support. Early reports of cartilage allograft viability have to be taken cautiously (Delaere et al. 1992).

Tissues which are more suitable for the requirements of aiway wall replacement should be selected because of the negative aspects encountered with cartilage allografts and perichondrial flaps.
The positive aspects observed with vascularized connective tissue and oral mucosal grafts should be preserved.

2.5. Improvement of the Experimental Model (Fig. 2.20)

2.5.1. Vascularized Connective Tissue Flap

The type of connective tissue (fascial, perichondrial) of the vascularized flap is important because of the necessity to maintain the original flap surface area. Similar observations of surface contraction with vascularized perichondrium were described (Donski et al. 1980) but the reason for this natural tendency of surface contraction is still not clear. Because of the perichondrial shrinkage we decided to look for an experimental connective tissue flap of fascial nature.

The rabbit lateral thoracic (L.T.) fascial flap was therefore designed. It is vascularized by the lateral thoracic artery and vein. This vascularized tissue can be taken after dissection of the overlying skin in the lateral thoracic area. A flap of 15 x 5 cm may be obtained with a thickness and vascular pattern similar to the perichondrial flap (Fig. 2.17). An additional advantage of this L.T. fascia is the possibility to rotate the flap to the neck with preservation of the vascular pedicle. This shortens the operative procedure greatly as microvascular reanastomosis is not necessary.

Lateral Thoracic Fascial Flap : Anatomy and Dissection

The fascial flap is situated on the lateral chest wall. The craniocaudal axis measures 15 cm; in ventrodorsal direction the flap is 5 cm wide. The flap consists mainly of a fascial connective tissue containing the vascular network. At the cranial end a small muscle layer is connected with the deep surface of the fascial flap to include the proximal vascular pedicle consisting of lateral thoracic artery and vein. This small muscle, known as the cutaneous trunci muscle (Hebel et al. 1986) is part of the panniculus carnosus and covers the whole trunc of the rabbit. The cutaneous trunci muscle moves the skin of the trunc and is thinning out distally (Werker et al. 1992). Caudally a purely fascial flap may be harvested.

The flap is supplied by the lateral thoracic vessels which emerge from the axillary vessels in a common pedicle with the subscapular vessels. After 4-5 mm, the lateral thoracic vessels divide into ventral and dorsal branches. The ventral branch is coagulated at the lateral border of the pectoralis major. The dorsal branch runs in the middle of the flap, axially towards the iliac crest (Fig. 2.18).

Fig. 2.17 : Lateral thoracic fascial flap, axially perfused through the dorsal branch of the lateral thoracic artery and vein (arrow).
The fascial complex, containing the blood vessels lies immediately subcutaneously. A thin muscular layer is connected with the fascia proximally.

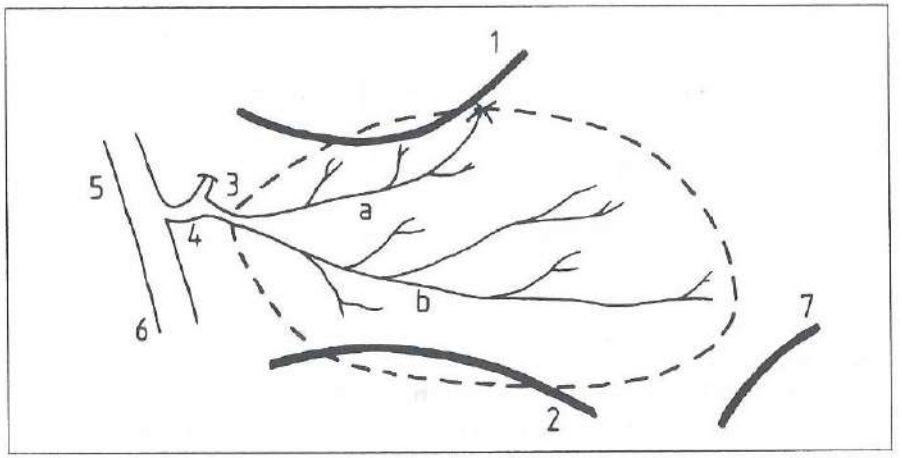


Fig. 2.18 : Position of the fascial flap and its vascular anatomy.
Outlining of the lateral thoracic fascial flap, related to the lateral border of the pectoralis major muscle (1) and the lateral border of the scapula (2); thoracolateral vessels (3) with a. ventral branch and b, dorsal branch; the subscapular pedicle (4); axillary vessels (5); brachial vessels (6); iliac crest (7).

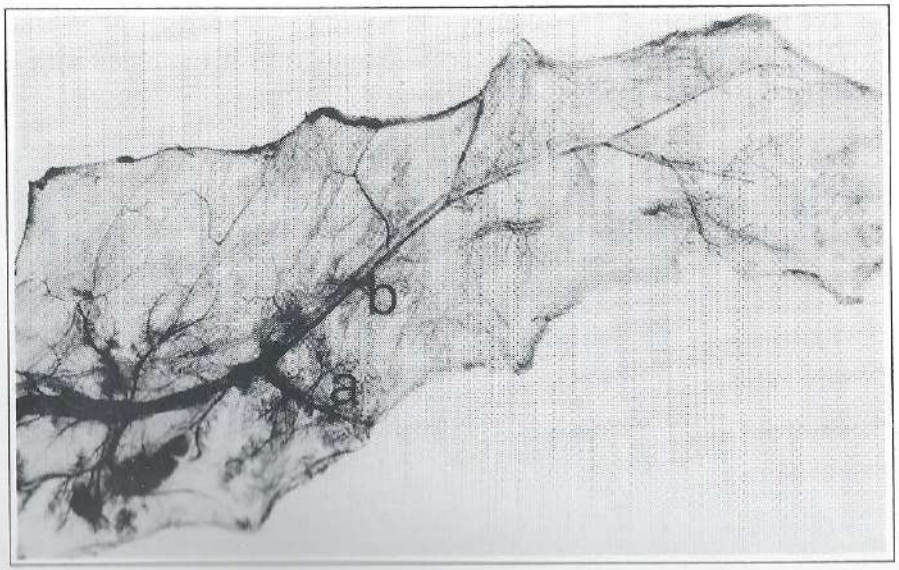


Fig. 2.19 : Vascular pattern of lateral thoracic fascial flap after injection with India ink-gelatin 10 %.
Thoracolateral vessels with a, ventral branch and b, dorsal branch

2.5.2. *Oral Mucosal Graft*

The easy revascularization and ingrowth of the full-thickness mucosal graft allows its further use as lining membrane.

2.5.3. *Cartilaginous Support*

Cartilage allografts were initially used because they are easily available and easy to use for circumferential tracheal reconstruction. Since the results with the allografts were disappointing, they were abandoned and replaced by autogenous cartilage grafts.

Several clinical (Dupertius 1959, Fry 1967) and experimental studies (Stall 1970) displayed long-term viability of cartilage autografts. In humans rib cartilage provides a major cartilage transplant source. In rabbits the outer ear is technically more easily available.

Laryngotracheal reconstruction with this improved model seems to be quite feasible. The contribution of the mucosal lining in wound contraction prevention and the nutritional needs of cartilage autografts are examined with a laryngeal reconstruction model (Chapter 3).

The supporting value of cartilage autografts is examined with a preformed tracheal tube model (Chapter 4).

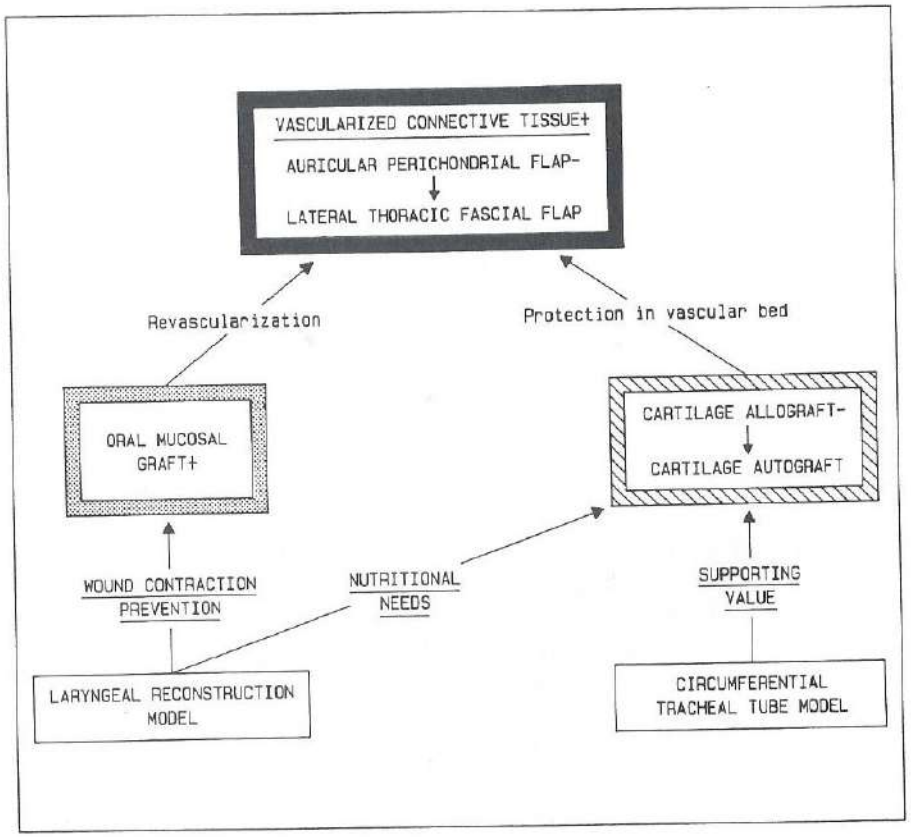


Fig. 2.20 : Concept of the 'improved' experimental reconstruction model.
+ : experimental results predominantly positive
- : experimental results predominantly negative

Chapter 3

Experimental Laryngeal Reconstruction

3.1. Introduction

After tumor removal, many reconstructive techniques for hemilaryngectomy defects have been described.
Introduction of strap muscles (Eliachar et al. 1989), regional myocutaneous flaps (Tovi et al. 1983), combined grafts (Duncavage et al. 1989) or epiglottis (Tucker et al. 1979) are possible. The limitations and drawbacks encountered with these techniques are due to the unavailability of sufficient quantities of tissue of the proper quality (Delaere et al. 1992). An experimental model was designed to study the feasibility of a transferable vascular bed in laryngeal reconstruction.

The rabbit lateral thoracic fascia may be transposed on its central vascular pedicle consisting of lateral thoracic artery and vein. By rotating this flap through 180° it is possible to bring an oral mucosal graft internally and to circumferentially cover and by that protect an autogenous cartilage graft for external support (Fig. 3.1 A, B). A rotation of 180° of the vascular bed has no influence on the vascularization distal of the rotation (Delaere et al. 1992). With this model, the framework and the internal lining can be reconstructed on a well-vascularized basis.

There are different reports of reepithelialization across flaps and grafts if no epithelial lining is provided (Tovi et al. 1983, Friedman et al. 1987, Friedman 1990). In these cases, reepithelialization starts from the cut margins of the defect with migration of epithelial cells over the reconstruction. Although mucosal migration is well established, less attention is given to the inevitable simultaneous process of scar contraction of the laryngeal reconstruction without a mucosal lining.

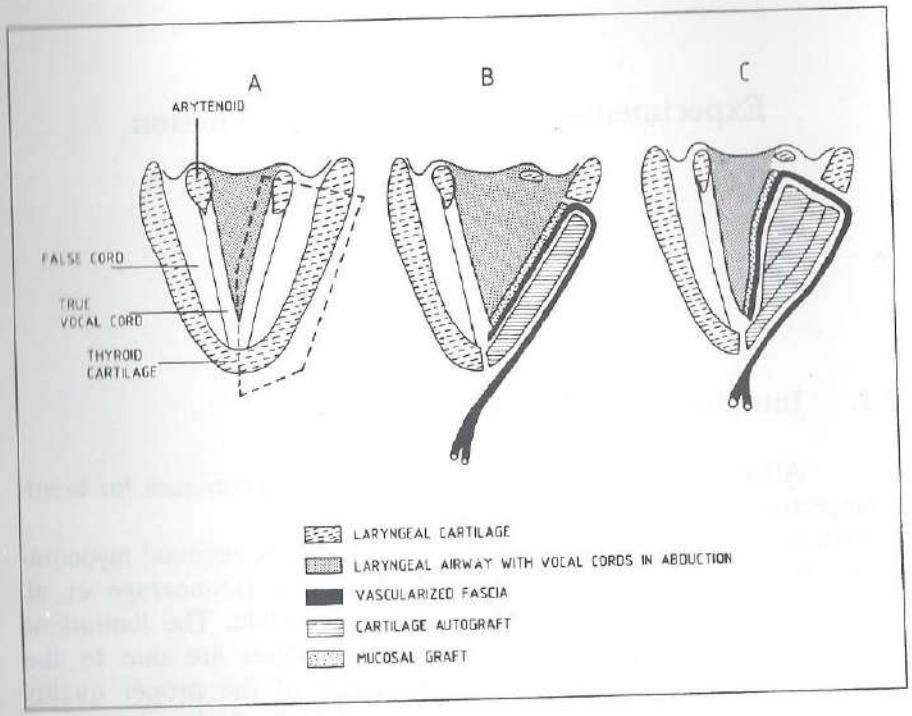


Fig. 3.1 : Laryngeal reconstruction with vascularized fascia.
A. Outlining the resection including the vocal processus of the arythenoid cartilage.
B. Reconstruction with vascularized fascia rotated 180° to bring the mucosal lining inside and to protect the cartilage autograft circumferentially in the vascularized bed.
C. Reconstruction of the posterior glottis by introduction of additional cartilage.

The **first** focus of interest of this experimental study was to investigate the necessity of epithelial lining in the repair of a full-thickness laryngeal wall defect. Laryngeal defects were reconstructed with a combined vascular flap consisting of L.T. fascia used as transferable vascular bed. This study compares reconstruction with and without lining to assess the role of an epithelialized surface in the prevention of scar contraction. The reconstructed cross sectional area was measured carefully after a follow-up period of 6 weeks.

Also important in laryngeal reconstruction is to provide bulk to the ipsilateral posterior laryngeal quadrant to restore the glottic sphincteric action.

A physiologic reconstruction after hemilaryngectomy requires glottic closure upon deglutition. To achieve postoperative glottic competence the resected vocal cord and arytenoid should be reconstructed to create a rigid pseudocord which extends to the midline (Fig. 3.1 C). This allows the normal vocal cord to reach the pseudocord on adduction. A long-term survival of the pseudocord without long term resorption is necessary (Blowgrund et al. 1975, Biller et al. 1984).

The **second** point of interest was to study reconstruction of the posterior glottis by introducing additional supporting material within the vascular bed.

3.2. Materials and Methods

3.2.1. Reconstruction with and without Mucosal Lining

Thirty New-Zealand white rabbits weighing ± 2800 g. were used in this investigation. The animals were divided into 3 groups. The first group (control group) consisted of 10 rabbits in which no surgical procedure was performed. The second group consisted of 10 rabbits in which a hemilaryngeal defect was reconstructed with a vascularized fascia, autogenous cartilage and an oral mucosal lining. The third group consisted of 10 rabbits in which the vascularized fascia served as internal lining with autogenous cartilage for support.

Surgical technique

The rabbits were placed in the supine position and anaesthetized with intravenous pentobarbital plus inhalation of halothane, nitrous oxide and oxygen through a mask.
After shaving and scrubbing of the lateral thoracic area with Betadine® and alcohol, the left L.T. skin was incised and dissected from the underlying fascia. The fascia with its axial vessels could be elevated from the muscles of the lateral chest wall and pedicled on the lateral thoracic artery and vein. A flap with a length of 15 cm and a width of 5 cm was obtained. A full-thickness oral mucosal graft of 0,8 by 1 cm was harvested from the buccal area. The oral defect was closed with catgut 4.0. This mucosal graft was applied at the distal end of the flap with nylon 9.0.

A midline incision was made to expose the larynx, followed by section of the left thyroid cartilage and underlying mucosa including the vocal processus of the arytenoïd. In this manner, a full-thickness laryngeal defect of 0,8 by 1 cm was created. The vascularized transferable bed with the mucosal graft at the distal end was brought over the clavicle with preservation of the lateral thoracic vessels. The edges of the mucosal graft were sutured to the margins of the laryngeal mucosal defect with nylon 9.0.

A section of cartilage 8 mm and 10 mm was removed from the root of the ear with intact perichondrium. It was placed over the inner fascia to repair the cartilaginous framework of the larynx. By rotating the fascia over 180° it was possible to circumferentially enclose the cartilage autograft (Fig. 3.1 B). The L.T. skin was closed with vicryl 3.0. Treatment and care of the rabbits followed the rules of the American Psychological Society.

The operative technique was identical for the second and third group except for the mucosal graft which was not used in the third group.

The vascular pedicle of the flap was dissected free 6 weeks after surgery and the subscapular artery was injected with blue Microfil in order to visualize the vascular pattern of the inner and outer fascial layer.

The animals were killed with an overdose of Nembutal® (pentobarbitone sodium), and the larynges were harvested.

From the isolated larynx cranial black-and-white photographs were taken and were developed at 5 x magnification. Representative samples of each group were wax imbedded, transversely sectioned and stained with hematoxylin and eosin. The black-and-white photographs were then used to trace out the perimeter of the glottic airway lumen. The cross sectional area was computed on an image analysis system program (CANVAS 3.0 ®).

Statistics were performed with STATVIEW 512+.

3.2.2. *Reconstruction of the Posterior Glottic Bulk*

Fifteen rabbits were used in this investigation. The animals were divided into 3 groups. The first group consisted of 5 rabbits with 1 cartilage strip (0,5/0,5 cm) added in the posterior glottic region between the inner fascia and the cartilage plate repairing the left thyroid

cartilage. The second and third group consisted of 5 rabbits each with respectively 2 and 3 additional cartilage strips (Fig. 3.1 C).

The surgical technique was identical as previously mentioned except for the cartilage component. Additional cartilage strips were attached to the inner aspect of the cartilage plate reconstructing the thyroid lamina with four transfixing sutures at the edges of the cartilage strips with nylon 6.0. The vessels of the flap were dissected free 6 weeks after surgery and the artery was injected with Microfil®. The animals were then killed and the larynges removed. Transverse sections were stained with hematoxylin and eosin for histological examination.

3.3. Results

3.3.1. Reconstruction with and without Mucosal Lining

All rabbits survived the operation. The rabbits of group 2 had no respiratory distress symptoms 6 weeks postoperatively. Six rabbits of group 3, the fascia lined group, were dyspnoeic after the follow-up period of 6 weeks.

On macroscopic examination, the glottic airway lumen in group 1 and 2 was nearly unchanged. The ipsilateral arytenoid remnant in group 3 was displaced more medially and caudally with resulting contraction of the lumen.

The mean laryngeal area measurements were 151.9 mm^2 (Standard Deviation (SD) 10.7) for controls (group 1), 135.5 mm^2 (SD 40.8) for group 2 and 57.5 mm^2 (SD 12.8) for group 3 (Fig. 3.2).

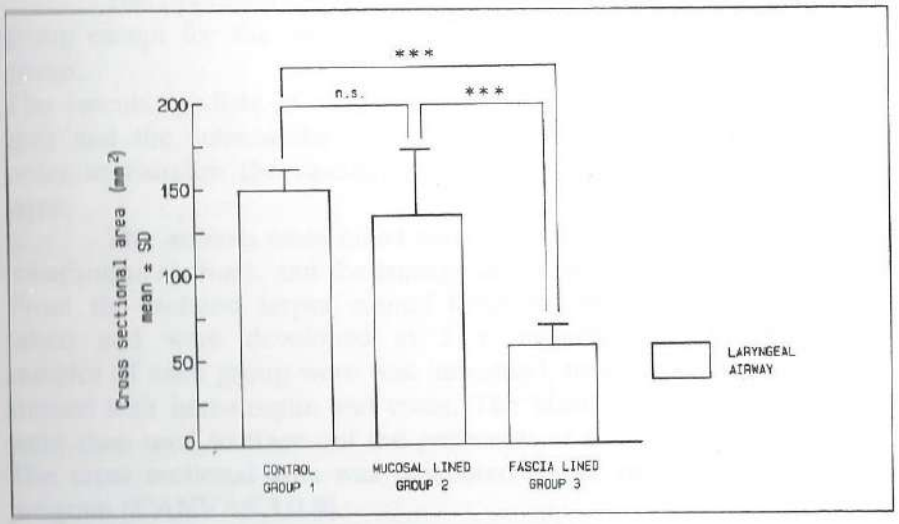


Fig. 3.2 : Comparison of laryngeal lumen area measurement.
*** : Difference from control significant at $p < 0.0001$.

The difference between the 3 groups was first investigated using the ANOVA-test. This test was positive at a significance level of 95 % ($p = 0.0001$). With the Dunnett t-test the control group was further compared with mucosal lined and fascial lined groups. The fascia lined group was significantly different from the control condition according to this statistic ($p < 0.0001$).

On histological examination group 2 showed ingrowth of oral mucosa over the microfil injected fascia with an abrupt transition between stratified non keratinised epithelium and respiratory ciliated epithelium. Over the oral mucosal graft in the subglottic area a hydropic swelling of the superficial (dyskeratotic) cells was visible (Fig. 3.3). The epithelial lining in group 3 consisted mainly of respiratory epithelium.

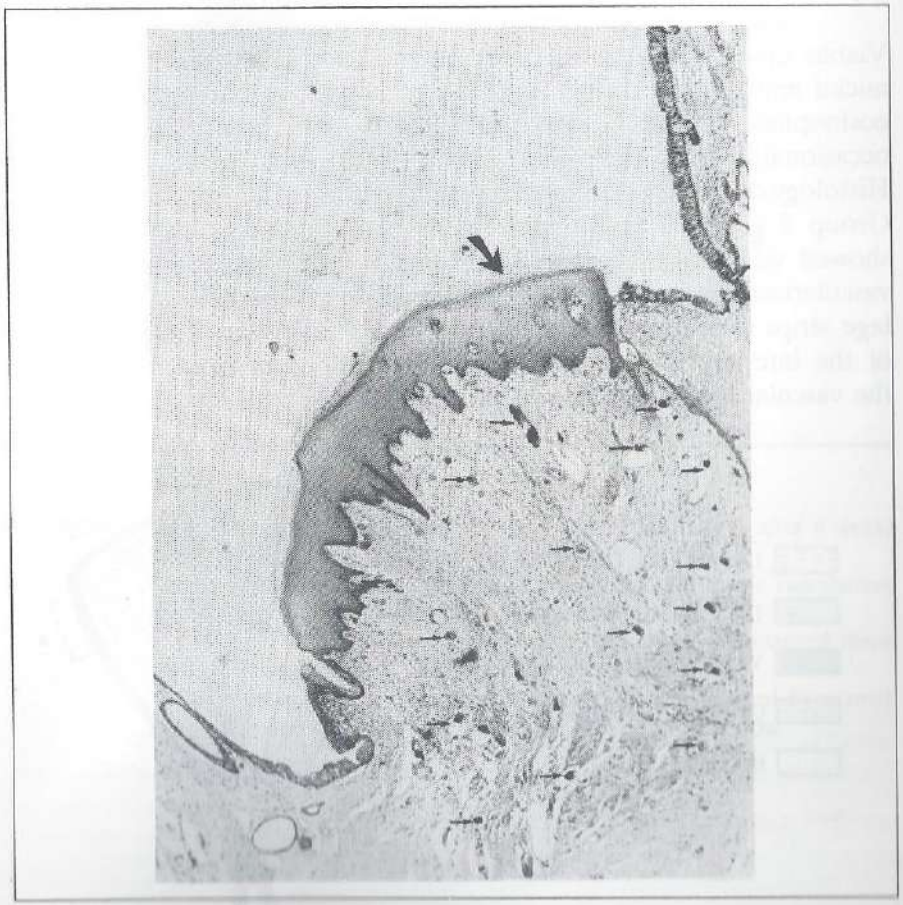


Fig. 3.3 : Photomicrograph (H.E. original x 25) of oral mucosal graft intralaryngeally in subglottic area with a hydropic swelling of the superficial cells (arrow). The vessels of the fascial flap are injected with blue Microfil® (small arrows). There is a sharp demarcation between the stratified and respiratory epithelium and between Microfil® injected and respiratory submucosal layer.

3.3.2. *Reconstruction of the Posterior Glottic Bulk*

The arytenoid mass is less pronounced in rabbits than in humans. So, no differences were noted clinically (respiration or glottic competence) between less (group 1) and more (group 3) arytenoid bulk.

Viability of the introduced cartilage graft could be examined with this experiment.

Cartilage viability was assessed by histologic examination. Viable cartilage is identified by the presence of central or eccentric nuclei and viable chromatin. Death of a graft is manifested by more eosinophilic ground substance, dead cells, with absence of nuclei and occasional massive infiltration with inflammatory cells.

Histology of fascia enclosed cartilage was normal.

Group 2 and 3 with respectively 2 and 3 additional cartilage strips showed viable cartilage only when this was in close contact with the vascularized layer. Cartilage strips squeezed in between 2 other cartilage strips showed cell death after 6 weeks follow-up. The extremities of the interjacent cartilage strips that remained in close contact with the vascular layer remained viable (Fig. 3.4).

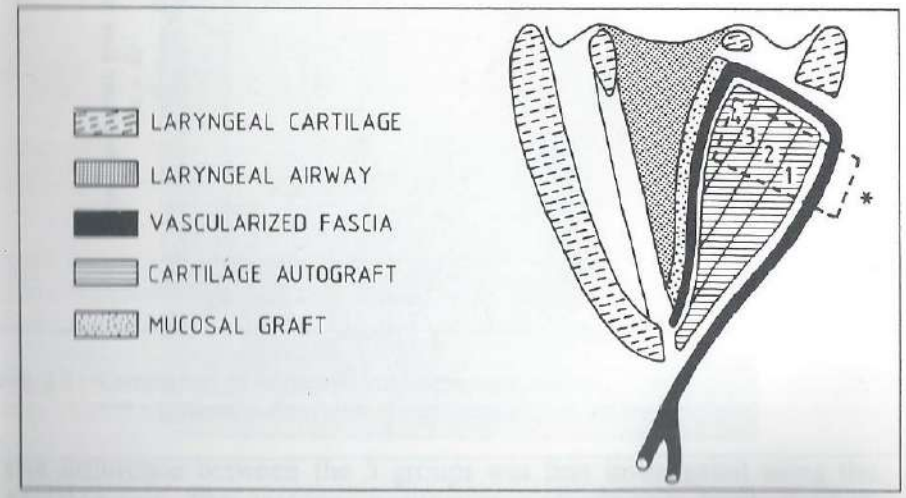


Fig. 3.4 A : Reconstruction of the posterior glottis by introduction of 4 autogenous cartilage strips. The grafts are fixed to each other by transfixing sutures. Graft no. 1 is the cartilage plate, reconstructing the thyroid lamina. Photomicrograph of quadrangular detail (asterisk) can be seen in Fig. 3.4 B.

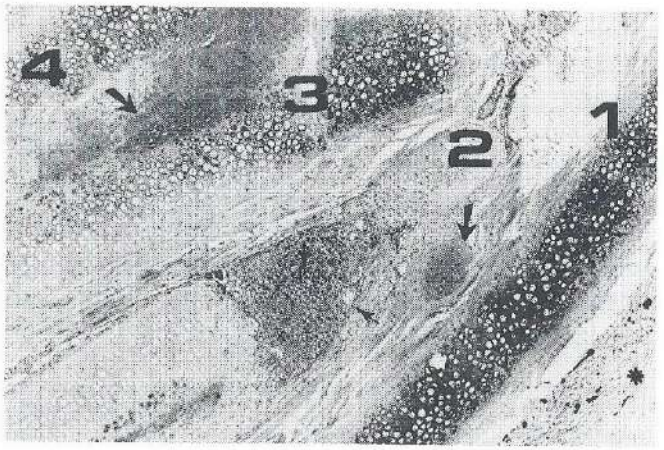


Fig. 3.4 B : Photomicrograph of the quadrangular detail of Fig. 3.4. A after 6 weeks follow-up (H.E. original x 40).
The outer and inner cartilage strip (1, 4) in contact with the vascularized fascia (Microfil injected) (asterisk) displays full viability.
The inserted cartilage strips (2, 3), separated from the vascularized tissue display cell death with more eosinophillic ground substance.
Areas of inflammation and cartilage resorption are indicated by a small arrow. Formation of new cartilage is indicated by a long arrow.

3.4. Discussion

The results demonstrate the contraction of wound healing by secondary intention when no epithelial lining is provided (Olson 1979). In the reconstruction without mucosal lining, the epithelial phase of healing is by extension of epithelial cells from the edges of the wound over the adjacent fascial surface. This process continues until the whole surface, though largely contracted, is epithelialized. Full-thickness defects of mucosal lining undergo changes in size and shape. Wound edges are moving actively towards the centre of the defect. These contraction forces are generated by myofibroblasts within the central granulation tissue (Majno et al. 1971, Madden 1973). Because of the importance of preserving the laryngeal lumen, healing by secondary intention should be avoided (Fig. 3.5).

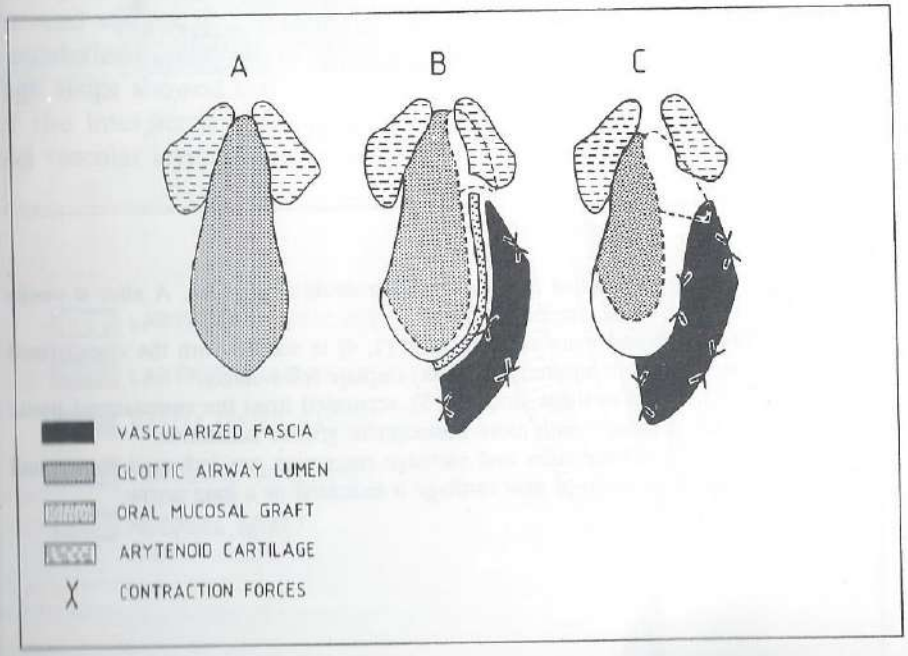


Fig. 3.5 : Wound contraction inside the larynx (cross section at glottic level).
A. Control
B. Mucosal lined reconstruction. Dotted lines indicate displacement of laryngeal wall and arytenoid due to wound contraction.
C. Fascia lined reconstruction with more lumen contraction and more arytenoid remnant displacement in comparison with B.

The subglottic area is lined with ciliated epithelium which contains a large amount of mucous cells. The cilia normally move mucus from the lower airway towards the pharynx where it is swallowed.
No mucociliary transport is possible in the reconstructed region (Fig. 3.3). The only way to get rid of secretions below the reconstructed segment is by coughing, which may be considered as a back-up system for mucus transportation in the airway.

Oral mucosal grafts seem to be the most appropriate at this moment in spite of the absence of ciliary activity. Respiratory mucosal grafts cannot be taken in sufficient amounts and are technically intractable as grafting material. Skin grafts have the disadvantage of crusting, desquamation and hair growth.

The laryngeal inlet acts as a sphincter to protect the airway. Normal sphincteric action produces a complete closure at the laryngeal inlet. In this study additional cartilage strips were introduced between the inner and outer fascial layer to restore the glottic and arytenoid bulk. The maintenance of a long-term survival of this pseudocord is important. Viability of cartilage may be assessed in different ways (Curran et al. 1956, Cotton 1991). We used histologic examination of the grafts to assess viability. It is generally accepted that cartilage grafts retain their form and viability if an adequate vascular pocket is provided. Cartilage has low metabolic activity which approaches anaerobic conditions, properties that are attributed both to sparsity of its cell population and to avascularity where the chondrocytes are nourished by diffusion (Hagerty et al. 1960).

The metabolic provision of cartilage strips inserted between other cartilage grafts with little or no contact with the vascular bed turned out to be inadequate.
Cartilage grafts need at least a vascular contact along one side. One additional cartilage strip can safely be used to provide bulk in the posterior glottis.

Chapter 4

Creation of an Experimental Tracheal Tube

4.1. Introduction

In this study a tracheal tube was preformed to evaluate the value of autogenous cartilage in supporting a defect and in maintaining a circular tracheal lumen.

There are few indications for circumferential tracheal reconstruction. Resection and primary anastomosis is the reparative method of choice when the involved segment is less than 5 cm (Grillo 1972, Neville et al. 1979, Grillo 1982).

The reason of this experiment was not to present a method for circumferential tracheal reconstruction. We rather wanted to evaluate the supporting value of autogenous cartilage when used for upper airway wall reconstruction with vascularized fascia as basic material and oral mucosa as internal lining. We believe that this problem could be evaluated best with the construction of a circumferential tracheal segment.

The construction of a neotracheal segment requires that the following criteria be met :

1. The tracheal inner surface must be lined with some sort of epithelium.
2. A stable and flexible structural framework should be provided.
3. An adequate vascularization should be provided to keep the reconstructing components viable.

These requirements are fulfilled when using vascularized fascia (Fig. 4.1), oral mucosa and autogenous cartilage grafts.

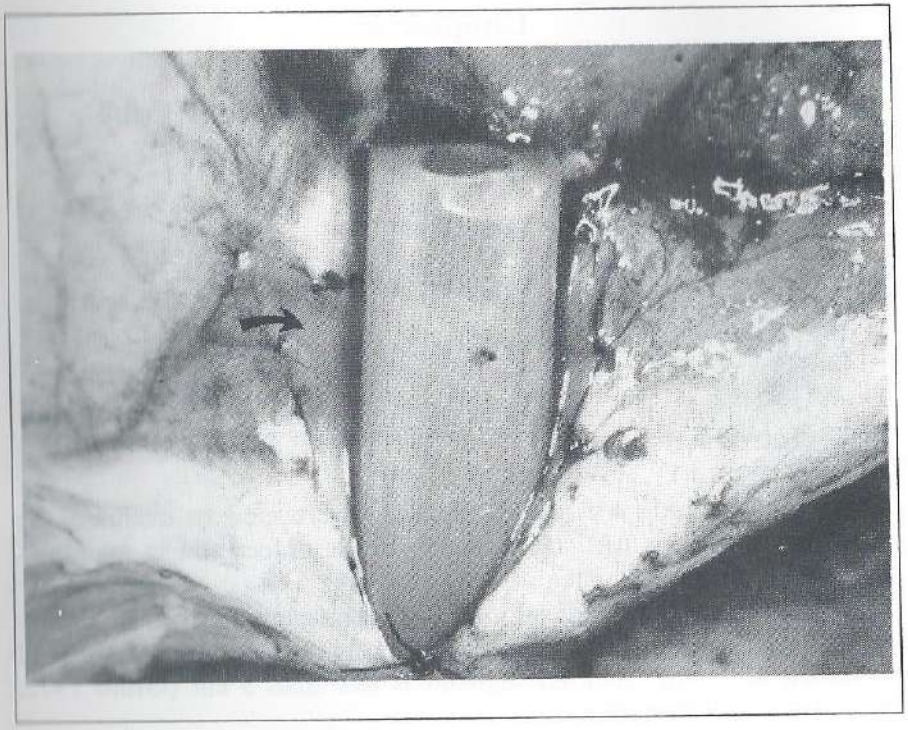


Fig. 4.1 : The mucosal graft (arrow) sutured to the vascularized fascia is circumferentially brought around a silicone tube.

A cartilaginous and membranous tracheal tube was created by suturing a mucosal graft, applied in the middle of the L.T. fascia, over a silicone tube. Four longitudinal cartilage strips were constructed over the fascia, bearing the mucosal graft, as support of the lumen. The cartilage strips were circumferentially embedded in vascularized tissue by rotating the distal end of the fascia over the reconstruction (Fig. 4.2, Fig. 4.3).
The effect of rotation of the vascularized bed on the blood supply was studied previously. No deleterious effect on the distal vascularization was found after rotating the fascia over 360° (Delaere et al. 1992).

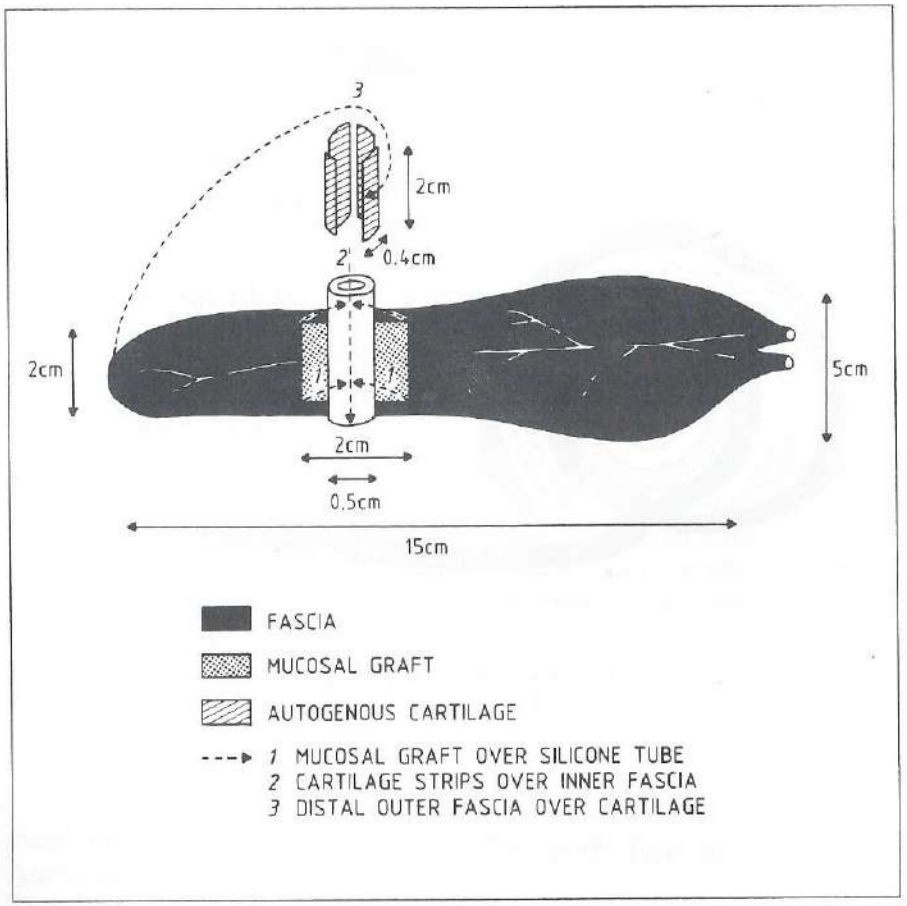


Fig. 4.2 : The different steps in creating a tracheal tube.
1. Mucosal graft circumferentially brought around the silicone tube.
2. Four cartilage strips applied over the fascia bearing the mucosal graft.
3. Distal end of fascia sutured over cartilage strips.

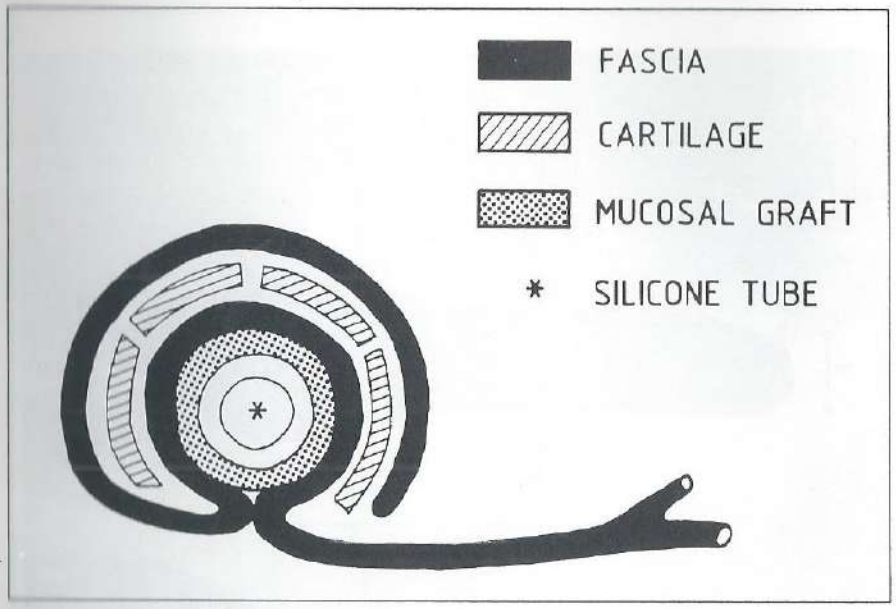


Fig. 4.3. : Cross section of neotrachea. Mucosal lined lumen with cartilage strips circumferentially enclosed in vascular bed.

4.2. Material and Methods

Twenty New-Zealand white rabbits weighing 2800 g. were used in this experiment. The animals were divided into 3 groups. The first group (control group) consisted of 10 rabbits in which no cartilaginous support was inserted into the tube reconstruction. They were followed 8 weeks after surgery. The second group consisted of 5 rabbits with cartilaginous support followed during 4 weeks. The third group consisted of 5 rabbits with cartilaginous support followed during 8 weeks.

Surgical technique

The rabbits were placed in the supine position.
Anaesthesia was induced by intramuscular administration of Hypnorm and maintained with a halothane-oxygen mixture through a mask. After shaving and scrubbing of the lateral thoracic area with Betadine® and alcohol, the left L.T. skin was incised and dissected from the underlying fascia. The fascia with its axial pattern vessels was lifted from the musculature and pedicled on the lateral thoracic artery and vein.
In this way, a fascial flap was harvested with a length of 15 cm and a width of 5 cm. Two full-thickness oral mucosal grafts of 1 x 2 cm were obtained from the left and right buccal area. The oral defect was closed with catgut 4.0.

The two oral mucosal grafts were placed side by side on the middle part of the fascial flap and sutured to the vascular bed with nylon 9.0. The mucosal graft with the underlying fascia was wrapped around a silicone rod (nylon 6.0) with a diameter of 0,5 cm to form a mucosal lined tube with a length of 2 cm (Fig. 4.1).

Two sections of cartilage 10 mm x 20 mm were removed from both ear roots with intact perichondrium. The perichondrium was included on the cartilage graft to ensure its mechanical strength and to improve its healing to surrounding tissues. Four cartilage strips of 4 mm x 20 mm were obtained from the 2 pieces and fixed on the inner fascia with nylon 6.0 to create a cartilaginous framework. The dorsal membranous part was formed by the fascia entering and leaving the created tube. Finally, the distal end of the fascia was brought over the cartilage framework which was enclosed by an inner and outer vascular fascial layer (Fig. 4.2).

The lateral thoracic skin was closed over the neotrachea with vicryl 3.0. Treatment and care of the rabbits followed the rules of the American Physiological Society.
The surgical technique was identical in the two groups except for the cartilaginous support which was not introduced between the two fascial layers in the first group.

The L.T. area was reopened after the follow-up period. The subscapular vascular pedicle was dissected and injected with India ink 10 % gelatin to visualize the blood vessels within the inner and outer vascular bed.
After injection, the vascular pedicle was cut and the neotrachea harvested with the silicone tube still in place.
Black-and-white photographs were taken from the neotracheal specimens with and without the tube and were developed at 5 x magnification.
Representative samples of each group were wax imbedded, transverse sectioned, and stained with haematoxylin-eosin. The black-and-white

photographs were then used to trace out two perimeters : the outer diameter of the silicone tube and the inner mucosal lining of the preserved lumen after removal of the silicone rod (Fig. 4.4, Fig. 4.5). Cross sectional area was computed on an image analysis system program (CANVAS 3.0 ®).

4.3. Results

The cross sectional area after removal of the silicone tube was substracted from the cross sectional area with the tube (= loss of tracheal area).

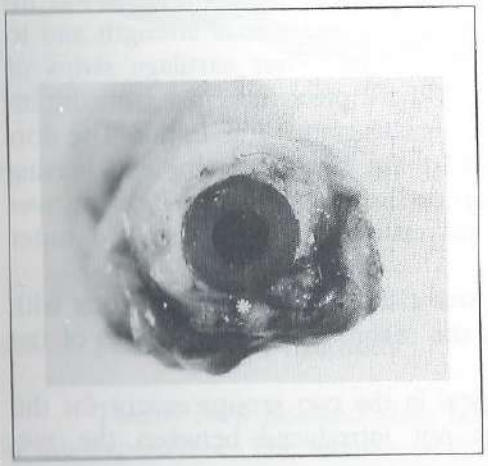


Fig. 4.4. A :
Photograph of the reconstructed lumen with silicone tube in place.
Membranous region is indicated by an asterisk.

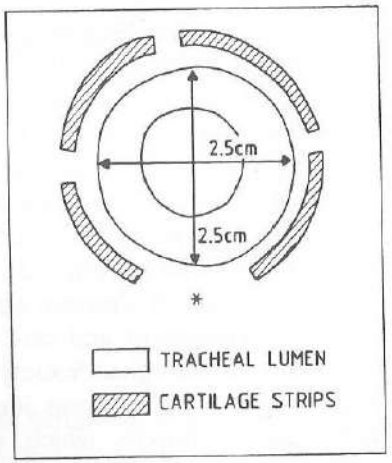


Fig. 4.4. B :
Cross section of tracheal tube with silicone tube in place.
The horizontal and the vertical axis measure 2.5 cm.

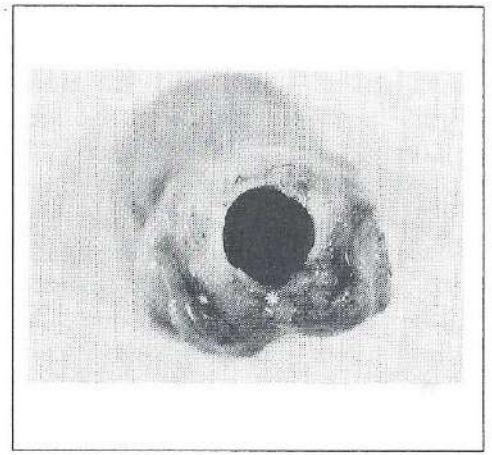


Fig. 4.5. A :
Photograph of tracheal lumen after removal of the silicone tube.
(4 weeks follow-up)

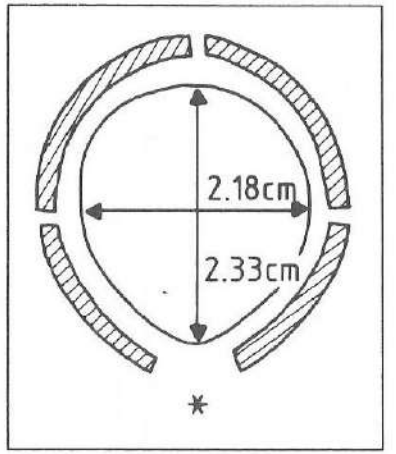


Fig. 4.5. B :
Cross section of tracheal tube after removal of the silicone tube.
Mean horizontal axis : 2.18 cm
Mean vertical axis : 2.33 cm
Loss of lumen diameter is more pronounced in the membranous region (asterisk).

The mean loss of tracheal area was 385.2 mm^2 (Standard Deviation (SD) 24.9) for group 1 (without cartilaginous support), 85.9 mm^2 (SD 33.3) after 4 weeks follow-up (group 2) and 59.1 mm^2 (SD 15.1) for the group 8 weeks after surgery (group 3) (Fig. 4.6).

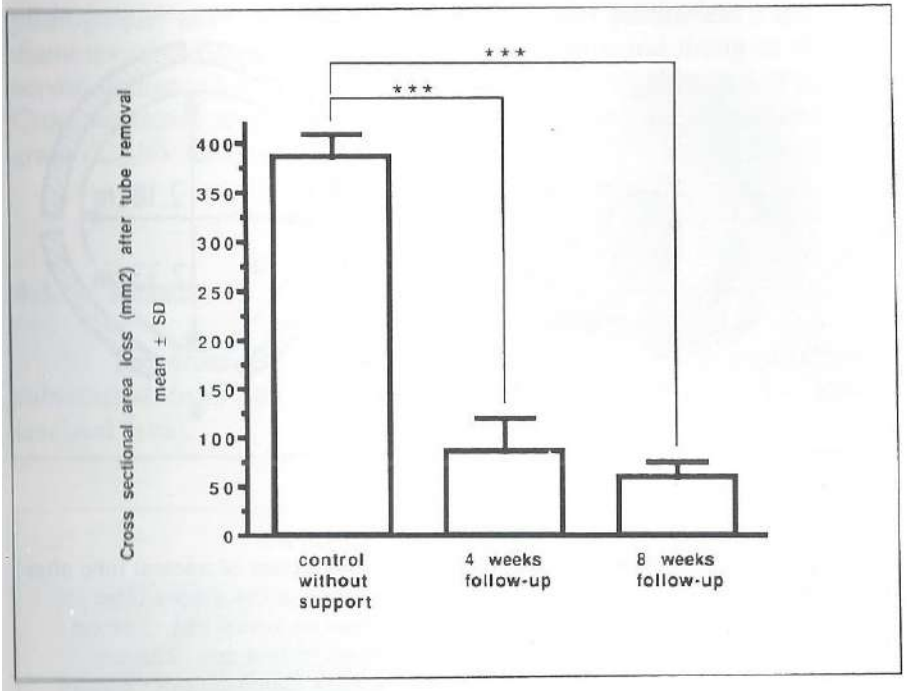


Fig. 4.6 : Comparison of loss of tracheal lumen : 79 % lumen preservation after 4 weeks, 86.6 % after 8 weeks versus 10.7 % for controls.
▭ = loss of tracheal lumen
*** : difference from control significant at $p < 0.001$

The histological appearance of the reconstructed tracheal wall (Fig. 4.9) can be evaluated best in comparison with the normal tracheal wall (Fig. 4.7). The non-keratinized stratified epithelium is visible on the internal layer of the fascial flap. The inner fascial layer with the India ink injected blood vessels and some muscle cells underneath the fascia is only 1 mm thick. It is however still 2.5 times thicker than the submucous layer of the normal trachea. The cartilaginous component is seen between the inner and outer fascial layer. The viability of the cartilage can be recognized by the presence of central or eccentric nuclei containing chromatin. Several areas of new cartilage formation by appositional growth can be observed. The new cartilage has smaller, more densely packed cells with less matrix.

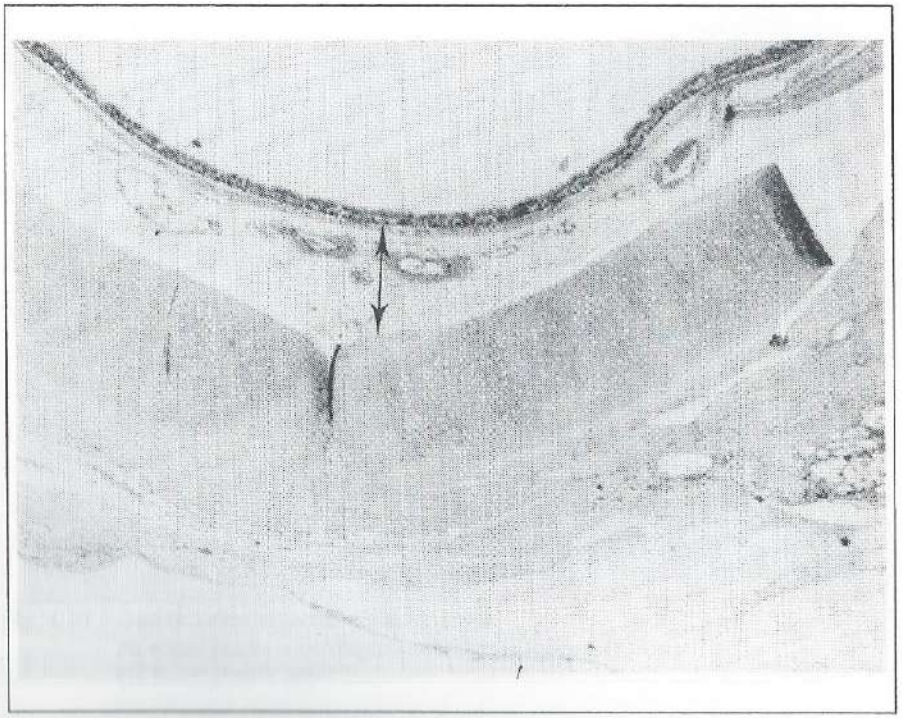


Fig. 4.7 : Cross section of normal tracheal wall.
Arrow indicates the thickness of the submucosal layer.
(H.E. original x 20)

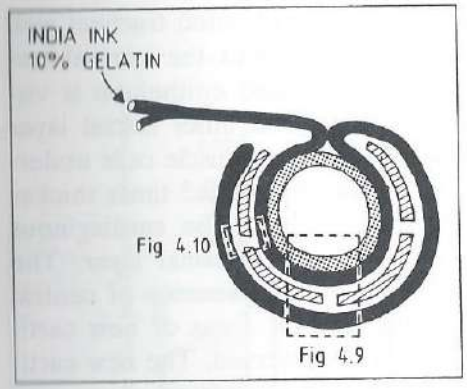


Fig. 4.8 :

Cross section of preformed tracheal tube with outlining of histological detail of Fig. 4.9 and Fig. 4.10.

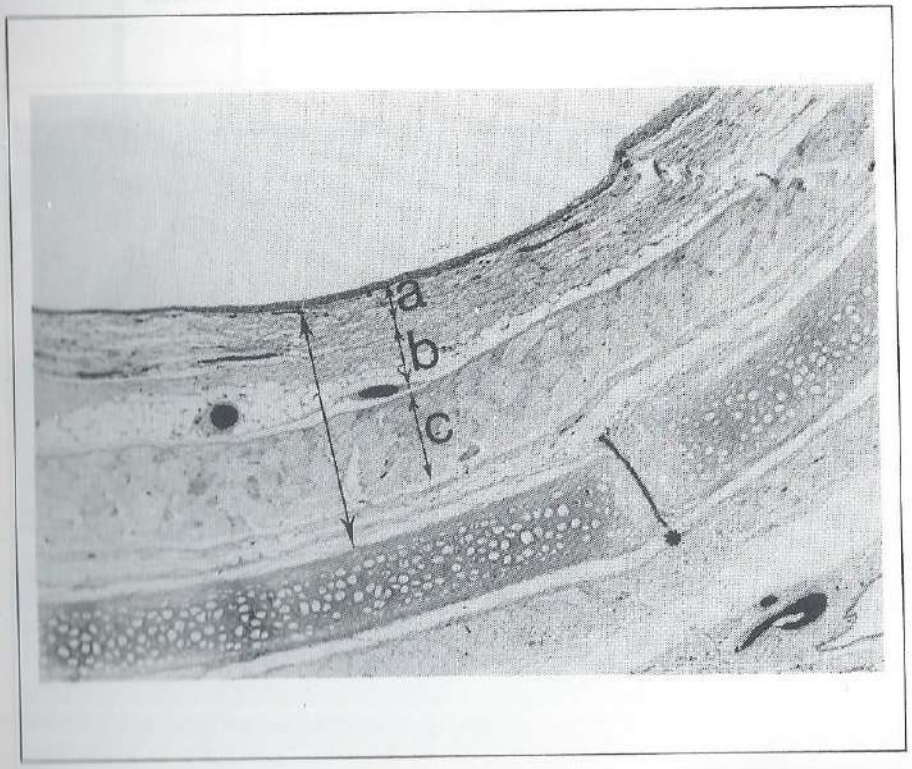


Fig. 4.9 : Cross section of reconstructed tracheal wall.
Arrow indicates thickness of submucosal tissue : a, revascularized full-thickness mucosal graft; b, vascularized fascia; c, cutaneous trunci muscle; asterisk indicates fibroconnective tissue between two adjacent cartilage strips with formation of a 'pseudarthrosis'. (H.E. original x 20)

The gap between the cartilage strips is filled with fibroconnective tissue which holds the strips in place (Fig. 4.9). At some places formation of newly formed cartilage bridges are found. This cartilaginous connection between 2 cartilage strips is established in 5 % of the intervening cartilage spaces after 4 weeks and in 10 % after 8 weeks (Fig. 4.10).

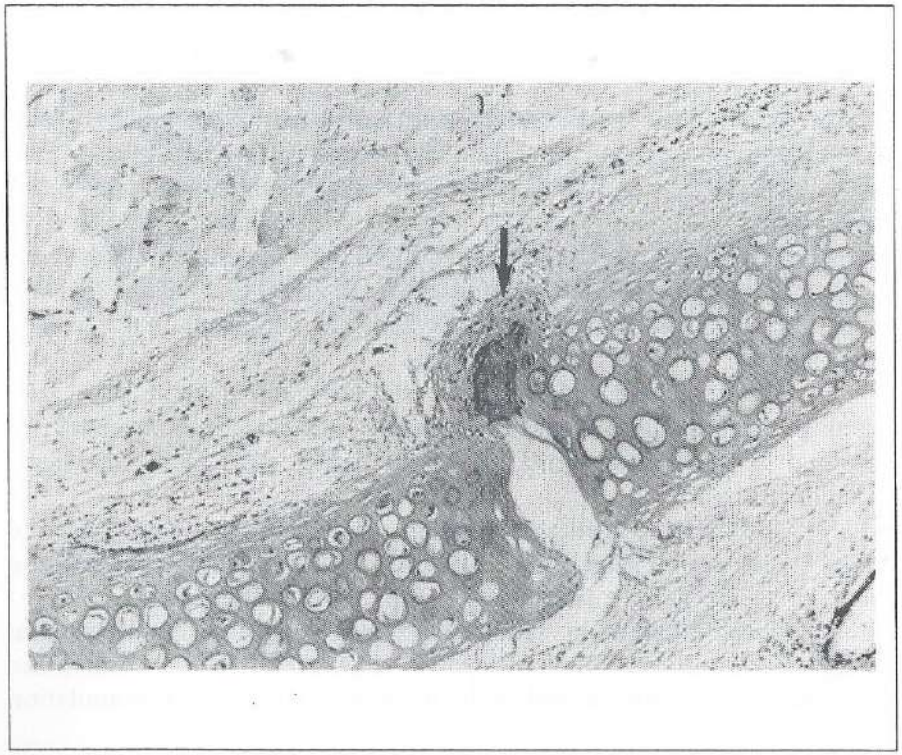


Fig. 4.10 : Gap between adjacent cartilage strips.
At some places a cartilaginous bridge is formed (arrow).
(H.E. original x 40)

4.4. Discussion

Circumferential tracheal reconstruction is rarely needed in clinical practice. In most patients, primary anastomosis after resection of up to 5 cm of the trachea is the method of choice. Preforming neotracheal segments is however possible. It seems simple to replace a tube intended primarily for air passage. The difficulties encountered with neotracheal segments however become obvious by reviewing the literature. Reconstruction of a tracheal defect has been tried with prosthetic material such as silicone rubber (Neville et al. 1979), porous mesh tubes (Pearson et al. 1988) and others (Bucker et al. 1951, Neville et al. 1976, Jacobs 1988). The problem with all synthetic materials is the absence of an epithelialized surface, formation of granulation tissue at the suture lines and subsequent infection and extrusion.

A cartilage tube can be formed taking advantage of the chondrogenetic effect of perichondrium (Kon et al. 1983). Again, the mucosal lining is lacking and will not easily be achieved in a cartilage tube.

When tracheal allografts are used avascular necrosis with graft expulsion will quickly occur. No vascular pedicle can reasonably be obtained to provide revascularization of such a graft by direct microvascular suture.

More recently, autogenous materials such as free vascularized bowel segments (Letan et al. 1990) and esophageal interposition (Kato et al. 1990) have been used to repair tracheal segments.
These techniques show an inherent absence of structural support but their well-vascularized mucosal layer is responsible for the observation that the anastomosis healed fully without formation of granulation tissue.

The preformed tracheal tubes on a vascularized fascia display a fully revascularized circumferential mucosal layer (Fig. 4.9). Of interest is the observation that the longitudinal cartilage strips are capable of preserving 79 % of the reconstructed lumen after a follow-up period of 4 weeks. After 2 months 86.6 % of the tracheal lumen area is preserved in contrast with only 10.7 % lumen preservation in the control group.
Autogenous cartilage applied longitudinally seems effective in supporting a circumferential tube when placed between the two layers of the fascial flap.

Fibroconnective tissue holds the cartilage strips in place even after a short period of 4 weeks. When perichondrium is included, production of new cartilage cells via appositional growth is ensured. Cartilage bridges filling the space between two adjacent cartilage strips are formed by the same mechanism of appositional growth.

The place where most of the tracheal lumen area is lost after removal of the silicone tube, is in the 'membranous' region where the fascia enters and leaves the tubes.

Cartilage autografts are preferable in order to restore external support. They do not bear the risk of extrusion as do allogenic implants. Preserved cartilage allografts have generally been disappointing as progressive cell dead and finally resorption occurs (Tanzer 1978). Unlike bone, autogenous cartilage grafts are indifferent to functional stress for survival and they retain form and bulk if an adequate vascular pocket is provided. Apart from a long-term success cartilage even has been proved to grow in size (Peer 1955, Skoog et al. 1972, Tanzer 1978, Duncan et al. 1984, Krutchinsky et al. 1984).

Addendum : Clinical Case Reports (Delaere et al. 1991)

Two patients with a posttraumatic laryngeal stenosis are presented. The history of both patients is a clinical illustration of the necessity to combine the three requirements : vascularity, support and mucosal lining. They are the keystones leading to successful reconstruction.

A1. Case 1

A 26-year-old man was admitted in December 1988 to a nearby hospital emergency room with severe laryngeal trauma and a mandibular fracture after a motorcycle accident. An urgent tracheotomy was necessary. After 2 weeks he was transferred to the University of Leuven for further care. An exploratory cervicotomy performed on January 2, 1989, indicated that the initial tracheotomy had been done through the multifragmented thyroid cartilage. The cannula was first replaced to the level of tracheal rings 2 and 3. Both vocal cords were luxated from the anterior commissure (Fig. 5.1 A). There was a rupture of the thyroepiglottic ligament with superior retraction of the epiglottis. The hypopharyngeal and ventricular band tears were approximated. The vocal cords were fixed laterally to the remnants of the thyroid cartilage. Because of the disrupted and displaced epiglottic cartilage, we preferred at that time to reconstruct the frontal thyroid defect with a free plate of bone from the iliac crest.

A Portex endotracheal tube, closed at the top, was inserted as a lumen-keeper. The petiole of the epiglottis was attached to the upper end of the avascular iliac crest bone (Fig. 5.1 B).

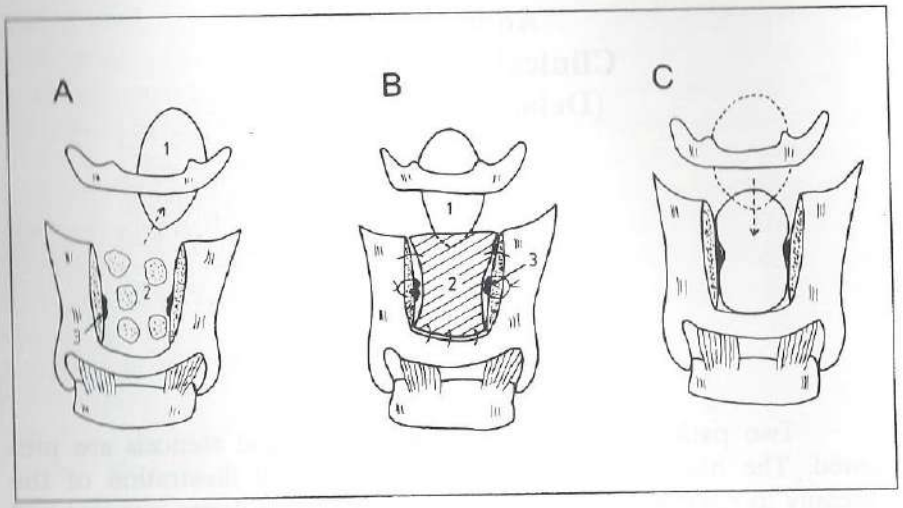


Fig. 5.1 : (case 1) Reconstruction of anterior laryngeal defect.
A. Multifragmentated thyroid cartilage (2), with both vocal cords luxated from anterior commissure (3). 1-superior retraction of epiglottis.
B. Reconstruction with iliac crest bone (2) with reattached epiglottic cartilage (1) and laterally fixed cords (3).
C. Reconstruction with epiglottoplasty.

A computed tomography (CT)scan of the larynx 1 month postoperatively revealed a peripheral resorption of the iliac crest graft with intrusion into the laryngeal lumen. There was a total obstruction of the lumen above the laryngeal stent, which was displaced caudally, due to formation of granulation and scar tissue (Fig. 5.2, Fig. 5.3).

Indirect laryngoscopy revealed a total obstruction of the supraglottic inlet. Arytenoid movement could not be assessed. In October 1989 the granulation tissue and iliac crest graft were removed. We decided to perform a reconstruction with the epiglottis, which was mobilized downwards as an advancement flap to form the anterior laryngeal wall (Fig. 5.1 C). Before mobilizing the epiglottis into position between the thyroid lamina, we placed a laryngeal silicone stent in the endolarynx, extending above the false cords at its upper level.

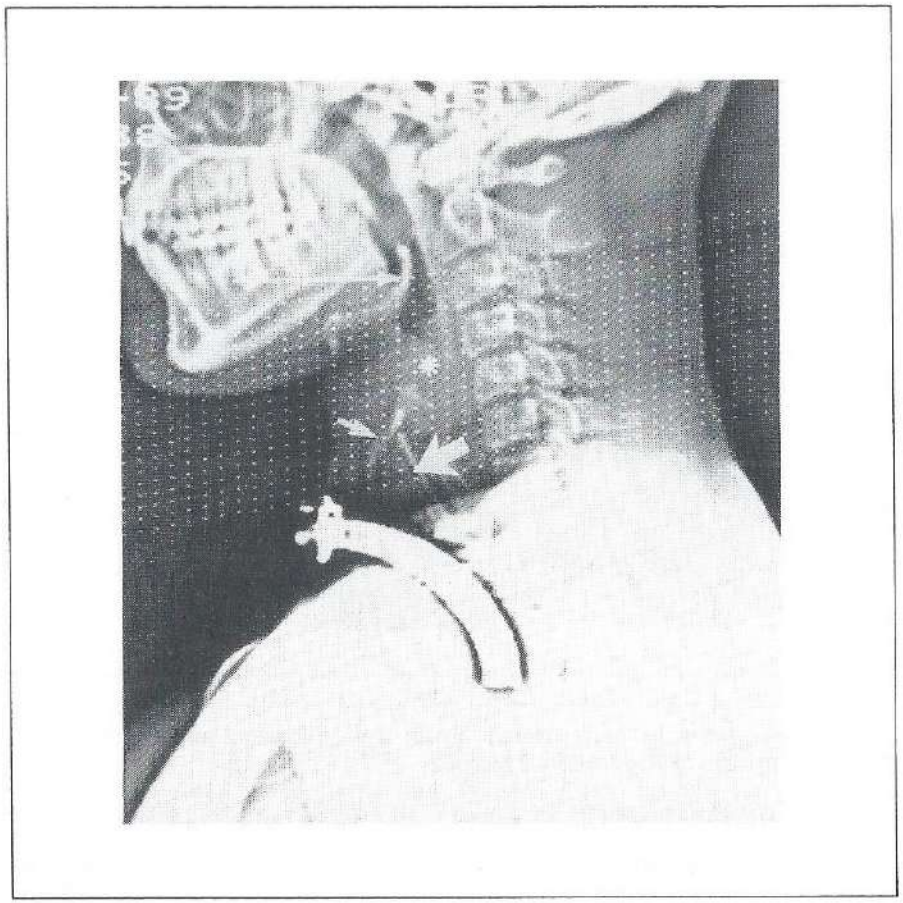


Fig. 5.2 : Sagittal computed tomography (CT)scan after reconstruction with iliac crest : granulation tissue at supraglottic and glottic level (star); superior retraction of epiglottis (large arrow); intrusion of iliac crest graft into laryngeal lumen (small arrow) over caudally displaced laryngeal stent (thick arrow).

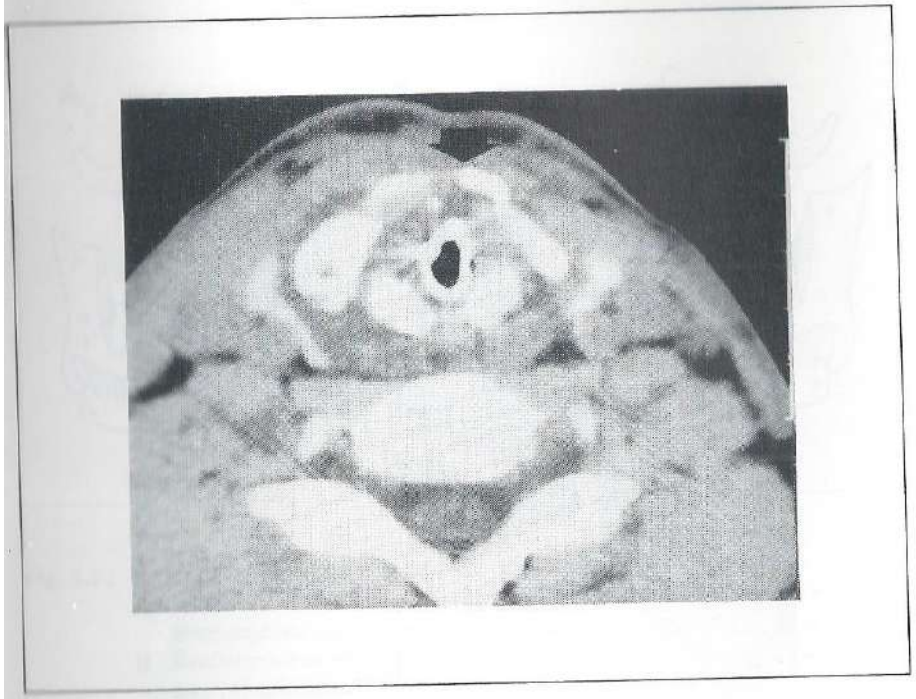


Fig. 5.3 : CT scan of laryngeal lumen at glottic level, obliterated with scar tissue and intrusion of iliac crest graft (arrow).

For maximum mobilization and descent, the epiglottis had to be stripped entirely of its lingual perichondrium up to the tip, without penetration of the remaining mucoperichondrial attachments of the vallecula, as they provide the blood supply to the epiglottic flap. This surgical technique was described by Tucker et al. (Tucker et al. 1979). The strap muscles were reapproximated and a drain was placed in the neck.

The soft silicone laryngeal stent was removed endoscopically 3 weeks postoperatively. A heavy silk loop, passed through its upper segment during the reconstructive process, is helpful at this stage. The nasogastric tube feedings were maintained for approximately 2 weeks postoperatively.

A CT scan displayed a sufficient laryngeal lumen (Fig. 5.4). The patient was able to swallow without aspiration and the tracheal cannula was removed 2 months postoperatively.

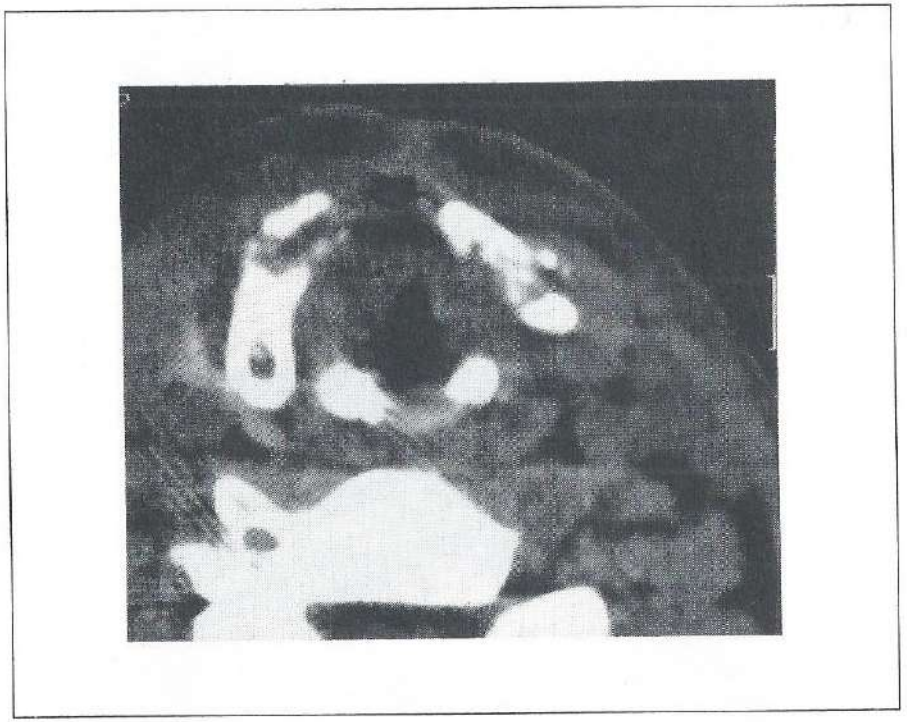


Fig. 5.4. : CT scan of reconstructed larynx at glottic level.
Note absence of calcification in elastic type of epiglottic cartilage.
Arrow - epiglottis.

A2. Case 2

A 43-year-old patient was referred to us in May 1989 with laryngeal stenosis. In November 1986, he had a car accident with a blunt laryngeal trauma for which he was treated in a nearby hospital with a tracheotomy and reconstruction of a frontal thyroid defect with a free iliac crest graft. He had not been able to be decannulated since his operation. A laryngoscopy revealed a decreased sagittal glottic diameter, supraglottic scar tissue, and bilaterally reduced arytenoid mobility with the right arytenoid in a more anterior position.

A CT scan displayed a reduction of the sagittal laryngeal diameter, the remnants of the iliac crest anteriorly, and granulation tissue

at the glottic and supraglottic levels with an inadequate airway (Fig. 5.5).

In December 1989 the iliac crest and granulation tissue were removed with repositioning of the right arytenoid cartilage. The frontal laryngeal defect was repaired with epiglottoplasty. A postoperative CT scan displayed a sufficient laryngeal lumen (Fig. 5.6). The tracheotomy tube could be removed after 1 month.

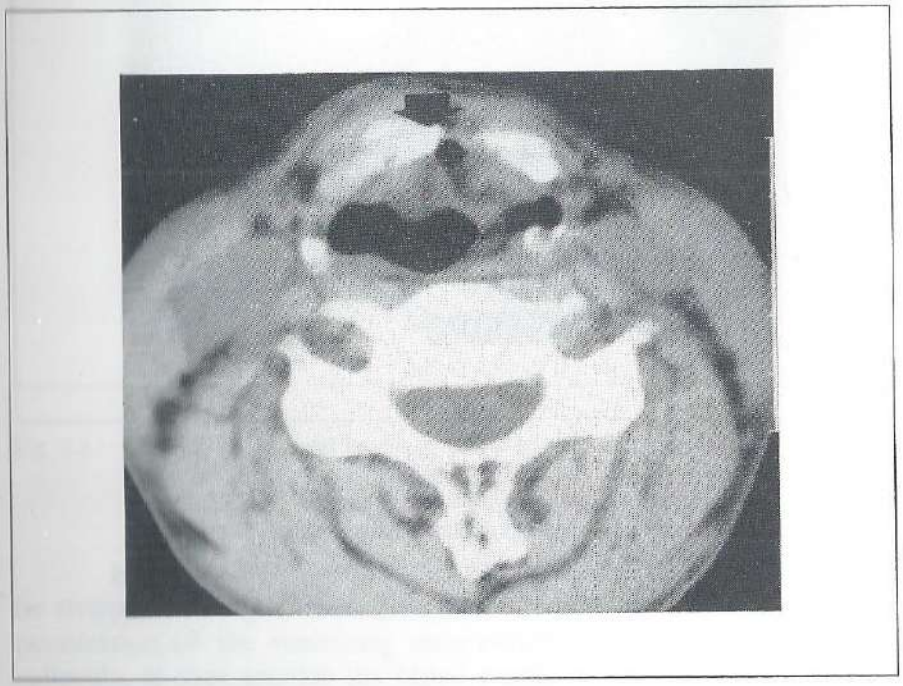


Fig. 5.5 : (case 2) Axial computed tomography (CT) scan at glottic level reveals intrusion of iliac crest remnant with granulation tissue (arrow).

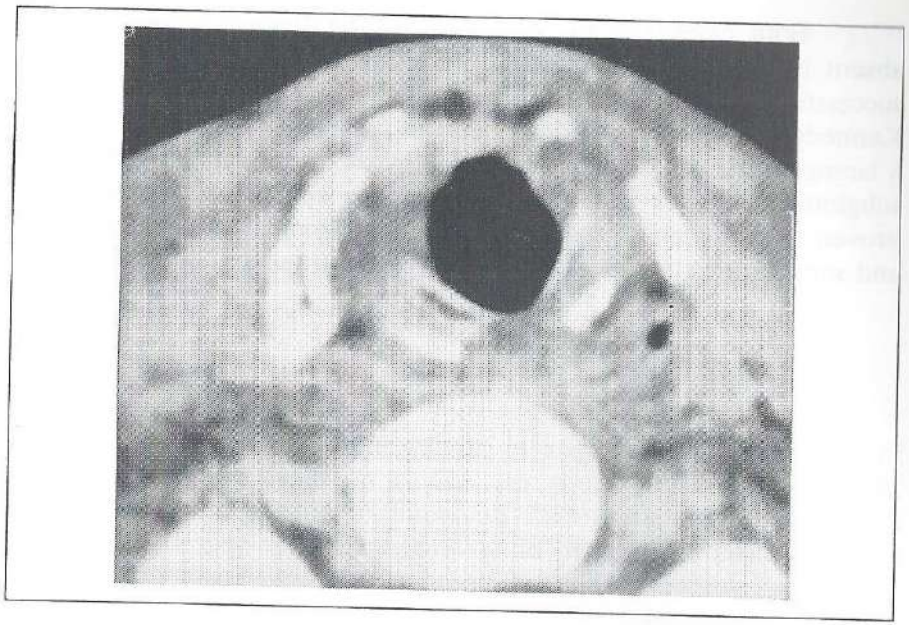


Fig. 5.6 : CT scan at glottic level of reconstructed larynx after epiglottoplasty.

A3. Discussion

Two cases of laryngeal stenosis repaired by epiglottoplasty are presented. With this therapeutic approach, the reconstruction was successful in providing an airway not requiring a tracheotomy tube and a voice capable of communication.

The elastic epiglottic cartilage provides the support needed to maintain the laryngeal lumen during respiration. It is well vascularized and provides a mucosal internal lining membrane.

The first reconstruction in both cases with iliac crest graft was unsuccessful in accordance with the theoretic considerations on laryngeal reconstruction. Peripheral resorption of the graft leads to intraluminal migration. The exposed bone, which lacks a blood supply, behaves almost like a foreign body and causes excessive granulation tissue formation and collagen deposition. The Portex endotracheal tube used in the first case to stabilize the iliac crest was an extra contribution in the scar tissue formation. Indwelling rigid round lumen-keepers that excoriate mucosal surfaces should be avoided.

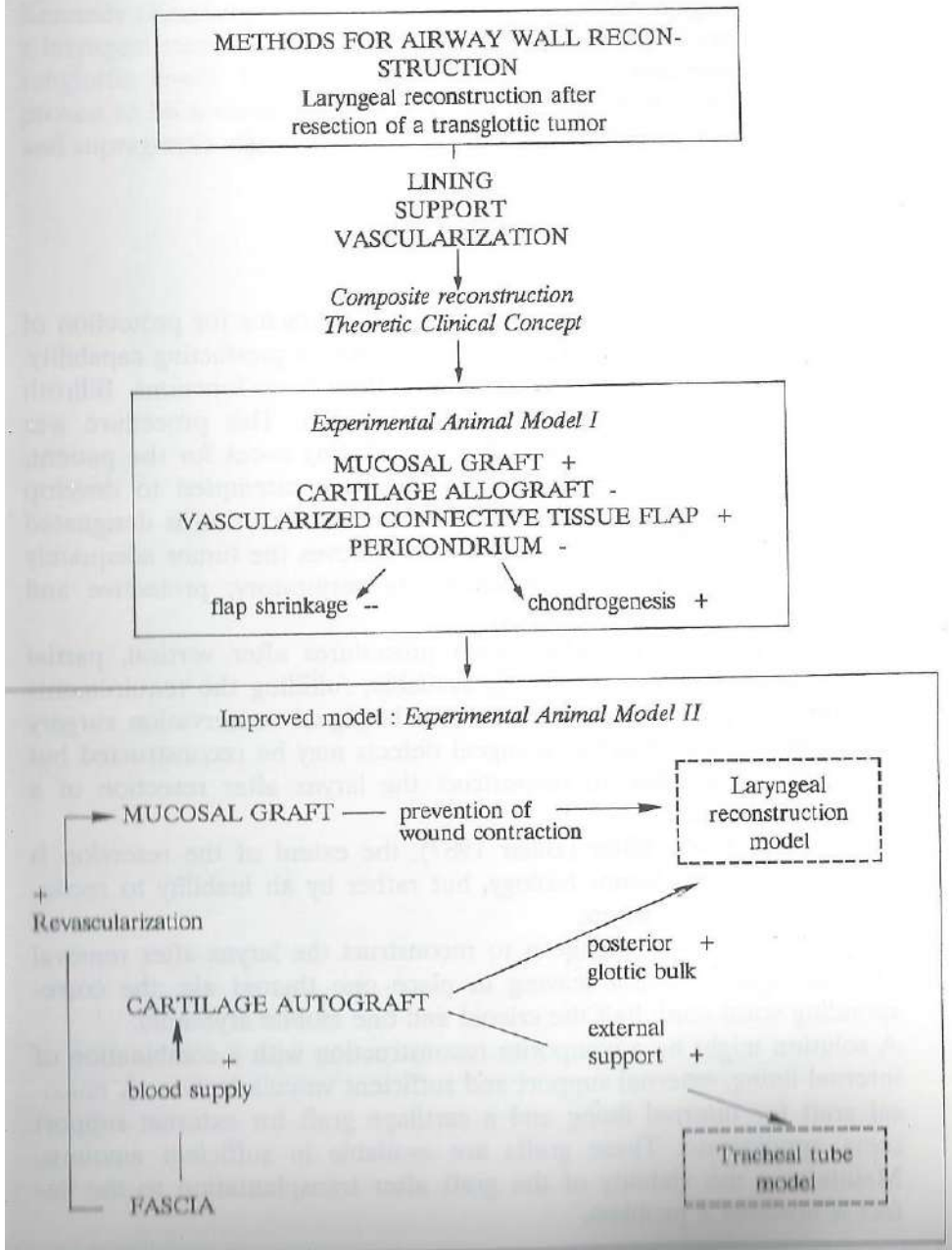
Both cases are an illustration of the theoretic prerequisites, absent in the first technique but present in the second, needed for a successful laryngeal reconstruction.
Kennedy (Kennedy 1980) described the use of the epiglottis to repair a laryngeal stenosis secondary to cricothyroidostomy at the glottic and subglottic levels. In our limited experience epiglottoplasty has been proven to be a viable procedure in the management of chronic glottic and supraglottic stenosis after blunt laryngeal trauma.

Summary and Conclusions

The larynx is an organ serving as a sphincter for protection of the lungs. Later in evolution it developed sound producting capability. Surgery for laryngeal tumors interrupts these basic functions. Billroth reported the first total laryngectomy in 1873. This procedure was physiologically and psychologically a devastating event for the patient. For over a century numerous surgeons have attempted to develop conservation surgical procedures. The term conservation is designated for that type of laryngeal surgery which removes the tumor adequately but which simultaneously preserves the respiratory, protective and phonatory functions of the larynx.
The problem with all conservation procedures after vertical, partial laryngectomy is, that no tissue is available, fulfilling the requirements for airway repair. Hence, a plateau in laryngeal conservation surgery has been reached. Smaller laryngeal defects may be reconstructed but it is still not possible to reconstruct the larynx after resection of a transglottic cancer.
As pointed out by Biller (Biller 1987), the extent of the resection is not limited by the tumor biology, but rather by an inability to reconstruct a functioning larynx.

Hence the challenge is to reconstruct the larynx after removal of a transglottic tumor leaving in place one thyroid ala, the corresponding vocal cord, half the cricoid and one mobile arytenoid.
A solution might be a composite reconstruction with a combination of internal lining, external support and sufficient vascularization. A mucosal graft for internal lining and a cartilage graft for external support seem appropriate. These grafts are available in sufficient amounts. Maintaining the viability of the graft after transplantation to the defect is however a problem.

SUMMARY : **Flow chart of composite reconstruction model**
+ : positive experimental results
- : negative experimental results



The first question of this study was the factor of **graft vascularization in the outcome of the laryngotracheal reconstruction.**
Locally capillary outgrowth does hardly happen or is very scarce near a full-thickness laryngotracheal defect. That is why vascularization should be provided for, particularly when non-vascularized grafts are implanted.
Available clinical and experimental data support the thesis that blood supply is the keystone for successful reconstruction of full-thickness laryngotracheal defects.
Hence a vascular bed should be brought into the reconstruction area to be able to implant free mucosa and cartilage. Indeed a vascular carrier should make a one-stage repair possible.

An experimental animal model was designed to study the **reliability of vascularized connective tissue flaps** serving as a vascular transferable bed for mucosa and cartilage in laryngeal reconstruction.
A suitable transferable vascular bed should have a feeding artery and a draining vein. It should be possible to transpose the vascular pedicle by rotation or by microvascular transfer. The vascular carrier should be as thin and pliable as possible with minimal contribution to the bulk of the reconstruction. The ideal vehicle for this is a connective tissue sheet containing a vascular network. It might be anything like fascia, perichondrium or periost.

Clinically fascia is used for this purpose when lining is needed, especially in reconstructive hand surgery (Brent et al. 1985, Kim et al. 1987, Ismail 1989, Yousif et al. 1990).

Experimentally, an auricular perichondrial flap in rabbits has similar physical and vascular characteristics. Being readily available, it was used by us to study the effects of flap rotation on the blood supply in the distal end of the flap. This rotation is used when tubular structures are needed. Persistence of distal vascularity was proved with flowmetry, with histological and with injection studies.

From these experiments, we learned that each **type of connective tissue**, which holds the blood vessels of the vascularized flap, has its influence on the outcome of the reconstruction.
Isolated, vascularized perichondrial flaps shrink when separated from their cartilaginous attachments (Delaere et al. 1992).
Similar observations were reported elsewhere for periosteal flaps when separated from the underlying bone (Acland et al. 1978, Takato et al. 1986) and for perichondrial flaps (Donski et al. 1980).

The rabbit perichondrial flap makes new cartilage by appositional growth within some weeks. This chondrogenesis results from loss of contact inhibition when the perichondrium is stripped from the underlying cartilage (Sohn et al. 1974, Ohlsen et al. 1975, Skoog et al. 1976).
The advantage of the chondrogenetic potential of the flap in contributing to external support is however small in comparison to the major disadvantage of flap shrinkage.

A better experimental connective tissue flap, which does not shrink and which also is readily available turned out to be the fascia overlying the chest wall muscles. It can be pedicled on the lateral thoracic artery and vein. This 'lateral thoracic fascial flap' may be transposed to the neck with preservation of the blood supply.
With this flap, mucosal and cartilage grafts were successfully brought into an airway defect, preserving the full viability and without shrinkage.

After having obtained experimental evidence for the superiority of the fascial flap as a vascular carrier, our attention was focused on the cartilaginous component. Should we use **autogenous or allogenous cartilage** and **which is the better supporting tissue** ?
Merthiolate-preserved tracheal cartilage rings (allografts), open at the membranous part may be brought in over a mucoperichondrium supported by a silicone tube. The external support provided by this allograft approaches the normal anatomy. The results of these allografts however were disappointing. Implanted cartilage grafts, preserved during 2 weeks, showed cell death, inflammation and resorption even when enwrapped by a 'protecting' vascular bed.
These findings agree with the majority of the reports on cartilage allografts (Converse 1977). Chondrocyts tend to die and (weak) antigenicity is not to be avoided. We therefore turned to autogenous cartilage. Autogenous cartilage usually has a long-term survival (Peer 1955, Tanzer 1978, Krutchinsky et al. 1984).

We added to these autogenous grafts special vascularity by placing it between an outer and inner fascial sheet. Whitin these sheets the grafts retain their viability and show areas of new cartilage formation. Lengthwise applied cartilage strips are able to preserve roughly 85 % of the diameter of a new-made trachea even after 2 months. Adjacent cartilage strips were connected by a fibroconnective 'pseudarthrosis' or by a newly formed cartilage bridge.

The importance of the **mucosal graft** as third component in the composite reconstruction and its value in the **prevention of scar contraction** was examined experimentally.

Wound healing by secondary intention is complicated by contraction. Intralaryngeal mucosal defects will ultimately be reepithelialized. This however takes time. In the meantime contraction forces are generated by myofibroblasts within the granulation tissue (Madden 1973). This leads to a reduction of the surface of the wound. Loss of lumen diameter is the result when this happens within a tubular structure.

It was possible to prevent this wound contraction in experimentally created airway defects by applying a mucosal lining. This mucosal graft leads to healing by primary intention.

From these results, we concluded that the airway wall may be reconstructed experimentally with mucosa and cartilage which are transplantated to the defect on a vascular carrier.

However, the resection of a portion of the structures responsible for the sphincteric function of the larynx automatically predisposes to aspiration. Therefore glottic closure should be surgically restored.
The possibility of such a composite reconstruction i.e. repair of the **posterior glottic bulk** was examined experimentally. The **blood supply needed for separated autogenous cartilage grafts** was studied in the meantime.

After a hemilaryngectomy each of the three laryngeal functions needs reconstruction : a sufficient airway lumen, prevention of aspiration and voice.
Reconstruction in such a case is usually unsuccessful. True, a sufficient airway lumen may be provided but the glottic opening can not be closed. The still working and mobile contralateral arytenoid is able to reach the midline on adduction but is not able to compensate completely for the missing arytenoid and posterior glottic bulk.

An augmentative reconstruction (pseudocord) of the resected hemilarynx is needed. This should provide bulk for the functioning vocal cord. Glottic closure, a reasonable voice, and prevention or reduction of aspiration should be sought. Such a pseudocord may be constructed by introducing some cartilage grafts between an inner and outer fascial layer.

We discovered that there is a limit to the introduction of supporting material. Cartilage grafts need at least blood supply at one side. Cartilage strips locked in between other cartilage grafts became necrotic.

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