ORIGINAL ARTICLE

Virtual Neck Exploration for Parathyroid Adenomas

A First Step Toward Minimally Invasive Image-Guided Surgery

Jacopo D'Agostino, MD; James Wall, MD, MSE; Luc Soler, PhD; Michel Vix, MD; Quan-Yang Duh, MD; Jacques Marescaux, MD, FRCS(Hon), FJSES(Hon)

Objective: To evaluate the performance of 3-dimensional (3D) virtual neck exploration (VNE) as a modality for preoperative localization of parathyroid adenomas in primary hyperparathyroidism and assess the feasibility of using augmented reality to guide parathyroidectomy as a step toward minimally invasive image-guided surgery.

Design: Enhanced 3D rendering methods can be used to transform computed tomographic scan images into a model for 3D VNE. In addition to a standard imaging modality, 3D VNE was performed in all patients and used to preoperatively plan minimally invasive parathyroidectomy. All preoperative localization studies were analyzed for their sensitivity, specificity, positive predictive value, and negative predictive value for the correct side of the adenoma(s) (lateralization) and the correct quadrant of the neck (localization). The 3D VNE model was used to generate intraoperative augmented reality in 3 cases.

Setting: Tertiary care center.

Patients: A total of 114 consecutive patients with primary hyperparathyroidism were included from January 8, 2008, through July 26, 2011.

Results: The accuracy of 3D VNE in lateralization and localization was 77.2% and 64.9%, respectively. Virtual neck exploration had superior sensitivity to ultrasonography ($P < .001$), sestamibi scanning ($P = .07$), and standard computed tomography ($P < .001$). Use of the 3D model for intraoperative augmented reality was feasible.

Conclusions: 3-Dimensional VNE is an excellent tool in preoperative localization of parathyroid adenomas with sensitivity, specificity, and diagnostic accuracy commensurate with accepted first-line imaging modalities. The added value of 3D VNE includes enhanced preoperative planning and intraoperative augmented reality to enable less-invasive image-guided surgery.

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Primary hyperparathyroidism (PHPT) is the third most common endocrine disorder globally. Symptomatic disease is routinely treated with parathyroidectomy, and the revised National Institutes of Health consensus guidelines from 2002 have further expanded the surgical indications for patients with asymptomatic disease.[1] The improved sensitivity of preoperative localizing studies and the advent of intraoperative parathyroid hormone (IOPTH) assays have enabled focused approaches. The treatment of localized single adenomas can now be reliably performed with minimally invasive approaches, avoiding a bilateral neck exploration when preoperative studies are concordant.

The first minimally invasive parathyroidectomy (MIP) was performed in 1996.[2] Since then, most studies have confirmed that MIP offers less pain, less cervical dissection, decreased hospitalization, decreased cost, and improved patient satisfaction.[3,4] Cure rates equal to classic bilateral neck exploration have been achieved with various combinations of preoperative localization studies and IOPTH assay.[5]

See Invited Critique at end of article

Multiple imaging modalities have been reported for the localization of parathyroid adenomas including ultrasonography, Tc 99m sestamibi scans, computed tomographic (CT) scans, and magnetic resonance imaging (MRI). Ultrasonography and sestamibi scans are the most sensitive, with reported values ranging from 57% to 89% and 54% to 84%, respectively.[6]

In the last decade, many high-volume centers have adopted the combination of ultrasonography and sestamibi for initial localization studies.[7] Two concordant pre-

Authors Affiliations: IRCAD/Institut Hospitalo Universitaire, Strasbourg, France (Drs D'Agostino, Wall, Soler, Vix, and Marescaux); University of California, and VA Medical Center, San Francisco, California (Dr Duh).

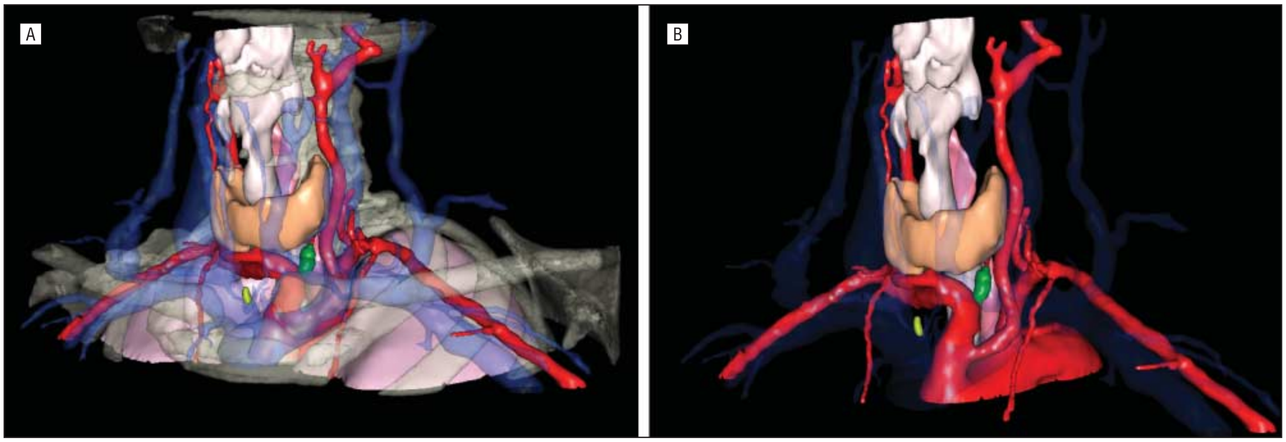

Figure 1. 3-Dimensional images. A, Rendering overlaid on computed tomographic images. B, Virtual neck exploration highlighting a left inferior parathyroid adenoma.

Figure 2. 3-Dimensional rendering applied externally for initial operative localization. Patient in the standard operative position (A), with external augmented reality overlaid (B). C, Augmented reality images delivered to monitors in the operating room.

operative imaging studies can lead to successful focused exploration in 79% to 89% of cases, and overall cure rates with MIP are 95% to 97%.[8-10] Some studies have found value in the use of IOPTH in all cases of focused exploration.[11] Others have found minimal benefit in cases of preoperative concordance, and they reserve the role of IOPTH for discordant or negative preoperative imaging.[12] The cost to benefit ratio of the IOPTH assay remains questionable.[13]

Ultrasonography is limited in lower-volume centers by the need for parathyroid-specific radiologic expertise owing to the high interoperator variability inherent to the modality.[14] Sestamibi is limited to centers that have the nuclear medicine expertise, and results vary widely among institutions.[15]

Computed tomographic scanners are becoming ubiquitous in the developed world owing to their versatility in both diagnostic and interventional radiology, as well as the modality's relatively low interoperator variability. Computed tomographic scan parathyroid localization was first reported in the 1970s.[16,17] Initial results were disappointing for parathyroid adenoma localization; however, improved sensitivity has been reported with thin-cut contrast-enhanced studies.[18] Recently, several studies have examined the use of 4-dimensional (4D) CT scanning.[19-22] This modality combines 3-dimensional (3D) reconstruction of CT images with the added dimension of contrast diffusion over time. When used in patients with PHPT, 4D CT scanning was found to have better lateralization (88%) and localization (70%) than either ul-

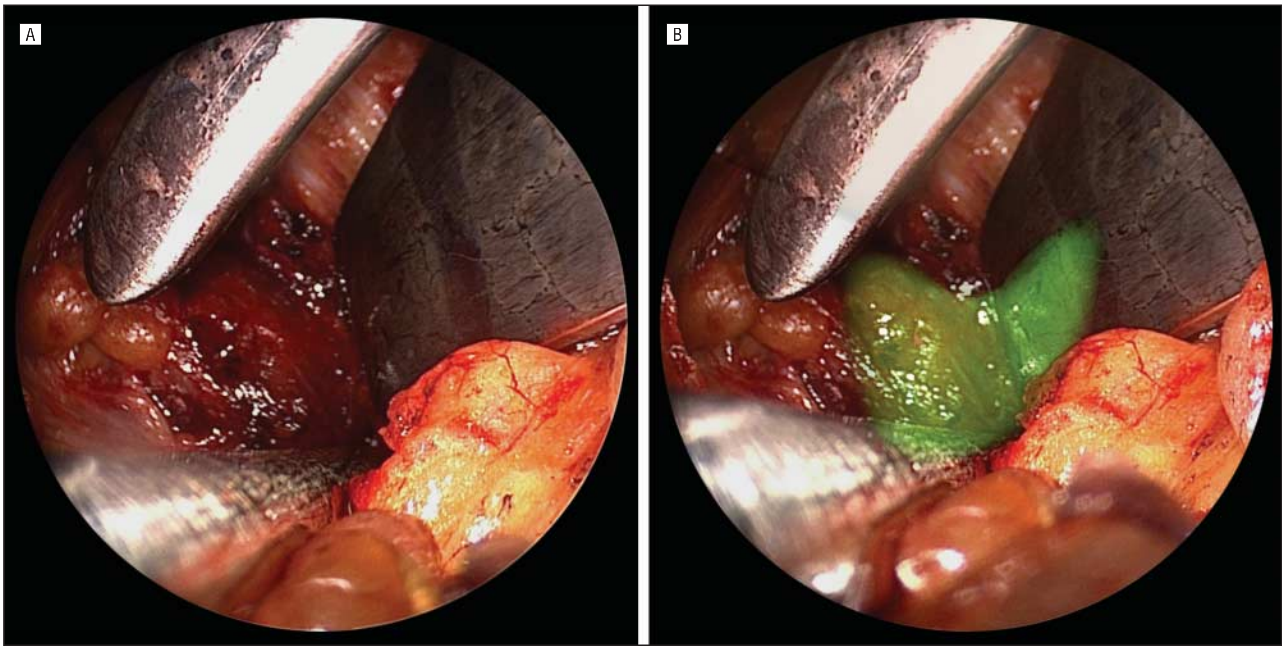

Figure 3. 3-Dimensional rendering applied through the videoscope for precise operative localization (A and B).

trasonography or sestamibi, which offered lateralization in 57% and 65% of cases, respectively, and localization in 29% and 33% of cases, respectively.[22] In patients with negative or discordant standard preoperative localization studies, 4D CT was recently found to accurately lateralize 73% and localize 60% of abnormal glands; however, the accuracy dropped considerably for when multiple lesions were seen.[21] In localization for reoperative parathyroidectomy, 4D CT was found to be more sensitive than sestamibi.[19] Concerns exist surrounding radiation exposure based on linear extrapolations from the known risk of high-dose radiation; however, no threshold for lower doses of radiation has been established.[23] At our institution, neck CT and sestamibi carry a similar radiation exposure in the range of 2 to 6 mSv.

Our group has an ongoing interest in the use of enhanced 3D rendering methods to create preoperative virtual models for surgical planning. 3-Dimensional models provide excellent anatomic detail for the purpose of surgical planning. The models can further be used during the procedure to create an augmented reality with realtime image overlay on both the exterior of the patient and on the laparoscopic images. The technology has proven beneficial in the preoperative planning of both adrenal and hepatic resections.[24,25]

In 2006, our group began to apply VR-Render–enhanced 3D models to parathyroid surgery, enabling interactive preoperative virtual neck explorations (VNEs) and intraoperative augmented reality.[26] Given our experience in the rendering of CT images for hepatic and adrenal surgical procedures, we began with 3D models generated from neck CT scans. The models provide the surgeon with excellent color contrast to differentiate the critical structures of the neck and highlight candidate parathyroid lesions (**Figure 1**). Individual layers of tissues, including bone, muscle, arteries, and veins, can be viewed in any combination to allow greater focus on the relevant anatomy. Using a 3D model of the patient, the endocrine surgical team can perform a 3D VNE to decide whether the anatomic location of the lesion is consistent with a typical adenoma and choose the target lesion(s) for the subsequent intervention. The model can further be used in the operating room to provide augmented reality by overlaying images on the exterior of the patient (**Figure 2**) or through the videoscopic image (**Figure 3**). The combination of preoperative 3D VNE with intraoperative augmented reality has the potential to improve preoperative localization and provide intraoperative guidance.

The aim of this study was to evaluate the performance of 3D VNE as a modality for preoperative localization of parathyroid adenomas in PHPT and report the feasibility of augmented reality to guide parathyroidectomy as a step toward minimally invasive image-guided surgery.

METHODS

PATIENTS

The study population consisted of all consecutive adult patients with biochemically confirmed PHPT treated at an academic tertiary referral center. From January 8, 2008, through July 26, 2011, 114 patients with PHPT underwent parathyroidectomy. This study covers a period in which our institution transitioned to a minimally invasive–focused surgical approach as described by Miccoli et al[2,27,28] with IOPTH. The study was performed and reported in accordance with the ethical guidelines of the University of Strasbourg Hospital.

IMAGING TECHNIQUE

All patients underwent at least 1 preoperative imaging modality before referral to our institution. Seventy-one patients underwent ultrasonography, 64 had a sestamibi scan, and 36 had both. Every patient subsequently had a single standard CT scan of the neck with intravenous iodine–based contrast and 0.75-mm slices in cervical hyperextension to simulate the operative positioning. The standard CT images were first interpreted by a general radiologist, without specific expertise in parathyroid imaging.

VR-Render software was then used on the same CT images to create an enhanced 3D virtual model of the neck. The rendering process included the visualization of multiplanar CT images (axial, sagittal, and coronal) by a specialized radiology technician. The technician applied color contrast to each layer of tissue in a semi-automatic fashion with manual corrections for obvious rendering errors. Candidate lesions were chosen and manually highlighted based on the criteria listed in **Table 1**. All 3D renderings were reviewed by a PhD expert with specialization in medical imaging software in collaboration with the team of endocrine surgeons. This team was blinded to the interpretation of the radiologist. The team performed a preoperative VNE with the rendering and decided on the likely location of the adenoma(s).

In cases of augmented reality, the 3D rendering was manually registered to visible rigid landmarks in the neck in real time by a medical imaging technician during the case. The surgeon was in direct communication with the medical imaging team to fine-tune registration and control the image contrast on the operating monitor.

Ultrasonography, sestamibi, standard CT, and 3D VNE were analyzed for their sensitivity, specificity, positive predictive value, and negative predictive value for the correct side of the adenoma(s) (lateralization) and the correct quadrant of the neck (localization). For localization, the neck was divided into 4 quadrants and each was analyzed independently true positive, true negative, false positive, or false negative using the imaging and operative pathology data. For lateralization, the same analysis was conducted for each side of the neck. No cases of ectopic glands were predicted by imaging or found at surgery, thus ectopic position was not included in our analysis. Glands were considered negative if they were either explored and deemed normal by the surgeon or not explored with drop in IOPTH that met the Miami criteria.[29]

To characterize the clinical use of the studies, we performed an analysis of diagnostic accuracy compared with operative findings by side and quadrant for each patient. For this analysis of accuracy, a true positive was a study that exactly localized or lateralized the adenoma in a given patient. A study that missed any gland or called any gland nonpathologic was false negative or false positive, respectively, for that given patient.

Statistical analysis of contingency data was performed using the epiR package for R (www.r-project.org). Fisher exact test was used to compare the operating characteristics of different modalities.

Table 1. Criteria for Determination of Candidate Parathyroid Lesions by CT Technologist Using VR-Render Software

No.	Criterion
1	Location: expected orthotopic or ectopic position of a parathyroid gland based on embryologic development
2	Size > 6 mm
3	Oval shape
4	Hounsfield units: relatively higher than baseline lymph node tissue
5	Visibility on at least 2 of 3 planar images
6	No correlation on any planar image with vascular or other known structures

Abbreviation: CT, computed tomography.

RESULTS

The median age of the population was 60.8 years (range, 21-87 years), with a female to male ratio of 3.7:1.0. Fifty patients were symptomatic. The preoperative mean serum calcium level was 11.5 mg/dL (to convert to millimoles per liter, multiply by 0.25) and the preoperative PTH level was 162.4 ng/L. A total of 112 patients underwent a primary procedure and 2 patients underwent reoperation for recurrent PHPT after previous bilateral neck explorations.

Among the 114 patients, 69 underwent planned MIP technique using the gasless method through a median 3.0-cm skin incision. All MIP patients had IOPTH drawn in the operating room and the Miami criteria were used to determine the need for further exploration. Of these cases, 20 were converted to bilateral neck exploration owing to either failure to meet the Miami criteria or surgeon choice. Forty-six patients underwent planned bilateral neck exploration for reexplorations (n = 2), coexisting thyroid disease (n = 10), large adenomas (>3.5 cm; n = 3), and early in our experience with MIP to verify the technique (n = 31). Among the 114 procedures, 316 parathyroid glands were visualized, 132 glands were resected, and 129 glands were pathologically confirmed adenomas. In 11 cases (9.6%), multiglandular disease was discovered.

3-Dimensional VNE correctly localized single adenomas in 82 patients. In 5 cases, VNE correctly identified a double adenoma. In 11 cases, a second enlarged gland was suspected but only 1 adenoma was found concordant at surgery. The mean size of the detected adenomas was 18.8 mm (95% CI, 8.8-27.4) and for missed glands was 13.5 mm (95% CI, 7.9-18.1). 3-Dimensional VNE missed a total of 29 abnormal glands that were found in the operating room. Nine of the missed glands were in the superior position and 20 were in the inferior position. There were no missed glands found in an ectopic location.

The test characteristics with 95% confidence intervals of all modalities for both lateralization and localization are shown in **Table 2**. For lateralization, VNE had superior sensitivity to ultrasonography ($P < .001$), sestamibi ($P < .001$), and standard CT ($P < .001$). Specificity of VNE was similar to ultrasonography ($P = .10$) but less than sestamibi ($P < .001$) and standard CT ($P < .001$). The diagnostic accuracy of 3D VNE in lateralization and localization was 77.2% and 64.9%, respectively (**Table 3**). Diagnostic accuracy of 3D VNE was equivalent to sestamibi ($P = .16$), but significantly higher than both ultrasonography ($P < .001$) and standard CT ($P = .003$).

In 3 cases, augmented reality was applied during the operation. A single adenoma was successfully identified using the interactive real-time image overlay in all 3 patients.

The average follow-up was 15.6 months (range, 6-44 months). Two patients were lost to follow-up. Of the remaining patients, the cure rate was 98.8%, with only 1 case of persistent disease from the 2 patients who had undergone a reoperation for recurrent PHPT.

Table 2. Contingency Characteristics of Imaging Modalities for Lateralization and Localization

Modality	Sensitivity, % (95% CI)	Specificity, % (95% CI)	Positive Predictive Value, % (95% CI)	Negative Predictive Value, % (95% CI)
Lateralization				
Ultrasonography (142 sides)	50.0 (37.8-62.2)	94.4 (86.4-98.5)	89.7 (75.8-97.1)	66.0 (56.0-75.1)
Sestamibi (128 sides)	70.8 (58.2-81.4)	95.2 (86.7-99.0)	93.9 (83.1-98.7)	75.9 (65.0-84.8)
Standard CT (228 sides)	63.2 (53.8-72.0)	96.3 (91.0-99.0)	94.8 (87.3-98.6)	71.3 (63.5-78.4)
3D VNE (228 sides)	88.5 (81.5-93.6)	83.0 (74.5-89.6)	85.7 (78.4-91.3)	86.2 (78.0-92.2)
Localization				
Ultrasonography (284 quadrants)	40.0 (28.9-52.0)	92.8 (88.4-95.9)	66.7 (51.0-80.0)	81.2 (75.6-85.9)
Sestamibi (256 quadrants)	63.7 (51.3-75.0)	96.3 (92.4-98.5)	86.2 (73.7-94.3)	87.8 (82.5-92.0)
Standard CT (456 quadrants)	53.6 (44.4-62.6)	94.6 (91.5-96.7)	78.8 (68.6-86.9)	84.3 (80.3-87.9)
3D VNE (456 quadrants)	78.4 (70.2-85.3)	90.0 (86.3-93.0)	74.8 (66.5-82.0)	91.7 (88.1-94.5)

Abbreviations: CT, computed tomography; 3D VNE, 3-dimensional virtual neck exploration.

Table 3. Diagnostic Accuracy per Patient for Lateralization and Localization

Modality	% (95% CI)
Lateralization	
Ultrasonography (n = 71)	49.3 (37.2-61.4)
Sestamibi (n = 64)	67.2 (54.3-78.4)
Standard CT (n = 114)	57.9 (48.3-67.1)
3D VNE (n = 114)	77.2 (68.4-84.5)
Localization	
Ultrasonography (n = 71)	33.8 (23.0-46.0)
Sestamibi (n = 64)	59.4 (46.4-71.4)
Standard CT (n = 114)	44.7 (35.4-54.3)
3D VNE (n = 114)	64.9 (55.4-73.6)

Abbreviations: CT, computed tomography; 3D VNE, 3-dimensional virtual neck exploration.

COMMENT

Surgery for PHPT has shifted from routine bilateral neck exploration to focused, minimally invasive techniques enabled by preoperative localization of parathyroid adenomas and IOPTH.[30] In theory, our center could have performed much fewer bilateral neck explorations with the preoperative localization that 3D VNE provided. However, in practice, owing to a lack of rapid IOPTH and initial surgeon experience with focused neck explorations, our overall rate of bilateral neck exploration was high. Our rate of bilateral neck exploration has decreased with increased experience.

The first-line studies for localization are routinely ultrasonography and sestamibi, with MRI and CT scans usually reserved for cases of negative or discordant studies. The advantage of planar imaging of both CT and MRI is the visualization of all cervical structures, making them particularly good for cases of ectopic glands. Recent developments in 4D CT scans have shown promising results as a localizing study with excellent sensitivity and specificity.

Computed tomography holds much appeal as it is becoming ubiquitously available, is familiar to surgeons, and has little interoperator variability. Using VR-Render software to generate a virtual neck model from CT images, we performed 3D preoperative neck explorations prior to surgery. 3-Dimensional VNE significantly improved the sensitivity of standard CT scans and resulted in significantly higher sensitivity than all modalities from our referring institutions. Specificity of 3D VNE was lower than CT and sestamibi. It would stand to reason that preoperative planning by surgeons committed to operating owing to the biochemical diagnosis might target a suspicious lesion more readily than a radiologist, increasing the sensitivity and driving down the specificity. The overall diagnostic accuracy of 3D VNE was better than referral center ultrasonography and standard CT, making it a clinically useful tool.

Centers of excellence in endocrine surgery achieve high sensitivity and specificity for preoperative ultrasonography and sestamibi. The sensitivity and diagnostic accuracy of 3D VNE in this study is comparable to the best results of ultrasonography, sestamibi, and 4D CT. In our practice, the quality of ultrasonography and sestamibi from referral centers is variable, making 3D VNE an attractive practical option.

One downside of CT and sestamibi is radiation exposure, although an unsafe threshold dose is yet to be established. While currently using CT images to generate the 3D model, a great advantage of 3D VNE is that it has also been applied to MRI images, which eliminates radiation exposure.

The limitations of 3D VNE are similar to other modalities in that smaller adenomas are harder to detect accurately as well as adenomas in the setting of concurrent thyroid nodules. Limitations specific to 3D VNE are that it is based on the morphologic data from a single contrast phase that does not offer functional information. Additionally, the system is only semi-automatic, requiring manual rendering correction and candidate lesion determination by a radiology technician. This is currently labor intensive, demanding approximately 30 to 60 minutes per study. Automated rendering of vascular structures has been very consistent to date, and work is ongoing to reliably automate the entire rendering process. Our institution plans to begin offering 3D VNE to referring institutions through a web-based interface that would allow DICOM images to be submitted for rendering.

The limitations of this study include uncontrolled initial preoperative imaging modalities performed and interpreted at referring institutions. Both ultrasonography and sestamibi have been shown to be user dependent. Reinterpretation or even repetition of these studies at our institution may have been ideal. However, the reality of our practice within a nationalized health system did not allow for repeat studies as are commonly performed elsewhere. Cases referred to a tertiary center always present the potential for being more difficult than average; the generally low sensitivity of the outside studies could reflect such a bias. Furthermore, costs are difficult to compare within the nationalized health system. There is no retail cost in our public institution, as seen in the United States. The costs of imaging studies are fixed by the Social Security system based primarily on the price of disposable materials used. The charge for CT and ultrasonography is approximately 100 euros, while the charge for sestamibi is approximately 600 euros.

Beyond preoperative localization, VR-Render was feasible for real-time intraoperative augmented reality. Our experience of using augmented reality is limited, but feedback from users is positive and the technique has proven particularly useful in cases of aberrant anatomy. While only used to date in conjunction with the MIP technique of Miccoli et al, the overlay of anatomic information as seen inFigure 2 has potential application to all surgical techniques. Limitations of the current augmented reality system are that it requires manual registration to the intraoperative image and has no compensation for patient movement (ie, respiration) or tissue deformation (ie, retraction). Both automatic registration and real-time compensation are being developed at our institution. With such improvement, augmented reality could play a major role in precision image-guided parathyroidectomy.

In conclusion, accurate preoperative localization of parathyroid adenomas is critical in enabling the surgeon to perform MIP. VR-Render is a novel software system that can generate an enhanced 3D virtual neck model from multiple imaging modalities including CT and MRI. 3-Dimensional VNE with VR-Render has operating characteristics commensurate with accepted first-line preoperative localizing study at our center. The ubiquity and low interoperator variability of CT scanning makes 3D VNE attractive to centers that do not have the expertise or capability in parathyroid ultrasonography, sestamibi, and single photon-emission CT. The VR-Render platform offers the flexibility of incorporating additional functional information through perfusion or spectroscopy that could increase the specificity of 3D VNE. 3-Dimensional VNE can also be performed with MRI imaging in place of CT scanning that would eliminate radiation exposure. 3-Dimensional VNE is an excellent tool in preoperative localization of parathyroid adenomas with the added value of enabling preoperative planning and intraoperative augmented reality. Precise image guidance is key to less-invasive surgical approaches to PHPT and the potential to approach the treatment via endovascular or extracorporeal methods.

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Correspondence: Jacques Marescaux, MD, FRCS (Hon), FJSES(Hon), IRCAD/Institut Hospitalo Universitaire, 1 Place de l'Hopital, 67091 Strasbourg, France (jacques.marescaux@ircad.fr).
Author Contributions: Drs D'Agostino and Wall share first authorship of this study. *Study concept and design:* D'Agostino, Wall, Soler, Vix, and Marescaux. *Acquisition of data:* D'Agostino, Soler, and Vix. *Analysis and interpretation of data:* D'Agostino, Wall, Vix, Duh, and Marescaux. *Drafting of the manuscript:* D'Agostino and Wall. *Critical revision of the manuscript for important intellectual content:* D'Agostino, Wall, Soler, Vix, Duh, and Marescaux. *Statistical analysis:* D'Agostino and Wall. *Administrative, technical, and material support:* Soler and Vix. *Study supervision:* D'Agostino, Soler, Vix, and Marescaux.
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REFERENCES

1. Bilezikian JP, Potts JT Jr, Fuleihan Gel-H, et al. Summary statement from a workshop on asymptomatic primary hyperparathyroidism: a perspective for the 21st century. *J Clin Endocrinol Metab*. 2002;87(12):5353-5361.
2. Miccoli P, Pinchera A, Cecchini G, et al. Minimally invasive, video-assisted parathyroid surgery for primary hyperparathyroidism. *J Endocrinol Invest*. 1997; 20(7):429-430.
3. Sosa JA, Udelsman R. Minimally invasive parathyroidectomy. *Surg Oncol*. 2003; 12(2):125-134.
4. Goldstein RE, Blevins L, Delbeke D, Martin WH. Effect of minimally invasive radioguided parathyroidectomy on efficacy, length of stay, and costs in the management of primary hyperparathyroidism. *Ann Surg*. 2000;231(5):732-742.
5. Grant CS, Thompson G, Farley D, van Heerden J. Primary hyperparathyroidism surgical management since the introduction of minimally invasive parathyroidectomy: Mayo Clinic experience. *Arch Surg*. 2005;140(5):472-478, discussion 478-479.
6. Mihai R, Simon D, Hellman P. Imaging for primary hyperparathyroidism: an evidence-based analysis. *Langenbecks Arch Surg*. 2009;394(5):765-784.
7. Quiros RM, Alioto J, Wilhelm SM, Ali A, Prinz RA. An algorithm to maximize use of minimally invasive parathyroidectomy. *Arch Surg*. 2004;139(5):501-506, discussion 506-507.
8. Udelsman R. Six hundred fifty-six consecutive explorations for primary hyperparathyroidism. *Ann Surg*. 2002;235(5):665-670; discussion 670-662.
9. Siperstein A, Berber E, Mackey R, Alghoul M, Wagner K, Milas M. Prospective evaluation of sestamibi scan, ultrasonography, and rapid PTH to predict the success of limited exploration for sporadic primary hyperparathyroidism. *Surgery*. 2004;136(4):872-880.
10. Russell CF, Dolan SJ, Laird JD. Randomized clinical trial comparing scan-directed unilateral versus bilateral cervical exploration for primary hyperparathyroidism due to solitary adenoma. *Br J Surg*. 2006;93(4):418-421.
11. Sugino K, Ito K, Nagahama M, et al. Minimally invasive surgery for primary hyperparathyroidism with or without intraoperative parathyroid hormone monitoring. *Endocr J*. 2010;57(11):953-958.
12. Gawande AA, Monchik JM, Abbruzzese TA, Iannuccilli JD, Ibrahim SI, Moore FD Jr. Reassessment of parathyroid hormone monitoring during parathyroidectomy for primary hyperparathyroidism after 2 preoperative localization studies. *Arch Surg*. 2006;141(4):381-384, discussion 384.
13. Morris LF, Zanocco K, Ituarte PH, et al. The value of intraoperative parathyroid hormone monitoring in localized primary hyperparathyroidism: a cost analysis. *Ann Surg Oncol*. 2010;17(3):679-685.
14. Van Husen R, Kim LT. Accuracy of surgeon-performed ultrasound in parathyroid localization. *World J Surg*. 2004;28(11):1122-1126.
15. Pappu S, Donovan P, Cheng D, Udelsman R. Sestamibi scans are not all created equally. *Arch Surg*. 2005;140(4):383-386.
16. Doppman JL, Brennan MF, Koehler JO, Marx SJ. Computed tomography for parathyroid localization. *J Comput Assist Tomogr*. 1977;1(1):30-36.
17. Kovarik J, Willvonseder R, Kuster W, Niederle B, Roka R, Imhof H. Localization of parathyroid tumors by computed tomography. *N Engl J Med*. 1980;303(15): 885-7412812.
18. Harari A, Zarnegar R, Lee J, Kazam E, Inabnet WB III, Fahey TJ III. Computed tomography can guide focused exploration in select patients with primary hyperparathyroidism and negative sestamibi scanning. *Surgery*. 2008;144(6): 970-976, discussion 976-979.

19. Mortenson MM, Evans DB, Lee JE, et al. Parathyroid exploration in the reoperative neck: improved preoperative localization with 4D-computed tomography. *J Am Coll Surg*. 2008;206(5):888-895; discussion 895-896.
20. Starker LF, Mahajan A, Bjorklund P, Sze G, Udelsman R, Carling T. 4D parathyroid CT as the initial localization study for patients with de novo primary hyperparathyroidism. *Ann Surg Oncol*. 2010;18(6):1723-1728.
21. Lubitz CC, Hunter GJ, Hamberg LM, et al. Accuracy of 4-dimensional computed tomography in poorly localized patients with primary hyperparathyroidism. *Surgery*. 2010;148(6):1129-1137; discussion 1137-1138.
22. Rodgers SE, Hunter GJ, Hamberg LM, et al. Improved preoperative planning for directed parathyroidectomy with 4-dimensional computed tomography. *Surgery*. 2006;140(6):932-940; discussion 940-941.
23. Brenner DJ, Hall EJ. Computed tomography: an increasing source of radiation exposure. *N Engl J Med*. 2007;357(22):2277-2284.
24. Mutter D, Dallemagne B, Bailey Ch, Soler L, Marescaux J. 3D virtual reality and selective vascular control for laparoscopic left hepatic lobectomy. *Surg Endosc*. 2009;23(2):432-435.
25. Marescaux J, Rubino F, Arenas M, Mutter D, Soler L. Augmented-reality-assisted laparoscopic adrenalectomy. *JAMA*. 2004;292(18):2214-2215.
26. D'Agostino J, Diana M, Vix M, Soler L, Marescaux J. Three-dimensional virtual neck exploration before parathyroidectomy. *N Engl J Med*. 2012;367(11):1072-1073.
27. Miccoli P, Berti P, Conte M, Raffaelli M, Materazzi G. Minimally invasive video-assisted parathyroidectomy: lesson learned from 137 cases. *J Am Coll Surg*. 2000;191(6):613-618.
28. Miccoli P, Monchik JM. Minimally invasive parathyroid surgery. *Surg Endosc*. 2000;14(11):987-990.
29. Greene AB, Butler RS, McIntyre S, et al. National trends in parathyroid surgery from 1998 to 2008: a decade of change. *J Am Coll Surg*. 2009;209(3):332-343.
30. Carneiro DM, Solorzano CC, Nader MC, Ramirez M, Irvin GL III. Comparison of intraoperative iPTH assay (QPTH) criteria in guiding parathyroidectomy: which criterion is the most accurate? *Surgery*. 2003;134(6):973-979, discussion 979-981.

INVITED CRITIQUE

Locating Parathyroid Adenomas via Virtual Neck Exploration

A Real-World Challenge for Surgeons

Despite recent advances in imaging and surgical methods, many patients with hyperparathyroidism continue to go to the operating room without their surgeons knowing where their abnormal parathyroid glands are located. In the article titled "Virtual neck exploration for parathyroid adenomas: a first step toward minimally invasive image-guided surgery," D'Agostino and colleagues[1] have provided a clear presentation of their use of multiple methods of enhanced 3-dimensional (3D) rendering to improve the ability to identify the location of parathyroid adenomas. Although the authors acknowledged that current 3D rendering techniques are time consuming and labor intensive, this study illustrates 2 important concepts. (1) The data gathered through conventional imaging techniques can be manipulated and reinterpreted to allow us to see things that we had not previously noticed. (2) Sometimes costly techniques must be fully explored to evaluate the potential benefits.

By applying a series of algorithms for 3D rendering and then reinterpreting the images, the authors have shown that parathyroid adenomas can be identified without additional imaging. Such an approach is a valuable demonstration of the realized promise that changing the presentation of the data allows us to see more than what was originally noticed in the images.

The problem with this approach is that in an era of increasing pressure to cut costs, 3D rendering techniques would seem to be a method of simply adding costs. However, as with any new innovation, it is unclear what the actual benefits in clinical practice will be until time and effort are expended to explore them. Most commonly, a new technique forces surgeons to move through the learning curve, potentially putting patients at risk as the novel approach is mastered. However, the virtual reality possible from 3D rendering has the potential of significantly shortening the learning curve, thereby significantly benefitting patients. Only by the continued exploration of this novel technique to determine its benefits in the real world of clinical practice, will we be in a position to assess its overall value.

Peter Angelos, MD, PhD

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Author Affiliation: Section of General Surgery and Surgical Oncology, Department of Surgery, The University of Chicago, Chicago, Illinois.
Correspondence: Dr Angelos, Section of General Surgery and Surgical Oncology, Department of Surgery, The University of Chicago, 5841 S Maryland Ave, MC 4052, Chicago, IL 60637 (pangelos@surgery.bsd.uchicago.edu).
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1. D'Agostino J, Wall J, Soler L, Vix M, Duh Q-Y, Marescaux J. Virtual neck exploration for parathyroid adenomas: a first step toward minimally invasive image-guided surgery [published online November 19, 2012]. *JAMA Surg*. 2013;148(3):232-238.