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Canadian Association of Radiologists Journal 64 (2013) 258−268
CANADIAN ASSOCIATION OF RADIOLOGISTS JOURNAL
www.carjonline.org

Neuroradiology / Neuroradiologie

Preoperative Localization of Parathyroid Adenomas Using 4-Dimensional Computed Tomography: A Pictorial Essay

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Abstract

Accurate preoperative localization is the key to successful parathyroid surgery in the era of minimally invasive parathyroid surgery. This article presents and discusses the embryologic basis of parathyroid gland and ectopic location and different imaging modalities helpful in diagnosing and localizing parathyroid adenomas and/or hyperplasia. We also aim to review the current surgical concepts in treatment of parathyroid adenomas and/or hyperplasia, the utility of 4-dimensional computed tomography for accurate preoperative localization of hyperfunctioning parathyroid glands, imaging classification of adenomas and/or hyperplasia, and, finally, present some of the limitations of 4-dimensional computed tomography.

Résumé

Il est essentiel d'effectuer une localisation préopératoire exacte pour assurer la réussite d'une chirurgie des parathyroïdes en cette ère de chirurgie parathyroïdienne à effraction minimale. Cet article présente et analyse les bases embryologiques des glandes parathyroïdes et de l'emplacement ectopique, ainsi que les différentes modalités d'imagerie pouvant aider à diagnostiquer et à localiser les adénomes parathyroïdiens et l'hyperplasie des glandes thyroïdes. Nous visons également à analyser les concepts chirurgicaux qui régissent actuellement le traitement des adénomes parathyroïdiens et l'hyperplasie des glandes parathyroïdes, l'utilité de la tomodensitométrie quadridimensionnelle pour la localisation préopératoire exacte de glandes parathyroïdes hyperactives et la classification des images d'adénomes et d'hyperplasie et enfin, à présenter certaines limites de la tomodensitométrie quadridimensionnelle.

Primary hyperparathyroidism (PHPT) is characterized by overproduction of parathyroid hormone (PTH) with high normal or increased serum calcium concentrations. The causes of PHPT include single adenomas (85%), double adenomas (2%-12%), multigland disease (MGD) (5%-15%), and, rarely, parathyroid carcinomas (<1%) [1−3]. PHPT may be symptomatic and present clinically with renal calculi, osteoporosis, neuropsychiatric symptoms, peptic ulcer disease, or pancreatitis. In the past few decades, the diagnosis of PHPT has become more common due to routine serum calcium measurements introduced in the 1970s [4]. The diagnosis in such cases is made biochemically, with no obvious symptoms; in fact, such patients may have vague neurocognitive symptoms or altered quality of life (pain, fatigue, depression, etc) that may not be recognized as being associated with PHPT [5].

Over the past decade, the surgical treatment of parathyroid disease has changed considerably. Surgical treatment of PHPT due to parathyroid adenoma or hyperplasia is successful in 95% of cases in which traditional bilateral 4-gland exploration is performed [6]. More recently, unilateral minimally invasive directed parathyroidectomy (MIP) has been preferred because it minimizes operative complications [7]. When combined with intraoperative PTH assay, this technique demonstrates high cure rates and low complications rates, and avoids both general anesthesia and overnight hospital stays associated with classic bilateral neck exploration [8]. High-quality preoperative localization imaging is important to the success of these strategies [9,10].

Imaging modalities such as sonography and sestamibi-SPECT (single photon emission computed tomography) demonstrate high specificity when concordant but suboptimal sensitivity in most hands. In addition, ectopic

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http://dx.doi.org/10.1016/j.carj.2012.03.002

parathyroid adenomas, located in sonographically inaccessible regions such as the mediastinum, benefit from evaluation with a cross-sectional imaging technique [11].

Four-dimensional (4D) computed tomography (CT) addresses many of the drawbacks of existing technology and is a novel method of multiphase CT imaging [10,12–14]. Moreover, 4D-CT is a rapid study, easily reproducible, and provides high-resolution anatomic detail useful for surgical planning. In several recent series, CT was found to be more sensitive than other modalities in localizing parathyroid adenomas [10,13].

Embryology and Anatomy

There are 2 superior and 2 inferior parathyroid glands in most individuals. The superior parathyroid glands along with the lateral lobes of the thyroid originate from the fourth pharyngeal pouch (Figure 1), and, as they lose their attachment with the pharyngeal wall, they attach to the posterior surface of the caudally migrating thyroid [15,16]. They have a much shorter migration distance compared with the inferior parathyroid glands, which accounts for their more predictable location [17]. They generally are at the level of the upper two-thirds of the thyroid gland. The inferior glands arise from the third pharyngeal pouch along with the thymus gland (Figure 1). While the dorsal wing of the third pharyngeal pouch gives rise to the inferior parathyroid glands, the ventral wing gives rise to the thymus [15]. As the primitive inferior parathyroid glands lose their connection with the pharyngeal wall, they join the thymus as it travels caudally and medially to its final position in the mediastinum [15,18]. This migration of the inferior parathyroid glands with the thymus accounts for the fact that they are usually found in a plane ventral to that of the superior parathyroid glands [18], and, for the same reason, ectopic inferior parathyroid glands can be found anywhere along this large area of descent up to the superior border of the pericardium [19] but are most commonly located inferior, posterior, or lateral to the lower thyroid pole (69%) (Figure 2) [9]. Because of normal embryologic migration of the parathyroid glands, there are characteristic locations in which to look for adenomas: the midline of the neck between the lateral margins of the carotid spaces and anterior or anterolateral to the spine [11]. Craniocaudally most are located between the hyoid and tracheal carina, posterior to the thyroid gland [14,20].

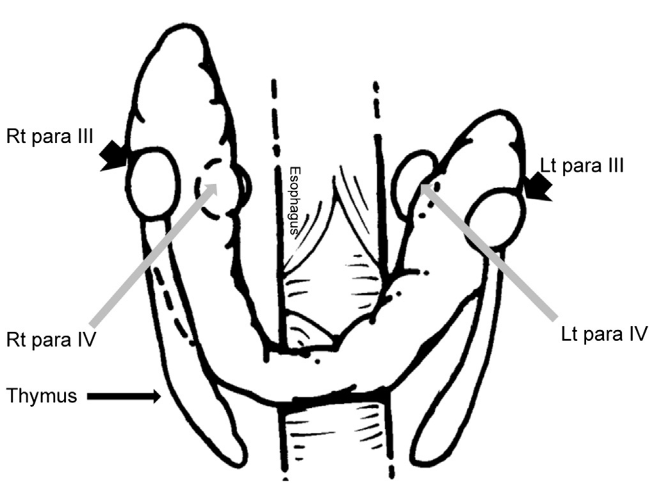

Figure 1. The superior parathyroid glands (long grey arrows) arise embryologically from fourth (IV) pharyngeal pouch and descend only slightly during embryologic development. The inferior parathyroid glands (short black arrows) arise from the third (III) pharyngeal pouch along with the thymus; hence, they often descend with the thymus (long black arrow).

Although oropharyngeal or parapharyngeal adenomas have been reported, they are rare [20]. As a general rule, ectopic adenomas in the upper neck are posteriorly located in the retropharyngeal or retrovisceral spaces, although they may be adjacent to the carotid space. Below the thyroid and in the upper mediastinum, adenomas are typically anteriorly positioned within the thymus or ventral mediastinum (Figure 2) [20]. The reported incidence of ectopic adenomas ranges from 20%-25% of cases of PHPT [11,13]. Ectopic locations for parathyroid adenomas include the following: paraesophageal-retroesophageal region (Figure 3), intra-carotid sheath (more commonly inferior glands) (Figure 4), mediastinal (Figure 5), intrathyroidal (more commonly superior glands), retropharyngeal (more commonly superior glands), intraneural sites, and associated with the thymus (more commonly inferior glands) [14,20–22]. An understanding of these variations and normal migration patterns of parathyroid glands is not only of utmost importance to the surgeon who is planning to resect a hypersecreting adenoma but also to the radiologist because it helps guide the radiologist's attention when reviewing scans [11].

Current Surgical Concepts for Parathyroid Adenoma and/or Hyperplasia

Parathyroidectomy is the only curative therapy for PHPT. Any symptomatic PHPT should be referred for surgical intervention. Most patients with hyperparathyroidism are "asymptomatic" and to address the management of these asymptomatic patients, the National Institutes of Health Consensus Development Panel recommended parathyroidectomy for the following asymptomatic patients: (a) patients <50 years old, (b) patients who cannot participate in appropriate follow-up, (c) patients with a serum calcium level >1.0 mg/dL above the reference range (8-10mg/dL), (d) patients with a urinary calcium level >400 mg for 24 hours, and (e) patients with a >30% decrease in renal function [23].

The treatment goal for patients with PHPT is operative excision of an adequate amount of hyperfunctioning parathyroid tissue to render the patient eucalcemic after surgery [24]. The criterion standard for many decades for the treatment of PHPT is bilateral neck exploration, with the patient under general anesthesia, for removal of hyperfunctioning parathyroid glands, with a cure rate of 90%-95% in the hands of an experienced endocrine surgeon [25–27]. A transverse cervical incision is made approximately 2 cm above the sternal notch, just below the cricoid cartilage, which permits identification of all 4 glands and allows access to nearly all

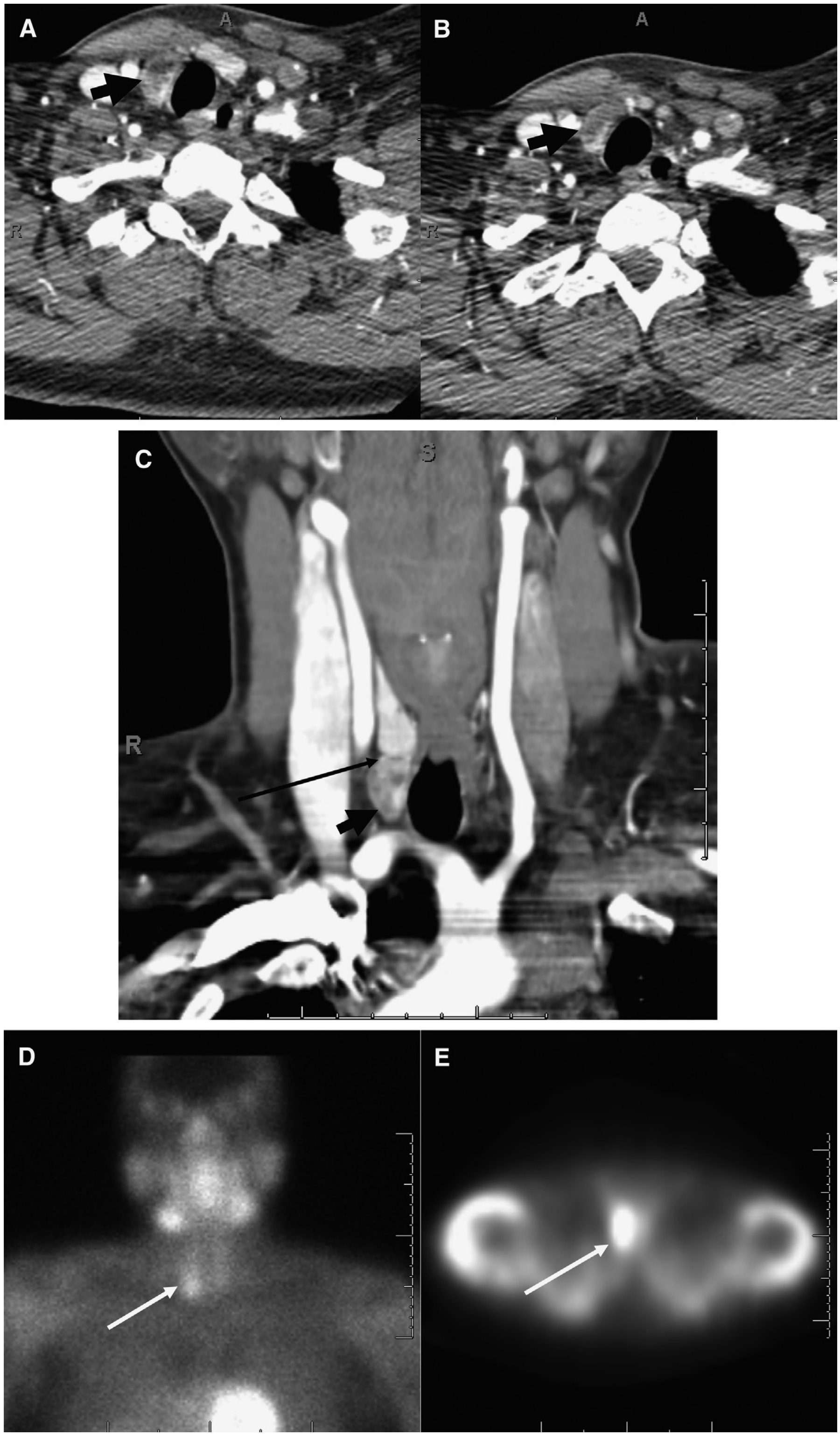

Figure 2. Consecutive axial 4-dimensional (4D) computed tomography (CT) in the venous phase from superior (A) to inferior (B), showing heterogeneously enhancing adenoma (short black arrows) at the posterior inferior margin of the right thyroid gland. The adenoma is in the anterior-posterior plane of thyroid and anterior to trachea. A coronal view from a 4D-CT study in the venous phase (C), showing heterogeneously enhancing adenoma (short black arrow) inferior to right lobe of the thyroid gland with the cleavage plane between adenoma and thyroid gland (long black arrow). Delayed sestamibi scans (D, E) shows persistent asymmetric radiotracer activity (white arrows) adjacent to thyroid gland posterior and inferior to inferior pole of the right thyroid gland.

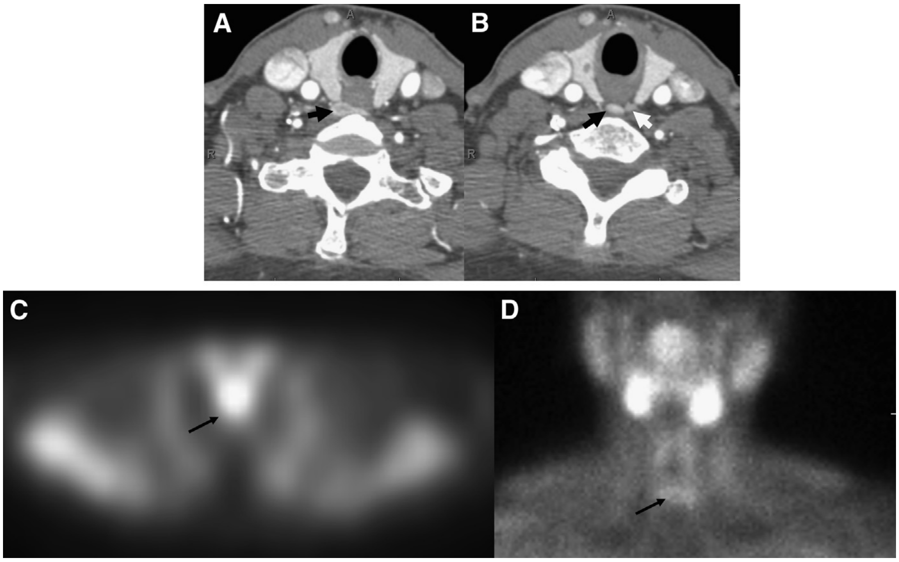

Figure 3. A 71-year-old woman with hypercalcemia noted on laboratory examination and who also had symptoms suggestive of osteoporosis. Axial 4-dimensional computed tomography from caudal (A) to cranial (B) in arterial phase shows an adenoma in the retroesphageal region (black arrows) that is straddling the midline. At the superior aspect of this retroesophageal adenoma is a small, rounded area of enhancement (white arrow) just posterior and medial to posterior aspect of middle third of the left lobe of thyroid gland. This is separate from the thyroid gland and is separate from the much larger retroesophageal adenoma. Delayed sestamibi scans (C, D) showing abnormal radiotracer accumulation on the delayed images about the midline (thin black arrows) just proximal to the thoracic inlet which is suspicious for a parathyroid adenoma. The more superior left sided lesion was not visualized on the nuclear scan.

ectopic parathyroid sites. This operation offers the surgeon the opportunity to inspect all 4 parathyroid glands and to resect the abnormal gland [28]. In cases of solitary parathyroid adenomas, all 4 glands are sampled, and the enlarged, adenomatous gland is resected [9], whereas for MGD, the approach involves either a subtotal 3.5-gland resection with cryopreservation or a total parathyroidectomy with autotransplantation into the forearm or neck muscle [9]. However, bilateral cervical exploration requires a larger incision, a longer operating time, and potentially higher morbidity. Because more than 85% of patients with PHPT have a single-gland adenoma, 4-gland exploration may not be necessary in most patients if the enlarged parathyroid gland can be identified and localized before surgery [29].

More recently, with improved preoperative localization, more targeted and focused surgical techniques have become available, collectively known as minimally invasive parathyroidectomy (MIP), with an approach to minimize surgical trauma that results in lower morbidity due to decreased operative time, reduced hospital stay, improved cosmetic result, use of local rather than general anesthesia, and no risk

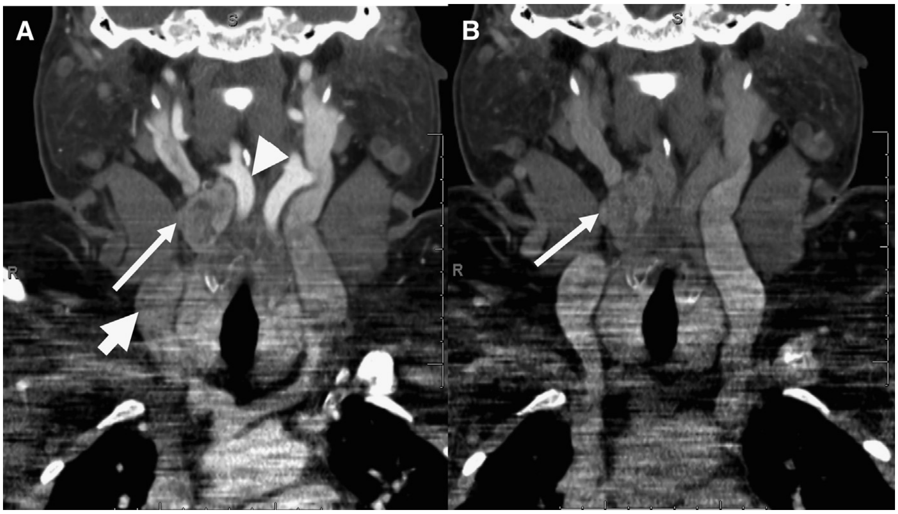

Figure 4. A 57-year-old woman who had routine laboratory workup, prior to knee surgery, which revealed hypercalcemia and elevated parathyroid hormone (PTH) levels (PTH = 296 pg/mL). Past medical history was significant for diabetes, hypertension, and renal stones. Coronal views from a 4-dimensional computed tomography study in the arterial phase (A) showing heterogeneously enhancing adenoma (long white arrows) superior to right lobe of thyroid gland situated within the carotid sheath, between and splaying internal jugular vein (short white arrow) and common carotid artery (white arrowhead). On the delayed images (B) there is washout of contrast within the adenoma (long white arrow).

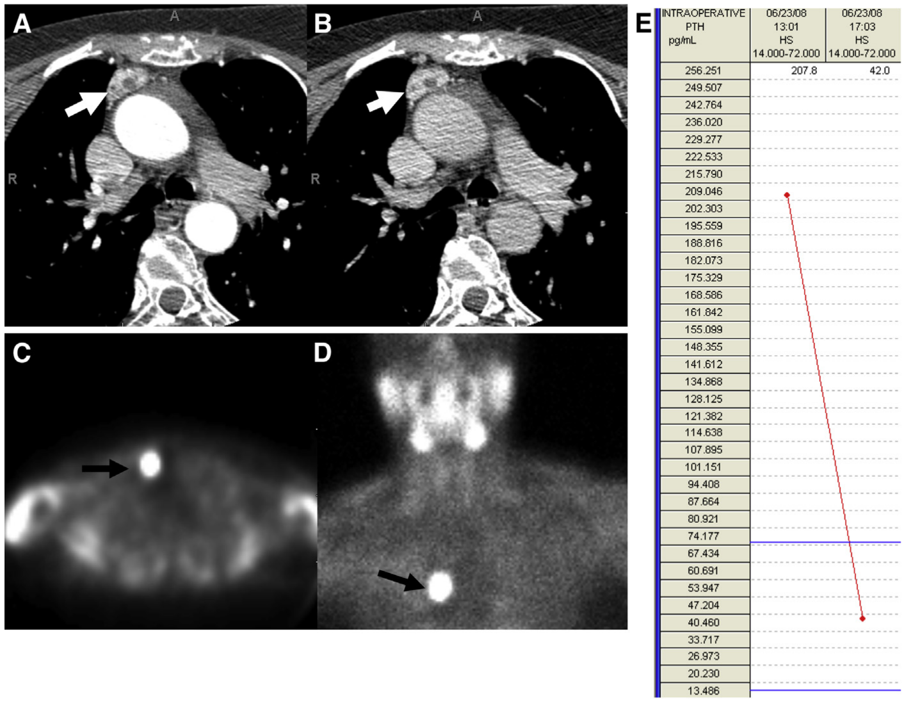

Figure 5. A 61-year-old woman with elevated calcium levels on biochemical profile. Axial 4-dimensional computed tomography images in the arterial (A) and venous phase (B) showing an anterior mediastinal adenoma (white arrows). The adenoma was not in continuity with thyroid gland and does not washout significantly on the delayed phase (white arrow) (B). Delayed sestamibi scans (C, D) shows persistent focal round area of intense radiotracer uptake within right anterior mediastinum (black arrows). At surgery the right inferior parathyroid gland was identified, noted to be very enlarged, and located in right thyrothymic ligament. Intraoperative parathyroid hormone (PTH) level (E) dropped from 207.8 to 42.0 after removal of the enlarged gland. This figure is available in colour online at http://carjonline.org/.

for permanent hypoparathyroidism [30–37]. Currently practiced minimally invasive techniques include unilateral open parathyroidectomy, video-assisted parathyroidectomy, and videoscopic parathyroidectomy [9]. The unilateral open technique involves a small unilateral transverse or lateral incision for access to the parathyroid adenoma [9]. The video-assisted technique is performed without insufflation by using a 5-mm endoscope and small conventional instruments through a 1.5-cm midline incision to identify and resect the abnormal gland or glands [9]. Videoscopic techniques use carbon dioxide insufflation to create a working space for dissection and use 3 small incisions and endoscopic instruments to remove the abnormal gland, usually from a lateral cervical approach [9].

MIP is guided by rapid intraoperative PTH assay, with a greater than 50% reduction in the peripheral venous PTH levels 10 minutes after parathyroid gland resection compared with the preexploration level, accurately predicts removal of all offending parathyroid tissue and is indicative of cure [9,29,38,39]. Intraoperative PTH is not uniformly used, and there are proponents who suggest use with every case [40], just as there are critics of the technique [41].

Preoperative Localization

Imaging has no role in the diagnosis of PHPT but is helpful for preoperative localization of enlarged parathyroid glands (adenomas and/or hyperplasia). If a minimally invasive operative approach is being considered, then preoperative localization is essential [5] and the goal of localization is to identify uniglandular disease and to help select patients most appropriate for unilateral and minimally invasive procedures [5,9,42].

A wide variety of imaging techniques, including sestamibi-based scintigraphy, ultrasonography, CT, magnetic resonance imaging, and more recently, 4D-CT have been used alone and in combination as first-line studies to localize abnormal parathyroid glands in patients with PHPT. Ultrasonography and technetium 99m–sestamibi scintigraphy are usually the first-line diagnostic modalities for routine preoperative imaging localization of a parathyroid adenoma because these tests are inexpensive, easy to perform, and have good detection rates [43]. Sestamibi-based scintigraphy has several major limitations, including poor anatomic detail of sestamibi scans that are done without CT, and its poor sensitivity in identifying patients with PHPT due to MGD. Anatomic detail can be improved with sestamibi-SPECT and SPECT-CT; however, this is time consuming, typically available in specialized centers, and images can be degraded by patient motion [44–46].

In contrast, ultrasonography provides good anatomic information about masses in the neck but is less informative about function. When used together, these imaging modalities complement each other and increase the success rate of MIP: nuclear medicine scan offers functional information, whereas ultrasound shows more detailed anatomic

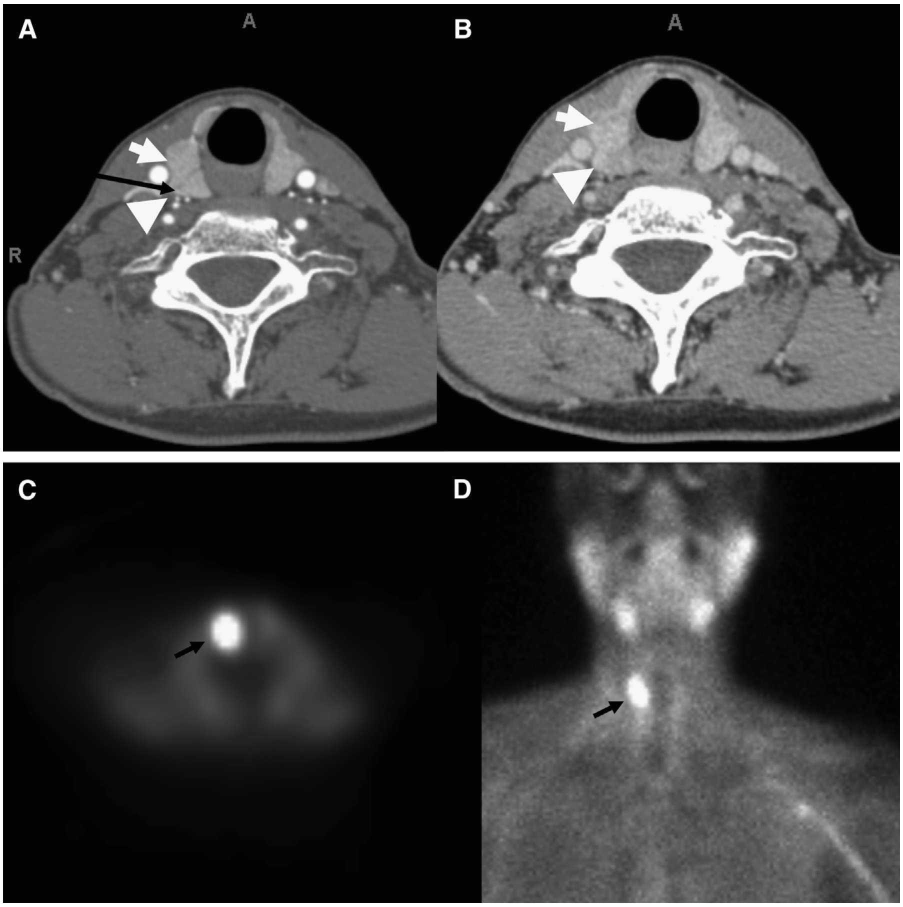

Figure 6. A 51-year-old woman found to have asymptomatic primary hyperparathyroidism on biochemical evaluation. Axial images from a 4-dimensional (4D) computed tomography (CT) examination in arterial (A) and venous (B) phase, showing an adenoma (white arrowheads) in close proximity to the posterior surface of upper lobe of right hemithyroid (white arrows), which enhances on the early arterial phase (A), with early washout on the venous phase (B). There is a cleavage plane between the adenoma and the thyroid gland (A, long black arrow). (C, D) Delayed sestamibi scans, showing focal persistent radiotracer uptake within the region of the upper aspect of the right lobe of the thyroid (short black arrows) consistent with parathyroid adenoma visualized on 4D-CT.

information [47–49]. However, sestamibi imaging and ultrasonography may still be inadequate for preoperative localization in patients with a history of previous neck surgery, in patients with coexisting thyroid disease (eg, thyroid nodules or Hashimoto thyroiditis), and in patients with an unfavorable body habitus (eg, obesity, short neck, or kyphosis) [10]. Most studies in the literature on parathyroid imaging report the ability of an imaging modality to localize and/or lateralize parathyroid tumours to the correct side of the neck [48,50–55]. Sensitivity for lateralization by ultrasonography varies from 61%-88% [48,50–55]; whereas sensitivity for lateralization by sestamibi varies from 68%-86% [48,51–55].

4D-CT

4D-CT allows identification of hyperfunctioning parathyroid glands; the name is derived from 3-dimensional CT scanning with an added ‘‘fourth’’ dimension that represents the perfusion information derived from noncontrast, arterial, and delayed (venous) phase imaging [10,14]. The images that are generated by 4D-CT provide both anatomic and functional information (based on changes in perfusion) in a single study that can be easily interpreted (Figures 6, 7) [10]. The hyperfunctioning parathyroid glands demonstrate intense arterial phase enhancement with early washout in the venous phase of 4D-CT (Figures 6, 7) [10,13]. One of the challenges in interpretation of 4D-CT images is differentiation of parathyroid adenomas from exophytic thyroid nodules. A recent study by Vu et al [56] that used muliphasic multidetector CT with unenhanced, arterial, venous, and delayed phases, showed that (a) parathyroid adenomas had lower baseline density than thyroid glands on unenhanced images, (b) parathyroid adenomas showed a greater increase in density from baseline to arterial phase than normal thyroid tissue on the enhanced scans, and (c) parathyroid adenomas washout contrast much faster than thyroid tissue in the venous and delayed phases (Figure 7) [56], which allows easy differentiation from thyroid nodules (minimal arterial phase and persistent venous enhancement). Another potential challenge while interpreting a 4D-CT includes differentiating parathyroid adenomas from normal lymph nodes and vascular structures. Lymph nodes do not show arterial phase enhancement and are most often isoenhancing relative to

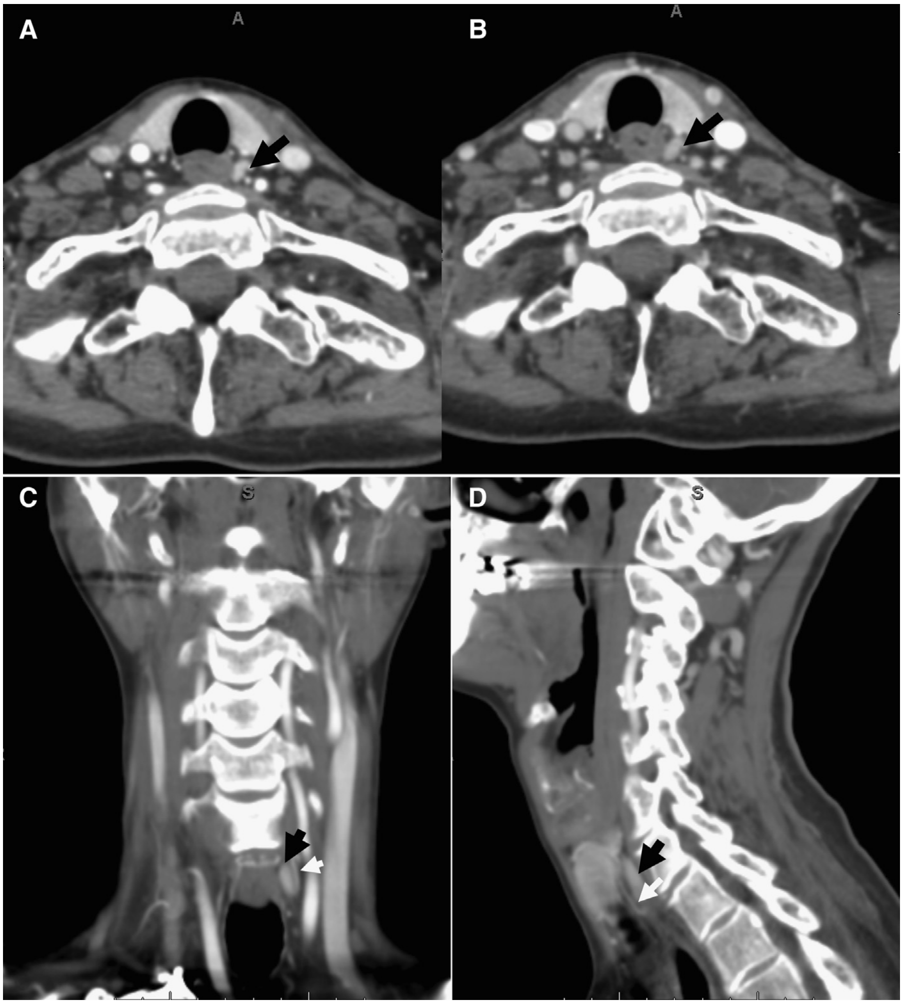

Figure 7. Axial images of a 4-dimensional (4D) computed tomography (CT) study in the arterial (A) and venous (B) phase, showing an adenoma (black arrows) posterior to left inferior third of thyroid. (B) On the venous phase, there is washout of this adenoma when compared with the thyroid gland. Coronal (C) and sagittal (D) reconstructions from a 4D-CT study in the arterial phase, showing the adenoma (black arrows) adjacent to the posterior aspect of the inferior portion of the left hemithyroid. Along its lateral margins is the inferior thyroidal artery (white arrows).

adjacent muscles [11]. Vascular structures can be identified by carefully tracking them in the CT performed during early arterial phase enhancement [11].

4D-CT showed significantly improved sensitivity for precise localization to a quadrant of the neck (range, 70%-88%) compared with both sestamibi scanning (range, 33%-65%) and ultrasonography (range, 29%-57%) [10,13]. More recently, Chazen et al [57] determined the accuracy of 4D-CT to correctly lateralize adenomas to be 93%, which allows the surgeon to perform a unilateral neck dissection with associated decreased morbidity and length of hospital stay. 4D-CT has also been shown to have better sensitivity for the detection of MGD, which is a common cause for repeated surgery (Figure 8) [10], with sensitivity that ranges from 44%-45% in detecting MGD [10,57], and 100% specificity for ruling out MGD [57]. This is in sharp contrast to sestamibi, which identified MGD in only 9%, and ultrasound, which was not able to recognize MGD, in a study done by Rodgers et al [10]. In addition, the finding of MGD on preoperative 4D-CT changed the operative approach (ie, from MIP to a 4-gland exploration) in some of their patients [10]. A recent study by Eichhorn-Wharry et al [58] showed that 4D-CT had an advantage in a specific subset of patients with mild hypercalcemia, elevated PTH, and smaller gland weights compared with sestamibi scanning.

Our practical experience in reviewing 4D-CT studies has shown a learning curve for identifying parathyroid adenomas, especially when they are ectopic. Familiarization with the usual appearance and locations of parathyroid adenomas leads to higher detection rates [11]. There are different imaging protocols for 4D-CT, with protocols that range from precontrast imaging to arterial, venous, and delayed phase imaging [10] to more modified 4D-CT protocols with 2 sets of CT imaging (one before the infusion of contrast and the second during and just after infusion of contrast) and no delayed imaging [45]. At our institute, the noncontrast phase has been removed from our protocol because we did not find that it helped with diagnosis, and it added to the radiation dose; this has also being described by other researchers [14]. We routinely obtain images presently in the arterial and venous phases only. Our protocol involves

Figure 8. A 31-year-old man with end stage renal disease and secondary hyperparathyroidism. Preoperative parathyroid hormone was 7376 pg/mL. (A-C) Axial images from a 4-dimensional (4D) computed tomography (CT) study in the arterial phase from superior to inferior, showing 3 adenomas. Two adenomas are located bilaterally along the posterior surface of the right and left lobes of the thyroid gland (black arrows). The largest lesion arises from the inferior aspect of the left lobe of the thyroid gland (short white arrow). (D) Coronal delayed sestamibi scan, demonstrating focus of increased radiotracer activity in the region of the inferior left thyroid lobe (long white arrow). The other 2 adenomas seen on 4D-CT were not visualized on the nuclear scan. At surgery, left inferior parathyroid gland was very large, along the lateral and inferior pole of the thyroid, right and left superior glands were enlarged. The right inferior parathyroid was identified within the thyrothymic tract and appeared normal.

imaging with a 16-slice or a 64-section multidetector row CT after intravenous administration of 100 mL of iodinated contrast (Optiray 350; Mallinckrodt, Hazelwood, MO; 350 mg/mL) at a rate of 5 mL/s. We acquire contiguous axial images from the base of the orbit to the level of the aorto-pulmonary window in arterial (22-second delay) and venous phases (immediately after the arterial phase) with the following settings: 1.25 section thickness; gantry rotation time, 0.8 seconds; 20-23 cm field of view (depending on patient body habitus); 120 kV (peak); and automatic tube current modulation. Reformatted images in the 2 phases are sent to Picture Archival and Communication System (PACS) as 2.5-mm-thick contiguous images in the coronal, and sagittal planes.

Imaging Classification of Parathyroid Adenomas and/or Hyperplasia

Currently, there is no standardized means of describing parathyroid adenoma locations. Description of an adenoma and/or hyperplasia location is important to facilitate surgical and anesthesia planning, especially for MIP and also for repeated surgery in cases of persistent or recurrent disease [10,58]. The nomenclature by Perrier et al [59] emphasizes the anterior-posterior location of enlarged parathyroid glands in reference to the thyroid parenchyma, trachea, and esophagus and also categorizes the glands embryologic origin [60]. Glands are classified from A-G: a type A gland is adherent to the posterior thyroid parenchyma in the expected location of the normal gland. A type B gland is behind the thyroid parenchyma and lies in the tracheoesophageal groove. An undescended gland high in the neck near the carotid bifurcation or mandible is classified as a type B plus gland. A type C gland is caudal to the thyroid parenchyma, in the tracheoesophageal groove, and type D glands are intimately attached to the mid posterior surface of the thyroid gland in proximity to the expected location of the recurrent laryngeal nerve. A type E gland is the most externally located gland because it is not deep in the neck and is easy to resect. A type F gland is an ectopic gland located in the thyrothymic ligament, and a type G gland is intrathyroidal [59]. This classification improves communication between radiologists and surgeons; however, one of the disadvantages of this classification is that it is more clinically derived.

More recently, Zald et al [61] described 4 quadrants and ectopic gland locations for parathyroid adenomas. Type A and type B adenomas are located to the right and to the left of the midline located above the most inferior extent of the right and left lobes of the thyroid gland, respectively. Type C and type D glands are located inferior to the right and left lobes of the thyroid, respectively, above the sternal notch, which thus allows surgical excision through a cervical approach. Type E glands are located in unusual ectopic location such as the carotid sheath, thoracic mediastinum, or retroesophageal region [61]. This classification system appears to be simpler and more amenable to use by radiologists and has been used in recent publications on 4D-CT of parathryroid adenomas [47,61].

Limitations of 4D-CT

Parathyroid glands located within the thyroid (subcapsular adenomas) are difficult to identify on CT and ultrasonography in these instances is useful to delineate the parathyroid gland by demonstrating a more hypoechoic structure in relation to the thyroid [62]. Other areas in which parathyroid glands are more difficult to distinguish on CT include the sternal notch area (given the location near bone) and in the mediastinum (where parathyroid adenomas can be confused for lymph nodes) [62]. Scanning artifacts related to swallowing and breathing may limit evaluation of the study [63]. Furthermore, streak artifact from the shoulders and clavicles can mask parathyroid adenomas on CT, and, in these instances, lifting the patient's shoulders while scanning the patient might be helpful [62]. Occasionally, streak artifact from contrast material in adjacent vessels can obscure parathyroid adenomas, and, in such cases, patient's surgical history and prior imaging should be reviewed before the 4D-CT examination to decide which side to use for intravenous injection to minimize streak artifact from dense inflowing contrast medium [47]. In addition, after identifying 1 adenoma, it is important to continue searching for additional adenomas because the discovery of a second adenoma may significantly alter the planned surgery [47].

The other major limitation of 4D-CT is the radiation dose to the patient, especially in cases in which images are acquired during multiple phases. We use dose-reduction techniques with 4D-CT, as described by Welling et al [14] and Chazen et al [57], including automatic tube current modulation, avoidance of the brain and orbits, and elimination of precontrast and the more delayed phases of imaging. Despite these techniques, 4D-CT delivers a significant radiation dose. The CT dose index for single phase of the CT is aproximately 15 mGy [63]. When using the published dose length product to effective dose conversion factor of 0.0054 mSv/(mGy/cm), the estimated effective dose from a 4D-CT is 10 mSv [64]. This compares with an effective dose from a technetium 99m–sestamibi nuclear medicine SPECT, which results in an effective dose of 6 mSv when assuming the administered radioactivity is 740 MBq or 20 mCi [65]. If additional CT localization is added to the SPECT, then the effective dose increases to about 8-9 mSv, depending on the technical factors used for the CT part of the study [66]. Finally, patients who cannot receive intravenous contrast benefit less from this study, given the importance of intravenous contrast to differentiate parathyroid glands from surrounding structures, especially lymph nodes [62].

Conclusion

4D-CT is a new and emerging imaging technique for preoperative parathyroid adenoma and/or hyperplasia localization to plan the best surgical approach. 4D-CT is helpful due to higher spatial resolution and additional functional information characteristic of parathyroid adenomas that it provides. The most high yield areas for a focused search included the locations between the carotid sheaths from hyoid bone to the carina. The locations of parathyroid adenomas missed by conventional methods and detected by 4D-CT include ectopic adenomas and those located in the tracheoesophageal groove, carotid sheath, and the mediastinum. The radiation dose, however, remains a limitation.

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