Parathyroid 4D CT: What the Surgeon Wants to Know

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Abbreviations: BNE = bilateral neck exploration, 4D = four dimensional, MGD = multiglandular disease, MIP = minimally invasive parathyroidectomy, PHPT = primary hyperparathyroidism, RLN = recurrent laryngeal nerve

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SA-CME LEARNING OBJECTIVES

After completing this journal-based SA-CME activity, participants will be able to:

- Describe parathyroid anatomy, embryology, and operative considerations relevant to the interpretation of parathyroid 4D CT images.
- Identify typical and atypical parathyroid lesions at parathyroid 4D CT.
- Report the most relevant information from a parathyroid 4D CT examination for the surgeon.

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Parathyroid four-dimensional (4D) CT is an increasingly used and powerful tool for preoperative localization of abnormal parathyroid tissue in the setting of primary hyperparathyroidism. Accurate and precise localization of a single adenoma facilitates minimally invasive parathyroidectomy, and localization of multiglandular disease aids bilateral neck exploration. However, many radiologists find the interpretation of these examinations to be an intimidating challenge. The authors review parathyroid 4D CT findings of typical and atypical parathyroid lesions and provide illustrative examples. Relevant anatomy, embryology, and operative considerations with which the radiologist should be familiar to provide clinically useful image interpretations are also discussed. The most important 4D CT information to the surgeon includes the number, size, and specific location of candidate parathyroid lesions with respect to relevant surgical landmarks; the radiologist's opinion and confidence level regarding what each candidate lesion represents; and the presence or absence of ectopic or supernumerary parathyroid tissue, concurrent thyroid pathologic conditions, and arterial anomalies associated with a nonrecurrent laryngeal nerve. The authors provide the radiologist with an accessible and practical approach to performing and interpreting parathyroid 4D CT images, detail what the surgeon really wants to know from the radiologist and why, and provide an accompanying structured report outlining the key information to be addressed. By accurately reporting and concisely addressing the key information the surgeon desires from a parathyroid 4D CT examination, the radiologist substantially impacts patient care by enabling the surgeon to develop and execute the best possible operative plan for each patient.

Introduction

Primary hyperparathyroidism (PHPT) refers to an intrinsic parathyroid gland abnormality resulting in excessive secretion of parathyroid hormone, which acts to increase serum calcium levels (1). PHPT represents the most common cause of hypercalcemia and the third most common endocrine disorder (2). The risk of PHPT increases with age, and PHPT more commonly affects women (one in 500) than men (one in 2000) (3,4).

The classic clinical symptoms of PHPT are related to skeletal disease, nephrolithiasis, and neurocognitive effects (5). However, PHPT is also associated with hypertension, hyperlipidemia, diabetes, and obesity (2). Moreover, PHPT conveys an increased risk of cardiovascular disease, cerebrovascular disease, renal disease, fractures, and all-cause mortality (6–11). Thus, the costs of PHPT to the health care system are substantial (12,13).

PHPT most commonly results from a single parathyroid adenoma (85%–90%) but can also be caused by multiglandular

TEACHING POINTS

- PHPT is diagnosed biochemically. All patients who undergo imaging should have biochemically proven PHPT, and the goal of imaging is localization, not diagnosis. Precise localization of a single adenoma facilitates MIP, whereas successful localization of MGD aids in BNE planning. If the imaging interpretation is nonlocalizing, the patient remains an operative candidate. However, performing BNE will likely be necessary.
- Relative superior or inferior position of a parathyroid gland does not reliably denote its embryologic origin. Not infrequently, an enlarged superior parathyroid gland will descend into the superior mediastinum, a phenomenon referred to as acquired ectopia. The plane of the RLN, which is approximated by the tracheoesophageal groove, more reliably distinguishes between superior and inferior glands, with the superior glands positioned posteriorly (dorsal) with respect to the RLN and the inferior glands positioned anteriorly (ventral).
- We advocate describing lesions relative to the cricoid cartilage and tracheoesophageal groove. The cricoid cartilage is consistently palpable, is able to be visualized in the standard operative field, and orients the surgeon to the anatomic midline, particularly in the reoperative neck. The plane of the tracheoesophageal groove informs superior versus inferior gland origin and has implications for operative risk to the RLN.
- Parathyroid adenomas are lower in attenuation than the normal (iodine-containing) thyroid gland on non–contrast-enhanced images. In the setting of chronic hypothyroidism (eg, Hashimoto disease), the thyroid parenchyma may appear abnormally hypoattenuating because of low iodine content, in which case parathyroid adenomas may appear similar in attenuation to that of abnormal thyroid gland on non–contrast-enhanced images. On contrast-enhanced images, adenomas are classically described as exhibiting higher attenuation than the thyroid in the arterial phase and lower attenuation than the thyroid (washing out) in the venous phase. However, this classic appearance is seen in only 20% of adenomas. In addition to varied enhancement patterns, parathyroid adenomas may also exhibit cystic foci, fat deposition, or calcification.
- The information that surgeons desire for purposes of operative planning includes the number, size, and specific location of candidate parathyroid lesions with respect to relevant surgical landmarks; the radiologist's opinion and confidence level regarding what each candidate lesion represents; and the presence or absence of ectopic or supernumerary parathyroid tissue, concurrent thyroid pathologic conditions, and arterial anomalies associated with a nonrecurrent laryngeal nerve.

hyperplasia (~6%), double parathyroid adenoma (~4%), and parathyroid carcinoma (<1%) (14). Surgical excision of the abnormal parathyroid tissue represents the only definitive cure.

Accurate and precise preoperative imaging localization of a single adenoma allows the surgeon to remove only the abnormal gland, which is desirable for both the surgeon and the patient. The most commonly performed and widely accepted imaging modalities for preoperative localization are US, nuclear medicine imaging, and multiphase (so-called four-dimensional [4D]) CT (1). Among these, 4D CT has been shown to have several advantages, including superior diagnostic performance in most comparative studies (15–19), as well as relative effectiveness in challenging clinical scenarios, such as nonlocalizing US and/or nuclear medicine imaging results (18,20,21), multiglandular disease (MGD) (18,22,23), and recurrent PHPT (18,24,25). However, in order for the potential advantages of 4D CT to be realized for a given patient, the interpreting radiologist must have the requisite knowledge and expertise to provide an accurate interpretation, and many radiologists find 4D CT image interpretation to be intimidating, time-consuming, and difficult.

The goals of this article are *(a)* to provide the radiologist with an accessible and practical approach to performing and interpreting parathyroid 4D CT images; *(b)* to detail what the surgeon really wants to know from the radiologist and why; and *(c)* to review the relevant operative considerations, anatomy, and embryology with which the radiologist should be familiar to provide clinically useful image interpretations that aid formulation of the operative plan. A corresponding structured report template outlining the key information desired by the surgeon is available at *https://radreport.org/home/50801*.

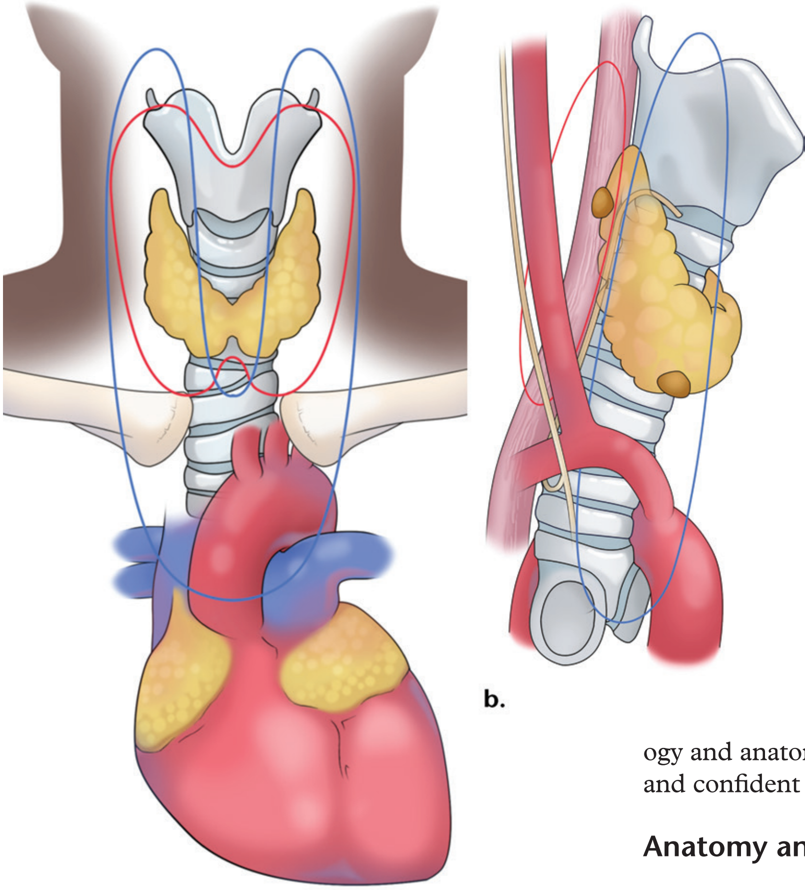
Relevant Background

Operative Strategies

Commonly performed operations for PHPT include bilateral neck exploration (BNE) and minimally invasive parathyroidectomy (MIP). BNE is the original parathyroid operation and involves examination of all parathyroid glands, with resection of diseased glands (26). This operation can often be performed with a single 2.5-cm midline incision. However, a larger incision is required in cases of ectopic or supernumerary glands (26). BNE places both recurrent laryngeal nerves (RLNs) at risk. However, the morbidity is considered to be low in experienced hands. BNE achieves excellent (>95%) long-term PHPT cure rates (27).

MIP is a unilateral operation that involves removing only the affected gland and is therefore less invasive than BNE. The demonstrated benefits of MIP include shorter operating times, shorter length of stay, lower cost, and smaller incisions associated with improved cosmesis (28,29). In experienced hands, the cure rates with MIP are equivalent to those of BNE (27). When appropriate, MIP is therefore preferred over BNE in many centers. However, MIP requires confident and precise preoperative localization of a single parathyroid adenoma. Thus, the radiologist provides the essential information allowing for MIP.

Given the high frequency of uniglandular disease and the surgeon's desire to offer the patient the benefits of MIP, many surgeons choose to perform preoperative imaging in all patients with



a. b.

Figure 1. Potential anatomic sites of superior (red outline) and inferior (blue outline) parathyroid glands on frontal **(a)** and lateral **(b)** views. On the frontal view, there appears to be considerable overlap. However, the superior glands (tan structure within red outline in **b**) consistently lie posterior to the RLN, whereas the inferior glands (tan structure within blue outline in **b**) lie anteriorly.

PHPT. Moreover, because of the higher risks associated with repeat parathyroid surgery, recent international guidelines (30) state that preoperative localization is mandatory in the subset of patients with persistent or recurrent PHPT after previous parathyroid surgery.

Imaging Role and Rationale

PHPT is diagnosed biochemically. All patients who undergo imaging should have biochemically proven PHPT, and the goal of imaging is localization, not diagnosis. Precise localization of a single adenoma facilitates MIP, whereas successful localization of MGD aids in BNE planning. If the imaging interpretation is nonlocalizing, the patient remains an operative candidate. However, performing BNE will likely be necessary.

The ideal parathyroid imaging professional is a vital contributor to a successful MIP program who substantially impacts patient care by aiding in the realization of MIP benefits. US, nuclear medicine imaging, and 4D CT are all valuable PHPT imaging techniques with relative strengths and weaknesses. The ideal parathyroid imaging professional is comfortable with and able to correlate the findings obtained from various imaging modalities and uses detailed knowledge of parathyroid embryology and anatomy to maximize chances of accurate and confident preoperative localization.

Anatomy and Embryology

Parathyroid.—Most commonly, there are four parathyroid glands: two superior and two inferior. In an autopsy series, fewer than four glands were reported in 3%–6% of individuals, and more than four glands were found in 5%–13% (31). Knowledge of parathyroid embryology informs the search for both orthotopic and ectopic parathyroid tissue (Fig 1).

The superior parathyroid glands derive from the fourth pharyngeal pouch, and their relatively limited embryologic migration accounts for their relatively constant position within the neck. The superior parathyroid glands are typically found along the posterior aspect of the thyroid gland superior pole (~80%), between the level of the cricoid and thyroid cartilages (31). Less commonly, the superior parathyroid glands are found in retropharyngeal or retroesophageal positions.

The inferior parathyroid glands derive from the third pharyngeal pouch, as does the thymus. The relatively long migration of the inferior parathyroid glands to reach their final anatomic position is thought to explain the more variable position of the inferior glands, ranging from the angle of the mandible to the pericardium. Nonetheless, the inferior parathyroid glands are most commonly found within 1 cm of the thyroid gland lower pole (~50%) (31).

An important and potentially counterintuitive fact is that relative superior or inferior position of

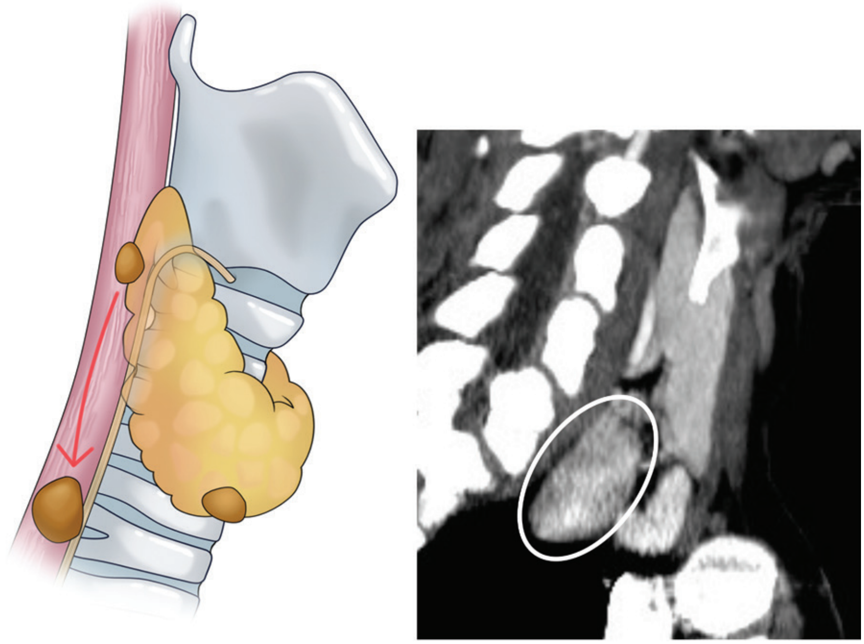


Figure 2. Illustration **(a)** and sagittal arterial phase CT image **(b)** show inferior descent (acquired ectopia) of an enlarged superior parathyroid gland (arrow in **a**, oval in **b**). The enlarged superior gland may extend below the level of the inferior gland, as depicted in the illustration. As such, relative superior or inferior position of a parathyroid lesion does not reliably denote embryologic origin.

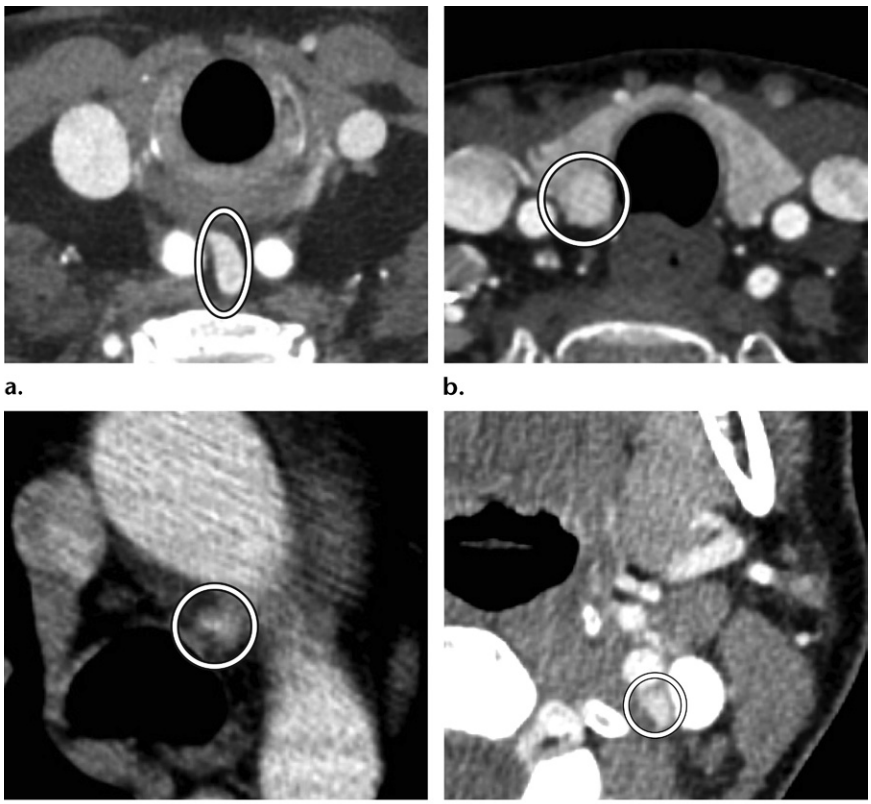
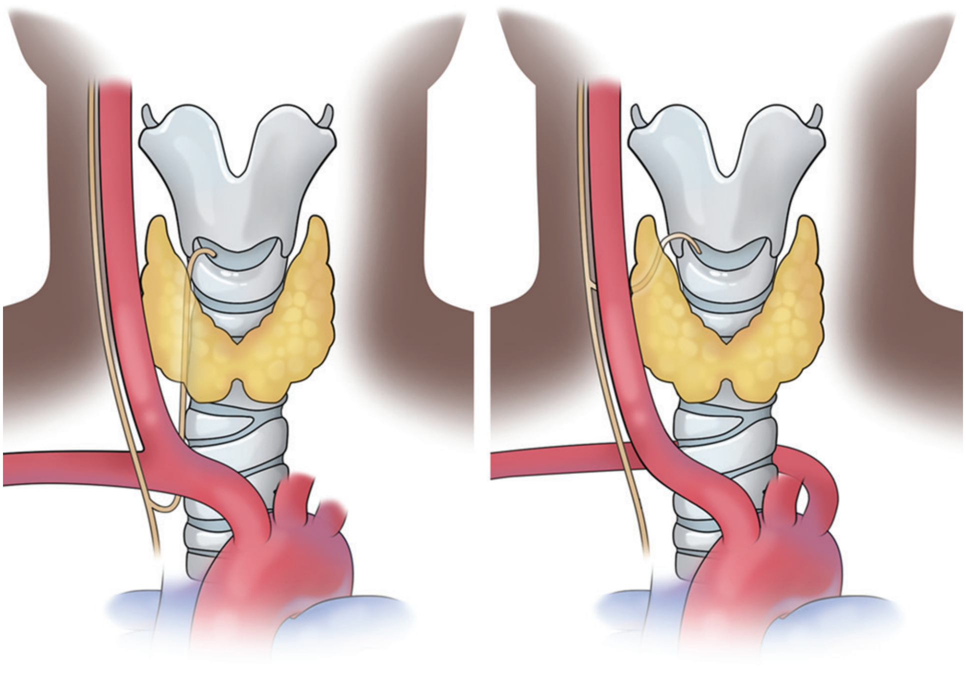


Figure 3. Axial arterial phase CT images in four patients show common locations of ectopic parathyroid glands (oval in **a**, circles in **b–d**), including retropharyngeal **(a)**, intrathyroidal **(b)**, and mediastinal **(c)** locations and within the carotid sheath **(d)** near the angle of the mandible.

a parathyroid gland does not reliably denote its embryologic origin. Not infrequently, an enlarged superior parathyroid gland will descend into the superior mediastinum (Fig 2), a phenomenon referred to as acquired ectopia (31). The plane of the RLN, which is approximated by the tracheoesophageal groove, more reliably distinguishes between superior and inferior glands, with the superior glands positioned posteriorly (dorsal) with respect to the RLN and the inferior glands positioned anteriorly (ventral) (31).

As many as 16% of parathyroid glands are ectopic in location (Fig 3), more commonly the inferior glands than the superior (32). Ectopic



a. b.

Figure 4. Frontal views of the course of the right RLN in the setting of normal **(a)** and variant **(b)** right subclavian artery anatomy. Normally, the right RLN arises from the right vagus nerve as the vagus passes anterior to the right subclavian artery. The RLN then loops beneath the right subclavian artery before ascending within the right tracheoesophageal groove to enter the larynx near the cricothyroid joint. In the setting of an aberrant right subclavian artery, both the branch point from the vagus and the subsequent path to the larynx are variable but are depicted here as a direct course.

superior parathyroid glands are most frequently found in retropharyngeal or retroesophageal positions (33). Ectopic inferior parathyroid glands are most often within the thyrothymic ligament, mediastinum, carotid sheath, or thyroid parenchyma (33).

Recurrent Laryngeal Nerve.—Protection of the RLN is of high importance to the surgeon during parathyroid surgery. As such, a priority of the radiologist should be to identify and report anatomic variants that place the nerve at increased operative risk. To better understand normal and variant anatomy of the RLN, a brief embryologic discussion is warranted.

The RLNs derive from the sixth pharyngeal arch. When the fifth aortic arch and distal portions of the sixth aortic arch regress, the RLNs remain anchored to fourth pharyngeal arch structures, specifically the subclavian artery on the right and the aortic arch on the left (31). The RLNs normally descend into the thorax with these arterial structures, which accounts for their typical recurrent course.

However, the normal descent of the right RLN is altered in the setting of an aberrant right subclavian artery (Fig 4). Similarly, the normal descent of the left RLN is altered in the setting of a right aortic arch with an aberrant left subclavian artery. In these situations, the respective RLN exhibits a variant nonrecurrent course (31).

Although relatively uncommon, the nonrecurrent laryngeal nerve is of considerable significance to the surgeon because the typical operative landmarks used for finding and protecting the nerve are less reliable. As a result, the nonrecurrent laryngeal nerve is at substantially increased risk of operative injury (up to 13%) (34), particularly if the surgeon is not alerted to this anatomic variant preoperatively. Thus, the radiologist should specifically look for and report the presence of aberrant right subclavian arteries and right aortic arches with aberrant left subclavian arteries.

Four-dimensional CT

Approach

When interpreting parathyroid 4D CT images, the radiologist's goal is to provide the surgeon with a detailed and accurate road map of the neck of the patient with PHPT, cataloging candidate parathyroid lesions and meticulously describing their locations with respect to relevant surgical landmarks. The question radiologists are asked to answer is not "Does the patient have PHPT?" but rather "Where is the abnormal parathyroid tissue located?"

On the basis of input from our surgeons, we advocate describing lesions relative to the cricoid cartilage and tracheoesophageal groove. The cricoid cartilage is consistently palpable, is able to be visualized in the standard operative field, and orients the surgeon to the anatomic midline, particularly in the reoperative neck. The plane of the tracheoesophageal groove informs superior versus inferior gland origin and has implications for operative risk to the RLN. The thyroid gland (eg, upper pole, lower pole, and isthmus) and suprasternal notch are also useful surgical landmarks. Describing lesions relative to the cervical vertebral level, although seemingly intuitive for the radiologist, is much less relevant for the surgeon because the cervical vertebrae are not useful operative landmarks.

When interpreting 4D CT images, the differential considerations (exophytic thyroid nodule and lymph node) are fortunately relatively limited. Unfortunately, the abnormal parathyroid glands can be small, and both their location and number are variable. No matter how many candidate lesions are found, there is always the risk that an additional unidentified parathyroid lesion is present. Obtaining high-quality images is critically important for interpretation accuracy and confidence.

Once high-quality images have been obtained, the typical and atypical sites of the parathyroid glands should be carefully searched on images from all CT phases. Typical and atypical 4D CT features of parathyroid lesions are subsequently described with accompanying pearls for interpretation. For additional interpretative tips and traps, we recommend Hoang et al's (35) 2014 article. Practically speaking, we advise viewing with suspicion anything that cannot be confidently classified as thyroid tissue, a lymph node, or a blood vessel. Descriptions of candidate lesions are most useful when accompanied by the radiologist's opinion of what the lesion represents and level of diagnostic confidence. If other parathyroid imaging has been performed, careful review of these images, particularly US images, for concordance with the putative 4D CT image interpretation results may substantially improve diagnostic confidence. Diagnostic confidence (or lack thereof) has implications for the operative plan and in certain high-risk scenarios (eg, reoperative neck) may impact whether an operation is offered at all.

The importance of comparing one's 4D CT image interpretation with the subsequent operative findings cannot be overstated as the best way to improve the quality of one's future work. Doing so also demonstrates a high level of interest to referring surgeons and can help foster these important relationships.

Table 1: Parathyroid 4D CT Protocol

Protocol Features	Descriptions and Parameters
Scan coverage	Maxilla to carina for all phases (non–contrast enhanced, arterial, and venous)
Iodinated contrast material administration	100 mL (370 mg iodine/mL) injected at 4 mL/sec, followed by 40-mL saline flush
Arterial phase	30 sec after the start of injection
Venous phase	60 sec after the start of injection
Thickness (mm)	1.25
Interval (mm)	1
Tube voltage (kVp)	140
Tube current (automatic modulation) (mA)	Minimum 180, maximum 300
Noise index	10
Pitch	1.375
DFOV (cm)	25

Note.—DFOV = display field of view.

Image Acquisition

Although the optimal number of CT phases to use has not been established, we use a three-phase protocol consisting of non–contrast material–enhanced, arterial (beginning 30 seconds after start of contrast material injection), and venous (beginning 60 seconds after start of contrast material injection) phases. We elect to use the more penetrating kilovolt peak of 140 rather than 120 for this examination to minimize the potential for beam-hardening artifacts obscuring small lesions in the lower neck and upper mediastinum. The full acquisition parameters used at our institutions are provided in Table 1. The use of automatic tube current modulation leads to expected variability in CT radiation dose output. However, the volume CT dose index ($CTDI_{vol}$) typically ranges between 19 and 24 mGy (32-cm phantom), and the dose-length product (DLP) typically ranges between 400 and 600 mGy · cm per CT phase.

Appropriate concerns have been raised regarding patient radiation exposure with a three-phase protocol (36,37). However, we believe the benefits of increased diagnostic accuracy (38) likely outweigh the small attributable risk (39) in the typical middle-aged patient with PHPT. Dual-energy CT and associated postprocessing techniques can be used to generate a virtual noncontrast (VNC) image with potential for substantial CT radiation dose reduction by eliminating the true non–

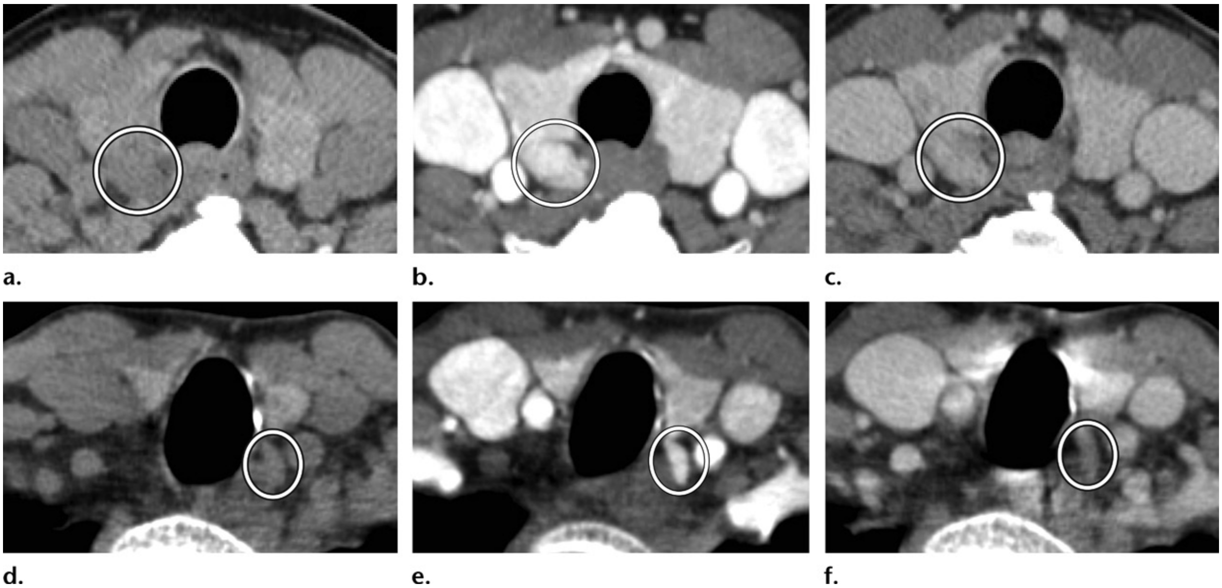


Figure 5. Classic parathyroid adenoma appearance at 4D CT in two patients. Images **a–c** were obtained in one patient, and images **d–f** were obtained in a second patient. Axial 4D CT images show that the parathyroid adenomas (circle) are hypoattenuating relative to the thyroid on non–contrast-enhanced images (**a, d**), are hyperattenuating on the arterial phase images **(b, e)**, and are hypoattenuating (washout) on the venous phase images **(c, f)**. This enhancement pattern is also referred to as type A.

contrast-enhanced phase. However, the intrinsic iodine within the thyroid gland is also masked by such techniques, such that the VNC images are an imperfect replacement for the (often useful) true non–contrast-enhanced images (40–42).

The use of shoulder-lowering positioning aids (eg, traction straps, improvised bedsheet) improves image quality through the lower neck and upper mediastinum, and a right arm iodinated contrast material injection is preferred when feasible to minimize streak and scatter artifacts within the central neck and superior mediastinum.

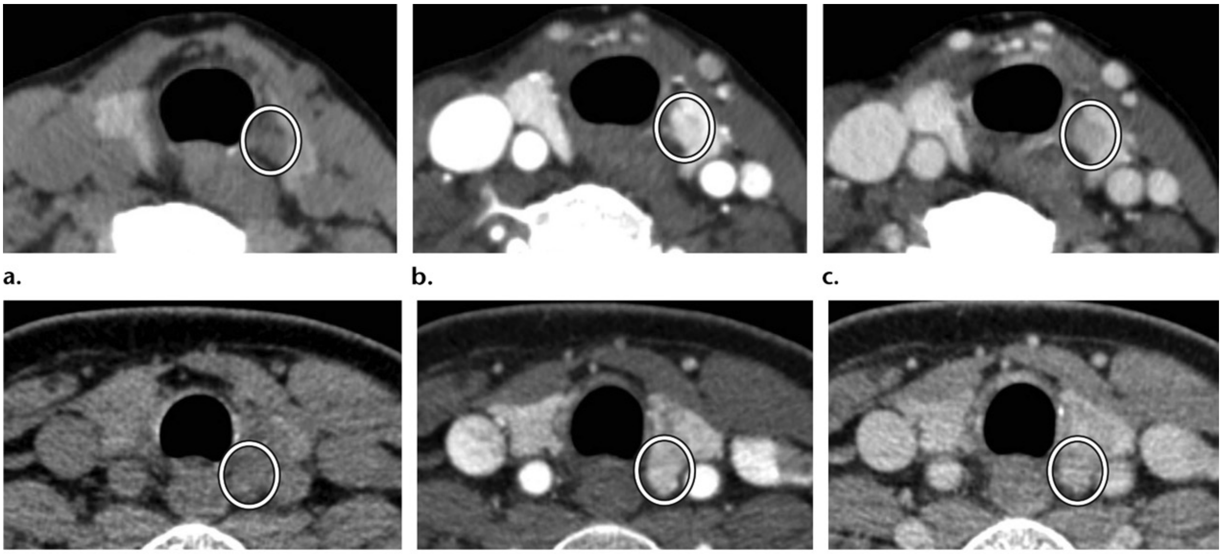
Image Interpretation

Parathyroid Lesions.—Parathyroid adenomas are lower in attenuation than the normal (iodine-containing) thyroid gland on non–contrast-enhanced images. In the setting of chronic hypothyroidism (eg, Hashimoto disease), the thyroid parenchyma may appear abnormally hypoattenuating because of low iodine content, in which case parathyroid adenomas may appear similar in attenuation to that of abnormal thyroid gland on non–contrast-enhanced images. On contrast-enhanced images, adenomas are classically described as exhibiting higher attenuation than the thyroid in the arterial phase and lower attenuation than the thyroid (washing out) in the venous phase (Fig 5). However, this classic appearance is seen in only 20% of adenomas (43). In addition to varied enhancement patterns (Fig 6), parathyroid adenomas may also exhibit cystic foci, fat deposition, or calcification (Fig 7). Knowledge of these variant appearances maximizes lesion detection. Finally, the presence of a polar vessel (Fig 8) (44) increases confidence that a lesion is of parathyroid origin, as opposed to the hilar blood supply of a lymph node.

Intuitively, MGD is more likely when multiple parathyroid lesions are identified (Fig 9). Perhaps counterintuitively, MGD is also more likely when no parathyroid lesions are identified (88% specificity) (23). Parathyroid lesions in MGD also tend to be smaller. More specifically, the largest candidate lesion identified at 4D CT measuring less than 7 mm is 79% specific for MGD, even when only a single lesion is identified (23). Imaging features favoring MGD are worth emphasizing to the surgeon because of the implications for the operative plan.

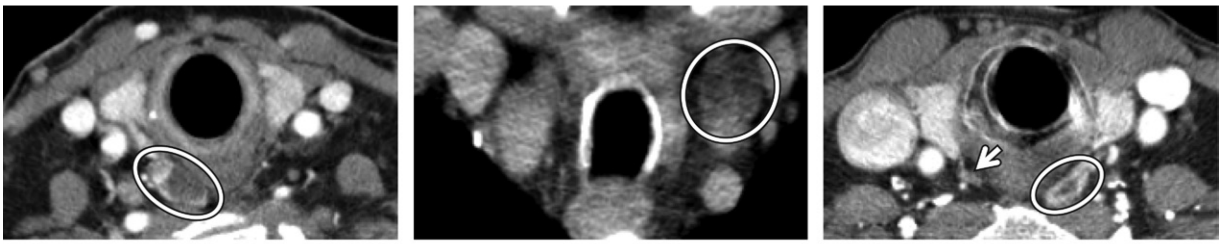
Parathyroid carcinoma is rare and difficult to diagnose preoperatively. Markedly elevated parathyroid hormone and young patient age are suggestive clinical features, and parathyroid calcifications (Fig 10) on images should raise suspicion, especially in large parathyroid lesions.

Thyroid Lesion.—Exophytic thyroid nodules may appear morphologically identical to parathyroid adenomas on contrast-enhanced images. However, careful scrutiny of the non–contrast-enhanced images often enables confident differentiation owing to increased attenuation relative to that of parathyroid lesions related to the intrinsic iodine content of thyroid tissue (Fig 11). If the radiologist suspects an exophytic thyroid nodule but is unable to confirm this suspicion using the non–contrast-enhanced CT images because of

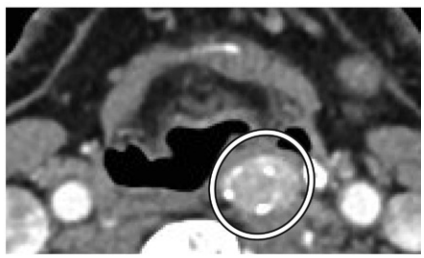


a. b. c.
d. e. f.

Figure 6. Variant parathyroid adenoma 4D CT enhancement patterns in two patients. Images **a–c** were obtained in one patient, and images **d–f** were obtained in a second patient. Axial 4D CT images show parathyroid adenomas (circle), which appear hypoattenuating relative to the thyroid on the non–contrast-enhanced images **(a, d)**. In the first patient **(a–c)**, the parathyroid adenoma is isoattenuating relative to the thyroid on the arterial phase image **(b)** and hypoattenuating on the venous phase image **(c)**. This enhancement pattern is referred to as type B. In the second patient **(d–f)**, the parathyroid adenoma is isoattenuating relative to the thyroid on both the arterial **(e)** and venous **(f)** phase images. This enhancement pattern is referred to as type C and illustrates the value of the non–contrast-enhanced phase for identification of the lesion.



a. b. c.



d.

Figure 7. Axial 4D CT images show variant parathyroid adenoma appearances (oval) in four patients, including internal cystic change **(a)**, internal fat **(b, c)**, and calcification **(d)**. Note the second pathologically proven parathyroid lesion in **c** (arrow), which emphasizes the importance of performing a thorough and systematic search even after identifying a parathyroid lesion with high diagnostic confidence.

the lack of sufficient iodine content within the thyroid gland or thyroid nodule, correlation with US when available is often useful. Parathyroid adenomas are typically hypoechoic, whereas thyroid nodules may commonly be isoechoic or hyperechoic relative to the thyroid gland.

If US has not yet been performed, reporting of thyroid nodules aids the surgeon in identifying lesions requiring further preoperative workup (eg, US with or without fine-needle aspiration) for possible concurrent resection.

Lymph Node.—Lymph nodes may mimic parathyroid lesions morphologically and on non–contrast-enhanced images, as both are hypoattenuating relative to the thyroid gland. On contrast-enhanced images, lymph nodes exhibit progressive enhancement (more enhancement in the venous phase relative to that in the arterial phase), which would be unusual for parathyroid lesions. Identification of a fatty hilum is also useful for differentiation.

Suggested Search Pattern.—On the basis of the likelihood of finding a parathyroid lesion in each of the typical locations (45), we suggest the following search patterns for the superior and inferior parathyroid glands. To minimize the risk of missing supernumerary parathyroid tissue, it is important that the search patterns be followed

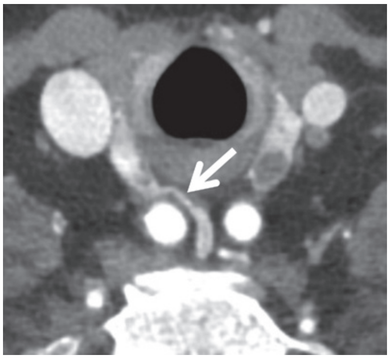
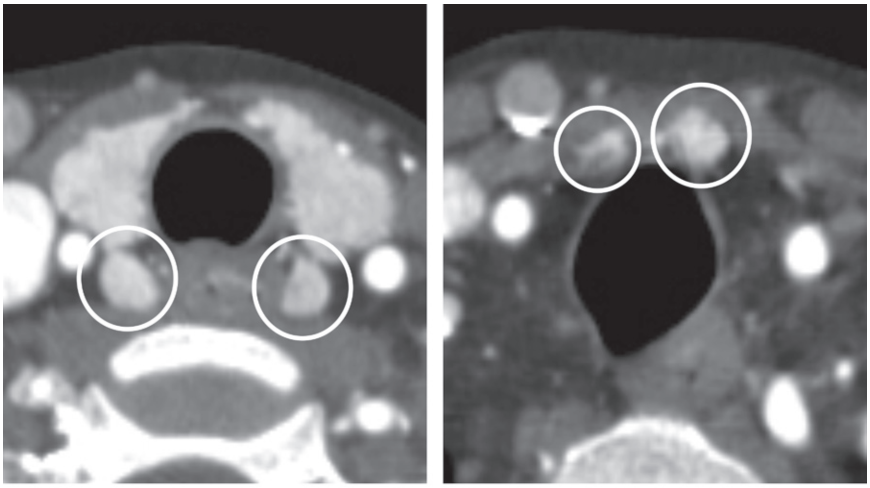
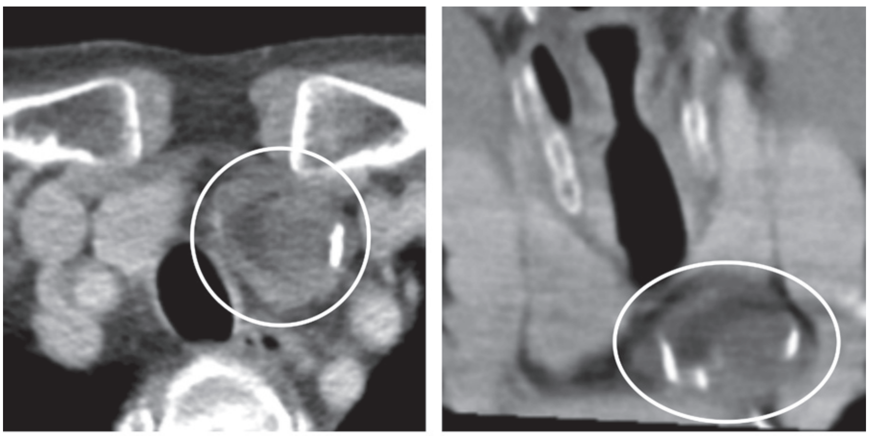


Figure 8. Axial arterial phase CT image shows a polar vessel (arrow) leading to a retroesophageal parathyroid adenoma. In contrast, vessels lead to the hilum of lymph nodes.



a. b.

Figure 9. Axial arterial phase CT images obtained at different levels show four mildly enlarged parathyroid glands (circles), findings consistent with MGD.



a. b.

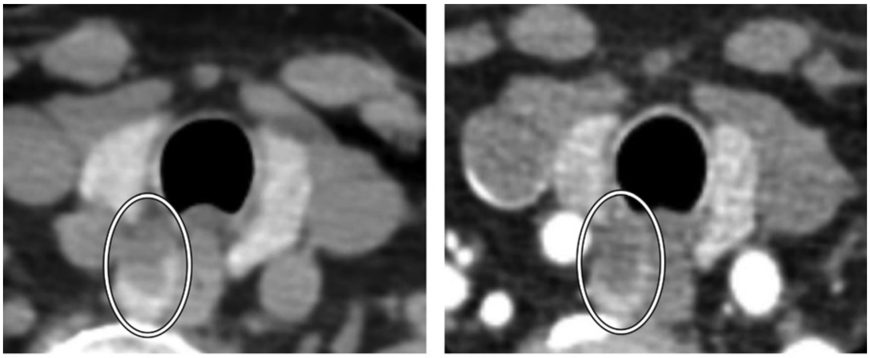
Figure 10. Axial **(a)** and coronal **(b)** venous phase CT images in a 16-year-old patient with markedly elevated parathyroid hormone levels show a heterogeneous partially calcified left inferior parathyroid lesion (oval), which was surgically resected. The results of histologic analysis confirmed parathyroid carcinoma.

through to completion, even if an obvious parathyroid lesion is identified early in the search.

In searching for the superior glands, start along the posterior aspects of the upper thyroid lobes (80%–95%) and then focus on retropharyngeal and retroesophageal (3%) positions. Much less commonly, the superior glands will be located within the carotid sheath (<1%), within the thyroid parenchyma (<1%), or in the scalene fat pad (<1%).

In searching for the inferior glands, start adjacent to the lower thyroid lobe (50%–60%) and then look along the thyrothymic ligament (25%) and within the mediastinum (3%). Much less commonly, the inferior glands will be within the carotid sheath (<1%) or intrathyroidal (<1%).

Reporting What the Surgeon Wants to Know.—The information that surgeons desire for purposes of operative planning includes the



a. b.

Figure 11. Axial non–contrast-enhanced **(a)** and arterial phase **(b)** CT images show an exophytic thyroid nodule (oval) arising from the posterior aspect of the right thyroid lobe. Note that the posterior aspect of the nodule appears isoattenuating relative to the thyroid gland on the non–contrast-enhanced image. This lesion could be mistaken for a parathyroid adenoma if the non–contrast-enhanced image were not carefully evaluated.

Table 2: What the Surgeon Wants to Know for Operative Planning for PHPT

What the Surgeon Wants to Know	Why this Information Is Important
Number of candidate lesions	Single lesion strongly favors parathyroid adenoma (MIP candidate); no lesion and multiple lesions favor MGD (BNE likely necessary)
Size of candidate lesions	Lesion larger than 13 mm favors adenoma; lesion less than 7 mm (even if single) favors MGD
Lesion location	Facilitates planning of incision and operative approach; be specific and describe with respect to relevant surgical landmarks (eg, cricoid cartilage, tracheoesophageal groove, thyroid gland, and suprasternal notch)
Opinion and confidence level of what the lesions represent	When faced with high- and low-confidence lesions in the same patient, the surgeon may start with MIP of the highest confidence target, with a plan to convert to BNE if intraoperative PTH levels do not respond appropriately
Ectopic or supernumerary parathyroid tissue	Implications for operative plan and approach
Concurrent thyroid pathologic condition	May require further preoperative workup and possible concurrent resection of suspicious or malignant nodules
Arterial anomalies associated with NRLN (aberrant right subclavian, most commonly)	Increased risk of operative injury to the nerve

Note.—NRLN = nonrecurrent laryngeal nerve, PTH = parathyroid hormone.

number, size, and specific location of candidate parathyroid lesions with respect to relevant surgical landmarks; the radiologist's opinion and confidence level regarding what each candidate lesion represents; and the presence or absence of ectopic or supernumerary parathyroid tissue, concurrent thyroid pathologic conditions, and arterial anomalies associated with a nonrecurrent laryngeal nerve. Table 2 provides accompanying explanations of why this information is important. As previously mentioned, a proposed structured report has also been provided.

Conclusion

PHPT contributes to substantial morbidity and health care costs. The disease is diagnosed by the results of biochemical testing and cured with surgical removal of the abnormal gland(s). The role of imaging is preoperative localization, which facilitates MIP when appropriate and otherwise aids BNE planning. The radiologist's knowledge of relevant embryology and anatomy maximizes localization success. By accurately reporting and concisely addressing the key information the surgeon desires from parathyroid 4D CT image interpretation, the radiologist substantially impacts patient care by enabling the surgeon to develop and execute the best possible operative plan for each PHPT patient. Finally, comparison of the radiologist's preoperative 4D CT image interpretation with the surgeon's operative findings is imperative for continually refining the radiologist's preoperative localization skill set.

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