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Review

Surgical Treatment of Substernal Goiter Part 2: Cervical and Extracervical Approaches, Complications

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Abstract

The most appropriate treatment of substernal goiter (SG) is surgery. These patients should be evaluated carefully and multidisciplinary in pre-operative period and surgical management should be planned preoperatively. Although most of the SGs can be resected by the cervical approach, an extracervical approach may be required in a small proportion of patients. Surgical complications of SG related to thyroidectomy are higher than other thyroidectomies. In addition to the complications related to thyroidectomy, complications related to the type of surgical intervention may also occur in SG. The patients who may be needed extracervical approaches should be consulted with thorax surgeons, cardiovascular surgeons, and anesthesiologists preoperatively; the surgical management should be planned together. In this part, we aimed to evaluate the cervical approach methods, extracervical approach methods, technical details, and complications in detail.

Keywords: Extracervical approaches, Sternotomy, Substernal goiter, Thoracotomy

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The most appropriate treatment of substernal goiter (SG) is surgery. Although most of SGs could be operated with cervical approaches, extracervical approaches may be needed in some patients. These patients should be evaluated carefully and multidisciplinary in pre-operative period and surgical management should be planned preoperatively. Pre-operative evaluation of these patients was discussed in detail in previous part. The patients who may be needed extracervical approaches should be consulted with thorax surgeons, cardiovascular surgeons, and anesthesiologists preoperatively; the surgical management should be planned together. In this part, we aimed to evaluate the cervical approach methods, extracervical approach methods, technical details, and complications in detail.

Cervical Approach

Incision

A transverse cervical Kocher incision of sufficient length should be made to provide appropriate exposure according to the size of the thyroid. The incision could be lengthened to the lateral side of both sternocleidomastoid muscle (SCM) according to the size of goiter. Superior skin flap is elevated up to the hyoid bone and inferior skin flap up to the sternal notch subplastimally. Although some studies have reported that typical lower flap preparation is not necessary, we think that it contributes especially to the dissection of the substernal part. In partial or complete ster-

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notomy, the cervical incision can be combined with a T incision and a sternotomy.

Strap Muscles

The strap muscles are divided vertically in midline from the superiorly from the level of at least the laryngeal prominence up to the sternal notch inferiorly. The strep muscles are dissected over the anterior and lateral aspects of the thyroid lobe.[1] To facilitate mobilization of the thyroid lobe, the strap muscles and the SCMs can be dissected.[2]

In SG, it is often necessary to transect the strap muscles to facilitate thyroid lobe lateral dissection and/or to better perform the upper pole exposure.[3] It should be kept in mind that the ansa cervicalis branches, which innervate the sternohyoid and sternothyroid muscles, enter the muscles 3 cm (centimeter) above the sternum notch. If there is a need for transection of strap muscles, transection should be performed at high level to prevent muscle denervation.[4] Strap muscles can be transected at the 1/3 cranial (only sternothyroid or both sternothyroid and sternohyoid muscle) part of sternothyroid muscle. Strep muscles can be transected with an energy device or cut with a proximal and distal clamp and a scalpel, and the both proximal and distal sides can be sutured with absorbable sutures for hemostasis. Although there is a common belief that transection of strap muscles might be a risk factor for non-neurogenic voice impairment, there is a lack of studies about that issue. Although Soninen claimed that bilateral transections of the strep muscles caused a decrease in pitch, Jaffe and Yang reported that unilateral and bilateral transections of the strep muscles did not cause any subjective complaints or objective functional and cosmetic sequelae.[5,6] Aygun et al. reported in their recent study that even if there is no recurrent laryngeal nerve (RLN) and external branch of superior laryngeal nerve (EBSLN) injury after thyroidectomy, complaints about voice and swallowing increase in the early period that these are temporary and are not related to the transection of the strep muscles.[3] Although there are temporary voice changes associated with transecting of the strep muscles, these are much milder than those associated with RLN injury or injury to the external branch of the superior laryngeal nerve. If the strep muscles are transected, they should be sutured and the perithyroidal plane should be preserved.[7]

In SGs particularly with large cervical part or in giant cervical goiters, the sternal attachment of SCM, the clavicular attachment of SCM if there is a need, can be transected. If the SCM is cut, it should be sutured similarly to the strap muscles at the end of the operation; and minimal effects will occur.[2,7]

IONM and Carotid Sheath

Intraoperative neuromonitoring (IONM) is an additional method in thyroidectomy in which the motor function of the nerve is evaluated dynamically in addition to visualization of the nerve. IONM has been applied for more than 50 years, and today, the IONM method with a surface electrode endotracheal tube has become the standard method. Guidelines for the standards and practice of IONM have been published by the International Neural Monitoring Study Group.[8] The use of IONM in thyroidectomy is gradually increasing.[9]

Although the effects of IONM in vocal cord paralysis (VCP) are still controversial, it is reported that the use of IONM reduces both temporary and permanent VCP rates in a review of approximately 6000 nerves.[10] The effect of IONM on reducing the risk of VCP is particularly evident in high-risk patients.[11] Although many clinical factors such as SG, recurrent goiter, Basedow Graves' disease can be predicted preoperatively, RLN variations that may increase the risk of VCP cannot be predicted preoperatively.[12,13]

IONM can be performed intermittent and continuously monitoring. Although intermittent IONM is an effective method for finding the intraoperative RLN, determining its anatomical variations, mapping its anatomical course, and preventing bilateral VCP, it gives information about the function of the RLN when stimulated with the probe. Since both dissection and stimulation cannot be performed at the same time with intermittent IONM, it does not provide information about nerve damage that may occur during surgical manipulation between two stimulations and does not prevent this action.[14] Continuously intraoperative nerve monitoring (C-IONM) is a superior method for preventing VCP.[15,16] However, the use of C-IONM is still very low.[9]

The traction trauma is the most common reason for RLN injury. Till the developing signal loss in RLN due to the surgical manipulation that causes traction trauma, the manipulation must have continued and a certain time must have been passed. C-IONM technique is a method in which periodic stimulation is given to the vocal cord with a probe applied to the vagus, and amplitude and EMG changes can be monitored instantly. It immediately warns the surgeon about surgical manipulations that may cause changes in EMG and amplitude. EMG changes can return to normal by ending the action and waiting for a while.[14]

In particular, primary and recurrent SG are high-risk operations, and we recommend the routine use of IONM in these. If possible, preferring C-IONM can provide additional advantages. For the successful and safe implementation of IONM, the standards of IONM have been defined by the IONM study group. These standards are laryngoscopic preoperative and post-operative vocal cord examination (L1

and L2; respectively), ipsilateral vagus stimulation before RLN exploration (V1), stimulation of RLN when the first found (R1), stimulation of RLN after the completion of dissection from the most proximal point (R2), and ipsilateral vagus stimulation (V2) at the end of all hemostasis.[8]

The first intraoperative phase of monitoring standards is ipsilateral vagus stimulation. Exposure of the ipsilateral carotid sheath for ipsilateral vagus stimulation is the first step. Vagus stimulation for intermittent IONM can be applied with or without opening the carotid sheath.[17] In C-IONM, it is necessary to open the carotid sheath and dissect the vagus to get vagus stimulation and apply the C-IONM probe to the vagus.[18]

In SGs, especially when it is enlarged in the cervical area or in recurrent cases, the carotid sheath may be pushed laterally, the carotid sheath elements (vena jugularis interna, carotis, and vagus) may be above the goiter mass.[7]

The lateral aspect of the mass can be accessed by transecting the strep muscles or by entering between the SCM and strep muscles. The carotid sheath can be reached, usually with the help of the reflex of the vena jugularis interna, sometimes with the help of visualization or palpation of the carotid beat.

Identification of the carotis in the neck and its follow-up in the mediastinum is an important step in understanding the relationship of SG with the mediastinum and aortic arch.[7]

The vagus probe can be applied with an anterior midline approach, usually by entering the midline and reaching the carotid sheath between the strep muscles and the thyroid lobe. However, it may be difficult to reach the carotid sheath with the anterior approach in large laterally enlarged goiters and recurrent cases. In this setting, the carotid sheath is reached by a lateral approach by entering between the medial edge of the SCM and the lateral edge of the strep muscles. The carotid sheath is opened and the vagus is found and dissected without devascularizing and the probe is applied.[18]

Dissection of Upper Pole and IONM of EBSLN

Upper pole dissection of thyroid can be performed before or after lateral dissection of thyroid. However, since the approach to the RLN is performed with a superior or medial approach, especially in SGs, performing the first upper pole dissection is a more rational option. For this reason, the upper pole dissection will be explained first. Several techniques have been described to minimize the risk of injury to the EBSLN in upper pole dissection. These techniques are upper pole dissection without looking for EBSLN, visual exploration of EBSLN, and upper pole dissection with identification of EBSLN with nerve stimulator or IONM (Fig. 1).[19]

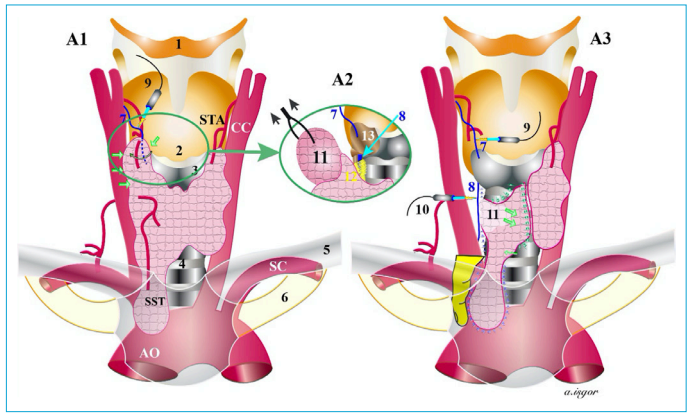

Figure 1. Intraoperative neuromonitoring in substernal goiter. A1: Secondary substernal goiter from anterior aspect. A2: Intraoperative neuromonitoring of external branch of superior laryngeal nerve with by superolateral traction of upper pole. A3: Intraoperative neuromonitoring of recurrent laryngeal nerve and delivery of retrosternal part from mediastinum.

In the present, most surgeons still perform upper pole dissection without EBSLN mapping because of the risks and invasiveness of nerve identification.[20] In thyroidectomies performed without identification of EBSLN, the sternothyroid muscle is dissected over the upper pole, then the upper pole is tractioned inferolaterally, and the upper pole dissection is performed by dissecting and separating the upper pole veins one by one as caudally as possible on the thyroid capsule.[19] EBSLN has a close anatomical relationship with upper pole vessels while goes through cricothyroid muscle which is innervated by it and this anatomical relationship is highly variable.[19] Especially in large goiters, the risk of EBSLN crossing the upper pole vessels from the more inferior level (Cernea type 2B) increases.[21] In addition, identification of EBSLN is more difficult than visual identification of RLN due to its relationship with inferior pharyngeal constrictor muscle and its thinner structure. It is not uncommon for this structure not to be an EBSLN unless the fibrillar structure that is visually assessed as an EBSLN is confirmed by IONM.[22] IONM makes an important contribution to both the visual and functional identification of the EBSLN.[23] It is reported that performing upper pole dissection with IONM reduces the injury of EBSLN in several studies.[24-26]

Like many endocrine surgeons, we believe that upper pole dissection should be performed with IONM in all thyroidectomies.

Over the upper pole, the strep muscles are gradually separated. It may be necessary to transect the strep muscles in large cervical goiters, patients with short necks, and SGs. The transecting of the strep muscles was described above. In some centers, partial transection of the medial 1/3 of the sternothyroid muscle is routinely recommended to increase

the upper pole exposure.[27] The sternothyroid muscle is gradually dissected over the upper pole and the retractors are retracted superolaterally. The upper pole of the thyroid is tractioned inferolaterally. The avascular tissue in the sternothyroid laryngeal triangle between the superior pole medial and the cricothyroid muscle is bluntly dissected, revealing the cricothyroid muscle and its innervating EBSLN where it travels over or between the fibers of inferior pharyngeal constrictor muscle on the lateral surface of the larynx.[19]

The cricothyroid muscle is stimulated directly with the IONM probe, and muscle contraction is observed. After the contraction of the muscle is observed, the EBSLN is visually investigated in the sternothyroid laryngeal triangle and the structure thought to be the nerve is stimulated with a probe and it is observed whether there is a contraction in the cricothyroid muscle. If the muscle does not contract with the stimulation of this structure, or if a structure that can be a nerve cannot be seen in this region, the EBSLN, which is obliquely on and between the inferior pharyngeal constrictor muscle fibers in the sternothyroid laryngeal triangle, inferior to the laryngeal head of the sternothyroid muscle, is searched with the help of a probe. In general, EBSLN can be found with this search prior to upper pole dissection. When the nerve is stimulated with the probe, contraction of the cricothyroid muscle is observed.[23,28] At the same time, 70–80% of the glottic EMG responses are obtained from the tube electrodes.[19]

If the EBSLN cannot be found with the probe, no additional dissection should be performed around the inferior pharyngeal constrictor muscle fibers or the superior pole vessels to locate the nerve. After the nerve is located with the probe, the upper pole vessels are individually dissected over the thyroid capsule. The dissected vascular structures should be stimulated with a probe at every stage before they are ligated or cut, and if there is no contraction in the cricothyroid muscle, they should be clamped and separated with cautery or an energy device. After the superior pole dissection is complete, the EBSLN should be stimulated proximal to the point where the vessels leave to confirm the integrity of the nerve.

Dissection of RLN

RLN is one of the most critical anatomical structures for injury risk during thyroidectomy. RLN's location may be varied significantly different in large goiters, SGs, and recurrent goiter. In 2015, anatomical classification system of RLN has been established. This classification system includes the embryological and acquired anatomical trajectory of RLN, significant clinical anatomical features, and the dynamics of the surgery performed.[29] The first multicenter study about this classification has been reported. In this study, anatomical course changes in RLN in the form of fixation, springing, entrapment at the level of the thyroid capsule due to changes in fascial bands, vessels, or goiter associated with the thyroid capsule were 30% in patients who underwent thyroidectomy, and this rate increased to 50% in SG.[30]

There could be some significant changes in course of RLN in SG. The risk of nerve injury due to traction and tension is higher in blunt dissection without nerve identification. In this patients, RLN should be identified first and substernal part should be delivered after nerve dissection.[29]

Identification of RLN can be done in four different techniques according to thyroid enlargement and surgeon's preferences, during thyroidectomy. These techniques are lateral approach, inferior approach, superior approach, and medial approach.[31] Finding the RLN with a lateral or inferior approach may be difficult, as medial rotation of the lobe will be difficult in large goiters or SGs. Therefore, the superior or medial approach should be preferred to find the RLN in SG.[32] Although the anatomical course of the RLN due to SG may change along its length, the entry point of the RLN to the larynx is fixed in the Berry ligament region, and the position of the RLN at this point does not change. The anatomical marker for the point where the RLN enters the larynx is the lower border of the cricopharyngeal muscle. Palpation of the inferior horn of the thyroid cartilage is a helpful method in detecting this anatomical region where the nerve is located. After the dissection of the upper pole of the thyroid is completed, it is retracted laterally. The cricopharyngeal muscle is exposed, and with careful dissection in this area, the RLN enters the larynx at the lower border of the cricopharyngeal muscle. In this region, the RLN can be searched and found with the IONM probe.[32] This region is a fibrous, easily bleeding vascular region attached to the ligament of Berry. In addition, the nerve can enter the larynx as more than 1 branch here. Although the anterior branch of the RLN often has motor function, the posterior and middle branch may also have motor function. All branches of the nerve should be preserved in this region.[33] After RLN identification, Berry ligament is dissected gradually and carefully.[32] After Berry dissection, fibrotic bands between thyroid and trachea in the medial side are dissected. The isthmus can be separated for an easier dissection. If the upper thyroid pole is enlarged, it may be difficult to reach the nerve with the superior approach. In this case, the RLN can be found with the medial approach. In this approach, first, the isthmus is separated and the medial of thyroid lobe is dissected from the trachea. The cricothyroid muscle fascia is dissected between the medial of the superior pole and the trachea. Cricopharyngeal muscle fibers may be found inferior to the cricothyroid muscle. The thyroid lobe is gently retracted laterally. The nerve can be found by minimiz-

ing the risk of RLN injury by dissection inferior to the area where the Berry ligament and thyroid overlap. After the nerve is found, the RLN is preserved and all connections of the thyroid with the trachea are separated by the medial inferior method.[32,34] The cervical part of the thyroid is retrogradely dissected from the RLN to the inferior neck, and the thyroid is separated from the trachea. The vascular structures of the thyroid are separated through the thyroid capsule. It also contributes significantly to the preservation of parathyroid vascularization. The inferior thyroid pole veins are separated over the thyroid capsule.

Delivery of SG: After the cervical connections of the thyroid are completely separated, the substernal part of thyroid can be slowly pulled to cervical area without interfering with the thorax by moving it rotationally right and left. This process should be done gradually, and as vascular connections appear on the substernal part arising from the cervical region, these should be checked and cut with IONM.[32] In the delivery of the substernal part of the thyroid, finger dissection can be performed in the capsular plane with the understanding of the mediastinal anatomy. The mediastinal part can be gently dissected by inserting the finger adjacent to the thyroid capsule from the medial carotid into the upper mediastinum. The same procedure can be performed medially by the trachea. Substernal part can be delivered by performing this procedure from both sides of the thyroid at the same time. One finger is applied by the trachea medial to the thyroid, the other finger is applied from the medial side of the carotid to the lateral thyroid lobe adjacent to the capsule, the goiter is slowly moved upward. The fascial bands on the pulled substernal part are stimulated with the IONM probe and separated with a cautery or energy device.[7]

Other Thyroidectomy Methods

Minimally Invasive Video-assisted Thyroidectomy (MIVAT)

MIVAT has become a widely practiced method in the world since it was first described in 1999. Although it was first applied to benign thyroid nodules, it has been adapted to all types of thyroid disease over time. This method is a procedure that is applied partly under direct vision and partly under endoscopic vision with a skin incision of 1.5–2 cm from the neck.[35,36] However, MIVAT is a feasible method in just 20–30% of all thyroid surgeries, and it seems to be applicable in a limited patient group in SG. In patients for whom the method can be applied, the thyroid volume should be below 25 cm^3 and the dominant nodule diameter should be below 35 mm. It is contraindicated in malignancies with extrathyroidal spread and in patients with lateral metastases. Thyroiditis should be excluded with ultrasonography and biochemical tests, as thyroiditis may complicate appropriate dissection. The complication rate of the MIVAT method is similar to other methods and does not increase the cost.[36] It can be applied in experienced surgeons and in selected patients.

Remote Access Thyroidectomy (RAT)

RAT is the removal of the thyroid from different parts of the body without incision in the neck. Different RAT techniques (endoscopic or robotic) are performed in whole world, especially in Asia. In 2016, the American Thyroid Association defined SG as a contraindication for RAT.[37] In general, adaptation and indications of surgical procedures can be changed in times. Recently, it has been reported that SGs can also be removed by endoscopic RAT. It has been reported that most of the patients with SG can be operated with the axillothoracic approach with the remote access endoscopic axillary approach and in some patients with thoracoscopy combined with the axillary approach.[38]

Transoral video-assisted thyroidectomy (TOETVA) is a surgical method that has become popular in recent years and its application is increasing. The upper mediastinum can potentially be reached on TOETVA. SG is among the contraindications in TOETVA, especially in the first cases of surgeons. As the surgeon's experience increases, SG and other diseases in which conventional thyroidectomy is applied may be among the indications.[39] However, the thyroid volume that can be removed with TOETVA should not exceed a certain size.

Extracervical Approaches for SG

Although most SGs can be operated by transcervical methods, approximately 2% of patients may require extracervical interventions (Fig. 2).[40]

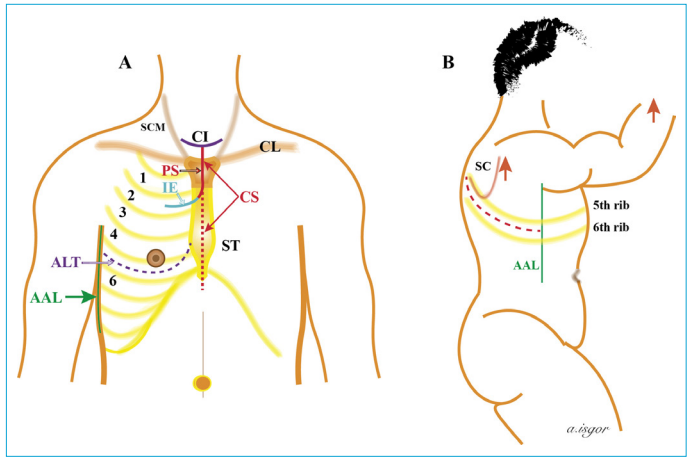

Figure 2. Sternotomy and thoracotomy incisions. **(a)** Anterolateral thoracotomy, partial sternotomy, complete sternotomy, trap-door incision, and cervical incision (Kocher incision). **(b)** Posterolateral thoracotomy incision.

Many different techniques have been described for the surgery of SGs from past to present. Morcellation method, which was first defined by Kocher in 1889 and popularized by Lahey in the 1920s, was applied in SG surgery. In this technique, it is aimed to reduce the size of the goiter by intracapsular fragmentation of the thyroid and suction of the colloid.[41,42] This technique may cause uncontrollable hemorrhage, even mortality.[43] If there is a malignant nodule with thyroid, carcinoma may spread because of this technique. For this reason, it is reported that this technique should be abandoned in present.[7] However, recently, it has been stated that this method can be successfully achieved with arthroscopic or sinus microdebrider in two limited series with 11 cases and 26 cases from two otorhinolaryngology (ENT) clinics who performed thyroidectomy, SG can be removed without sternotomy. It has been defined as a safe method and there has been no major bleeding and complications.[44,45] Dagan and Kleid who were one of these two study groups recommended that this technique should be performed in selected patients especially in elder and in patients whom have comorbidities that increase complication risk with sternotomy.[45] However, this technique is not particularly recommended by endocrine surgeons. We do not recommend this technique either, since this surgical method which is performed without direct vision may cause undetected complications that may result in disaster.

By resected the 1/3 medial part of the clavicle and increasing the thoracic inlet limited to the bone structure, it can contribute to the delivery of the mediastinal part of the SG.

These are techniques that support transcervical resection. However, some patients may require sternotomy or thoracotomy. Isolated sternotomy or thoracotomy is not appropriate in primary or recurrent SG of cervical thyroid origin, and it should be combined with a cervical incision. Because RLN is at great risk in isolated surgeries and the inferior thyroid artery cannot be effectively controlled.[2,7]

Partial Sternotomy

Although many imaging methods can be performed to reveal the necessity of partial and/or total sternotomy, it is not possible to obtain a definite result in the pre-operative period. In patients with sternotomy risk, the patient should be examined multidisciplinary, and in the pre-operative and perioperative period, thoracic surgery or cardiovascular surgery clinics and anesthesia clinic must be in communication (Fig. 3).[46]

Sternotomy is a common surgical procedure for anterior mediastinal masses.[47] Partial sternotomy, also called sternal split, is suitable for resection of SGs extending to the level of the aortic arch.

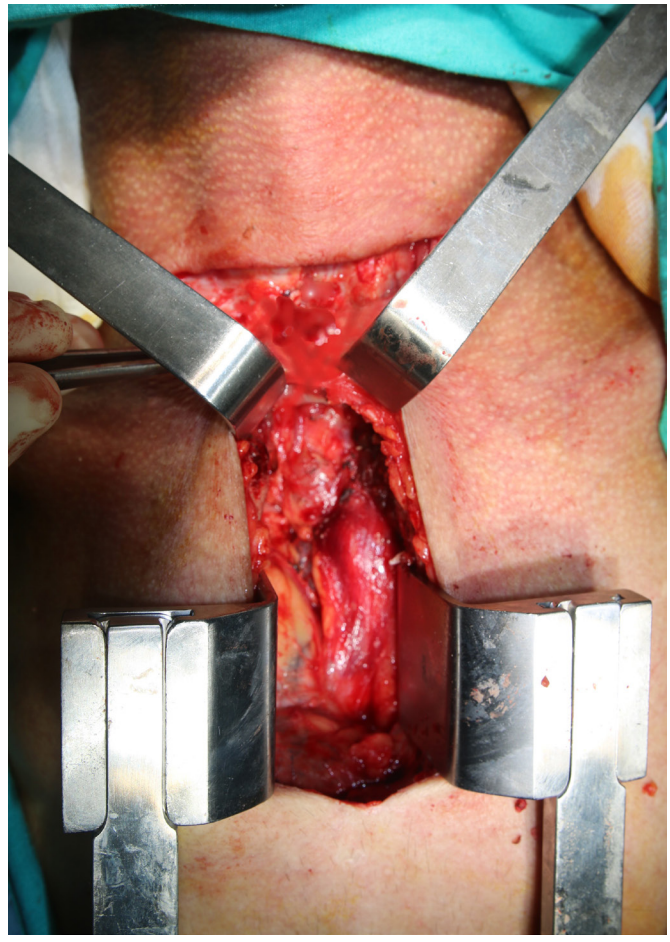

Figure 3. Partial sternotomy.

In sternotomy, it is recommended to start with a cervical incision first to expose the mediastinum to external factors less. In general, sternotomy is performed by first mobilizing the cervical part of the SG with a cervical incision and then making a T-shaped skin incision. However, in patients with superior vena cava syndrome (SVCS) with severely increased neck venous filling, sternotomy before cervical dissection of the thyroid may reduce venous pressure and reduce bleeding in cervical dissection and allow appropriate dissection.[2]

Although partial sternotomy is a method generally used in cardiac surgeries, it is one of the appropriate intervention methods if an extracervical intervention is to be performed in SGs.[48] When an extracervical approach is required, a skin incision is made just below the angle of Louis where the manubrium sterni and corpus sterni are conjoined, or 6 cm from the manubrium to below the sternal notch.[49,50]

The sternum and the cartilage part of the second rib articulate at the level of Louis angle. The number of ribs is important especially when determining the level of thoracic incisions, and an incorrectly determined level may make

it difficult to reach the thoracic organs to be reached.[51] After the skin and subcutaneous incisions are made up to the sternum, the sternal notch is exposed and the posterior fascial connections are separated with the electrocautery until the surgeon's finger enters the posterior of the sternal notch. The surgeon creates an adequate space by dissecting the posterior sternal notch with his finger, removing the innominate vein and pleura posteriorly from the posterior sternum. The edges of the cut bone are cauterized for hemostasis, and bone wax or other hemostatic agents can be used if necessary to stop bleeding from the bone marrow. After the upper part of the sternum is opened, it is retracted laterally with a pediatric retractor and the anterior fascia of the upper mediastinum is dissected. By the sternotomy, a wide exploration area is obtained. With this incision, the surgeon can access the upper mediastinal trachea and esophagus, the innominate vein, and the innominate artery. The mediastinal part of the SG can be easily excised without damaging these surrounding tissues. After thyroidectomy, hemostasis should be ensured carefully, tube thoracostomy should be applied when necessary, and the sternum should be closed with metal ligations. Median full sternotomy can be performed in cases where partial sternotomy does not provide adequate exploration.[50]

Complications in Partial Sternotomy

Complications such as mediastinal bleeding, cardiac arrhythmia, pneumothorax, deep wound infections, and sternal instability can be seen after partial sternotomy.[47]

One of the reasons of bleeding may be the injury of innominate vein due to sternal split. The compression to the posterior surface of sternum should be applied until repair of vein, if there is an injury like that. In general, full sternotomy may be required for repair. Innominate vein can be ligated if it cannot be repaired. If the innominate vein is ligated, the left arm swelling may occur, which can be treated with arm elevation. Intravenous fluids given from the left arm should be stopped in innominate vein injuries, and the intravenous treatment should be applied from the right arm or lower extremity. Apart from this, bleeding causes may be due to rupture of other venous branches during dissection, from the sternum, and internal mammary artery injury due to steel wires applied during sternotomy or closure.[50]

Trap-door incision: When it is necessary to explore the bottom of the clavicle head, the partial sternotomy can be extended to the right or left lateral from the second intercostal space and converted into an incision called a trap-door. After the partial sternotomy is completed, the sternum is cut laterally toward the pathology side. The internal thoracic vessels are ligated and cut. Removal of the clavicle head may contribute to better exposure of the subclavian vessels. This incision may rarely be needed, especially for the removal of masses around the subclavian and jugular vessels or metastatic lymph nodes involved in this area. With this incision, the jugular and subclavian veins can be completely dissected and ligated if necessary. At the end of the procedure, a pleural drain is placed in the lodge. While closing the wound, the ribs are reapproximated with number 2 Vicryl suture.

Full Sternotomy

Full sternotomy may be necessary in large SGs that the full exploration of anterior mediastinum should be performed. Although full sternotomy is rare in SG surgery, it should be preferred over partial sternotomy, especially in large SGs that go below the aortic arch and reach the tracheal carina, and in SGs that cause SVCS. The need for sternotomy may be felt more frequently, especially in patients with a small cervical part and conical morphology extending to the posterior mediastinum (Figs. 4 and 5).[52]

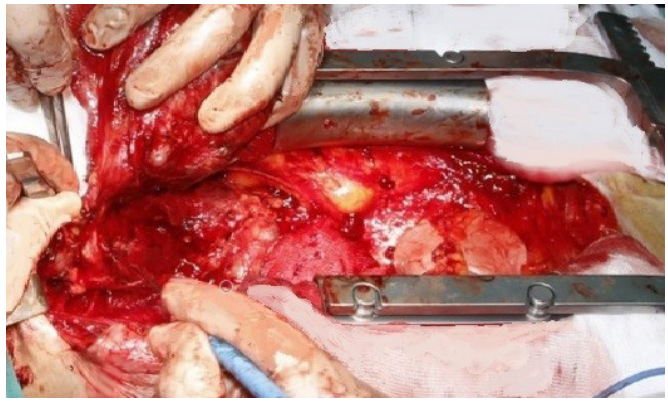

Figure 4. Resection of substernal goiter with IONM by full sternotomy (blue probe is the IONM probe).

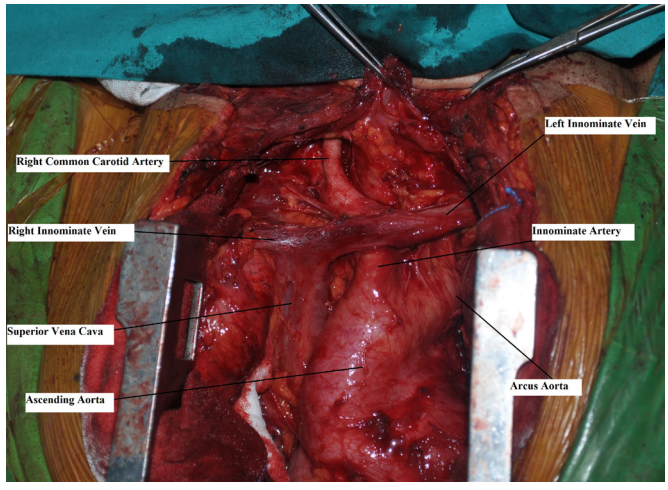

Figure 5. Mediastinum and vascular structures after resection of the substernal goiter with full sternotomy.

In a full sternotomy, the skin incision extends from the sternal notch to the xiphoid, the skin and subcutaneous tissue are dissected up to the sternum, and the posterior of the sternal notch is liberated as in partial sternotomy. Similarly, the tip of the xiphoid is dissected inferiorly, the diaphragm fibers and pericardial adhesions are removed from the xiphoid process posteriorly and inferiorly. For sternotomy, the mid-sternum is marked for incision. Cutting the sternum from the midline is important to ensure proper healing and stability of the bone, and to minimize the risk of postoperative separation and mediastinitis (Fig. 6).[50]

Complications in Full Sternotomy

Complications of full sternotomy are similar as in partial sternotomy. In addition to these, pericardial injury and heart injury may occur while performing a full sternotomy. While this is rare in the virgin chest, it is common in preoperative surgery. In these patients, the sternum should be opened with an electric oscillating saw instead of a standard sternal saw. At least one mediastinal or pleural drain is placed in the thorax before the wound is closed. Air or fluid that may accumulate is evacuated and mediastinal hematoma accumulation that may exert pressure on the heart and mediastinal structures is prevented.[50]

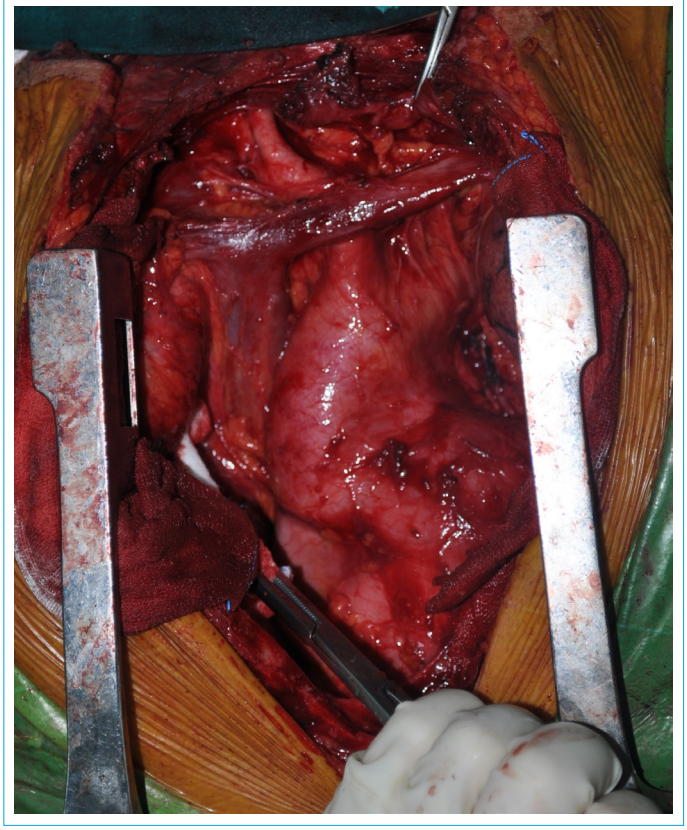

Figure 6. Full sternotomy.

Thoracotomy

Although sternotomy is usually preferred in SGs when there is requirement of extracervical approach, some surgical groups advocate thoracotomy. Thoracotomy methods may be preferred, especially in patients extending to the posterior mediastinum or in whom the mediastinal extension cannot be fully evaluated and where other methods of reaching the mass and safe dissection cannot be performed.[53] Patients who may need thoracotomy should be consulted with the thoracic surgeon and anesthesia, and the operation should be planned together (Fig. 2).

Posterolateral Thoracotomy

Posterolateral thoracotomy is an incision that can provide more exposure to all areas of the hemithorax than other incisions, and especially the posterior mediastinum is perfectly exposed.[54] Although posterolateral thoracotomy is the most commonly performed incision in thoracic surgery in general, it is one of the rarely needed extracervical intervention methods in SG surgery. It may be necessary especially in type IIB SGs located posteriorly and crossing to the opposite side. Such patients who are scheduled for thoracotomy should be intubated with a double lumen endotracheal tube and the non-operative side should be ventilated during thoracotomy.[50]

In SGs which are derived from cervical area, a cervical incision is made first and the vascular connections are separated according to the principles of cervical thyroidectomy, the RLN is identified, and the cervical connections of the thyroid are separated by cervical method. After the cervical dissection is completed, the wound is covered sterile, the patient is turned to the lateral position with the side to be operated up, and the back and abdomen are fixed with pillows or sandbags, and fixed to the table over the hip with adhesive tape. A roll pillow is placed under the chest on the inferior arm of the patient. The lower arm is fixed to the table with an upright arm board, while the upper arm is fixed with an arm board in forward and upward rotation. During positioning, it is important to support the arm and shoulder to prevent brachial plexus or shoulder injuries. These common injuries are not uncommon and can cause pain or immobility in the shoulder after surgery. To open the intercostal space and facilitate entry into the pleural space, the table is angled from the area where the roll pillow is placed.[54]

In general, an incision long enough to remove the mass to be excised, in the level of 5th or 6th intercostal space, is extended approximately 2 cm inferior to the scapula, obliquely from the paraspinous muscles in the posterior to the anterior axillary line as needed, in accordance with the

rib projection.[50,54] The latissimus dorsi muscle is cut with cautery perpendicularly to its fibers for easier reapproximation at the end of the operation. The serratus anterior muscle is retracted anteriorly to prevent post-operative weakness. The scapula is lifted anteriorly with a retractor and palpated with the hand inserted to superior through under the scapula until the first rib, which is the widest and most horizontal anteriorly, is felt. From here, the intercostal space is determined by counting the ribs and entering the thorax. It is usually entered into the thoracic cavity through the 5th or 6th intercostal space.[54] To avoid injury of the neurovascular bundle existing in the inferior of rib when entering thorax, entering should be through the superior edge of rib. For more comfortable surgery, 1 cm or more part of rib can be resected if necessary. The endothoracic fascia is opened in the thorax and the thoracic cavity is entered. To avoid rib fracture, retractor should be use slowly when opening intercostal space with retractor. However, rib fractures usually occur especially in elderly patients and patients with osteoporosis. Rib fractures are painful and may complicate post-operative coughing.[54] The lung is deflated and the mass in the posterior mediastinum is liberated and resected. A pleural drain is placed and the ribs are approximated with 4–5 number 2 Vicryl. The serratus anterior muscle is reapproximated closer, to the adjacent fascia. The cut latissimus dorsi muscle is brought together.[50] The chest tube is usually placed in line with the ipsilateral spina iliaca anterosuperior through a small skin incision below the incision so that the tube does not bend and disengage when supine.[54]

Anterior or Anterolateral Thoracotomy

Anterior or anterolateral thoracotomy is an incision that can performed to explore upper mediastinum without changing position when the patient in supine position.[53] Some researchers report that this incision can also be applied in posteriorly extending SG.[55] The intercostal spaces are two levels below in the anterior side compared to the posterior side. This incision is usually applied through 3rd intercostal space in SG.[53]

A small roll pillow is placed under the ipsilateral shoulder of the patient who will undergo anterolateral thoracotomy. The skin incision is made parallel to the sub-mammary line from the lateral sternum to the anterior axillary line over the 4th intercostal space. Pectoral muscle fascia is reached by passing through the skin and subcutaneous tissue, and the pectoral muscle fascia is separated at the level of the 3rd intercostal space, then the intercostal muscles are separated along the incision. Mamaria interna veins are ligated and cut. The retractor placed in the intercostal space is opened and exposure of the area is provided. This incision provides a good approach, is easy to apply, and the cosmetic results of this incision are superior to sternotomy and posterolateral thoracotomy. In this incision, reaching the posterior pleural space is more limited than in posterolateral thoracotomy, and this incision should be avoided in cases where the posterior region should be well exposed.[56]

The lower pole of SG, which has a mass effect on organs and vascular structures in the upper mediastinum that cannot be reached from the cervical region, can be easily reached with thoracotomy. In patients with SG originating from the cervical thyroid, first vascular control is provided from the cervical region, the RLN is identified, and the cervical connections of the thyroid are separated. If it is decided that the thyroid cannot be removed by the cervical method, then the mediastinal thyroid can be easily released and removed by thoracotomy. Thoracotomy can be performed as a first step in mediastinal goiters that are not connected to the cervical thyroid. However, it is not clear whether thoracotomy provides an advantage over sternotomy.[53] Drain is placed in thorax, ribs are reapproximated with 3–4 pericostal number 2 Vicryl sutures and pectoralis major muscle is reapproximated.[56]

In both thoracotomy techniques, post-operative incision site pain is more severe, and stronger analgesia should be provided in these approaches compared to cervical incisions. Pain is more especially in posterolateral thoracotomy. Dissection of the respiratory muscles and decreased mobility of the chest wall may impair the respiratory mechanism. In these patients, pre-operative epidural catheterization and epidural analgesia can effectively minimize pain and reduce perioperative morbidity.[54] Post-operative aggressive chest physiotherapy has a critical role to prevent post-operative pulmonary complications.[50]

If the patient is positioned appropriate and the surgical technique is applied carefully, many complications related to procedure can be prevented. This begins with careful positioning of the patient to avoid shoulder or brachial plexus injuries. The skin incision should be properly placed and slightly oblique anteriorly. The serratus muscle should not be cut and should be entered into the pleural space through the appropriate intercostal space. This space should be opened slowly to avoid rib fractures. Chest tubes should be placed appropriately and anatomical layers should be closed in a systematic way. Paying attention to all these details will reduce the level of pain and distress that may occur after surgery and ultimately the incidence of pulmonary complications and post-operative mortality.[54]

Chronical pain may also be developed in these patients. Although there are many reasons for this, the most common cause is intercostal nerve damage or rib fractures

due to trauma of the thoracic retractor. The pain typically occurs along the dermatome innervated by the intercostal nerve that fits through the thoracotomy incision. Most of these pains can be controlled with conservative treatment. First-line agents in treatment are tricyclic antidepressants, nonsteroidal anti-inflammatories, and low-dose opioids.[57,58]

Other Extracervical Methods

In recent years, minimally invasive methods to the mediastinum have become standard techniques for resection of both anterior and posterior mediastinal masses. These approaches allow dissection of mediastinal structures with less pain, faster healing, and superior cosmetic results than standard open approaches. Before applying these methods, the relationship of the mass with surrounding organs, especially large vascular structures, should be evaluated together with thoracic and cardiovascular surgical teams experienced in these operations, and patients who may be suitable for minimally invasive intervention should be selected.[50]

Mediastinoscopy and video-assisted mediastinoscopy (VAM) are surgical methods that can be performed in SGs extending to the aortic arch. A cervical incision is required for mediastinoscopy. Major bleeding requiring thoracotomy may occur in only 0.4% of VAM surgeries.[46] In addition, it is reported that video-assisted thoracoscopic surgery can be applied in anterior and posterior SGs.[59,60]

The main limitations of video-assisted surgery are 2D imaging (2D) and difficulties in accessing some areas. To eliminate these disadvantages, some centers have started to apply robotic-assisted thoracoscopy due to 3D imaging (3D), depth perception, and more developed maneuverability of the instruments.[61]

It was stated that distant areas in the mediastinum can be reached and dissection can be performed safely with the robot.[62,63] However, experience with the robot-assisted method is still limited. High price and long learning curve are its main limitations.[61]

Complications of Thyroidectomy

Most of the surgical complications that occur in SG are similar to the complications that occur in cervical goiter; transient and permanent hypoparathyroidism, temporary and permanent RLN palsy, inability to make high-pitched sounds related to injury of the external branch of the superior laryngeal nerve, post-operative bleeding, hematoma, seroma, and wound infection.[64]

In the multicentric study of Testini et al. including 19,662 patients, total morbidity was higher in SG than in cervical goiter (35% vs. 23.7%, p<0.001). When SG is compared with cervical goiter; temporary hypocalcemia (33.8% vs. 21.6%, p<0.001, respectively), permanent hypocalcemia (2.2% vs. 1%, p<0.001), temporary and permanent unilateral RLN palsy (5.5% vs. 3.2%, p<0.001 and 3.2% vs. 1%, p<0.001, respectively), temporary and permanent bilateral RLN palsy (0.5% vs. 0.2%, p=0.033 and 0.1% vs. 0.005%, p=0.005, respectively), and hematoma/seroma (1.9% vs. 1%, p=0.003) rate was higher. As a result, complications related to thyroidectomy are increasing in SG.[65]

Post-operative Hemorrhage

The incidence of post-operative hemorrhage after thyroidectomy is approximately 1.5% and may be fatal.[66] SG and reoperation are among the independent risk factors that may cause bleeding requiring exploration after thyroidectomy. The increase in the surgeon's thyroidectomy volume is a factor that reduces the risk.[67]

Hemorrhage after thyroidectomy usually occurs in the first 24 h postoperatively, approximately half of it occurs in the first 6 h, and it is extremely rare to occur after 24 h. Therefore, all patients with thyroidectomy should be followed carefully and closely for the first 24 h.[68]

Additional parasitic venous and arterial vessels develop from the neck to the mediastinum, often in secondary SG, to provide the vascular demand of the enlarged gland. Careful isolation and ligation of the inferior thyroid venous vessels and venous vessels extending from the mediastinum to the neck are critical to minimizing post-operative bleeding. Because they are quickly retracted into the mediastinum when cut, these vessels are often responsible for bleeding. Although the use of drains in thyroid surgery is controversial, they can generally be used in large volume SSG cases. Drains may contribute to minimize the risk of catastrophic morbidities and to detect it early.[47] With careful follow-up of these patients, early recognition of post-operative hematoma and evaluation of the patient's airway and oxygenation are critical. If the patient has respiratory distress, the wound should be opened at the bedside and the hematoma should be drained. If the patient cannot be stabilized by evacuation of the hematoma, the patient should be intubated, especially by an experienced anesthesiologist. The probability of intubation is higher in the first intubation attempt, and it should not be forgotten that intubation will become more difficult with increasing laryngeal edema with unsuccessful intubation attempts. If the patient cannot be intubated, a tracheostomy may be required for the airway. Multidisciplinary teamwork is important in the successful treatment of post-operative hematomas.[68]

Tracheomalacia

One of the feared complications of thyroid surgery is tracheomalacia. It has been reported that the incidence of tracheomalacia increases up to 6% in large goiters and up to 7.5% in SGs. However, with advances in anesthesia technique, early treatment of large substernal goiters in modern thyroid surgery, the risk is minimal even in high-risk patients with significant tracheal compression.[69-71]

Bennett et al. reported tracheomalacia incidence 0.3% in their review including 12 studies and 1969 SG.[72]

In tracheomalacia, the tracheal rings soften and lose their strength due to chronic compression, and the cartilage framework of the trachea cannot maintain the airway patency. Accordingly, in the post-operative period, paroxysmal collapse occurs in inspiration and airway obstruction develops, and clinical findings occur in the patient.[2] In patients with suspected tracheomalacia, at the end of thyroidectomy, the surgeon should check the integrity of the trachea by asking the anesthetist to pull the endotracheal tube above the suspicious area, observing this area during the respiratory cycle, and applying gentle pressure to the trachea between the thumb and index finger. Obvious collapse or softening of the tracheal rings is indicative of tracheomalacia.[2] The patients who develop significant tracheal collapse after pulling the endotracheal tube above the suspicious area should not be extubated and should be transferred to intensive care unit (ICU) for follow-up.[73] It has been stated that patients with tracheomalacia can be successfully treated with prolonged intubation between 18 and 48 h and without the development of tracheal stenosis in their postoperative follow-up.[74] However, other reasons should be excluded when respiratory distress develops in patients who are extubated early or after being intubated in the ICU for a while. It has been reported that patients who are thought to have tracheomalacia after excluding other causes can be treated safely and effectively with non-invasive positive pressure ventilation. In patients with respiratory distress after extubation, tracheomalacia should be differentiated from complications such as bilateral VCP, laryngeal edema, and post-operative bleeding that may require tracheostomy.[2] It is among the treatment options with tracheostomy after thyroidectomy, and in some studies, intraoperative tracheostomy is recommended for patients with suspected tracheomalacia.[75] Tracheal compression for long time due to SG may cause some degree of tracheomalacia, but extubation is almost always possible.[46] However, routine prophylactic tracheostomy is not generally recommended because it cannot be predicted with certainty which of the patients with suspected tracheomalacia will develop airway obstruction. When patients with SG are extubated, those who develop respiratory distress can generally be reintubated without a problem.[2,7,70] Tracheostomy can be considered in patients who have problems in reintubation and who continue to have respiratory distress. Agarwal et al. suggested that it may contribute to the early healing of tracheomalacia by causing fibrosis in the soft tissue around the tracheostomy in patients with tracheomalacia. They reported that the tracheostomy tube could be removed before 10 days in these patients and tracheal stenosis did not develop in the post-operative follow-up.[75]

In the treatment of tracheomalacia, besides intubation and tracheostomy, treatment alternatives such as surgical tracheopexy methods, tracheal stents, surgical external stabilization, and tracheal resection are recommended.[2,7,70]

Tracheal resection may rarely be necessary. If the goiter is due to thyroid cancer and there is invasion of the trachea, tracheal resection may be required.[76]

Other Complications Related SG

SVCS due to compression of SG in neck veins is a rare clinical finding and is reported between 0.5 and 2.8% in the literature. The incidence increases as the SG mass descends into the thorax, and it may exceed 10% when the SG descends below the aortic arch.[65,77]

Although the risk of infection is low in thyroidectomy, the risk and severity of infection increase in SGs requiring extracervical intervention.[47,78] Extracervical approaches are particularly associated with increased pulmonary complications such as atelectasis, pneumonia, pneumothorax, and pleural effusion.[79] Complications such as sternotomy separation and mediastinitis may rarely be seen in extrathyroidal approaches.[78,80]

Associated with adjacent anatomical organs; trachea, esophagus, phrenic nerve injuries, major intraoperative hemorrhages, mediastinal hematoma, Horner's syndrome, atrial fibrillation, and cardiac arrhythmias are rarely seen, and it has been reported that complications such as chylous fistula and air embolism may rarely develop.[7,46,81] Complications due to adjacent organ injuries are mainly associated with malignant or recurrent cases.[46]

Although the mortality risk is low in SG, the risk of mortality may increase in extrathyroidal approaches.[47]

Conclusion

Surgery is the main treatment in SG. Although SG surgery is among the high-risk thyroidectomies, it can be safely performed by experienced surgeons with low risk and excellent results can be obtained. Most of the SGs can be

resected by the cervical approach, and an extracervical approach may be required in a small proportion of patients. Surgical complications of SG related to thyroidectomy are higher than other thyroidectomies. In addition to the complications related to thyroidectomy, complications related to the type of surgical intervention may also occur in SG. It should be known that complications related to both thyroidectomy and intervention type may develop in these patients, and they should be followed carefully.

Disclosures

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