# RADYOLOJİ KONULARI

**Editör: Dr.Öğr.Üyesi Betül TİRYAKİ BAŞTUĞ**

yaz
yayınları

# Radyolojide İleri Araştırmalar

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**2025**

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# TİROİD VE PARATİROİD BEZLERİNİN EMBRİYOLOJİSİ, GELİŞİMSEL ANOMALİLERİ VE ANATOMİK VARYASYONLARI

**Ahmet BAYTOK[1]**

## 1. GİRİŞ

Tiroid ve paratiroid bezleri, insan vücudunun metabolizma, kalsiyum ve fosfor dengesinde kritik rol oynayan endokrin organlardır (Shaker & Deftos, 2023). Tiroid bezi, başlıca tiroksin (T4) ve triiyodotironin (T3) hormonlarını salgılarken; paratiroid bezleri, parathormon (PTH) üretimiyle kan kalsiyum seviyesini düzenler (Summers & Macnab, 2017). Bu bezlerin embriyolojik gelişimi karmaşık bir süreçtir ve bu süreçte meydana gelen bozukluklar çeşitli anomalilere yol açabilir.

Gelişimsel anomaliler ve anatomik varyasyonlar, tiroid ve paratiroid bezlerinin işlevsel bozukluklarına ve cerrahi komplikasyonlara neden olabilir. Radyologlardan sıklıkla planlanan cerrahi müdahaleden önce tiroid ve paratiroid bezleriyle ilgili patolojiyi değerlendirmeleri istenir. Bu nedenle, bu yapıların embriyolojik gelişim süreçlerini anlamak ve olası varyasyonlara aşina olmak klinik pratiğin vazgeçilmez bir parçası olup tedavi planlanmasında ve olası cerrahi işlemler ile oluşabilecek komplikasyon risklerinin azaltılmasında kritik rol oynar (Srinivasan et al., 2022).

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# 2. TİROİD BEZİ GELİŞİMİ: EMBRİYOLOJİK SÜREÇLER VE ANOMALİLER

Tiroid bezi, endokrin sistemin en büyük ve metabolik olarak en aktif organlarından biridir. Embriyolojik kökeni faringeal tabandan başlayan tiroid bezinin gelişimi, kompleks bir göç ve farklılaşma süreci içerir. Bu süreç, üçüncü ve dördüncü faringeal ceplerin yanı sıra foramen çekumdan başlayan epitel hücrelerinin invajinasyonu ile şekillenir. Tiroidin normal gelişimi, belirli genetik ve moleküler mekanizmaların hassas kontrolünü gerektirir.

Ancak bu dinamik süreçte meydana gelebilecek aksaklıklar, tiroid bezinin yerleşimi, yapısı ve fonksiyonunu etkileyebilen çeşitli gelişimsel anomalilere yol açabilir. En sık görülen anomaliler arasında ektopik tiroid dokuları, lingual tiroid, tiroglossal kanal kistleri ve konjenital hipotiroidizm yer alır (Oomen, Modi, & Maddalozzo, 2015). Bu anomaliler, tiroid bezinin embriyolojik gelişimindeki bozukluklara bağlı olarak ortaya çıkar ve çoğu zaman doğumsal veya pediatrik endokrinolojide önemli klinik sorunlara neden olabilir.

Tiroid gelişimindeki bu anomalilerin anlaşılması, yalnızca hastalıkların tanı ve tedavisinde değil, aynı zamanda embriyolojik süreçlerin daha derinlemesine incelenmesi için de temel oluşturmaktadır.

## 2.1. Tiroid Bezinin Embriyolojik Kökeni

Tiroid bezi; türlerin evriminde ortaya çıkan ilk bez olmakla birlikte insan gelişiminde de ortaya çıkan ilk bez olarak bilinmektedir (P. Som et al., 2011). Endodermden köken alan yetişkin tiroid bezi, tiroid foliküler hücreleri ve parafoliküler hücreler (C hücreleri) olarak iki farklı hücre tipinden oluşur. Tiroid foliküler hücreleri, birinci ve ikinci faringeal arklar arasındaki endodermal kalınlaşma olan median tiroid anlage'den kaynaklanır (Noussios, Anagnostis, Goulis, Lappas, & Natsis, 2011). 24. günde, bu doku tiroid tomurcuğu denen küçük bir çukur oluşturur (De Felice & Di Lauro, 2004). Bu yapı, bilobat bir divertiküle uzar ve aort primordiumuyla temas halindeyken kaudal olarak aşağı iner. Küçük bir kanal olan tiroglossal kanal, dil ile tiroid primordiumunun kaudal göçü arasında geçici bir bağlantı olarak varlığını sürdürür ve daha sonra kesin tiroid oluşumundan önce, gebeliğin 8. ve 10. haftaları arasında involusyona uğrar (Koeller, Alamo, Adair, & Smirniotopoulos, 1999).

Tiroid primordiumu boynun orta hattında kaudale doğru ilerler. Tiroid primordiumu ilk önce primordiyal hyoid kemiğinin önünde ilerler ve daha sonra hyoid kemiğe doğru aşağıya ve arkaya doğru kıvrılır ve ardından boynun infrahyoid kısmına, tirohiyoid membranın, tiroid kıkırdağının ve trakeanın önüne doğru inmeye devam eder. Tiroglossal kanalın alt kısmı tiroid bezinin piramidal lobuna farklılaşır (P. Som et al., 2011).

Parafoliküler hücreler; dördüncü faringeal kesesinde lateral olarak ortaya çıkan, ultimobrankial cisimler olarak da bilinen lateral tiroid anlage'den köken alır (Noussios et al., 2011). Lateral anlage, boynun infrahyoid kısmına indikten sonra median anlage'nin ürünleriyle birleşir ve bu da tiroid bezi boyunca dağılmış parafoliküler hücrelerle sonuçlanır (De Felice & Di Lauro, 2004).

### 2.2. Tiroid Bezinin Gelişimsel Anomalileri

Tiroid bezinin median veya lateral anlage (veya her ikisi) ile ilgili çeşitli gelişimsel anomalileri tanımlanmıştır. Tiroid bezini ilgilendiren gelişimsel varyasyonlar aşağıdaki gruplar altında kategorize edilebilir (Pradhan, Agarwal, Lombardi, & Raffaelli, 2021).

*A-Median Tiroid Anlage Anomalileri*

- Tiroid ektopileri: tiroid kalıntıları, lingual tiroid, orta hat ektopik tiroid
- Tiroglossal kanal kistleri (TKK) ve fistüller
- Piramidal lob
- Agenezis/hemiagenezis
- Septum

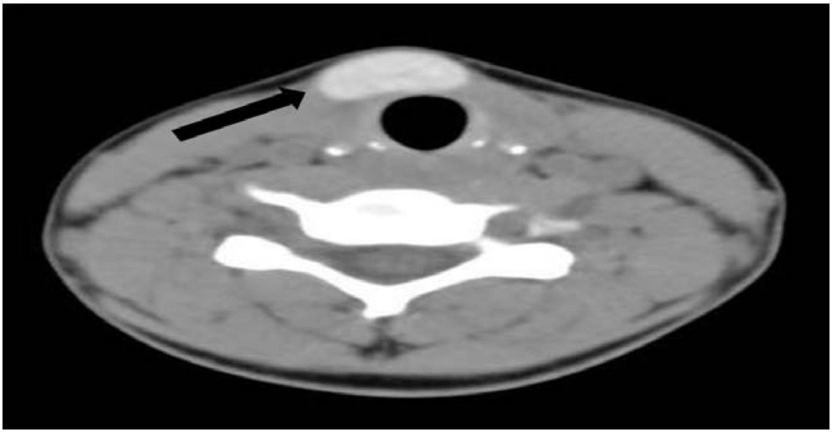
*B- Lateral Tiroid Anlage Anomalileri*

- Zuckerkandl tüberkülü

*C. Anormal/devam eden iniş anomalileri*

### 2.2.1. Tiroid Ektopileri

Ektopik tiroid dokusu foramen çekum ile tiroid bezinin normal pozisyonu arasında bulunabilmesine rağmen, inmemiş tiroid bezlerinin en yaygın iki yeri lingual tiroid (%90) ve ön boyundur (%10). Bunların çoğu çocukluk çağında tespit edilir ve sıklıkla hipotiroidizmle ilişkilidir. Sürekli tiroid stimülan hormon (TSH) uyarımının etkisi altında büyüyebilir ve disfaji, disfoni ve nefes darlığı gibi semptomlar ortaya çıkabilir. Ön boyundaki ektopik tiroid dokusu orta hat kitlesi olarak görülebilir ve tiroglossal kist olarak yanlış tanı alabilir (Damiano, Glickman, Rubin, & Cohen, 1996). Ektopik tiroid dokusunu TKK'den ayırmak önemlidir çünkü sıklıkla tiroid hormonlarının tek kaynağını temsil eder.



**Resim 1. İntravenöz kontrastlı Bilgisayarlı tomografi (BT) görüntülerinde pretrakeal alanda lokalize ektopik tiroid olgusu (siyah ok).**

### 2.2.1.1. Tiroid Kalıntıları

Tiroid kalıntıları, tiroid bezinin inferior kutbunun altında, tirotimik yol boyunca uzanan, hatta ön üst mediastende bulunan normal tiroid dokusunun izole kalıntılarıdır. Ayrıca, dar bir pedikül veya hatta sadece fibrovasküler bir bantla tiroid bezinin alt kutbuna bağlı tiroid dokusunun bir uzantısı veya uzaması olabilir. Bu kalıntılar muhtemelen tiroid bezinin sağ ve sol loblara ayrıldıktan sonra normal embriyolojik inişinin bir uzantısıdır ve hastaların %50'sinden fazlasında bulunur.

Tiroid parankiminin değişken projeksiyonlarının veya uzantılarının farkında olmak, tüm tiroid dokusunun tamamen çıkarılmasını sağlamak için kritik öneme sahiptir. Tiroid kalıntıları ön mediastende bulunabilir ve bazen küçük lenf düğümleri veya hatta paratiroid bezleriyle karıştırılabilir. Böyle bir kalıntıda nodüler değişimin gelişimi, tiroid bezinin alt kutbundan tamamen ayrı ve kaudalde bulunan bir tiroid nodülü olarak tanınabilir. Böyle bir nodül daha da kaudalde, ön mediastende, kalbin ve büyük damarların inişini takiben yer alırsa, "izole" mediastinal veya "primer" intratorasik guatra yol açabilir (Pradhan et al., 2021). Bu intratorasik kalıntıların vasküler beslenmesi genellikle intratorasik damarlardan sağlanır. Bu durum, primer intratorasik guatrların vasküler kontrolü sağlamak için torasik cerrahi yaklaşıma neden ihtiyaç duyabileceğini açıklar.

Tiroid bezleri bazen tirotimik ligamana bağlanması nedeniyle inferior tiroid kutbunun mobilizasyonunda intraoperatif zorluğa yol açar. Bazen bir paratiroid bezi tirotimik bezin ve bitişik tirotimik ligamanın yakınında bulunur. İnferior paratiroid bezi timus beziyle birlikte kaudal olarak göç eder (Sheahan & O'Duffy, 2016).

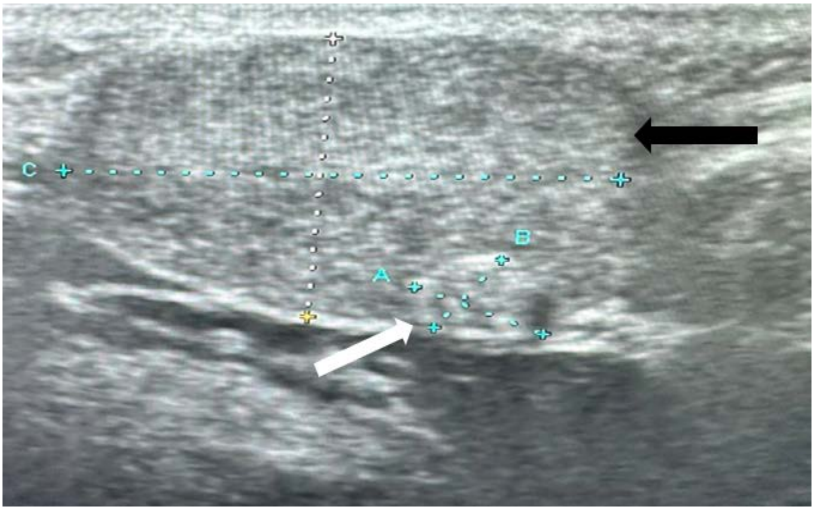
Tiroid kalıntıları klinik öneme sahiptir çünkü rekürren guatrların kaynağı olup kompresyon semptomlarına yol açabilirler. Ayrıca karsinom için yapılan total tiroidektomiden sonra radyoaktif iyot alımının kaynağı da olabilirler. Bu nedenle, total tiroidektomi sırasında tüm tiroid dokusunun tamamen çıkarılmasını sağlamak için tiroid bezinin gelişimsel anomalilerinin bilinmesi önemlidir.

#### 2.2.1.2. Lingual Tiroid

Dil tabanındaki foramen çekum en yaygın ektopik tiroid yeridir ve vakaların %90'ını oluşturur. Ektopik tiroid dokusunun %10'a kadarı dilaltı boşluk, tyroglossal kanal, mediastinum, kalp ve özefagus dahil olmak üzere çeşitli ek yerlerde bulunabilir (Sargın, Kabacam, Köseoğulları, Şanlı, & Erdoğan, 2003). Tiroglossal kanal yolunun dışındaki bu yerlerin kökeni muhtemelen dördüncü kesenin ultimobranşiyal gövdeleriyle ilişkilidir. Ancak bu teori tartışılmaktadır çünkü bu hücrelerin foliküler hücreler oluşturma potansiyeli olup olmadığı net değildir ve bazı yazarlar ektopik tiroid dokusunun alışılmadık yerlerinin anormal göçle ilişkili olabileceğine inanmaktadır (Foley & Fallat, 2006). Klinik çalışmalarda lingual tiroid dokusunun görülme sıklığının 3000'de 1 ile 100.000 vakada 1 arasında değiştiği tahmin edilmektedir; ancak, post mortem çalışmalar yaklaşık %10'luk bir insidans göstermiştir (Hari, Kumar, Abo-Khatwa, Adams-Williams, & Zeitoun, 2009).

Lingual tiroid, klinik olarak dilin tabanında epitelyumla kaplı sert, pembemsi, ağrısız bir kitle olarak ortaya çıkar (Guneri, Ceryan, Igci, & Kovanlikaya, 1991). Lingual tiroid dokusu, vakaların yalnızca %30'unda tiroid beziyle birliktelik gösterirken, vakaların kalan %70'inde izole olarak bulunmaktadır.

Ektopik tiroid dokusu genellikle nükleer sintigrafi ile görüntülenir, bu sadece lingual ektopik tiroidde tutulumu göstermekle kalmaz, aynı zamanda beklenen tiroid bölgesinde normal işlev gören bir doku olup olmadığını da değerlendirir. Manyetik rezonans (MR) ve bilgisayarlı tomografide (BT), bu lezyonlar normal bezle benzer sinyal özelliklerine sahiptir ve yüksek iyot içeriği nedeniyle BT'de hiperdens ve bitişik dil kaslarına kıyasla T1 ve T2 ağırlıklı MR dizilerinde yüksek sinyal gösterir. Lingual tiroid dokusu T2 ağırlıklı dizilerde daha belirgindir. Ektopik tiroid dokusu normal bezle aynı patolojik süreçlere tabidir. Lingual tiroid dokusunda kanser gelişimi son derece nadirdir, hem klinik hem de radyografik olarak iyi huylu lingual tiroid dokusuna benzer görünebilir ve maligniteyi düşündüren görüntüleme bulguları varlığında biyopsi gerektirebilir (Kennedy & Riefkohl, 2007).




**Resim 2. Gri-skala ultrasonografi incelemesinde lingual tiroid dokusu (siyah ok) ve lingual tiroid sol posterolateral kesimde izlenen tiroid nodülü (beyaz ok).**

### 2.2.1.3. Tiroglossal Kanal Kisti (TKK)

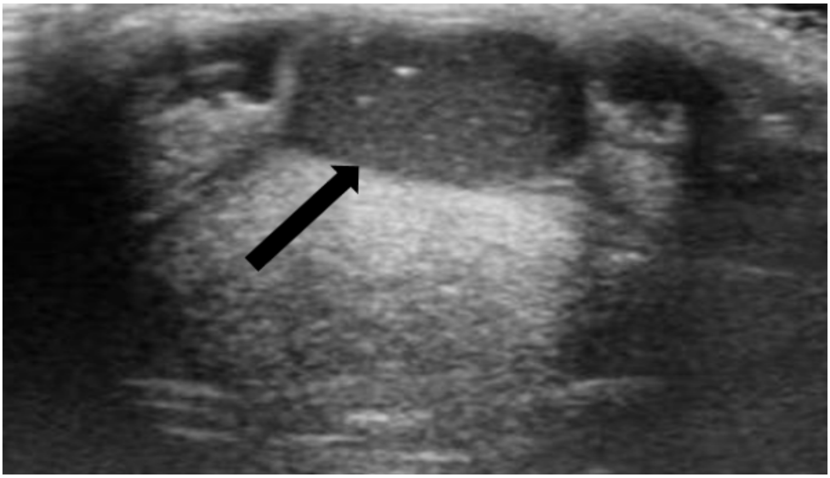
Beşinci haftanın başlarında, zayıflamış kanalın lümenini kaybetmesinin ardından kısa bir süre sonra parçalara ayrılır. Gebeliğin beşinci ila yedinci haftaları arasında, hiyoid kemik, mezodermin yoğunlaşması ve ardından ikinci ve üçüncü brankial arkların kıkırdaklaşmasıyla oluşur, arkadan öne doğru büyür ve tiroglossal kanal yolunu suprahyoid ve infrahyoid kısımlara böler (Organ & Organ, 2000). Zayıflamış tiroglossal kanal yolu genellikle atrofiye uğrar ve sekizinci haftanın sonunda kaybolur. Bu yol, lifli bir kordon veya küçük bir epitel tüp olarak varlığını sürdürebilir ve bu kalıcı tüp/kanal/kordon, bezi ve foramen çekumu birbirine bağlayan tiroglossal kanal olarak adlandırılır. Tiroid bezi normal pozisyonuna ulaşabilir veya bu embriyonik yol boyunca herhangi bir yerde (dil altı, prelaringeal veya nadiren suprasternal) hücre kalıntıları bırakarak doğum sonrası kist gelişimine yol açabilir. TKK'nin, bazı brankial kleft kistlerinin karakteristiği olan birincil bir dış açıklığı yoktur, çünkü yolun embriyolojik seyri asla boyun yüzeyine ulaşmaz [5].

TKK'ler en yaygın konjenital servikal anomalilerdir, brankial kleft kalıntılarından üç kat daha yaygındır. Kistler genellikle hiyoid kemiğinin altında ağrısız, asemptomatik bir orta hat şişliği olarak bulunur ve herhangi bir yaşta görülebilir. TKK'ler vakaların yaklaşık %25'inde doğumda bulunur, çoğu çocukluk döneminde fark edilir ve son üçte biri 30 yaşından sonra belirginleşir. Cinsiyet insidansı eşittir. Orta hattın herhangi bir yerinde, submental bölgeden suprasternal çentiğe kadar bulunabilirler, ancak en sık bu uçların ortasında, hiyoid kemiğinin yakınında bulunurlar. Klinik muayenede, kistler yuvarlak, düzgün bir yüzeye sahip olup yutma veya dilin dışarı çıkmasıyla, genellikle hiyoid kemiğe ve dil kaslarına bağlanmış olmaları sonucu boyunda yükselirler (Pradhan et al., 2021).

Genellikle 1 ila 2 cm çapında, hafif hareketlidirler ve süperpoze bir enfeksiyon olmadığı sürece hassas değildirler. Oral bakteriler foramen çekum yoluyla kistleri enfekte edebilir. Tiroglossal kanal sinüsleri, kistlerin kendiliğinden veya cerrahi drenaj sonucu enfeksiyonuna sekonder olarak gelişir.

Ameliyat öncesi tiroid görüntüleme ve tiroid fonksiyon değerlendirmesi, normal tiroid bezini görmek için TKK'li tüm hastalarda yapılmalıdır. Normal tiroidin varlığını saptamak ve ektopik tiroid olasılığını dışlamak amacıyla TKK'li olduğu varsayılan hastalarda tiroid sintigrafisi ve preoperatif ultrasonografi (USG) de yapılabilir.

Tiroglossal kisti çıkarma operasyonu, kistin hiyoid kemiğinin merkezi kısmı ve kistten çekuma kadar uzanan epitelyum kaplı yolu ile birlikte çıkarılmasını içerir ve buna Sistrunk operasyonu denir (Sistrunk, 1920). Sistrunk operasyonu, en blok kistektomi ve merkezi hiyoidektomiden oluşur ve foramen çekuma kadar yol eksizyonu yapılır.

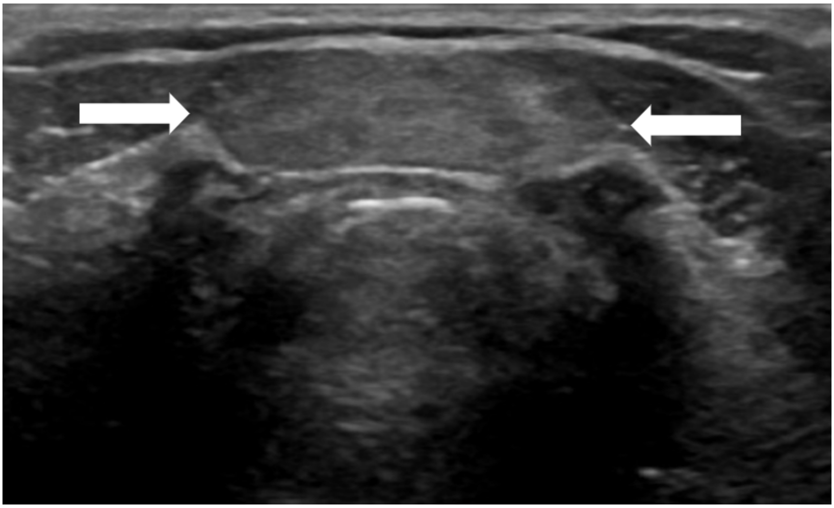


**Resim 3. Gri-skala ultrasonografi incelemesinde boyun orta hatta hyoid kemik düzeyinde izlenen posteriorunda akustik güçlenme oluşturan tiroglossal kanal kisti ile uyumlu lezyon (siyah ok).**

### 2.2.1.4. Piramidal Lob

Piramidal lob, tiroglossal yolun embriyolojik kalıntısı olup tiroid dokusunun isthmustan hiyoid kemiğe doğru değişken bir uzantısıdır. Piramidal lobun bulunma sıklığı, operatif örneklerde %55 ila %76 arasında değişir (Braun, Windisch, Wolf, Hausleitner, & Anderhuber, 2007). Mevcut olduğunda, daha çok isthmusun sol tarafıyla ilişkilidir.

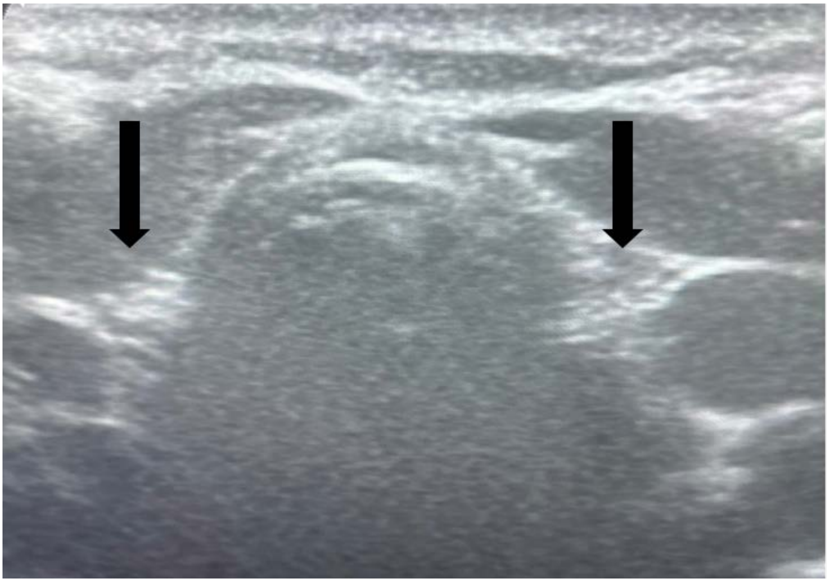
Piramidal lob, tiroid foliküler hücreleri içerir ve herhangi bir lifli kalıntıyla birlikte bütüncül şekilde tanımlanmalı ve çıkarılmalıdır. Ameliyat sırasında gözden kaçırılırsa, orta hat veya sol paramedian boyun şişliği olarak gelişebileceği gibi tekrarlayan iyi huylu nodüler guatrlara veya tekrarlayan hipertiroidizme veya malign karekterde patolojilere neden olabilir.



**Resim 4. Gri-skala ultrasonografi incelemesinde tiroid bezi parankimi ile devamlılık gösteren ve orta hatta bez süperiorunda izlenen piramidal lob (beyaz oklar).**

### 2.2.1.5. Agenezi/Hemi-Agenezi.

Bunlar iniş bozukluğu ve/veya lobülasyon defekti ile ilişkili olduğu düşünülen nadir anatomik varyantlardır. Bez kısmen veya tamamen olağan anatomik konumunda bulunmadığında, muhtemel ektopik tiroid bezi, tiroglossal kanalın tüm yolu boyunca USG ile aranmalıdır. Bazen, lingual tiroid mevcut olan tek tiroid dokusudur. Sol lob sağ lobdan daha sık yoktur (Peña, Loehn, Robertson, & Walvekar, 2010). Hemiagenezi, daha önce ameliyat yapılmamışsa, bir lob ve/veya istmus tanımlanmadığında, USG muayenesinde kolayca tanınır.



**Resim 5. Gri-skala ultrasonografi incelemesinde tiroid bezi sağ ve sol lojlarında (siyah ok) tiroid parankim dokusu izlenmeyen tiroid agenezisi ile uyumlu olgu.**

#### 2.2.1.6. Septum

Sıklıkla tiroid loblarında posterior kesimde bulunan septumun belirgin bir klinik önemi bulunmamakla birlikte USG incelemesinde nodül olarak adlandırılmamalı veya paratiroid beziyle karıştırılmamalıdır. Ayrıca var olmayan bir nodülün inkomplet halosu olarak değerlendirilmemelidir. USG taramalarının farklı düzlemlerde yapılarak parankim ile devamlılığın gösterilmesi olası tüm şüpheleri ortadan kaldıracaktır (Choi, Kim, Kim, & Kwak, 2014).

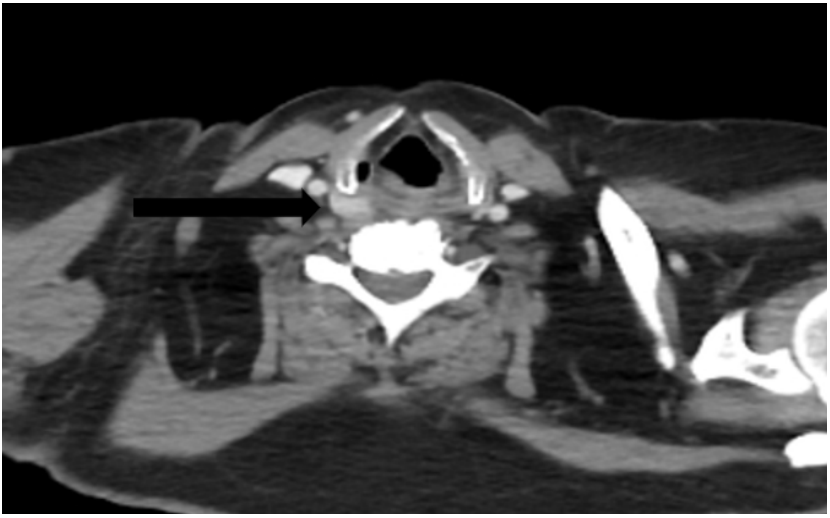
### 2.2.2. Zuckerkandl Tüberkülü (ZT)

ZT'nin lateral tiroid çıkıntılarının (ultimobranşiyal cisimler) kalıntılarını temsil ettiği düşünülmektedir. Bu bilateral yapılar, dördüncü faringeal kesenin ventral kısmından ve beşinci vestigial keseden gelen faringeal endodermin proliferasyonu olarak ortaya çıkar. Ultimobranşiyal cisimler, tiroid bezine üst paratiroid bezini ve parafoliküler hücreleri getirir.

Sonunda lateral ultimobranşiyal cisimler, genellikle beşinci haftada median tiroid çıkıntısıyla birleşir ve farinksten ayrılır. Mevcut olduğunda farinkse doğru kalan posterolateral projeksiyon, ZT'yi oluşturur. ZT, lateral ve medial bileşenlerin kaynaştığı noktada bulunan tiroid lobundan gelen posterolateral bir projeksiyondur (Singh, Sharma, & Agarwal, 2017). ZT'nin insidansı sağ tarafta daha yüksek olsa da, genellikle bilateral olarak bulunur (Irawati, Vaish, Chaukar, Deshmukh, & D'Cruz, 2016).

ZT; boyuta göre grade I, <0,5 cm; grade II, 0,5 ila 1,0 cm; grade III, >1 cm olarak sınıflandırılır. En yaygın olanı, vakaların %60 ila %70'inde bulunan grade II tüberküldür. Grade III tüberkül, önemli bası semptomlarıyla ilişkilendirilebilir ve sub-total tiroidektomiden sonra kalıcı semptomların nedeni olabilir. Boynun düz lateral röntgenlerinde görülen genişlemiş prevertebral boşluk ZT'yi işaret edebilir.

ZT, rekürren laringeal sinir (RLS) ve üst paratiroid ile yakından ilişkilidir. Tüberkülün büyümesi genellikle RLS'nin lateralinde meydana gelir; sinir, genişlemiş tüberkülün medialindeki bir yarıktan geçer gibi görünür. Nadir görülen ancak yüksek riskli bir varyant, RLS'nin genişlemiş bir tüberkülün ventralinde uzanmasıdır. ZT'nin elevasyonu, RLS'nin medial seyrinde güvenli bir şekilde diseksiyonuna olanak tanır.



**Resim 6. İntravenöz kontrastlı Bilgisayarlı tomografi (BT) görüntülerinde sağ paratrakeoözefagial alanda tiroid bezi sağ posteromedialinde parankim ile devamlılık gösteren ZT ile uyumlu olgu (siyah ok).**

## 3. PARATİROİD BEZİ GELİŞİMİ: EMBRİYOLOJİK SÜREÇLER VE ANOMALİLER

Paratiroid bezleri boyut, şekil, sayı ve konum bakımından önemli ölçüde farklılıklar gösterebilir. Bu geniş çeşitlilik, paratiroid hastalıklarıyla uğraşan cerrahlar için ciddi bir zorluk oluşturmaktadır. Paratiroidlerin gelişimsel embriyolojisi ve cerrahi anatomisi yakından bağlantılıdır. Bu nedenle, embriyolojik gelişim ve dolayısıyla paratiroid bezlerinin olası anatomik varyasyonları hakkında ayrıntılı bir anlayış ve bilgi, hiperparatiroidizmli hastalar için başarılı bir cerrahi strateji geliştirmek ve tiroid cerrahi prosedürleri sırasında paratiroid bezlerini korumak için ön koşullardır.

### 3.1. Paratiroid Bezinin Embriyolojisi

Paratiroid bezleri, insanlarda gebeliğin 5. ve 12. haftaları arasında üçüncü ve dördüncü faringeal poşlardan gelişir (Zajac & Danks, 2008). Alt paratiroid bezleri üçüncü faringeal poştan kaynaklanır ve kökenleri ile uyumlu olarak paratiroid III (PIII) olarak adlandırılır (Peissig, Condie, & Manley, 2018). Timus, aynı brankial kesenin ventral kısmından kaynaklanır. Bu ortak köken, PIII'ün timik paratiroid olarak gösterilmesini açıklamaktadır (Henry, 2003). PIII ve timus kompleksi ayrıca paratimus olarak adlandırılmıştır (Peissig et al., 2018). Paratimus kompleksi, son anatomik pozisyona ulaşmak için nispeten uzun bir kuyruk inişine sahiptir.

Üst paratiroid bezleri dördüncü brankial poşların dorsal kısmından kaynaklanır ve bu nedenle paratiroid IV (PIV) olarak adlandırılır (Peissig et al., 2018). PIV'in ve dördüncü faringeal poşların türevlerinin kaderi beşinci keselerin kaderiyle ilişkilidir. Beşinci kese genellikle rudimenter veya körelmiştir, dördüncü faringeal keseye dahil edilmiştir ve lateral tiroid oluşumuna katkıda bulunur. Dördüncü ve rudimenter beşinci faringeal keseler birlikte bazen kaudal faringeal kompleks olarak belirtilir. Bu, PIV'ün ilkel olan dorsal kısmını, ventral divertikülü (konum olarak üçüncü kesenin thymus kısmına karşılık gelir) ve esas olarak beşinci keseden türetilen ultimobrankial cismi içerir. Ventral divertikülün nihai kaderi insanlarda kesin olmamakla birlikte, oluşumundan kısa bir süre sonra kaybolan rudimenter timus dokusuna yol açabilir. Normal yerlerinde PIV ile birlikte nadiren karşılaşılan yağlı lobüller, tamamen kaybolmamış olan bu timik dokunun kalıntılarını oluşturabilir (Henry, 2005). Lateral tiroidle ortak kökenleri nedeniyle, PIV'ler bazen PIII'ün timik paratiroidine benzer şekilde tiroid paratiroidleri olarak belirtilir.

Genellikle her iki tarafta 2 paratiroid bezi gelişir, ancak bu sayı 2 ila 6 bez arasında değişebilir, hatta bazı yazarlar 12 beze kadar olduğunu bildirmektedir (O'rahilly & Müller, 1996; P. M. Som & Curtin, 2003).

### 3.2. Paratiroid Bezinin Anatomisi

Üst paratiroid bezlerinin anatomik konumu, bu bezler ile tiroid bezi arasındaki yakın ilişki nedeniyle nispeten sabittir. Genellikle krikoid kıkırdağın alt sınırı seviyesinde üst tiroid loblarının dorsal tarafında bulunurlar. Alt paratiroid bezleri, timusla embriyolojik ilişkileri nedeniyle daha değişken bir konuma sahiptir. Vakaların %50'sinde, alt paratiroid bezleri tiroid bezinin lateral alt kutbu boyunca yer alır. Vakaların %15'inde, bu bezler alt tiroid lobunun 1 cm altında angulus mandibula ile üst mediasten arasındaki herhangi bir yerde lokalize olabilirler. İntratiroidal paratiroid dokusunun insidansı yaklaşık %2'dir [19]. Paratiroid bezlerinin arteriyel beslenmesi, sırasıyla üst ve alt bezleri besleyen süperior ve inferior tiroidal arterlerinden gelir. Venöz drenaj genellikle tiroidal venlere olur.

Bu bezler çok küçük olup kraniyokaudal boyutta yaklaşık 6 mm, enine boyutta 3-4 mm'dir ve düzleştirilmiş "oval disk" görünümündedir. Boyutları normal olduğunda, genellikle çoğu görüntüleme çalışmasında tanımlanamazlar. Buna karşılık, paratiroid adenomları ve bez hiperplazisi gibi durumlarda görüntüleme çalışmalarında daha kolay tanımlanabilirler (Policeni, Smoker, & Reede, 2012). Büyüdüklerinde, bu yapılar USG'de hipoekoik nodüller olarak görünür ve bitişik anterior tiroid parankimini komprese ederek yanlışlıkla tiroid nodülleri olarak sınıflandırılabilirler. Ayrımda klinik ve laboratuvar verileriyle korelasyon çok önemlidir.

### 3.3. Paratiroid Bezlerinin Embriyolojik Migrasyon Anomalileri ve Konjenital Ektopiler

PIV'lerin pozisyonları sınırlı embriyolojik göç nedeniyle nispeten sabittir. Vakaların %80'inden fazlasında, PIV'ler tiroid lobunun arka tarafında, 2 cm çapında ve inferior tiroid arter ile

RLS'nin kesiştiği noktanın 1 cm yukarısında, krikoid ve tiroid kıkırdağının birleştiği yerin yakınında yer alır (Akerström, Malmaeus, & Bergström, 1984). PIV genellikle yağdan oluşan bir haloya sahiptir ve tiroid kapsülü üzerinde serbestçe hareket edebilir. Çevreleyen yağ, ventral divertikülden kaynaklanan atrofik timik dokuyu temsil edebilir (Sadler, 2018). Bazen, PIV'ler tiroid kapsülüyle yakından ilişkilidir. Vakaların yaklaşık %15'inde, PIV'ler peritiroidal fasya katmanları arasında gizlenmiş şekilde üst tiroid kutbunun posterolateral yüzeyinde yer alır (GW, 2003; Henry, 2005). Bu gibi vakalarda tiroid lobunun posterolateral yönüne bağlıdır ve bu nedenle daha az hareketlidir. PIV ayrıca daha ileride, bazen RLS, inferior tiroid arter veya ZT tarafından kısmen gizlenmiş kaudal bir pozisyonda yer alabilir ve daha da aşağıda, alt tiroid kutbunun arkasında da bulunabilir (Akerström et al., 1984).

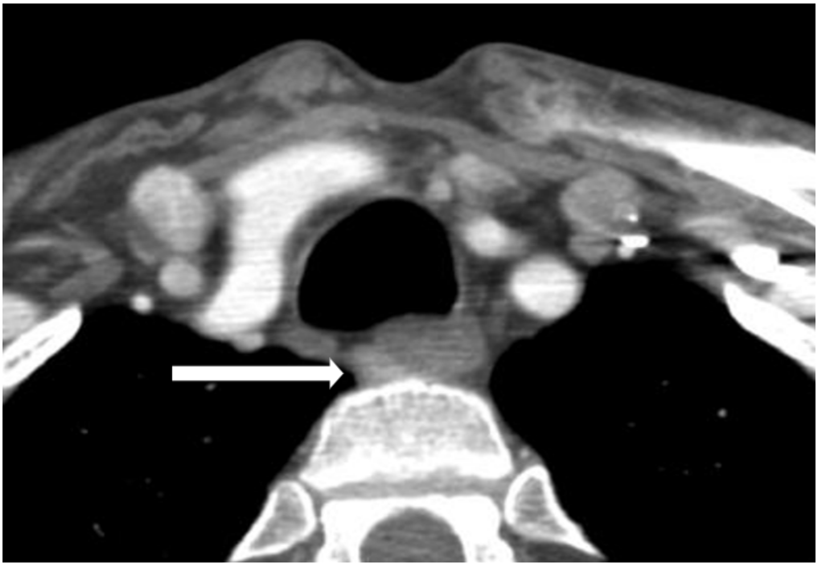
Paratiroid ağırlığıyla ilişkili göçün sonucu olarak nadiren (%3 ila %4 vakaya kadar), normal PIV'ler boyunda daha posteriorda, retrofarengeal veya retroözofageal bir konumda bulunurken, patolojik olarak genişlemiş paratiroid bezleri vakaların üçte birine kadar retrofarengeal veya retroözofageal bir konumda bulunabilir (Thompson, Eckhauser, & Harness, 1982). Vakaların %1'inden azında, PIV'ler daha yüksekte, üst tiroid kutbunun üzerinde yer alabilir (Akerström et al., 1984).

PIV'in majör ektopik konumları nadir olup bunlar sıklıkla iniş başarısızlığından veya lateral yönlendirilmiş inişten kaynaklanabilir ve üst paratiroid bezi common karotid artere bitişik bir yerleşim gösterebilir (GW, 2003). Bu lokasyonlar vakaların %1'inden azını oluşturur. Üst paratiroid bezleri bazen subkapsüler pozisyonda bulunur veya tiroid kapsülünün bir yarığı tarafından gizlenir. PIV ultimobranşiyal cisimlerin median tiroid rudimentiyle füzyonu sırasında tiroidin içine dahil olsa bile gerçek intratiroidal üst bezler nadirdir ve PIII'den daha az sıklıkta görülür (GW, 2003). Üst paratiroid primordiumu dördüncü faringeal poşun kalan endoderminden ayrılmayı başaramazsa, piriform sinüs primordiumuyla birlikte retrofaringeal bir yere göç edebilir (Chan et al., 2003). Piriform sinüste lokalize olmuş birkaç patolojik paratiroid bezi vakası tanımlanmıştır (Fukumoto et al., 2002).

Daha uzun embriyolojik göç nedeniyle, normal olarak yerleşmiş PIII'lerin bölgesi çok daha geniş bir alana yayılmıştır ve PIV'lerden daha fazla ektopik olma olasılıkları vardır. Vakaların yaklaşık yarısında (%42 ila %61), tiroid lobunun alt kutbu seviyesinde, ön, yan veya arka tarafta yerleşmişlerdir (Edis, Purnell, & van Heerden, 1979). Bez tipik olarak alt kutupta veya ona bitişik bir yağ lobülünde yer alır. Bazı vakalarda, PIII'ler tiroid lobunun postero-süperiorunda, tiroid kapsülüne yakın bir şekilde yerleşmiştir. Böyle bir pozisyonda, PIV'ler ile karıştırılabilirler (Henry, 2003, 2005). Birkaç bez, intratiroid bezini taklit ederek tiroid lobunun bir kıvrımında daha derin bir şekilde gizlenebilir. Vakaların yaklaşık dörtte birinde, PIII tirotimik bağda veya timusun servikal kısmında yerleşmiştir.

Timusun embriyolojik iniş yolu angulus mandibuladan perikarda kadar uzandığından, paratimus kompleksinin göç anomalileri, PIII'lerin yüksek veya düşük ektopilerinden sorumludur [23]. Paratimus kompleksi tam olarak inmediğinde, inferior paratiroid bezleri boynun süperior kesimlerinde, tipik olarak karotis kılıfı boyunca sıkışabilir. Bu nedenle, paratiroid eksplorasyonu sırasında inferior bez yoksa, genellikle tiroid bezinin üstünde ve PIV'in üstünde bir timik doku parçasıyla bulunur. Bez genellikle karotis bifurkasyonunun bitişiğinde, tiroid üst kutbunun yaklaşık 2 ila 3 cm lateralinde yer alır (GW, 2003). İnmemiş PIII, boyunda daha da yukarıda, karotis bifurkasyonunun üstünde, angulus mandibula bitişiğinde, hiyoid kemiğinin yakınında bulunabilir. Tüm bu vakalarda, superior tiroid arterler vaskülarizasyonu sağlar. Paratimusun kusurlu embriyolojik inişinden kaynaklanan bu yüksek ektopinin insidansı %1 ila %2'yi geçmemektedir (Henry, 2005). Öte yandan, timustan ayrılma gecikirse, PIII ön mediastende değişen derecelerde aşağı çekilebilir. Vakaların yaklaşık %4 ila %5'inde, alt paratiroid bezi göğüste, retrosternal timus içinde veya kapsülünün arka tarafında veya büyük mediastinal damarlarla (innominant ven ve çıkan aort) temas halinde bulunur. Sadece birkaçı timusun dışında, aort arkına ve büyük damarların kökenine bitişik olarak bulunur. Daha da düşük bir pozisyon, alt paratiroidin plevra veya perikard ile temas halinde olmasına neden olur (Wheeler, 2009). İnnominant ven ve aort arkı seviyesinin altına inen ektopik PIII'lerin çoğu, sıklıkla internal mammarian arterden ektopik bir arteriyel beslenme geliştirir. Bazen kan temini timik arterden veya direk aorttan orjin alan daldan gelebilir (DoppMAN et al., 1977). Alt paratiroid bezi, bireylerin %1 ila %3'ünde tiroidin alt kutbunda intratiroidal yerleşimlidir.

Bezlerin konumu önemli ölçüde değişebilmesine rağmen genellikle paratiroid bezlerinin belirgin simetrisi bulunmaktadır. Paratiroid simetrisi cerrahi boyun eksplorasyonu sırasında paratiroid bezinin tanımlanmasını kolaylaştırabilir ve cerrah tiroid ve paratiroid prosedürleri gerçekleştirirken bunu aklında tutmalıdır. En yaygın asimetrik konum, PIII'lerden yalnızca birinin timusta yer aldığı konumdur. Başka bir asimetrik konum, bir taraftaki her iki bezin RNS ve inferior tiroid arterinin kesiştiği noktanın üstünde veya altında yer aldığı konumdur. Gerçekten de PIV'ler inişleri sırasında PIII tarafından çaprazlanır. Bu embriyolojik çaprazlama, PIII ve PIV'in, PIII'in göç etme derecesine bağlı olarak, tiroid lobunun orta ve alt üçte birinin birleştiği yerde, inferior tiroid arter seviyesinde neden çok yakından ilişkili olabileceğini açıklar. Bu geçiş nedeniyle, bazı durumlarda her iki homolateral paratiroid aynı seviyede olabilir ve Grisoli'nin orta pozisyonundaki paratiroidlere karşılık gelebilir. Bu gibi durumlarda, bazen PIII ve PIV'i ayırt etmek neredeyse imkansızdır (Henry, 2005). Nadir durumlarda, iki bez birbirine yapışıktır ve kaynaşmış gibi görünür (Clark & Duh, 1997). Bu duruma öpüşme çiftleri denir (Clark & Duh, 1997). Öpüşen çiftte bir yarık çizgisi ve ayrı bir vasküler pedikülün varlığı nedeniyle bu durumu bilobat bir bezden ayırt etmek mümkündür ve paratiroid prosedürleri sırasında bu pedikülleri dikkatlice tanımlamak, bilobar bir bezi bitişik paratiroidlerle karıştırmamak için önemlidir. Böyle bir karışıklık, cerrahların hatalı bir şekilde dört bezi de tanımladıkları sonucuna varabilecekleri için cerrahi bir eksplorasyonun bulgularını değerlendirmede bir hata kaynağı olabilir.



**Resim 7. İntravenöz kontrastlı Bilgisayarlı tomografi (BT) görüntülerinde sağ paraözefagial alanda 7x5 mm boyutlarında ektopik paratiroid bezi izlenmektedir (beyaz ok).**

### 3.4. Paratiroid Bezlerinin Sayısal Anomalileri

Paratiroid agenezisi, paratiroid bezlerinin doğuştan yokluğu durumudur. Bu durum, paratiroid bezlerinin embriyonik gelişimi sırasında oluşamaması sonucu meydana gelir ve hipokalsemi ile sonuçlanabilir. Paratiroid agenezisi, genetik veya çevresel faktörlerden kaynaklanabilir. En yaygın sebepler arasında DiGeorge Sendromu (22q11.2 delesyon sendromu), TBX1 gibi genlerdeki kalıcı mutasyonlar ile 3. ve 4. faringeal cep kökenli embriyonik bozukluklar gösterilmektedir (Gordon & Levine, 2018; Hannan & Thakker, 2020).

Hiperparatiroidizmi olmayan kişilerde yapılan otopsi çalışmaları, vakaların %3 ila %6'sında dörtten az paratiroid bezi bulunduğunu göstermiştir (Clark & Duh, 1997). Ancak, bu rakamın paratiroid bezi gelişiminde gerçek bir değişiklikten ziyade tanımlanamamış bezlerin varlığını da düşündürmelidir (Wheeler, 2009). Öte yandan otopsi serileri vakaların %5 ila %13'ünde dörtten fazla bez olduğunu bildirmektedir ve literatürde tek bir denekte 11'e kadar paratiroid sayılan vakalar bildirilmektedir (Aly & Douglas, 2003; Pattou et al., 2000). Buna karşılık, böbrek yetmezliği olan hastalarda yapılan operatif serilerde %25 ila %30'luk insidanslar bildirilmiştir (Kraimps, Duh, Demeure, & Clark, 1992). Bir cerrahi raporda, böbrek yetmezliği veya yaygın paratiroid hiperplazisi yokluğunda daha yüksek oranda (>%30) mikroskobik embriyonik paratiroid artıkları olduğunu belirtmektedir (Kraimps et al., 1992). Bu fazladan paratiroid bezleri, faringeal keseler farinksten ayrıldığında faringotrakeal kanaldan kaynaklanan aksesuar paratiroid parçalarından gelişir (Henry, 2003). Göç sürecinde paratiroid hücrelerinin ana göç eden kütleden ayrılması ve ektopik mikroskobik paratiroid dokusu artığı oluşması olasıdır (Kraimps et al., 1992). Embriyolojik paratiroid artıklarından türeyen küçük rudimenter paratiroid doku artıkları ile gerçek fazladan bezler arasında ayrım yapmak önemlidir. İlki, ortalama 24 mg ağırlığında olan gerçek fazladan bezlerle karşılaştırıldığında 5 mg'dan daha az ağırlığa sahiptir (Akerström et al., 1984). Ayrıca hem birincil hem de ikincil paratiroid hiperplazisindeki sürekli büyüme uyarımı, rudimenter paratiroid bezlerinin büyümesini uyarabilir ve bu nedenle birçoğu fazladan bezler olarak görünebilir.

Peritiroid yağ dokusunda, genellikle ana beze yakın bir yerde rudimenter bezler saklanabilir. Gerçek fazladan bezler vakaların sadece %5'inde görülür ve normalde bulunan dört bezden tamamen ayrı bir yeri işgal eder. Çoğu vakada tiroid bezinin altında, alt tiroid kutbuna yakın, timus veya tirotimik ligament içinde yer alırlar. Bu nedenle timus dillerinin rutin olarak çıkarılması ve tiroidin alt kutupları etrafındaki yağ dokusunun dikkatli bir şekilde incelenmesi ve temizlenmesi, sekonder hiperparatiroidizm veya MEN tip I ile ilişkili hiperparatiroidizm gibi daha virülan hiperparatiroidizm formları olan hastaların cerrahi tedavisinde önemli adımlardır (Aly & Douglas, 2003).

Gelişim sırasında bileşenlerin birbirine yakın ve hatta sıklıkla birbirleriyle temas halinde olduğu anormal veya iki loblu bezlerin bölünmesi sonucu bazı bireylerde beşinci bir bez oluşur.

Ayrıca genellikle patolojik olduklarında ve hiperparatiroidizmden sorumlu olduklarında istisnai ektopik lokasyonlarda da süpernümerer bezler bulunabilir. Patolojik paratiroid bezleri juguler karotid kompleksinin lateralinde, piriform fossa içinde, aortopulmoner pencerede ve orta mediastende toraksın derinliklerinde bulunabilir (Arnault et al., 2010). Bir vakada, sağ ana bronş ve sağ pulmoner arter arasında patolojik bir paratiroid bezi tanımlanmıştır (McHenry et al., 1988). Bu tür vakalarda patolojik dokunun göçü olası görünmemektedir; bunun yerine bu vakalar muhtemelen PIV'in erken parçalanmasını temsil etmektedir (Curley, Wheeler, Thompson, & Grant, 1988). Yapılan çok merkezli bir klinik çalışma, aortopulmoner penceredeki paratiroid bezlerinin kökeninin PIV'in erken parçalanmasından kaynaklandığını ileri sürmüştür (Nishiyama, Ogiso, Oota, Kimura, & Seki, 1996).

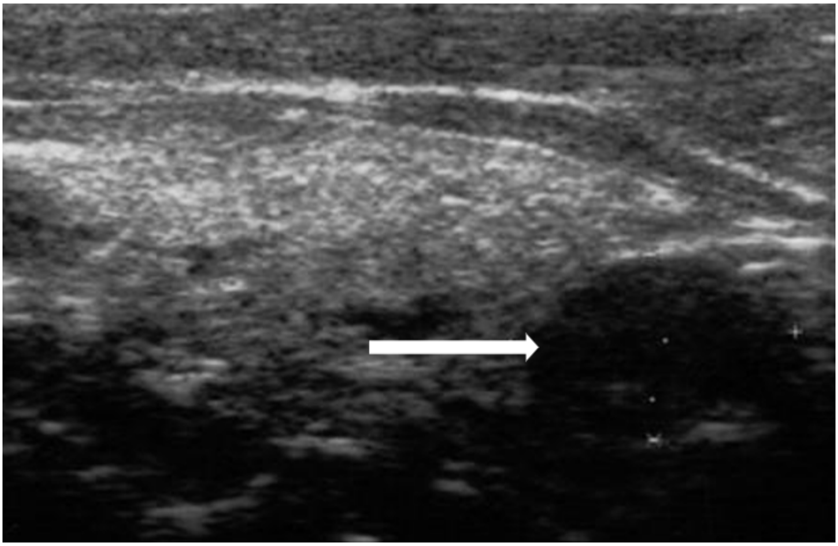
MEN 1 sendromlu bir hastanın sternohyoid kasında süpernümerer hiperplastik bir bezin istisnai bir lokalizasyonu bildirilmiştir (Hung, Lin, Lee, Chen, & Chen, 2002). Ontolojik paratiroid dinlenmesinin varlığı, daha önce cerrahi eksplorasyon yapılmamış olmasına rağmen paratiromatozisin ortaya çıkmasını da açıklayabilir (Kraimps et al., 1992). Paratiromatozis terimi, boyun veya mediastinum boyunca dağılmış çoklu paratiroid dokusu nodüllerinin bulunmasını ifade eder ve tekrarlayan hiperparatiroidizm vakalarından sorumlu olabilir. Bununla birlikte, hiperparatiroidizm için ilk boyun eksplorasyonu sırasında birkaç paratiromatozis vakası bildirilmiştir (Hung et al., 2002; Pawlik, Richards, Giordano, Burney, & Thompson, 2001). Bu durum bilinmeyen proliferasyon uyaranlarına yanıt olarak paratiroid dinlenmelerinin aşırı büyümesini (ontojenik paratiromatozis) düşündürmektedir.

### 3.5. Paratiroid Bezinin Edinsel Ektopik Lokalizasyonları

Bazı durumlarda embriyolojik gelişimdeki değişkenlik kökenli ektopilerin yanı sıra patolojik olarak genişlemiş bezler, genişlemeden sonraki göç nedeniyle ektopik bir pozisyona sahip olabilir. Nitekim büyümüş bezler, yer çekimi ve bölgesel dinamiklerin, yani yutma sırasında larinks ve farenksin hareketinin, negatif intratorasik basınç ve servikal-mediastinal planların neden olduğu bir emme olayının etkisiyle göç edebilir. Daha sonra genişlemiş bir bez uygun yerini terk edebilir ve giderek ektopik bir yer edinebilir. Bu göçler, bezin genişlemeden önceki ilk topografisine bağlıdır. Bu nedenle, krikotiroid alanda yerlerinde nispeten sabit kalan PIV'ler, sıklıkla üst posterior mediastende, inferior tiroid arterin gövdesinin arkasında prevertebral düzlem boyunca göç eder ve aşağı doğru az veya çok kayabilirler. Bu seyir sırasında genellikle özofagusla çok yakın temas halinde kalırlar. Bu "edinilmiş" ektopi, normal PIV'lerin %1 ila %4'ünün para-retroözofageal pozisyonlarda olmasına karşın, PIV adenomlarının %40'ının posterior lokasyonlarda bulunmasını açıklar (Thompson et al., 1982). Genellikle adenomatöz bezler, inferior tiroid arterin gövdesinin hemen üstünde, tiroidin alt lobları seviyesindedir. Diğer vakalarda, adenom ya paraözefagial alanda ya da trakeo-özofageal açıdadır. Tüm vakalarda, bu genişlemiş bezler, posterior mediastende çok aşağıda yer alsalar bile, tiroid sisteminden kaynaklanan servikal vaskülarizasyonlarını korurlar. Bu inen servikal pedikül, başlangıç yerlerini gösterir ve derin bir şekilde göç etmiş olsalar bile, kanama riski olmadan servikal kesi yoluyla çıkarılmalarını kolaylaştırır. İnen pedikül üzerindeki çekme, PIV'den kaynaklanan inen adenomun güvenli bir şekilde yukarı kaldırılmasını sağlar.

Muhtemelen bitişik anatomik yapılar yerçekimi kaynaklı yer değiştirmeye daha az elverişli olduğundan PIII'den gelişen adenomların bu tür göçe daha az eğilimli olduğu düşünülmektedir. Genellikle patolojik PIII'ün göçü ön üst mediastene doğru, tirotimik ligament ve timus içinden gerçekleşir. Ancak bu iniş sınırlı görünmektedir. Daha nadiren, patolojik PIII bezi başlangıçta tiroid lobunun alt kutbunun posterolateral kısmında yerleşmişse, genişlemesi posterosuperior mediastene inerek paraözofageal bir pozisyon edinmesine yol açabilir (Miura, 2005). Bu vakalarda, PIV'den gelişen adenomların aksine, vasküler pedikül inferior tiroid arterin gövdesini geçmez.

Genel bakış açısı, anormal embriyolojik göçün neden olduğu konjenital ektopilerin genellikle PIII'ü etkilediği, buna karşın patolojik olarak genişlemiş bezlerin yerçekiminin etkisi altında göçüyle belirlenen edinilmiş ektopilerin genellikle PIV'i etkilediği şeklindedir (Skandalakis, Rowe Jr, Gray, & Skandalakis, 1993).



**Resim 8. Gri-skala ultrasonografi incelemesinde tiroid bezi sol posterolateralinde paratiroid adenomu ile uyumlu hipoekoik nodüler lezyon (beyaz ok) izlenmektedir.**

## 4. SONUÇ

Tiroid ve paratiroid bezleri, embriyolojik gelişimleri ve anatomik konumlarıyla endokrin sistemin karmaşık ve hayati bir parçasını oluşturur. Bu bezlerin embriyolojik kökeni, faringeal arklar, cepler ve göç mekanizmaları gibi dinamik süreçleri içerir ve bu süreçlerin herhangi bir aşamasındaki aksaklıklar geniş bir yelpazede gelişimsel anomalilere yol açabilir. Tiroid bezinin ektopik yerleşimleri, aksesuar tiroid dokuları veya paratiroid bezlerinin sayısal varyasyonları, cerrahi ve klinik pratikte dikkate alınması gereken önemli konular arasındadır.

Anatomik varyasyonların ve gelişimsel anomalilerin anlaşılması, yalnızca doğru tanı ve tedavi için değil, aynı zamanda cerrahi komplikasyon risklerini azaltmak için de kritik öneme sahiptir. Özellikle tiroid ve paratiroid cerrahisinde, hastaya özgü anatomik farklılıkların bilinmesi, cerrahın planlama yapmasını ve komplikasyonları en aza indirmesini sağlar.

Embriyolojik gelişim mekanizmalarının derinlemesine incelenmesi ve anatomik varyasyonların klinik etkilerinin daha iyi anlaşılması, bu bezlerle ilişkili endokrin hastalıkların daha etkili yönetilmesine olanak tanıyacaktır. Güncel teknolojiler ve görüntüleme yöntemleri, bireyselleştirilmiş tıbbi ve cerrahi yaklaşımları daha erişilebilir hale getirirken, bu bağlamda multidisipliner bir anlayış geliştirilmesi önemlidir.

Tiroid ve paratiroid bezlerinin embriyolojisi ve anatomisi üzerine yapılan çalışmalar, yalnızca mevcut bilgilerimizi derinleştirmekle kalmamakta, aynı zamanda endokrin cerrahisi ve tedavi stratejilerindeki yeniliklerin önünü açmaktadır. Bu bilgiler ışığında, tiroid ve paratiroid hastalıklarına daha etkili çözümler geliştirmek mümkün hale gelecektir.

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# INTERVENTIONAL RADIOLOGICAL PROCEDURES AS AN ALTERNATIVE TO SURGERY IN THYROID NODULES: CURRENT STATUS AND FUTURE PERSPECTIVES

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## 1. INTRODUCTION

Thyroid nodules are a common clinical finding, with an estimated prevalence of 19% to 68% in the general population, increasing with age and improved imaging modalities. While the majority of these nodules are benign, a subset of patients experiences symptoms such as compression of adjacent structures, cosmetic concerns, or suspicious cytological findings requiring further intervention. Traditional management options include observation, thyroid hormone suppression therapy, and surgical intervention. However, surgery, while effective, carries potential risks such as hypothyroidism, surgical complications, and the need for lifelong thyroid hormone replacement therapy.

Over the past two decades, interventional radiology has played an increasing role in the management of thyroid nodules by offering minimally invasive procedures as alternatives to surgery. These techniques have gained popularity due to their ability to significantly reduce nodule volume while preserving thyroid function and minimizing procedural risks.

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Radiofrequency ablation (RFA), microwave ablation (MWA), laser ablation (LA), high-intensity focused ultrasound (HIFU), and percutaneous ethanol injection (PEI) have been extensively studied and integrated into clinical practice for treating benign thyroid nodules.

Each of these interventional methods operates through different mechanisms but shares the common goal of achieving nodule shrinkage with minimal patient discomfort. RFA and MWA use thermal energy to induce coagulative necrosis, effectively reducing nodule size over time. LA utilizes focused laser energy to achieve targeted tissue destruction. HIFU is a completely non-invasive technique that employs ultrasound waves to create localized heating and nodule ablation without requiring direct tissue penetration. PEI, primarily used for cystic nodules, relies on the sclerosing effect of ethanol to collapse cystic components. These approaches allow for outpatient treatment with faster recovery and fewer complications compared to surgery.

Despite their advantages, the adoption of these techniques varies based on institutional expertise, availability of advanced equipment, and the specific characteristics of thyroid nodules. Factors influencing treatment selection include nodule composition (solid vs. cystic), size, location, patient preference, and physician expertise. While promising, these procedures require careful patient selection and standardized protocols to optimize outcomes and minimize complications.

This review aims to provide an in-depth analysis of interventional radiological techniques as alternatives to thyroid surgery. It will cover the indications, mechanisms of action, benefits, risks, and long-term outcomes of each procedure. Additionally, it will discuss future developments, ongoing research, and the role of interventional radiology in the evolving landscape of thyroid nodule management.

## 2. INTERVENTIONAL RADIOLOGICAL TREATMENT METHODS

### 2.1. Radiofrequency Ablation (RFA)

Radiofrequency ablation (RFA) is a widely used minimally invasive thermal ablation technique performed under ultrasound guidance. The procedure involves inserting a needle electrode into the thyroid nodule, which generates high-frequency alternating current, producing heat that induces coagulative necrosis in the targeted tissue. The necrotic tissue is then gradually reabsorbed by the body, leading to significant volume reduction of the nodule over time.

- Mechanism of Action

RFA operates on the principle of thermal ablation, where radiofrequency waves induce ionic agitation within tissue, resulting in localized heating. When tissue temperatures reach 60–100°C, irreversible cellular damage occurs, leading to coagulative necrosis. The ablated nodule shrinks over time as the necrotic tissue is resorbed.

- Indications

RFA is primarily indicated for the treatment of benign thyroid nodules, particularly in patients who experience compressive symptoms such as dysphagia, dyspnea, or cosmetic concerns. It is also considered for patients who are not surgical candidates due to medical comorbidities or those who wish to avoid surgery.

Key indications include:

- Symptomatic benign thyroid nodules (compressive symptoms or cosmetic concerns)
- Autonomously functioning thyroid nodules (AFTNs) causing subclinical or overt hyperthyroidism
- Patients unwilling or unfit for surgery
- Postoperative thyroid nodule recurrence

- Procedure

The RFA procedure is performed under local anesthesia with continuous ultrasound guidance. A percutaneous approach is used to insert a thin electrode into the nodule. The moving-shot technique is commonly employed, where multiple ablation zones are created sequentially to ensure comprehensive coverage of the nodule.

A typical RFA procedure involves the following steps:

Patient Preparation:

- Pre-procedural ultrasound to assess nodule characteristics
- Fine-needle aspiration (FNA) if malignancy is suspected
- Local anesthesia administered to the skin and subcutaneous tissue

Electrode Placement:

- A specialized electrode is inserted into the thyroid nodule under ultrasound guidance
- The moving-shot technique is employed to ensure even thermal ablation

Ablation Process:

- Radiofrequency energy is delivered in controlled pulses

- o Temperature monitoring ensures adequate coagulation while minimizing complications

Post-procedure Monitoring:

- o Immediate ultrasound assessment for potential complications
- o Patients are typically discharged on the same day with minimal downtime
- • Advantages
- o Minimally invasive: Performed under local anesthesia, avoiding general anesthesia risks
- o Preserves thyroid function: Unlike surgery, RFA allows the remaining thyroid tissue to function normally
- o Outpatient procedure: Short recovery time, allowing patients to return to normal activities quickly
- o Effective volume reduction: Studies report an average nodule volume reduction of 50–80% within six months
- o Low complication rate: Few major complications when performed by experienced operators
- • Disadvantages and Potential Complications
- o Transient pain and discomfort in the neck region
- o Potential risk of voice changes due to thermal injury to the recurrent laryngeal nerve (rare)
- o Nodule regrowth in some cases, requiring repeat sessions
- o Minor bleeding or hematoma formation
- • Efficacy and Clinical Outcomes

Several clinical studies have demonstrated that RFA leads to substantial nodule shrinkage and improvement in compressive symptoms and cosmetic concerns. Long-term follow-up studies indicate that volume reduction is sustained for several years post-treatment. In patients with autonomously functioning nodules, RFA has been shown to improve or normalize thyroid hormone levels, reducing the need for antithyroid medication.

- Comparison with Other Ablation Techniques

Compared to other thermal ablation methods such as microwave ablation (MWA) and laser ablation (LA), RFA has shown comparable efficacy with a favorable safety profile. While MWA provides faster heating and may be beneficial for larger nodules, RFA is widely preferred due to its controlled ablation process and extensive clinical validation.

- Future Perspectives

Advancements in RFA technology, including the development of multi-tined electrodes and improved real-time monitoring systems, are expected to enhance treatment precision and efficacy. Future research should focus on optimizing patient selection criteria, exploring combination therapies, and evaluating the long-term effects of RFA on thyroid function.

## 3. MICROWAVE ABLATION (MWA)

Microwave ablation (MWA) is a minimally invasive thermal ablation technique that has gained popularity as an alternative to surgery for treating benign thyroid nodules. Similar to radiofrequency ablation (RFA), MWA uses electromagnetic energy to generate heat and induce coagulative necrosis in the targeted nodule. However, MWA operates at a higher frequency and temperature, enabling more rapid and extensive ablation.

- Mechanism of Action

MWA employs microwave energy, typically at frequencies ranging from 900 MHz to 2.45 GHz, to excite water molecules within the target tissue. This molecular agitation generates heat, leading to coagulative necrosis and subsequent nodule shrinkage. The primary advantage of MWA over RFA is its ability to produce a larger and more uniform ablation zone, reducing the risk of incomplete treatment and nodule recurrence.

- Indications

MWA is indicated for the treatment of:

- Symptomatic benign thyroid nodules causing compressive symptoms (e.g., difficulty swallowing or breathing)
- Autonomously functioning thyroid nodules (AFTNs) causing subclinical or overt hyperthyroidism
- Large-volume nodules where faster and more extensive ablation is required
- Patients who prefer a non-surgical approach or have contraindications to surgery

- Procedure

MWA is performed under local anesthesia with continuous ultrasound guidance. The procedure typically involves the following steps:

Pre-procedural Evaluation:

- Comprehensive ultrasound assessment of nodule characteristics
- Fine-needle aspiration (FNA) to confirm benignity
- Patient counseling on the procedure, risks, and expected outcomes

Electrode Insertion:

- A microwave antenna is inserted into the thyroid nodule under real-time ultrasound guidance
- The antenna is positioned to ensure optimal energy delivery and uniform ablation

Energy Application:

- Microwave energy is delivered at controlled power levels (typically 30–60 W)
- The moving-shot technique may be used to cover different parts of the nodule sequentially
- Continuous temperature monitoring helps prevent overheating and adjacent tissue damage

Post-procedural Monitoring:

- Immediate ultrasound examination to assess for potential complications such as hematoma or thermal injury
- Patients are monitored for a few hours and typically discharged on the same day

- Advantages
  - Higher ablation efficiency: MWA achieves faster and more uniform tissue destruction compared to RFA.
  - Larger treatment zones: Enables effective ablation of larger thyroid nodules in a single session.
  - Minimal invasiveness: Avoids the risks and extended recovery time associated with surgery.
  - Preservation of thyroid function: Surrounding healthy thyroid tissue remains largely unaffected, reducing the risk of hypothyroidism.
  - Outpatient procedure: Short procedure duration with rapid post-procedure recovery.

Disadvantages and Potential Complications

- Transient neck pain and discomfort following the procedure
- Risk of thermal injury to surrounding structures, including the recurrent laryngeal nerve (though rare)
- Potential for nodule regrowth or incomplete ablation, necessitating additional treatment sessions

  - o Minor complications such as hematoma or edema at the insertion site
- Efficacy and Clinical Outcomes

Multiple studies have demonstrated that MWA leads to significant thyroid nodule volume reduction and symptom relief. Compared to RFA, MWA has been shown to achieve similar or superior results in terms of ablation efficiency and long-term efficacy. MWA has also shown promise in treating autonomously functioning thyroid nodules, with many patients achieving euthyroid status post-treatment without the need for antithyroid medications.

- Comparison with Other Ablation Techniques

Compared to RFA, MWA operates at a higher frequency, resulting in:

  - o Faster ablation times due to increased heating efficiency
  - o Larger and more predictable ablation zones, reducing the likelihood of residual tissue
  - o Potentially lower recurrence rates, particularly for larger nodules
  - o However, MWA also carries a slightly higher risk of thermal damage to adjacent structures, necessitating careful operator expertise.
- Future Perspectives

The future of MWA in thyroid nodule treatment is promising, with ongoing research focusing on refining energy delivery systems, improving real-time monitoring techniques, and optimizing patient selection criteria. As more clinical data become available, MWA is expected to gain broader acceptance as a primary treatment option for benign thyroid nodules.

## 4. LASER ABLATİON (LA)

Laser Ablation (LA) is a minimally invasive thermal ablation technique that employs laser energy to induce localized hyperthermia, resulting in controlled tissue necrosis. It has been increasingly used for the treatment of benign thyroid nodules due to its precision, minimal invasiveness, and ability to preserve thyroid function while effectively reducing nodule volume.

- Mechanism of Action

LA operates by delivering laser energy through a fine optical fiber inserted into the thyroid nodule under ultrasound guidance. The emitted laser light is absorbed by the tissue, generating heat and causing coagulative necrosis. The degree of ablation depends on the laser wavelength, power settings, and exposure time. Over time, the necrotic tissue undergoes resorption, leading to a gradual reduction in nodule size.

- Indications

LA is indicated for:

  - Benign thyroid nodules, particularly solid or partially cystic nodules
  - Nodules causing compressive symptoms or cosmetic concerns
  - Patients who prefer a non-surgical approach or have contraindications to surgery
  - Autonomously functioning thyroid nodules (AFTNs), although its efficacy in controlling hyperthyroidism is still under investigation
- Procedure

LA is typically performed under local anesthesia with continuous ultrasound monitoring to ensure precise fiber placement and controlled energy delivery. The procedure consists of the following steps:

Pre-procedural Evaluation:

- Ultrasound assessment to determine nodule characteristics (size, composition, vascularity)
- Fine-needle aspiration biopsy (FNAB) to confirm benign pathology
- Discussion with the patient regarding procedural expectations, risks, and follow-up

Laser Fiber Insertion:

- A fine optical fiber is introduced into the nodule using a thin needle under ultrasound guidance
- The laser fiber is positioned in the central or multiple strategic locations within the nodule for effective ablation

Laser Energy Delivery:

- Laser energy is applied in pulses at controlled power settings (typically 1–3 W per fiber)
- The energy is delivered gradually, using a moving-shot technique to ensure uniform ablation without excessive heat buildup
- Real-time ultrasound monitoring allows adjustment of fiber positioning to optimize treatment coverage

Post-procedural Monitoring:

- Immediate ultrasound assessment to evaluate tissue response and potential complications
- Patients are monitored briefly and discharged the same day with post-procedure instructions

- Advantages
    - Minimally invasive: Performed under local anesthesia, avoiding surgical risks
    - Highly precise: Laser energy can be finely controlled, minimizing damage to adjacent structures

    - Preserves thyroid function: Unlike surgery, LA maintains the integrity of the thyroid gland
    - Low complication rate: Studies report fewer adverse effects compared to surgical interventions
    - Outpatient procedure: Allows for a quick return to daily activities
- Disadvantages and Potential Complications
    - Possible transient pain or mild discomfort during and after the procedure
    - Temporary inflammation or swelling at the treatment site
    - Rare cases of injury to adjacent structures, such as the recurrent laryngeal nerve
    - Some nodules may require repeat sessions for optimal volume reduction
- Efficacy and Clinical Outcomes

Multiple studies have demonstrated the effectiveness of LA in reducing thyroid nodule volume and alleviating compressive symptoms. On average, studies report a 50–75% reduction in nodule size within six months, with continued shrinkage over time. Symptomatic relief is achieved in the majority of patients, and complications remain minimal when performed by experienced operators.

- Comparison with Other Ablation Techniques

Compared to RFA and MWA, LA offers a more controlled and localized ablation process, making it particularly useful for smaller nodules or nodules in critical locations. However, it typically requires a longer procedure time due to lower energy delivery rates and may necessitate multiple fiber insertions for adequate ablation.

**Table 1. Comparison of Ablation Techniques**

| Feature | Laser Ablation (LA) | Radiofrequency Ablation (RFA) | Microwave Ablation (MWA) |
|---|---|---|---|
| Energy Source | Laser light | Radiofrequency waves | Microwave energy |
| Precision | High | Moderate | Moderate |
| Heat Distribution | Localized | More diffuse | Broad and rapid |
| Speed of Ablation | Slow | Moderate | Fast |
| Recommended for | Small to medium nodules | Medium to large nodules | Large nodules |
| Outpatient Procedure | Yes | Yes | Yes |
| Risk of Nodule Regrowth | Low to moderate | Low to moderate | Moderate |

- Future Perspectives

Advancements in laser fiber technology, improved real-time ultrasound monitoring, and enhanced treatment protocols will likely refine LA's effectiveness in the coming years. Future research will focus on optimizing energy parameters, developing combination approaches with other ablation techniques, and further evaluating long-term efficacy in treating autonomously functioning nodules.

## 5. HIGH-INTENSITY FOCUSED ULTRASOUND (HIFU)

High-Intensity Focused Ultrasound (HIFU) is a completely non-invasive ablation technique that uses focused ultrasound waves to generate localized heat and induce coagulative necrosis in thyroid nodules. HIFU represents a promising alternative for patients who prefer a non-surgical and non-percutaneous treatment option. This technique allows precise thermal ablation while preserving the surrounding thyroid tissue and avoiding surgical risks.

- Mechanism of Action

HIFU operates by delivering high-intensity ultrasound waves that converge at a focal point within the targeted nodule. The ultrasound waves pass through the skin and soft tissues without causing damage, and their energy is concentrated at the focal zone, leading to a rapid temperature increase (60–80°C). This thermal effect induces coagulative necrosis, causing progressive shrinkage of the treated nodule over time. Additionally, HIFU triggers cavitation effects, which may further disrupt tumor cells and improve the efficiency of ablation.

- Indications

HIFU is primarily indicated for:

  - Benign thyroid nodules that are symptomatic due to compressive effects
  - Cosmetic concerns associated with large or visible nodules
  - Patients who refuse or are ineligible for surgery and percutaneous ablation techniques
  - Cases where a completely non-invasive approach is preferred
- Procedure

HIFU is performed without any skin puncture or incision, making it an attractive option for patients who prefer a completely non-invasive method. The procedure consists of the following steps:

Pre-procedural Assessment:

  - Comprehensive ultrasound evaluation of the thyroid nodule

- o Fine-needle aspiration biopsy (FNAB) to confirm benign pathology
- o Explanation of the procedure, potential benefits, and risks to the patient

Patient Positioning and Anesthesia:

- o The patient lies in a supine position with slight neck extension
- o A coupling gel is applied to ensure efficient energy transmission
- o Local anesthesia or mild sedation may be administered to minimize discomfort

HIFU Energy Delivery:

- o A focused ultrasound transducer is placed over the skin surface
- o High-intensity ultrasound waves are emitted in short pulses, converging within the nodule
- o The ablation process is monitored in real-time using ultrasound imaging
- o Cooling mechanisms protect the overlying skin from excessive heating

Post-procedural Monitoring:

- o Immediate ultrasound imaging to evaluate treatment response
- o Observation for a few hours before patient discharge
- o Follow-up ultrasound assessments at 1, 3, and 6 months post-procedure

- • Advantages
  - o Completely non-invasive: No skin puncture, no bleeding, and no risk of infection
  - o Preserves thyroid function: Unlike surgery, HIFU maintains thyroid gland integrity

- Real-time monitoring: Continuous ultrasound guidance ensures precise targeting
- Minimal recovery time: Patients can resume normal activities immediately
- No anesthesia required: Reduces procedure-related risks

• Disadvantages and Potential Complications

- Transient neck discomfort or a mild burning sensation during or after the procedure
- Temporary swelling of the treated nodule due to inflammatory response
- Potential risk of incomplete ablation, requiring repeat sessions
- Limited data on long-term effectiveness compared to other ablation techniques
- Not suitable for nodules located close to critical structures such as the recurrent laryngeal nerve

• Efficacy and Clinical Outcomes

HIFU has demonstrated promising results in clinical studies, with significant nodule volume reduction and symptom improvement. However, because it is a relatively new technique, more long-term data are needed to establish its definitive role in thyroid nodule management.

• Comparison with Other Ablation Techniques

Compared to RFA, MWA, and LA, HIFU offers the distinct advantage of being completely non-invasive. However, its efficacy may be slightly lower, and it may not be suitable for all nodule locations.

**Table 2. Comparison of HIFU with Other Techniques**

| Feature | High-Intensity Focused Ultrasound (HIFU) | Radiofrequency Ablation (RFA) | Microwave Ablation (MWA) | Laser Ablation (LA) |
|---|---|---|---|---|
| Energy Source | Ultrasound waves | Radiofrequency waves | Microwave energy | Laser light |
| Invasiveness | Non-invasive | Minimally invasive | Minimally invasive | Minimally invasive |
| Heat Distribution | Highly focused | Moderate | Broad and rapid | Localized |
| Speed of Ablation | Slow to moderate | Moderate | Fast | Slow |
| Recommended for | Small to medium nodules | Medium to large nodules | Large nodules | Small to medium nodules |
| Outpatient Procedure | Yes | Yes | Yes | Yes |
| Risk of Nodule Regrowth | Low to moderate | Low to moderate | Moderate | Low to moderate |

- Future Perspectives

With ongoing technological advancements, HIFU is expected to improve in precision, efficacy, and safety. Future studies should focus on optimizing energy delivery protocols, assessing long-term outcomes, and expanding indications to include larger and more complex nodules. As data continue to accumulate, HIFU may become a preferred option for patients seeking a completely non-invasive treatment alternative for thyroid nodules.

## 6. PERCUTANEOUS ETHANOL INJECTION (PEI)

Percutaneous Ethanol Injection (PEI) is a minimally invasive procedure that involves injecting ethanol into a thyroid nodule to induce coagulative necrosis and fibrosis. This technique is particularly effective for cystic or predominantly cystic thyroid nodules and has been widely adopted due to its simplicity, low cost, and effectiveness in reducing nodule volume while preserving thyroid function.

- Mechanism of Action

PEI works by introducing absolute ethanol (95–99%) into the thyroid nodule under ultrasound guidance. Ethanol exerts its therapeutic effect through three main mechanisms:

  - Cellular dehydration: Ethanol extracts water from cells, leading to protein denaturation and cell death.
  - Coagulative necrosis: The toxic effect of ethanol on thyroid cells induces necrosis and fibrosis, preventing further growth of the nodule.
  - Vascular thrombosis: Ethanol occludes microvasculature within the nodule, cutting off its blood supply and further enhancing tissue necrosis.

- Indications
  - PEI is primarily indicated for:
  - Cystic or predominantly cystic benign thyroid nodules (>70% fluid content)
  - Symptomatic cystic nodules causing compression-related issues
  - Recurrent cystic nodules following aspiration or drainage
  - Patients unsuitable for surgery due to medical comorbidities or personal preference
- Procedure

PEI is typically performed in an outpatient setting under ultrasound guidance. The steps of the procedure include:

Pre-procedural Assessment:

- Ultrasound examination to confirm the cystic nature of the nodule
- Fine-needle aspiration biopsy (FNAB) to rule out malignancy
- Patient counseling on the procedure, expected outcomes, and potential complications

Ethanol Injection Procedure:

- The patient is placed in a supine position with slight neck extension
- Local anesthesia is administered to minimize discomfort
- A fine-gauge needle is inserted into the cystic portion of the nodule under ultrasound guidance
- The cystic fluid is aspirated completely to collapse the cavity
- Ethanol is slowly injected, typically in a volume corresponding to 30–50% of the aspirated fluid
- The ethanol is retained in the nodule for 2–10 minutes before being partially or completely aspirated
- The needle is removed, and the site is monitored for immediate complications

Post-procedural Monitoring:

- Patients are observed for 30–60 minutes for any immediate side effects
- Follow-up ultrasound is scheduled at 1, 3, and 6 months to evaluate nodule shrinkage and symptom relief

- Advantages
  - Minimally invasive: No incision or sutures required
  - Preserves thyroid function: Unlike surgery, PEI does not affect overall thyroid hormone levels

  - Cost-effective: Significantly lower cost compared to surgical interventions
  - Outpatient procedure: Quick recovery with minimal post-procedure discomfort
  - Effective for cystic nodules: High success rates in reducing nodule volume and improving symptoms
- Disadvantages and Potential Complications
  - Transient pain or discomfort: Mild burning sensation at the injection site
  - Ethanol leakage: May cause irritation to surrounding tissues, including the trachea or recurrent laryngeal nerve
  - Temporary voice changes: Hoarseness in rare cases due to ethanol-induced inflammation
  - Incomplete resolution: Some nodules may require repeat PEI sessions for optimal shrinkage
  - Not effective for solid nodules: Primarily beneficial for cystic or predominantly cystic nodules
- Efficacy and Clinical Outcomes
  - PEI has been extensively studied and has demonstrated high success rates, particularly for cystic thyroid nodules.
  - Compared to other ablation techniques, PEI remains the treatment of choice for cystic nodules due to its simplicity and effectiveness.
- Comparison with Other Ablation Techniques

While PEI is effective for cystic nodules, it is generally not recommended for solid thyroid nodules. In such cases, thermal ablation techniques like RFA, MWA, and LA provide better long-term outcomes.

**Table 3. Comparison of PEI with Other Techniques**

| Feature | Percutaneous Ethanol Injection (PEI) | Radiofrequency Ablation (RFA) | Microwave Ablation (MWA) | Laser Ablation (LA) | High-Intensity Focused Ultrasound (HIFU) |
|---|---|---|---|---|---|
| Energy Source | Ethanol | Radiofrequency waves | Microwave energy | Laser light | Ultrasound waves |
| Invasiveness | Minimally invasive | Minimally invasive | Minimally invasive | Minimally invasive | Non-invasive |
| Best for | Cystic nodules | Solid nodules | Solid and large nodules | Small to medium nodules | Small to medium nodules |
| Risk of Recurrence | Low | Low to moderate | Moderate | Low to moderate | Low to moderate |
| Outpatient Procedure | Yes | Yes | Yes | Yes | Yes |
| Recovery Time | Short | Short | Short | Short | Immediate |

- Future Perspectives

Although PEI has established itself as the first-line treatment for cystic thyroid nodules, future research will focus on optimizing injection techniques, exploring combination therapies with other ablation modalities, and assessing long-term efficacy in larger patient cohorts. The development of standardized guidelines for ethanol concentration, volume, and retention time will further enhance the effectiveness and safety of PEI in clinical practice.

## 7. CONCLUSION

The management of benign thyroid nodules has evolved significantly with the advent of interventional radiological procedures, offering effective, minimally invasive alternatives to traditional surgery. Techniques such as Radiofrequency Ablation

(RFA), Microwave Ablation (MWA), Laser Ablation (LA), High-Intensity Focused Ultrasound (HIFU), and Percutaneous Ethanol Injection (PEI) have demonstrated considerable success in reducing nodule volume, alleviating symptoms, and improving patients' quality of life while preserving thyroid function.

Each technique has its own set of advantages and limitations. RFA and MWA are particularly well-suited for solid nodules, offering significant volume reduction and symptom relief. LA provides precise and controlled ablation, making it ideal for small-to-medium-sized nodules. HIFU stands out as a completely non-invasive method, though its long-term efficacy requires further validation. PEI remains the preferred choice for cystic thyroid nodules due to its simplicity and cost-effectiveness.

Comparative studies have consistently shown that these methods yield excellent clinical outcomes with fewer complications compared to surgery. The minimally invasive nature of these procedures translates into shorter recovery times, lower costs, and reduced risks associated with general anesthesia and thyroid hormone dependence. Furthermore, as experience with these modalities increases and technological advancements refine treatment protocols, these approaches are expected to become even more effective and accessible.

Despite these promising developments, the choice of treatment should be tailored to individual patient characteristics, including nodule composition, size, symptoms, and personal preferences. A multidisciplinary approach involving radiologists, endocrinologists, and surgeons remains essential to ensure optimal patient selection and management.

Future research should focus on optimizing treatment protocols, exploring combination therapies, and conducting long-term studies to establish standardized guidelines. With ongoing advancements in imaging technology, energy delivery systems, and patient selection criteria, interventional radiology is poised to play an increasingly significant role in thyroid nodule management, reducing the need for surgical interventions and improving patient outcomes worldwide.

Interventional radiological procedures, including RFA, MWA, LA, HIFU, and PEI, offer effective, minimally invasive alternatives to thyroid surgery. These techniques provide significant symptom relief, preserve thyroid function, and reduce the risks associated with conventional surgical interventions. As these modalities continue to evolve, they are expected to play an increasingly prominent role in the management of thyroid nodules, improving patient outcomes while minimizing procedural morbidity.

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# PEDIATRIC NECK MASSES AND INTERVENTIONAL RADIOLOGY: INNOVATIONS IN DIAGNOSIS AND TREATMENT

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## 1. INTRODUCTION

Pediatric neck masses are a common clinical presentation in children and can arise from a broad spectrum of conditions, ranging from benign congenital anomalies to life-threatening malignant tumors. These masses can be classified into congenital, inflammatory/infectious, neoplastic, and traumatic categories. Congenital neck masses, such as branchial cleft cysts, thyroglossal duct cysts, and lymphatic malformations, are often diagnosed in infancy or early childhood. Infectious or inflammatory masses, including reactive lymphadenopathy, bacterial abscesses, and tuberculous lymphadenitis, are frequently encountered in pediatric practice and may require antimicrobial therapy or drainage. Neoplastic lesions, both benign (such as hemangiomas and lipomas) and malignant (such as lymphoma, rhabdomyosarcoma, and thyroid carcinoma), require precise diagnostic approaches for appropriate management. Traumatic causes, including hematomas, may also present as neck masses following injury.

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The clinical presentation of neck masses varies depending on their underlying pathology. Some lesions present as painless, slow-growing swellings, while others may exhibit rapid enlargement, tenderness, erythema, or systemic symptoms such as fever and weight loss. The location, consistency, and mobility of a mass can provide important diagnostic clues. Midline lesions are commonly congenital, whereas lateral masses are more likely to be of infectious, neoplastic, or vascular origin.

Traditionally, the evaluation of pediatric neck masses begins with a detailed history and thorough physical examination, followed by imaging studies. Ultrasound (US) is the preferred initial imaging modality due to its non-invasiveness, lack of ionizing radiation, and high sensitivity in assessing cystic versus solid lesions. Doppler ultrasound further aids in evaluating vascularity. Computed tomography (CT) and magnetic resonance imaging (MRI) provide additional anatomical detail, particularly in deep-seated or complex lesions, and help assess the extent of disease involvement.

Despite advances in imaging, definitive diagnosis often requires tissue sampling. Interventional radiology (IR) has become an indispensable tool in this regard, offering minimally invasive techniques for both diagnosis and treatment. Ultrasound-guided fine-needle aspiration biopsy (FNAB) and core needle biopsy (CNB) provide histopathological confirmation with minimal discomfort and reduced risk compared to open surgical biopsy. Additionally, interventional procedures such as percutaneous drainage, sclerotherapy, and embolization have emerged as effective treatment options for various neck masses, reducing the need for extensive surgery and hospitalization.

The evolution of interventional radiology has revolutionized the management of pediatric neck masses, offering safer, more efficient alternatives to traditional surgical interventions. This review aims to provide a comprehensive overview of interventional radiological techniques used in pediatric neck masses, highlighting their indications, effectiveness, and potential complications.

## 2. INTERVENTIONAL RADIOLOGICAL TREATMENT METHODS

### 1. Diagnostic Interventional Methods

**Fine-Needle Aspiration Biopsy (FNAB):** Fine-needle aspiration biopsy (FNAB) is a widely used, minimally invasive technique for evaluating pediatric neck masses. It is performed under ultrasound guidance, which enhances accuracy and minimizes complications. FNAB is particularly useful in distinguishing between benign and malignant lesions, identifying infectious etiologies, and guiding further management decisions. The procedure involves inserting a fine-gauge needle (typically 22-27 gauge) into the target lesion to aspirate cellular material for cytological analysis.

FNAB offers several advantages, including its rapid execution, cost-effectiveness, and low complication rate. It is especially beneficial in pediatric patients, where minimizing the need for invasive surgical biopsies is crucial. The technique can be repeated if necessary and is often well tolerated without the need for general anesthesia. However, FNAB has limitations, including the potential for inadequate sampling, particularly in heterogeneous or deep-seated lesions. False-negative results may occur due to sampling errors or insufficient cellular yield, necessitating further diagnostic evaluation with core needle biopsy (CNB) or open surgical biopsy in some cases.

The interpretation of FNAB results requires expertise in cytopathology, and ancillary studies such as immunocytochemistry and molecular testing may be necessary for certain neoplastic lesions. In inflammatory or infectious neck masses, FNAB can aid in identifying causative organisms through microbiological analysis, helping to guide targeted antibiotic or antifungal therapy.

**Core Needle Biopsy (CNB):** Core needle biopsy (CNB) is a percutaneous biopsy technique that allows for the acquisition of a larger tissue sample compared to fine-needle aspiration biopsy (FNAB). It is typically performed under ultrasound or CT guidance using a spring-loaded or vacuum-assisted biopsy device, with needle gauges ranging from 14 to 18. CNB is particularly useful in cases where a more extensive histopathological evaluation is necessary, such as distinguishing between reactive lymphadenopathy and lymphoma, confirming soft tissue neoplasms, or assessing deep-seated lesions.

The procedure involves the insertion of a hollow-core needle into the lesion, allowing the retrieval of intact tissue cores, which preserve the architecture of the sampled tissue. This structural integrity enables more detailed histopathological analysis, including immunohistochemistry and molecular testing, which are crucial for the diagnosis and classification of neoplastic lesions. CNB is preferred over FNAB in cases where cytological evaluation alone is insufficient, such as in distinguishing subtypes of lymphoma or sarcomas, which require evaluation of tissue architecture.

CNB has several advantages, including a higher diagnostic yield and lower false-negative rates compared to FNAB. It is well tolerated in pediatric patients, with a low risk of complications such as bleeding, hematoma formation, and infection. However, the procedure does require local anesthesia and, in some cases, mild sedation, particularly in younger children who may have difficulty remaining still during the procedure. While CNB provides a higher diagnostic accuracy than FNAB, it is still a minimally invasive alternative to open surgical biopsy and is increasingly being utilized as a primary diagnostic approach for pediatric neck masses.

**Aspiration and Drainage:** Aspiration and drainage are commonly performed interventional procedures used in the management of pediatric neck masses, particularly in cases of abscesses and cystic lesions. The procedure is typically performed under ultrasound or CT guidance to ensure accurate needle placement and effective fluid evacuation. In cases of abscesses, drainage is often combined with antibiotic therapy to facilitate resolution of infection and prevent recurrence.

For simple cystic lesions, aspiration alone may be sufficient for symptomatic relief; however, recurrent cysts may require sclerotherapy or surgical excision. In cases of infected cystic masses or deep-seated abscesses, a percutaneous catheter may be placed to allow continuous drainage, reducing the need for open surgical intervention. Aspiration and drainage provide a minimally invasive approach to fluid collection management with a low complication rate, making them particularly advantageous in pediatric patients.

Potential complications include bleeding, infection, and incomplete drainage, which may necessitate repeat procedures. However, with appropriate patient selection and image-guided technique, aspiration and drainage remain highly effective in the management of pediatric neck masses.

**2. Therapeutic Interventional Methods**

**Sclerotherapy:** Sclerotherapy is a minimally invasive treatment modality used for managing cystic lesions, particularly lymphatic malformations and vascular anomalies in pediatric patients. The procedure involves injecting a sclerosing agent into the lesion under ultrasound or fluoroscopic guidance, leading to endothelial damage, fibrosis, and gradual resolution of the malformation.

Various sclerosants can be used depending on the lesion type and size. The most commonly employed agents include OK-432 (Picibanil), ethanol, doxycycline, sodium tetradecyl sulfate, and bleomycin. OK-432 is widely used for lymphatic malformations due to its ability to induce an immune-mediated inflammatory response that results in lesion shrinkage with minimal side effects. Ethanol, while effective, has a higher risk of complications such as nerve damage and tissue necrosis, making it a less favored choice in delicate anatomical locations like the neck.

Sclerotherapy is typically performed as an outpatient procedure and may require multiple sessions depending on the lesion's response. It has been shown to significantly reduce lesion size and associated symptoms, such as airway compression or cosmetic disfigurement. Compared to surgical excision, sclerotherapy offers advantages such as reduced procedural morbidity, shorter recovery time, and lower risk of scarring.

However, potential complications include localized swelling, pain, infection, and transient nerve irritation. In rare cases, severe complications such as airway obstruction or significant inflammatory reactions can occur, particularly if the lesion is large or located near critical structures. Close post-procedural monitoring and careful patient selection are essential for optimizing outcomes and minimizing risks.

**Radiofrequency Ablation (RFA):** Radiofrequency ablation (RFA) is an image-guided, minimally invasive procedure that utilizes thermal energy to induce coagulative necrosis in targeted tissues. It is commonly used in the management of both benign and malignant neck masses, particularly in cases where surgical resection is not feasible or carries high morbidity risks.

RFA involves the percutaneous insertion of a specialized electrode needle into the lesion under ultrasound or CT guidance. Once positioned, high-frequency alternating electrical currents generate localized heat, leading to tissue destruction. The technique is effective for ablating solid tumors, including thyroid nodules, metastatic lymph nodes, and some vascular lesions. It is especially beneficial for patients with unresectable tumors or those requiring palliative treatment for symptom relief.

One of the key advantages of RFA is its ability to selectively target diseased tissues while sparing surrounding healthy structures. This makes it a favorable option for pediatric patients, as it minimizes post-procedural complications and recovery time. Additionally, RFA can be performed on an outpatient basis with minimal anesthesia requirements, reducing the need for prolonged hospitalization.

However, RFA is not without risks. Potential complications include pain, skin burns, transient nerve injury, and, in rare cases, unintended thermal damage to adjacent critical structures. Close imaging guidance and careful electrode placement are essential to mitigating these risks. While RFA is a promising alternative to surgery, its use in pediatric neck masses remains a developing field, with ongoing studies evaluating long-term efficacy and safety.

**Percutaneous Drainage and Catheterization:** Percutaneous drainage and catheterization are essential interventional radiological techniques for the management of fluid-filled or infected lesions in pediatric neck masses. These procedures are particularly beneficial for treating abscesses, infected cysts, and large fluid collections that cause compression symptoms or discomfort.

The procedure involves the insertion of a fine needle or catheter into the fluid collection under ultrasound or CT guidance, ensuring precise localization and effective evacuation of the contents. In cases of simple fluid collections, aspiration alone may suffice, while persistent or recurrent lesions often necessitate catheter placement for continuous drainage. The choice of catheter size and type depends on the viscosity and volume of the fluid being drained.

Percutaneous catheter drainage is frequently used in the treatment of deep-seated neck abscesses, particularly in pediatric patients where surgical drainage may pose higher risks or require general anesthesia. Infected congenital cysts, such as branchial cleft cysts or thyroglossal duct cysts, also respond well to percutaneous drainage, which can be combined with antibiotic therapy to enhance treatment efficacy.

One major advantage of percutaneous drainage is its minimally invasive nature, reducing the need for open surgical procedures, shortening hospital stays, and promoting faster recovery. However, complications such as incomplete drainage, catheter blockage, secondary infection, or bleeding may occur, necessitating careful patient monitoring. In cases where percutaneous drainage is insufficient, sclerosing agents may be introduced to prevent recurrence or promote fibrosis of the residual cavity.

Overall, percutaneous drainage and catheterization provide a safe and effective alternative to surgical intervention for fluid-filled pediatric neck masses, ensuring better clinical outcomes with reduced procedural risks.

**Intra-Arterial Embolization:** Intra-arterial embolization is an advanced interventional radiological technique used for managing vascular anomalies, hemorrhagic lesions, and hypervascular tumors in pediatric neck masses. This procedure involves the selective catheterization of feeding arteries supplying the abnormal lesion, followed by the administration of embolic agents to reduce or completely block blood flow.

Embolization is most commonly employed in the treatment of arteriovenous malformations (AVMs), hemangiomas, and tumors with significant vascularity, such as juvenile nasopharyngeal angiofibromas or hypervascular metastatic lesions. In cases of life-threatening hemorrhage, embolization serves as an emergency intervention to achieve hemostasis and prevent further blood loss.

Various embolic materials can be used depending on the lesion type and desired therapeutic effect. These include polyvinyl alcohol (PVA) particles, coils, gelfoam, liquid embolic agents (such as Onyx or N-butyl cyanoacrylate), and autologous clot. The choice of embolic agent is determined by factors such as vessel size, flow dynamics, and the permanence of occlusion required.

The procedure is performed under fluoroscopic guidance, with access typically obtained via the femoral artery using a catheter-based approach. Superselective catheterization of the target vessels ensures precise embolization while preserving the integrity of surrounding healthy tissues. Embolization can be performed as a standalone therapy or as a preoperative adjunct to reduce intraoperative bleeding and facilitate surgical resection.

While intra-arterial embolization is highly effective, it is not without risks. Potential complications include non-target embolization leading to ischemic injury, transient or permanent cranial nerve deficits, and post-embolization syndrome characterized by pain, fever, and localized inflammation. Close post-procedural monitoring is essential to detect and manage any adverse effects early.

Overall, intra-arterial embolization is a valuable technique in the management of pediatric vascular neck lesions, offering a minimally invasive and highly targeted approach for controlling blood flow and reducing procedural morbidity.

**Table 1: Interventional Methods**

| Method | Indications | Advantages | Complications |
|---|---|---|---|
| Fine-Needle Aspiration Biopsy (FNAB) | Suspected malignancies, infectious lesions | Minimally invasive, rapid results | Risk of inadequate sampling, false negatives |
| Core Needle Biopsy (CNB) | Solid masses, lymphoma evaluation | Higher diagnostic yield, preserves tissue structure | Risk of bleeding, requires local anesthesia |
| Aspiration and Drainage | Abscesses, cystic lesions | Symptomatic relief, infection control | Incomplete drainage, risk of reaccumulation |
| Sclerotherapy | Lymphatic malformations, vascular anomalies | Non-surgical, effective lesion shrinkage | Local swelling, inflammatory reaction |
| Radiofrequency Ablation (RFA) | Benign/malignant solid tumors, recurrent lesions | Targeted tissue destruction, preserves function | Risk of nerve damage, thermal injury |
| Percutaneous Drainage and Catheterization | Infected cysts, persistent fluid collections | Continuous drainage, reduces infection risk | Catheter blockage, infection |
| Intra-Arterial Embolization | Arteriovenous malformations, hypervascular tumors | Controls bleeding, adjunct to surgery | Risk of ischemia, non-target embolization |

## 3. Advantages and Complications of Interventional Techniques

Interventional radiological techniques offer several advantages over traditional surgical approaches in the management of pediatric neck masses. These procedures are minimally invasive, providing effective diagnostic and therapeutic solutions with reduced procedural morbidity.

However, as with any medical intervention, these techniques come with potential risks and complications.

**Advantages**

- Minimally Invasive Approach: Compared to open surgery, interventional techniques require only small needle or catheter insertions, leading to reduced trauma and scarring.
- Shorter Recovery Time: Patients undergoing interventional procedures typically experience faster recovery times, allowing for earlier discharge and return to normal activities.
- Reduced Need for General Anesthesia: Many interventional techniques, such as fine-needle aspiration biopsy (FNAB) and sclerotherapy, can be performed under local anesthesia or mild sedation, which is particularly beneficial for pediatric patients.
- Lower Risk of Surgical Complications: Since interventional techniques avoid large surgical incisions, the risk of excessive bleeding, infection, and post-operative complications is significantly reduced.
- Preservation of Healthy Tissue: Procedures such as radiofrequency ablation (RFA) and intra-arterial embolization selectively target pathological tissues while preserving surrounding structures, minimizing functional impairment.
- Repeatability and Adjustability: Many interventional procedures can be repeated if necessary, providing a flexible and adaptive approach to disease management.

## Complications

While interventional radiology procedures are generally safe, complications may arise depending on the technique used and the patient's underlying condition. Some of the most common risks include:

- Bleeding and Hematoma Formation: Although rare, bleeding can occur after biopsies, percutaneous drainage, or embolization, particularly in highly vascularized lesions.
- Infection: Any percutaneous procedure carries a small risk of introducing infection, requiring close post-procedural monitoring.
- Nerve Injury: Procedures in the neck region carry the risk of damaging nearby nerves, potentially leading to temporary or permanent deficits such as hoarseness, dysphagia, or facial weakness.
- Non-Target Tissue Damage: In intra-arterial embolization, there is a risk of accidental embolization of healthy tissues, which can lead to ischemic injury or tissue necrosis.
- Post-Procedural Pain and Swelling: Patients undergoing sclerotherapy, RFA, or embolization may experience transient pain, swelling, or inflammatory reactions at the treatment site.
- Incomplete Treatment or Recurrence: Some interventional procedures, particularly sclerotherapy and percutaneous drainage, may require multiple sessions to achieve complete resolution of the lesion. In some cases, residual disease or recurrence may necessitate additional intervention.

- Airway Compromise: In rare cases, swelling following procedures in the neck region may result in airway compression, necessitating close post-procedural monitoring and, in extreme cases, emergency intervention.

### 4. Risk Mitigation and Patient Selection

To maximize safety and efficacy, proper patient selection and procedural planning are crucial. Pre-procedural imaging plays a vital role in guiding interventional techniques, ensuring precise targeting, and avoiding critical structures. Additionally, post-procedural monitoring and follow-up imaging help detect complications early and ensure optimal treatment outcomes.

Overall, interventional radiology provides a highly effective and safer alternative to traditional surgical approaches in pediatric neck masses. With careful patient selection, experienced procedural execution, and appropriate post-procedural care, the benefits of these techniques outweigh their potential risks, making them a valuable tool in pediatric head and neck pathology management.

**Table 2: Risk Mitigation Strategies**

| **Strategy** | **Implementation** |
|---|---|
| Pre-Procedural Imaging | Use ultrasound, CT, or MRI to assess lesion characteristics and guide intervention planning |
| Patient Selection | Evaluate age, lesion type, comorbidities, and prior treatments for tailored approaches |
| Proper Technique Execution | Use real-time imaging guidance (ultrasound, fluoroscopy) to ensure precision and safety |
| Sedation and Anesthesia Management | Select appropriate anesthesia (local, sedation, or general) based on patient tolerance and procedure complexity |
| Infection Control | Maintain strict aseptic technique and administer prophylactic antibiotics when needed |
| Monitoring and Follow-Up | Conduct post-procedural imaging and clinical assessments to detect complications early |
| Multidisciplinary Collaboration | Engage radiologists, pediatricians, surgeons, and anesthesiologists for comprehensive patient care planning |

**Table 3: Patient Selection Algorithm**

| Step | Criteria and Considerations |
|---|---|
| **Initial Assessment** | Clinical history, physical examination, mass characteristics (size, location, consistency, mobility, tenderness) |
| **Imaging Evaluation** | Ultrasound for initial assessment; CT or MRI for deeper lesions or suspected malignancy |
| **Categorization Based on Etiology** | **Congenital** (e.g., thyroglossal duct cyst, branchial cleft cyst) → Consider aspiration or sclerotherapy |
| | **Infectious/Inflammatory** (e.g., abscess, reactive lymphadenopathy) → Drainage, antibiotic therapy |
| | **Neoplastic** (e.g., lymphoma, sarcoma) → FNAB or CNB for tissue diagnosis |
| | **Vascular** (e.g., AV malformation, hemangioma) → Embolization, sclerotherapy |
| **Procedure Selection** | Fine-needle aspiration for initial cytology; Core needle biopsy for histopathological confirmation |
| | Sclerotherapy for lymphatic malformations; RFA for selected benign or malignant lesions |
| | Embolization for hypervascular tumors; Percutaneous drainage for fluid-filled lesions |
| **Post-Procedure Monitoring** | Assess for complications; Repeat imaging or intervention if necessary |

## 3. CONCLUSION

Interventional radiology has significantly advanced the management of pediatric neck masses, offering precise, minimally invasive diagnostic and therapeutic options. These techniques provide improved patient outcomes by reducing the need for extensive surgical procedures, decreasing hospital stays, and minimizing complications. The integration of real-time imaging guidance enhances procedural accuracy and safety, making interventional radiology an invaluable tool in modern pediatric healthcare.

As technology advances, ongoing research and clinical trials will further refine these techniques, leading to greater efficacy and expanded indications. Collaboration between radiologists, pediatricians, surgeons, and other healthcare professionals remains crucial in optimizing patient care. Future studies should focus on long-term outcomes, cost-effectiveness, and developing standardized guidelines to further enhance the role of interventional radiology in pediatric neck mass management.

Additionally, the integration of artificial intelligence and machine learning in imaging analysis and procedural guidance may further enhance the precision of interventional techniques. By automating certain aspects of image interpretation and procedural planning, AI has the potential to reduce operator dependency and improve consistency in treatment outcomes.

Furthermore, patient-centered approaches should be emphasized to ensure optimal quality of care. Efforts should focus on minimizing patient discomfort, enhancing recovery protocols, and improving follow-up strategies to monitor long-term effectiveness. As new materials and techniques emerge, the continued evolution of interventional radiology will play a pivotal role in expanding its applicability to a broader range of pediatric conditions.

With ongoing advancements and multidisciplinary collaboration, interventional radiology will continue to shape the future of pediatric neck mass management, offering safer, more efficient, and patient-friendly alternatives to traditional surgical interventions.

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