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PICTORIAL ESSAY

Pediatric thyroid ultrasound: a radiologist's checklist

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Abstract

Ultrasonography (US) is the imaging method of choice for evaluating the pediatric thyroid gland, complemented by scintigraphy and thyroid function tests, especially when evaluating children with suspected congenital hypothyroidism, goiter, infectious or autoimmune diseases, or neoplasm. Diagnostic considerations in newborns with congenital hypothyroidism mainly include dysgenesis, dyshormonogenesis, transient hypothyroidism and central (hypophyseal) hypothyroidism. The midline of the neck should be scrutinized for thyroid tissue from the floor of the mouth to the thoracic inlet. Cystic and echogenic ultimobranchial remnants should not be misinterpreted as orthotopic thyroid tissue. Diffuse thyroid diseases affect older children; these comprise Hashimoto and Graves diseases and infectious thyroiditis and exhibit features similar to those in adults. It is important to note that the diffuse sclerosing variant of papillary thyroid cancer can complicate thyroiditis and should not be confused with Hashimoto disease. In children with solid nodules the threshold for fine-needle aspiration biopsy or surgery should be lower compared to adults because of a higher likelihood of malignancy compared with adults. Biopsy should be considered in nodules with suspicious ultrasonographic features, even when smaller than 1 cm. Adult classification systems of thyroid nodules, although useful, are not sufficient to safely discriminate the nodules' likelihood of malignancy in children. We describe key sonographic findings and suggest a standard checklist that might be considered while performing and interpreting thyroid US in neonates and children.

Keywords Child · Congenital hypothyroidism · Gland · Intrathyroid thymus · Nodules · Thyroid · Thyroiditis · Ultrasonography

Introduction

Thyroid disease is a frequent endocrine problem in children and adolescents [1]. US is the test of choice, especially when combined with thyroid function tests and scintigraphy in select cases [2]. Indications for US include evaluation of suspected congenital hypothyroidism, thyroid dysfunction in older children, characterization of a palpable lump over the thyroid, investigation of a possible goiter, screening for thyroid carcinoma, follow-up of a known lesion/condition, as well as screening for iodine deficiency by measuring thyroid volume in epidemiological studies. We describe key sonographic findings, emphasize pitfalls and suggest a checklist to consider when performing and interpreting pediatric thyroid US.

CME activity This article has been selected as the CME activity for the current month. Please visit the SPR website at https://www.pedrad.org on the Education page and follow the instructions to complete this CME activity.

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Technique

The child's positioning during thyroid US with a folded towel under the shoulders to ensure neck extension is important. The examiner has to place the US probe in a transverse plane and sweep the entire embryological path of the thyroid from the base of the tongue to the mediastinum. This can be difficult in neonates with a short neck and excess fat [3–5]. A complete scan includes transverse and longitudinal planes of the gland, isthmus, cervical lymph nodes and mediastinal thymus.

High-frequency linear-array (10- to 17-mHz) and small linear-array hockey-stick-shape (7- to 15-mHz) transducers are used to obtain detailed anatomical information [3–7]. Important adjustments include focal zone placement at the thyroid's depth, appropriate settings to achieve optimal contrast, and application of advanced US technologies where available [8]. Color Doppler should be employed routinely with appropriate constant settings during follow-up. Regarding elastography, available studies describe elasticity of normal thyroid parenchyma as well as focal and diffuse thyroid diseases in children [8–10].

Thyroid size

There is no universal consensus about normal dimensions of the pediatric thyroid. Two formulas have been used: the ellipsoid formula of width x length x height × 0.523, and an alternative thyroid formula of width x length x height × 0.47 [11–18]. In epidemiological studies, somatometric characteristics, ethnicity and local iodine burden/intake affect the pediatric thyroid size [16, 17]. These factors and operator technique differences might explain discrepancies in reported normal values [13, 18, 19]. Neonatal thyroid volumes can be affected by gestational age and vary from 0.84±0.38 mL to 1.62±0.41 mL [6, 18]. A simpler method uses the tracheal index (Fig. 1); a thyroid/trachea ratio of 1.7–2.4 is considered the normal range [20].

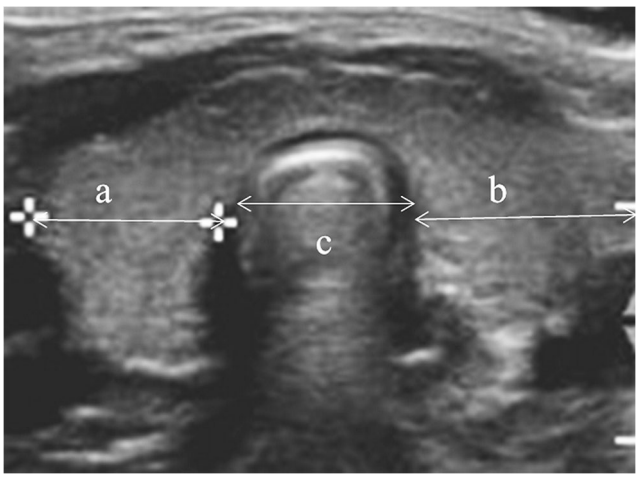

Fig. 1 Calculating the tracheal index to evaluate thyroid size. Transverse scan in a normal 4-month-old boy through the isthmus. *Arrows* show measurements of each lobe's width (*a* and *b*) and tracheal width (*c*). Tracheal index is calculated by using the formula Th/Tr=a+b/c, where Th represents the total transverse diameter of the thyroid lobes and Tr the width of the trachea. A Th/Tr ratio of 1.7–2.4 is in the normal range. In this normal neonate, the width of each lobe is wider and about 1.2 times the width of the trachea

Congenital hypothyroidism

Congenital hypothyroidism affects 1 in 1,400–4,000 neonates [4, 6]. Early diagnosis by screening with a Guthrie test performed at Day 5 is crucial. An abnormal Guthrie test prompts further investigation and potential initiation of hormonal replacement therapy with L-thyroxine-4 continuously for the first 3 years of age to ensure proper neuronal and psychological growth [4, 6, 21].

Congenital hypothyroidism can be divided into two major categories: transient and permanent, caused by thyroid dysgenesis or dyshormonogenesis. Few cases are caused by central hypothyroidism secondary to pituitary or hypothalamic abnormality (Table 1) [3, 6]. Neonates with transient congenital hypothyroidism do not have to take lifelong replacement therapy. Consequently, determination of the cause can significantly reduce parents' concern for delayed diagnosis, guide genetic counseling, predict severity and outcome and affect management accordingly. When children reach 3 years some physicians stop treatment for 1 month to discriminate between permanent congenital hypothyroidism that requires lifelong therapy and transient hypothyroidism that requires no further treatment [5, 21, 22]. This process is not necessary after the diagnosis of athyreosis and lack of functioning thyroid is established by the combination of US and scintigraphy [6, 22–24]. Imaging should be performed within 5 days of treatment onset, before shrinkage and suppression of function of existing thyroid occur [2, 3, 22, 25]. Consequently, referred children <3 years old with suspected congenital hypothyroidism should be considered emergency imaging requests.

Athyreosis refers to an empty thyroid region resulting from agenesis or ectopia and manifests as empty fossa [22]. The presence of small echogenic triangles at each side of the trachea (usually <5 mm), should not be misinterpreted as hypoplastic or dysplastic thyroid (Fig. 2) [7, 25]. This tissue exhibits minimal or no flow on color Doppler examination, occasionally contains microcysts and represents remnants of connective tissue and ultimobranchial structures [7, 21, 25].

In hemiagenesis these findings are unilateral (Fig. 3) and discovered incidentally or in puberty when adolescence places greater stress on the thyroid [2, 3, 24, 26]. US reveals an absent lobe and a normal or goitrous contralateral lobe caused by overstimulation by thyroid stimulating hormone (TSH). Scintigraphy complementarily excludes any additional orthotopic/ectopic functional thyroid tissue [21]. In athyreosis, examiners have to sweep the neck looking for thyroid along the path of the thyroid's embryological migration at the midline from the tongue base to the superior mediastinum [6, 21].

Ectopic gland can be lingual, suprahyoid sublingual, hyoid, infrahyoid, double ectopic, mediastinal (retrosternal, endotracheal, endoesophageal, in the pericardial sac and heart) and rarely lateral cervical [6, 21]. Lingual thyroid, the most common form of thyroid dysgenesis, contains the only functioning

Table 1 Ultrasound findings in congenital hypothyroidism, modified from [3]

Abnormality	Ultrasound considerations and findings
Thyroid dysgenesis	Inspect thyroid fossa and consider ultimobranchial remnants
Agenesis	Athyreosis, no ectopic thyroid on gray-scale and color Doppler of entire neck
Hemiagenesis	Unilateral empty fossa, no ectopic thyroid
Ectopia	Empty fossa, identifiable thyroid from base of tongue to upper mediastinum
Hypoplasia	Orthotopic small gland, tracheal index <1.7, prominent strap muscles
Thyroid dyshormonogenesis	Orthotopic large or normal-size gland
Transient hypothyroidism	Orthotopic gland of normal size on US regardless of cause
Iodine deficiency	
Iodine excess	
Maternal autoimmune disease (iatrogenic, functional)	
Central hypothyroidism	Orthotopic normal gland on US, consider pituitary magnetic resonance imaging
Pituitary gland abnormality	
Hypothalamic abnormality	

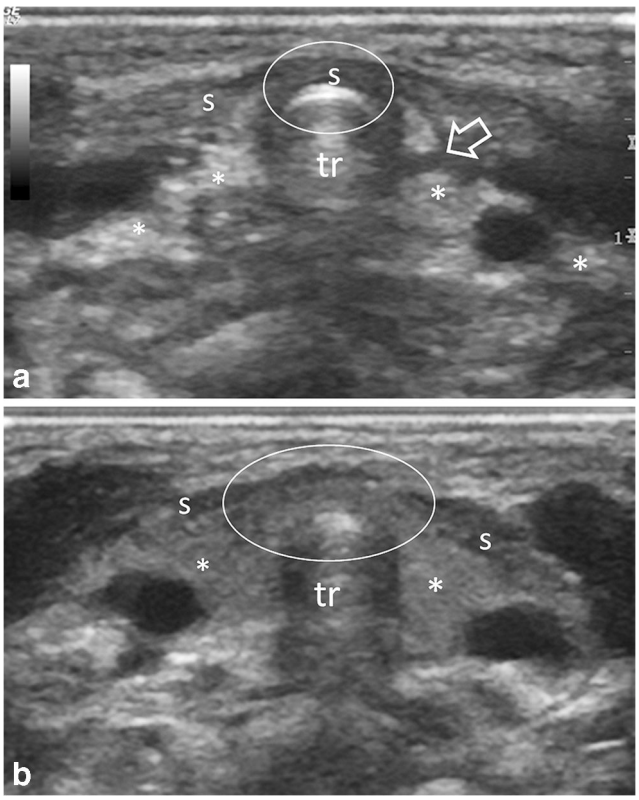

Fig. 2 Appreciation of athyreosis. **a** Sonography in a 20-day-old girl neonate with an abnormal Guthrie test and athyreosis. Transverse US scan shows a lack of isthmus (*oval*). Note echogenic triangular structures (*) with blurred margins extending from the sides of the trachea (*tr*) posterolaterally, behind the large cervical blood vessels. These represent ultimobranchial remnants and not normal thyroid tissue. *Arrow* points at a microcyst. *s* strap muscles. **b** The normal neonatal thyroid is shown for comparison in a 10-day-old euthyroid girl neonate with suspected branchial anomaly. Visible isthmus (oval) and moderately hyperechoic parenchyma (*) appear deep to the strap muscles (*s*)

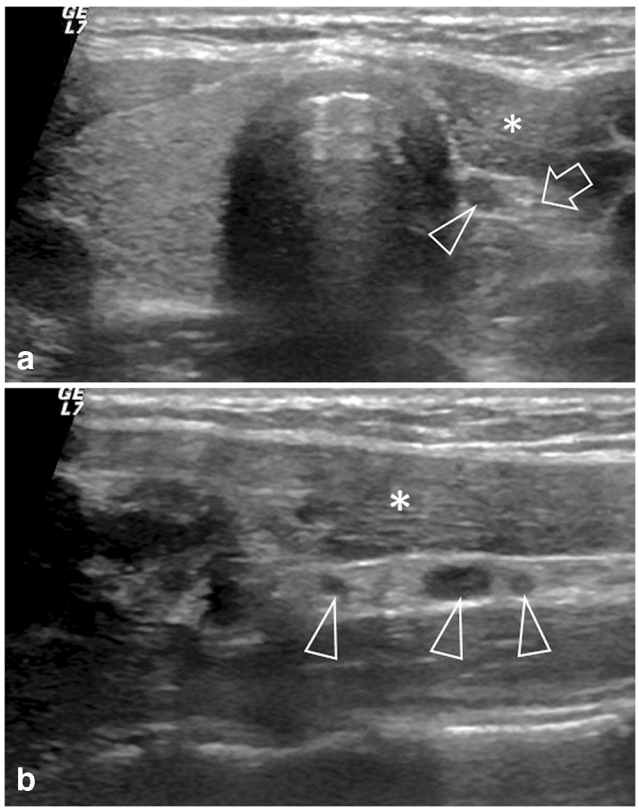

Fig. 3 Recent diagnosis of hypothyroidism and unilateral agenesis in a 15-year-old girl. **a** Transverse US scan shows indentation of the strap muscles (*) into the thyroid bed, over a small echogenic ill-defined triangle (*arrow*) at the left side of the trachea that contains a microcyst (*arrowhead*). **b** Longitudinal US scan of the left lobe shows thickened strap muscles (*) and three microcysts (*arrowheads*) surrounded by echogenic tissue considered to represent cysts and connective tissue from the ultimobranchial remnants. This child remained asymptomatic because the normal side compensated until adolescence

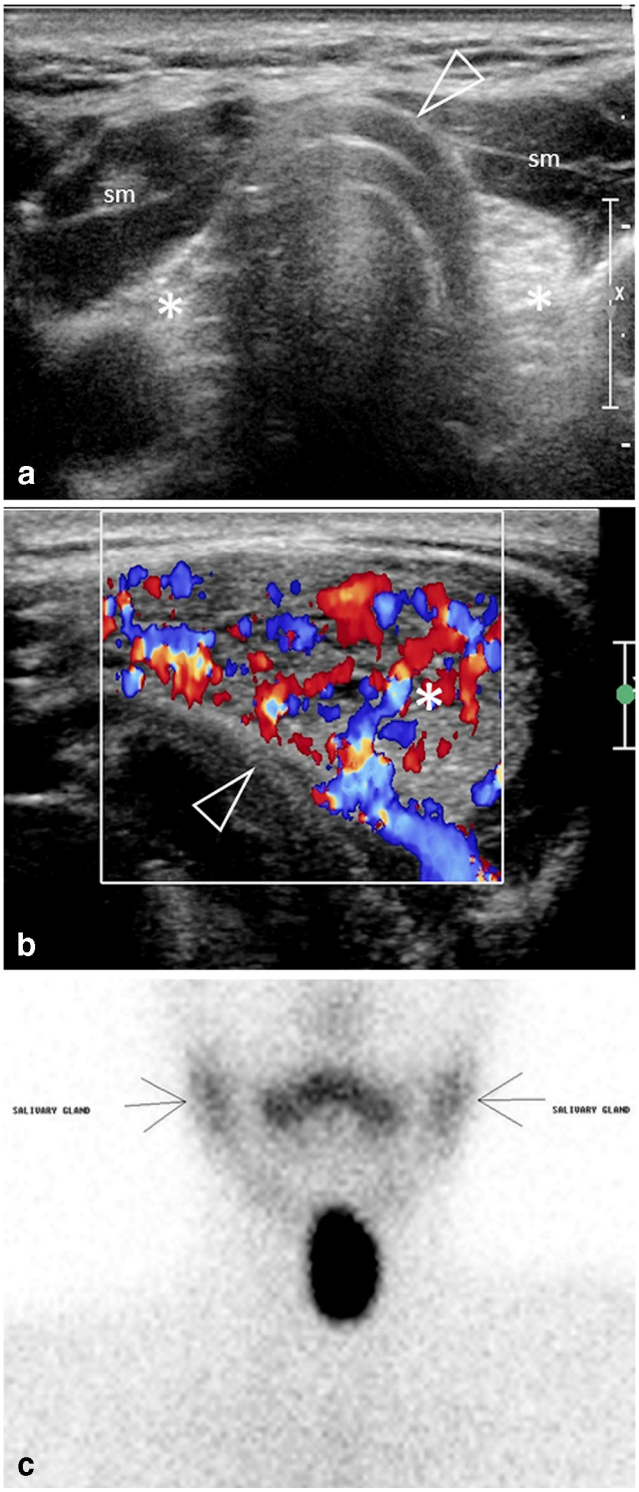

Fig. 4 Ectopic thyroid in a 17-year-old girl with late onset of hypothyroidism and low neck ectopia. **a** Axial US scan shows athyreosis with an empty thyroid fossa, prominent strap muscles (*sm*), echogenic fibrous tissue (*) surrounding the great vessels, and lack of isthmus over the trachea (*arrowhead*). **b** Axial US color Doppler scan at a more cranial level than (**a**) shows hypervascular echogenic tissue (*) of similar echogenicity to the normal thyroid, abutting the cricoid cartilage (*arrowhead*), consistent with ectopic thyroid. **c** Iodine-123 scintigraphy complements the diagnosis and exhibits iodine uptake by a midline globular ectopic thyroid. *Arrows* point to salivary glands

tissue in 75% of congenital hypothyroidism cases [2, 27]. Ectopic thyroid is a well-defined oval structure that is occasionally hyperemic on color Doppler (Fig. 4) [2, 5, 25, 27–30]. It can be missed in neonatal screening because it initially produces sufficient hormones, which decrease during early childhood [25]. The retrosternal, endolaryngeal or endotracheal ectopic thyroids are usually sonographically missed and identified by scintigraphy, if large and functioning enough [3, 26–28].

The most misdiagnosed form of congenital hypothyroidism is thyroid hypoplasia, which is responsible for 5% of these cases [29]. The gland appears orthotopic, with a normal shape and normal or small-for-age size, and is often hypoechoic (Fig. 5). Hormonal production is usually reduced because of a defective response of thyroid tissue to TSH [25, 29]. Volumetry of neonatal thyroids or tracheal index <1.7 is indicative of a small thyroid, which might also exhibit decreased uptake on scintigraphy [6, 27, 30, 31].

Unilateral hypoplasia occurs in one lobe, usually the left one. It rarely results in hypothyroidism and might be discovered incidentally [21].

Dyshormonogenesis (orthotopic gland with impaired function) is a less frequent cause of congenital hypothyroidism (10–15%) and is caused by defects in any of the multiple enzymatic steps of thyroid hormone synthesis [3]. In 10% of dyshormonogenesis cases, an inborn error of thyroxine synthesis with hereditary trait is seen. The thyroid appears orthotopic, with prominent isthmus and enlarged lobes from increased TSH levels (Fig. 6). Scintigraphy with I-123 might show visible gland in some forms of dyshormonogenesis and no gland in other forms [2, 3, 5].

Transient hypothyroidism is a condition in which the thyroid temporarily malfunctions without any morphological

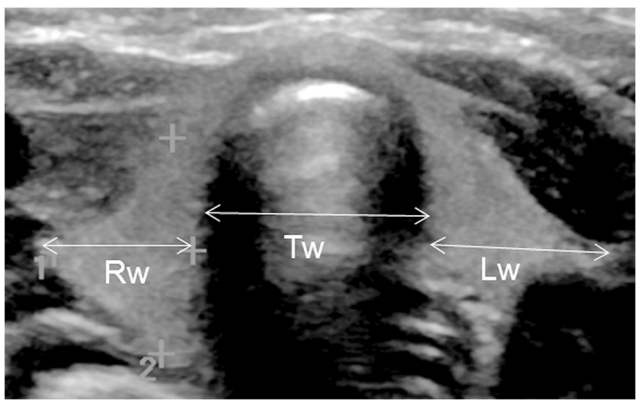

Fig. 5 Transverse US scan in a 2-month-old boy with congenital hypothyroidism from hypoplasia. Each lobe's transverse diameter (Rw = width of right lobe, Lw = width of left lobe) is much smaller compared to the trachea's width (*Tw*). Findings are consistent with a visually small thyroid. The tracheal index was less than 1.7, which is the cut-off value for small thyroids. Note that the shape of the sharply demarcated thyroid is normal, and aside from the size, the remaining US features are unremarkable

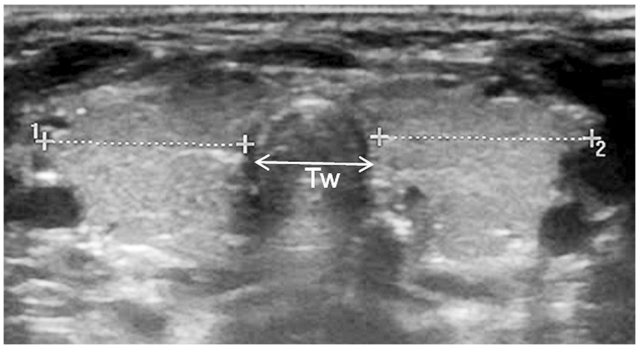

Fig. 6 Dyshormonogenesis in a newborn boy with congenital hypothyroidism. Transverse US scan allows for qualitative evaluation of the size of the thyroid by comparing each lobe's width to the width of the trachea. Here, each lobe's width (*between cursors*) is more than 2.5 times the tracheal width (*Tw*), consistent with an enlarged thyroid. Note that the thyroid is relatively hypoechoic and exhibits convex, lobulated lateral borders, features encountered in neonatal goiter caused by dyshormonogenesis

abnormalities. This is caused by several factors, including hypothyroxinemia of prematurity, medications (steroids, dopamine), blood transfusion, maternal thyrotropin-receptor-blocking IgG antibodies and maternal iodine excess or deficiency. US shows a normal or enlarged thyroid irrespective of the cause. Scintigraphy shows uptake in hypothyroidism caused by maternal antithyroid medication and absent or decreased uptake in hypothyroidism caused by TSH blocking receptor antibodies [3, 6].

In congenital hypothyroidism, US examination is the primary method for distinguishing orthotopic from ectopic thyroid. An orthotopic thyroid suggests lack of dysgenesis in the form of agenesis or ectopia and should be measured to discriminate hypoplasia (small gland) from dyshormonogenesis and transient hypothyroidism (normal or large gland). Enlarged neonatal thyroid, or neonatal goiter, is usually caused by transient hypothyroidism or dyshormonogenesis and can be diagnosed antenatally [32]. An orthotopic thyroid accompanied by absent uptake on scintigraphy can be a diagnostic challenge [23]. No gland visible at I-123 scintigraphy is associated with dysgenesis, including agenesis and hypoplasia, or with transient hypothyroidism (antibodies blocking TSH receptors) and some forms of dyshormonogenesis. If absent scintigraphic uptake persists in the setting of normal US findings, dyshormonogenesis is a likely cause of permanent hypothyroidism [3, 5, 22, 23]. If the thyroid is visible at I-123 scintigraphy it is not always normal; other associations include low ectopia, hypoplasia and some forms of dyshormonogenesis [3, 21]. A recommended strategy by Sedassari et al. [22] is to perform US for localization of the thyroid, proceed to molecular investigation of congenital hypothyroidism and thereby achieve earlier genetic counseling without the need for scintigraphy and therapy interruption.

Diffuse diseases of the thyroid

US in goitrous thyroids is used to depict characteristic changes supporting the diagnosis of conditions diffusely affecting the gland and to detect features suspicious for superimposed malignancy [33–35]. Hashimoto lymphocytic thyroiditis, an autoimmune chronic inflammatory disease, represents the most common cause of acquired hypothyroidism in children and adolescents ages 6–16 years [36]. Its prevalence is 0.3–2% in children and 4–9% in adolescents, and rising [4, 37]. The diagnosis is confirmed by elevated levels of anti-thyroid peroxidase antibodies or thyroglobulin antibodies in the serum. Hashimoto disease has been associated with Down syndrome, Turner syndrome, juvenile diabetes and treated Hodgkin lymphoma [38]. Children with Hashimoto disease might be euthyroid or have subclinical or overt hypothyroidism, depending on severity of immunological damage, and these children

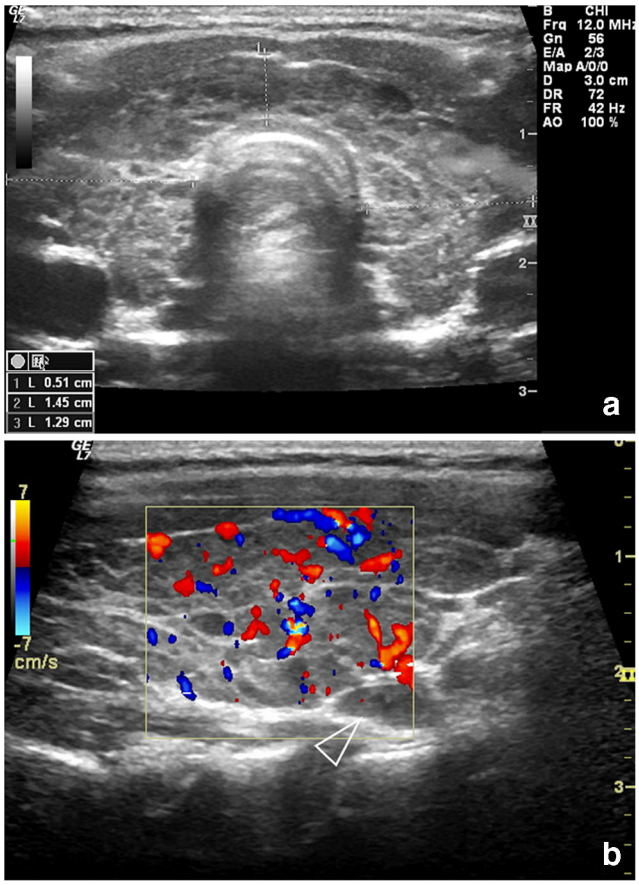

Fig. 7 Hypothyroidism caused by Hashimoto thyroiditis in an 11-year-old boy. **a** Axial US scan through the isthmus shows an enlarged (goitrous) thyroid (*calipers*) with multiple micronodules scattered in the parenchyma, each measuring 1–6 mm in diameter and representing lymphocytic infiltration. Micronodularity favors this diagnosis and occurs in a net of fibrotic echogenic lines. **b** Sagittal section of the right lobe with color Doppler application shows hyperemia and an adjacent lymph node (*arrowhead*), which is a common finding in Hashimoto thyroiditis and should not be misdiagnosed as potential malignancy

occasionally present with hyperthyroidism, a state called hashitoxicosis in which destruction of thyroid follicles leads to elevated thyroid hormones and hyperthyroidism [39].

At diagnosis, the thyroid gland can be normal or slightly enlarged with normal or mild heterogeneous echotexture, and with normal or increased Doppler flow [40, 41]. Progressively the gland becomes enlarged with inhomogeneous echotexture (Fig. 7) [3]. In large nodules, biopsy can be used to exclude malignancy because children with Hashimoto disease carry an increased risk for carcinoma [2, 42, 43]. In chronic atrophic thyroiditis, which is uncommon in children, the gland decreases in size and exhibits lobular contour and diffuse heterogeneity from fibrosis. Detection of adjacent lymph nodes is common (Fig. 7) [44]. Sonographic changes can take up to 4 years to develop; therefore, periodic US examinations are indicated for long-term follow-up [40].

Children with the diffuse sclerosing variant of papillary carcinoma in the background of pediatric thyroiditis might present with enlarged inhomogeneous thyroid containing echogenic spots representing microcalcifications; this should be recognized as such, prompting biopsy (Fig. 8). This inhomogeneous distribution of a snowstorm appearance should not be misinterpreted as the micronodular pattern of thyroiditis (Figs. 7 and 8) [45].

Graves disease, which affects 0.02% of children, is the most common autoimmune cause of hyperthyroidism in childhood, with a peak incidence between 11 years and 15 years of age [4]. Eighty percent of pediatric cases occur after 11 years [46–48]. Thyroid stimulating hormone receptor antibodies are produced, leading to increased thyroid hormone levels. In cases where the classic triad of diffuse goiter, ophthalmopathy and hyperthyroidism is lacking, scintigraphy is of crucial importance for the diagnosis [49]. US findings on gray-scale are nonspecific and include a diffusely enlarged heterogeneous and hypoechoic gland. Color Doppler demonstrates a hypervascular pattern referred to as "thyroid inferno" (Fig. 9) with a relatively high specificity (91.7%) for the diagnosis [47].

Suppurative thyroiditis affects the thyroid gland and adjacent soft tissues in children. Causative organisms include anaerobic and Gram-positive bacteria (like staphylococcus and streptococcus); symptoms are fever, painful swelling and a tender, off-midline swelling close to the thyroid area [50, 51]. US demonstrates an area of heterogeneity within the thyroid gland with peripheral hyperemia and occasionally adjacent inflammation [2, 4]. Any neck abscess identified by US should be

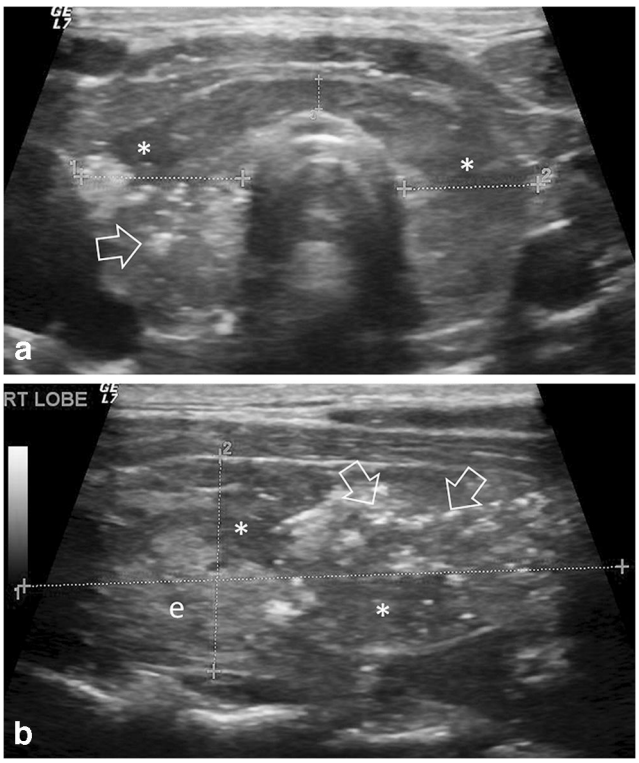

Fig. 8 Hashimoto thyroiditis and biopsy-proven diffuse sclerosing variant of papillary carcinoma in a 14-year-old boy. **a** Axial US scan shows a large heterogeneous gland (*calipers*) with asymmetry in distribution of extensive hypoechoic areas (*) and hyperechoic speckles (*arrow*). **b** Sagittal scan through the right lobe shows echogenic areas (*e*) alternating with hypoechoic areas (*), with scattered speckles indicative of the snowstorm appearance (*arrows*), not to be confused with the echogenic net of fibrosis encountered in Hashimoto thyroiditis

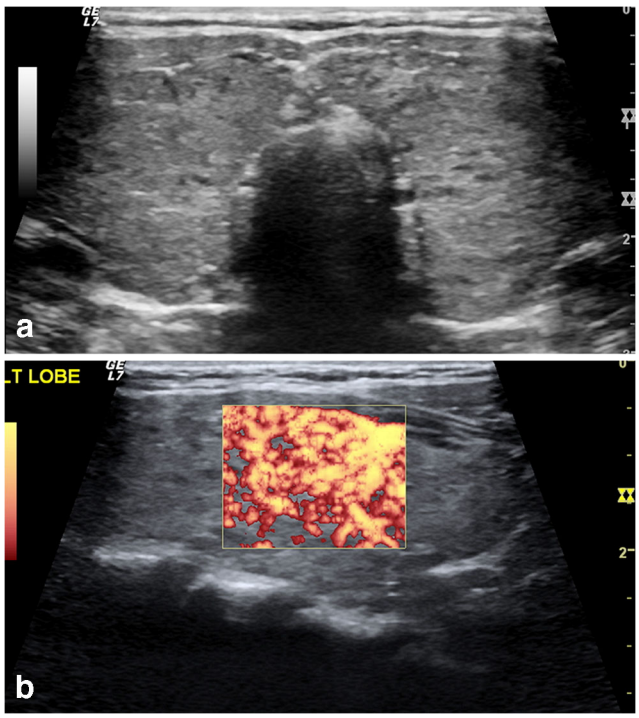

Fig. 9 Graves disease in a 15-year-old girl. **a** Transverse US scan shows a large, rather hypoechoic heterogeneous gland. **b** Power Doppler demonstrates excessive hypervascularity suggestive of the "thyroid inferno" sign. In hyperthyroidism, lack of micronodularity in large heterogeneous hyperemic thyroids is more consistent with Graves disease and less likely with hashitoxicosis, although the distinction can be challenging based on imaging features alone

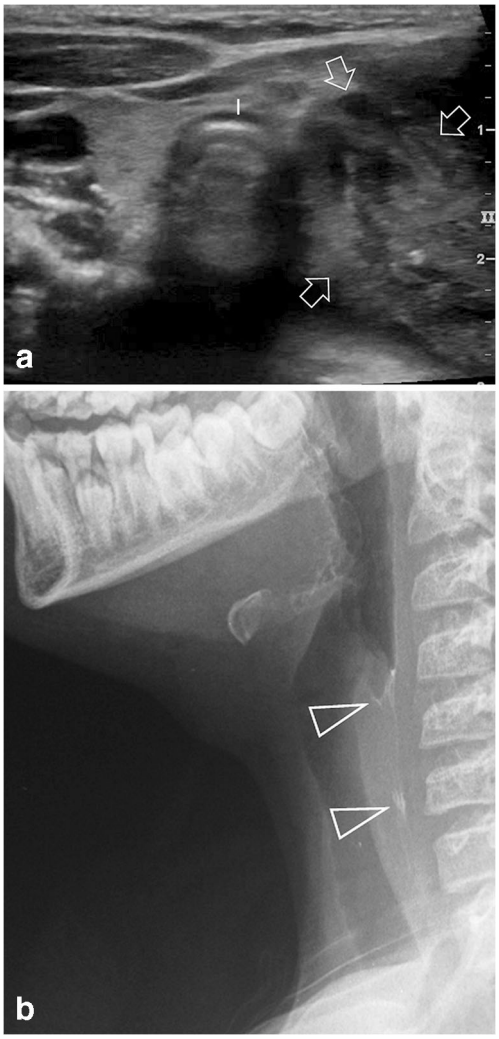

Fig. 10 Acute suppurative thyroiditis in an 8-year-old girl with fever and painful swelling over the left cervical area. **a** Transverse US scan shows a large heterogeneous lesion suggestive of an abscess (*arrows*) related to the left thyroid lobe. *I* isthmus. **b** Sagittal contrast swallow examination focusing on the pyriform sinus shows the sinus tract coursing from the left pyriform sinus toward the thyroid (*arrowheads*). CT might be requested to exclude other lateral cervical pathology and for surgical planning

scrutinized for possible relationship with the thyroid (Fig. 10). Recurrent suppurative thyroiditis should raise the possibility of pyriform sinus fistula originating from 3rd or 4th branchial arches, prompting a contrast swallow (Fig. 10) [40, 52].

Subacute non-suppurative thyroiditis (De Quervain) is rare in children and presents with enlarged tender thyroid, malaise, fatigue and weakness following an upper respiratory tract infection [1]. US might reveal at the acute stage diffuse or ill-defined focal hypoechogenicity of the gland with no vascularity [52].

Focal thyroid lesions

When detecting a focal lesion, one should decide whether it represents a true nodule and, if yes, whether it is suspicious for

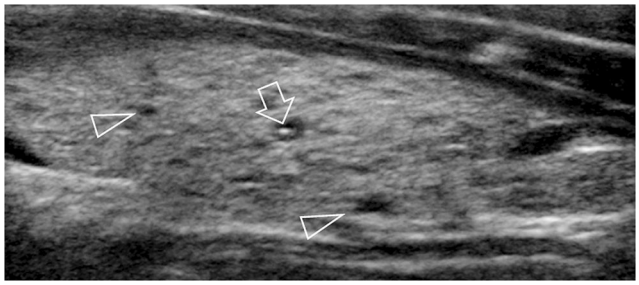

Fig. 11 Colloid follicle in a 16-year-old asymptomatic adolescent boy with subclinical Hashimoto thyroiditis. Sagittal US scan of the left lobe shows micronodularity (*arrowheads*) and a cystic structure with an internal echogenic dot (*arrow*) from concentrated colloid microcrystals. The findings are consistent with a colloid follicle and autoimmune thyroiditis

malignancy and requires biopsy. Cystic lesions exhibiting an echogenic dot and posterior comet tail artifact are referred to as colloid follicles when ≤0.3 cm and as colloid cysts when 0.3–1 cm (Fig. 11). Rarely multiple cysts, either coalescing (Fig. 12) or separate, the so-called polycystic thyroid disease, are incidental findings in euthyroid or mildly hypothyroid school-age children and adolescents [53–55].

Intrathyroid thymus is a thymic embryological remnant and appears as a small (<1 cm), sharply demarcated hypovascular lesion, located posteriorly and caudally; it sometimes has angulated borders, and it exhibits the starry-sky pattern identical to the same patient's mediastinal thymus (Fig. 13) [56, 57]. Occasionally these lesions show extrathyroidal extension with a tongue of thymic tissue projecting toward the mediastinum or connecting the lesion with the thymus [56].

The pyramidal lobe is a thyroidal embryological remnant. Thyroid tissue extends from the isthmus toward the hyoid bone at a variable distance along the course

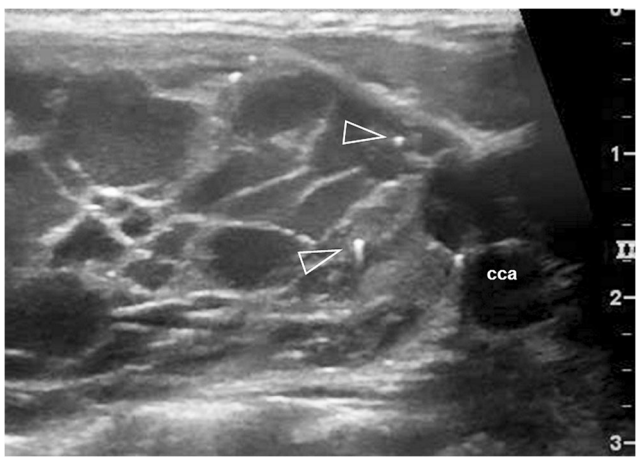

Fig. 12 Coalescent colloid cysts in a 6-month-old boy euthyroid infant with a palpable lump. Transverse US scan of the left lobe shows numerous cysts, some containing echogenic dots with a posterior comet tail artifact, the so-called colloid ring-down artifact (*arrowheads*). *cca* common carotid artery

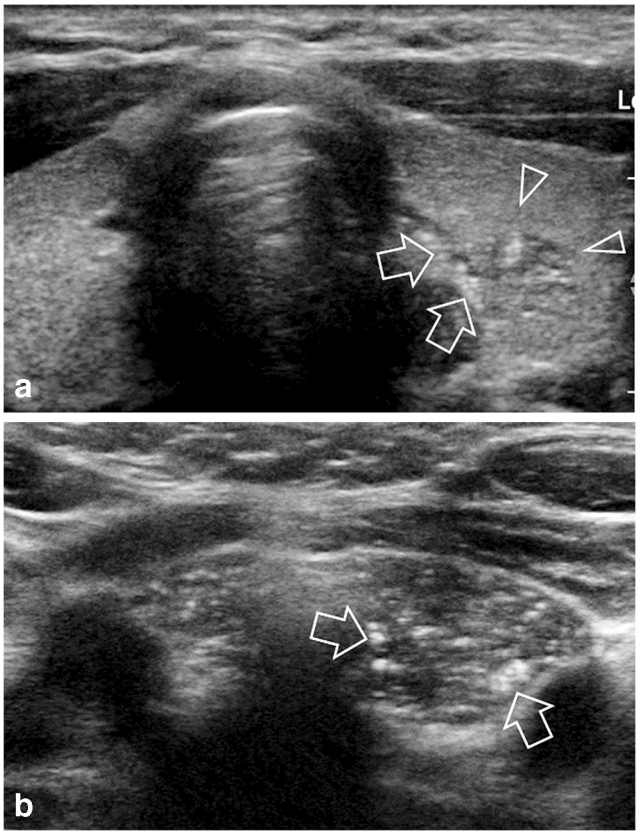

Fig. 13 Incidentally found intrathyroid thymus in a 5-year-old girl. **a** Transverse US scan of the thyroid shows a map-like hypoechoic lesion with sharply demarcated angulated borders (*arrowheads*), situated posteriorly, measuring up to 1 cm, and containing scattered bright spots with an uneven distribution (*arrows*). **b** Transverse US scan of the mediastinal thymus exhibits an identical echo pattern with uneven distribution of speckles (*arrows*) in a hypoechoic background, consistent with the starry-sky pattern of normal thymus

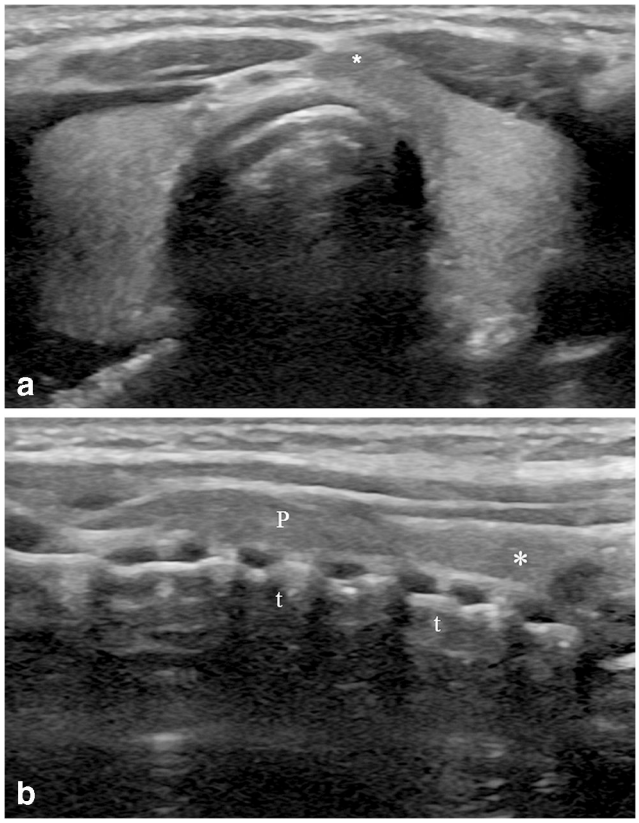

Fig. 14 Pyramidal lobe in a 3-year-old boy scanned for a palpable nodule. **a** Transverse US scan of the thyroid shows lack of the right aspect of the isthmus and a focal bulging to the left of the midline (*) and deep to the strap muscles. **b** Longitudinal US scan over the same area (*) shows the pyramidal lobe as a tongue of thyroid tissue (*P*) extending from the isthmus (*) toward the hyoid bone, over the trachea (*t*). The pyramidal lobe appears hypoechogenic compared to the remaining thyroid because of its superficial position

of the thyroglossal duct [5, 6, 58]. Pyramidal lobes typically lie deep into the medial border of the strap muscles; can be central, to the left or to the right of the midline (Fig. 14); and might be affected by the same pathology (focal or diffuse diseases) as the remaining gland [21]. The presence of a pyramidal lobe should be particularly mentioned prior to thyroidectomy, to ensure planning of a complete resection [58].

The cricoid cartilage might mimic a lesion when scanned at a sagittal level in school-age children and adolescents. Quite often it contains calcifications (Fig. 15) and should not be misinterpreted as malignancy, which can lead to unnecessary biopsy or surgery [59, 60].

Entirely cystic, anechoic thin-walled lesions are rare and represent true epithelial-lined cysts [2, 4].

A mixed solid and cystic thyroid nodule is either predominantly solid with a discrete countable number of cystic spaces, carrying a possibility of malignancy (Fig. 16), or predominantly cystic with a mural solid nodule, usually representing a benign hyperplastic nodule with cystic degeneration [2, 4]. Color Doppler without compression may show no flow, a finding indicative of retracted clot. Spongiform lesions are

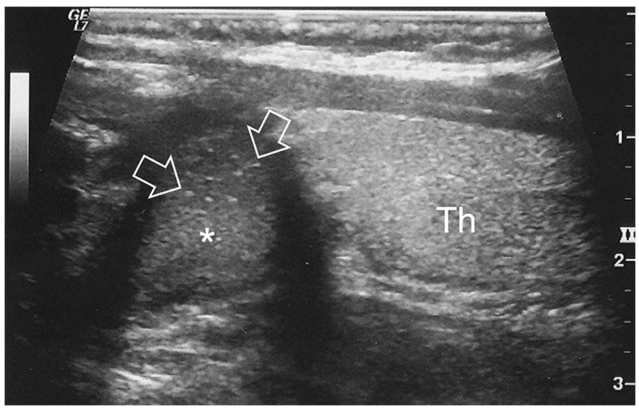

Fig. 15 The pitfall of the cricoid cartilage seen on a sagittal US scan of the left lobe in a 5-year-old girl. There is a round hypoechoic structure (*) situated cephalad to the thyroid (*Th*) and containing punctate foci (*arrows*). This lesion was invisible on axial US scans because it is situated outside the thyroid. It should not be erroneously interpreted as a suspicious thyroid nodule with calcifications

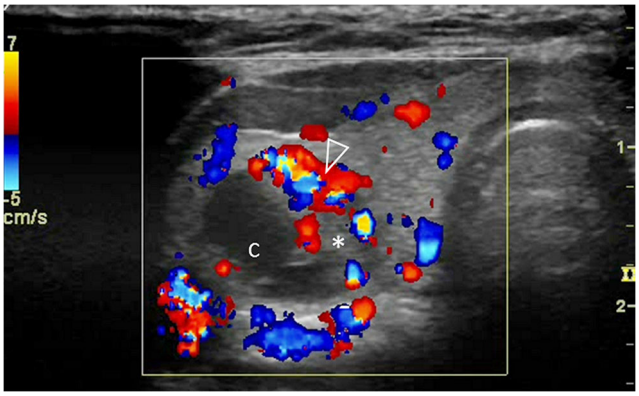

Fig. 16 Biopsy-proven papillary carcinoma in an 11-year-old girl with a positive family history. Transverse color Doppler with as little probe pressure as possible demonstrates a nodule with a cystic component (*C*) and an apparent mural nodule (*). There is flow in the superficial echogenic part of the nodule (*arrowhead*), suggesting a nodule with a mural solid part which should be biopsied. A retracted clot in a cystic hyperplastic nodule would have exhibited no flow

characterized by numerous small cysts cumulatively occupying a large portion of the nodule and are usually benign [2, 35, 57].

Solid thyroid nodules are uncommon in children, with an incidence of 0.05–5% [61, 62]. They harbor approximately 25% risk of malignancy, higher compared to 5–15% in adults [63]. A scintigraphically hot/autonomous nodule, although typically benign in adults, carries a 30% chance of malignancy in a child [35, 64]. Predisposing factors for pediatric thyroid cancer include radiation exposure; radiotherapy, especially for lymphoma; iodine deficiency; history of autoimmune thyroiditis; predisposing genetic disorders like *RET, DICER1* or *PTEN* gene mutations; as well as a positive family history [35, 64–66]. In these children, long-term follow-up and a low threshold for biopsy are required.

The proportion of malignant nodules is independent of the child's age, gender or pubertal status [57, 61, 63]. Children have more advanced cancer at presentation compared to adults with lymph node and pulmonary metastases, carrying a higher recurrence risk; however, their prognosis is favorable [61, 66].

When solid thyroid nodules are detected, each one should be independently evaluated regarding echogenicity (hyper-, iso-, hypoechoic), composition (solid, cystic, mixed), margins (smooth or ill-defined, lobulated, extrathyroidal extension), presence of halo (complete, incomplete or absent), calcifications (micro-, macro-), shape (ratio of anteroposterior to transverse diameter) and vascularity (central or peripheral). Cervical lymph nodes are also assessed for size, shape, echotexture, presence of intranodal calcifications and vascularity [62, 67]. Identification of sonographic features of thyroid malignancy in children and application of adult classification schemes can be useful but not always accurate [68–70]. Suspicious findings include the presence of internal microcalcifications, ill-defined or microlobulated margins, hypoechogenicity, taller-than-wide shape, anterior-subcapsular location, interrupted halo, chaotic vascularity and abnormal cervical lymph nodes (Figs. 17 and 18) [68–70]. It is important to note that the combination of microcalcifications, ill-defined margins in a nodule >35 mm and the presence of abnormal lymph nodes carries a higher sensitivity and specificity for malignancy compared to each feature alone [67]. In pediatric elastography, there are no standardized cut-off values for differentiating benign from malignant thyroid lesions; nevertheless, elastography might prove useful in individual cases (Fig. 19).

The diffuse sclerosing variant of papillary thyroid carcinoma accounts for approximately 19.1% of pediatric papillary thyroid cancer, has a more aggressive behavior than other

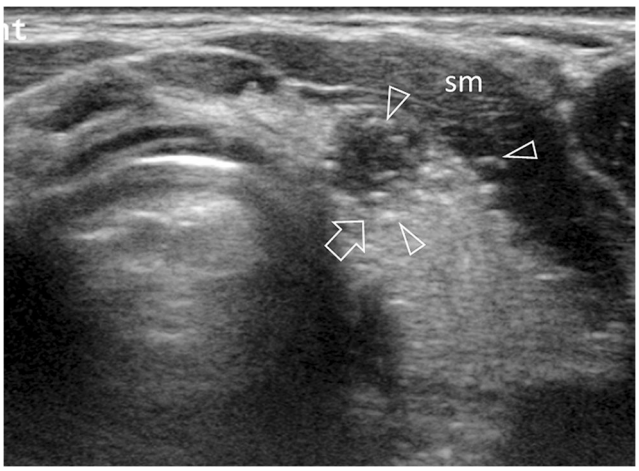

Fig. 17 Biopsy-proven papillary carcinoma in a 15-year-old girl. Transverse US scan shows an anterior hypoechoic lesion with ill-defined margins posteriorly (*arrow*), defined as more than 25% of the lesion's margin being ill-defined. Echogenic dots, indicative of microcalcifications (*arrowheads*), both within the lesion and in its vicinity, suggest an aggressive parenchymal lesion with extrathyroidal growth. Note marked hypoechogenicity of the lesion compared to the thyroid and, more important, to the strap muscles (*sm*)

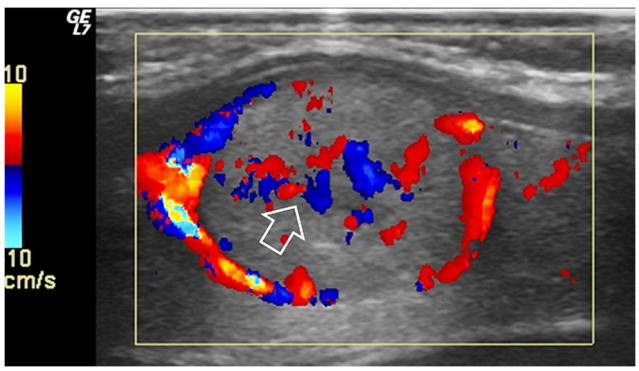

Fig. 18 Histologically proven papillary carcinoma in a 13-year-old girl with a palpable nodule. The so-called chaotic vascularity manifests as both peripheral and central vascularity, with a random non-branching central vessel distribution (*arrow*)

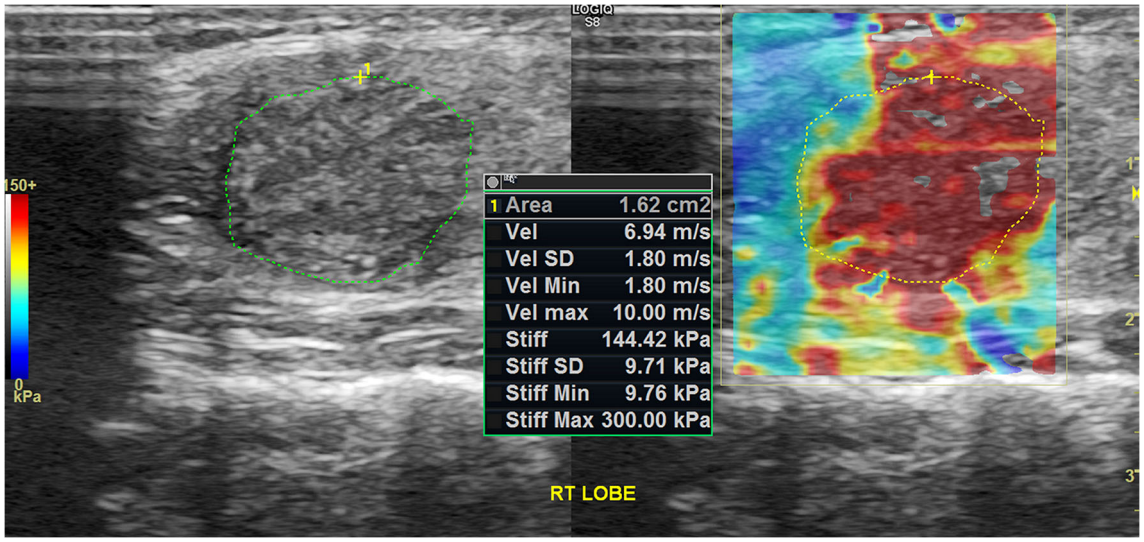

Fig. 19 Histologically confirmed papillary carcinoma in a 10-year-old boy. Split conventional and shear-wave elastography image shows a large lesion that is hypoechoic compared to the thyroid parenchyma, with ill-defined margins, at the right thyroid lobe. Shear-wave elastography confirms the increased likelihood for malignancy with increased tissue stiffness (*red areas*) and values more than 100 kPa. Increased stiffness represented by red color and values of about 100 kPa in focal lesions are considered highly suspicious for malignancy

types, and is frequently associated with metastatic adenopathy at presentation [35, 45, 61, 62]. Biopsy remains the mainstay choice for suspicious nodules and should be performed independently of their size because of different biological behavior of pediatric thyroid cancer and because the thyroid volume changes with age [35, 61, 62, 68, 69].

Table 2 The radiologist's thyroid ultrasound checklist: questions that should be routinely answered when performing and interpreting US in neonates and children

In neonates with congenital hypothyroidism	In children with identified focal lesions
Is there moderately echogenic thyroid tissue consistent with orthotopic thyroid?	Is it a true nodule?
Is there athyreosis, i.e. echogenic triangular tissue, extending behind the large vessels with or without cysts and no isthmus?	Does it represent: • An *intrathyroid thymus*? Have I scanned the thymus and compared its pattern with a small intrathyroid hypoechoic lesion?
Have I scanned the entire embryological pathway of the thyroid from the base of the tongue to the mediastinum for ectopic thyroid?	• A *colloid follicle or cyst*? Is there a ring-down artifact?
Have I used color Doppler during this?	• The *cricoid cartilage*? Can I see the lesion in two planes?
Have I used thyroid volume or tracheal index to identify a small thyroid consistent with hypoplasia?	
Have I understood the importance of performing scintigraphy combined with US within the first 5 days of therapy initiation?	Are there discriminating US features suspicious of malignancy, e.g.: • Internal microcalcifications?
In children who undergo ultrasound for screening, endocrinological disturbances, thyroid enlargement or lump, or predisposing factors for malignancy:	• Ill-defined (≥25%) or lobulated margins? • Hypoechogenicity compared to thyroid parenchyma or to strap muscles?
Is the size of the gland appropriate for age?	• Taller-than-wide shape? • Anterior-subcapsular location? • Interrupted halo?
Is the echotexture of the thyroid parenchyma homogeneous? Is there hyperemia with color Doppler either focally or diffusely?	What is the pattern of vascularity? • Peripheral or central? • Chaotic (both peripheral and central, non-branching)?
Is there adjacent lymphadenopathy?	Can elastography contribute to the diagnosis in this particular patient?
Are there calcifications?	Should I consider US for guiding biopsy of suspicious nodules or lymph nodes?

Conclusion

Ultrasonography is the test of choice for evaluating pediatric thyroid morphology. US complements scintigraphy in children with congenital hypothyroidism, reveals features of diffuse thyroid diseases and can help identify children with probable malignancy. Routine application of a suggested checklist (Table 2) is important for correct recognition and interpretation of key findings.

Compliance with ethical standards

Conflicts of interest None

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