COLOR FLOW AND DOPPLER

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AACE-ACE-MAYO CLINIC

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Doppler Physics

• When an interface is moving with respect to the reflected sound wave, the frequency of the reflected sound is altered.
  • Frequency shifted up by approaching target
  • Frequency shifted down by receding target
  • Degree of frequency shift proportional to velocity

• Doppler Signal Processing and Display
  • Doppler Frequency Spectrum
  • Color Flow
  • Power Mode
“The apparent change in the frequency of a wave caused by relative motion between the source of the wave and the observer”

“DOPPLER EFFECT”
Dr. Sheldon Cooper
BIG BANG THEORY
Doppler Shift
Illustration of Doppler Shift
Uses of Doppler

- Vascular
  - Imaging and flow analysis of blood vessels
- Vascularity of tissue
  - Probability of Malignancy
  - Graves v. Thyroiditis
  - Amiodarone Thyrotoxicosis
  - Image Clarification
Doppler
Spectral Doppler

- Peak Systolic Velocity
- End Diastolic Velocity
- Mean Velocity
  - Resistive Index: \((A-B)/A\)
  - Pulsatility Index: \((A-B)/M\)
Color and Power Doppler

Meritt, 1998
Color and Power Doppler
Color and Power Doppler

- **Color Doppler**
  - Provides information regarding direction (of the shift) and velocity.
  - More useful in vascular studies

- **Power Doppler**
  - No information regarding velocity
  - Less angle dependence
  - Less noise
  - Increased sensitivity for detection of flow
  - Particularly low flow organs and small tumors (thyroid nodules / LN and PA)
Doppler clinical considerations…

- High Sensitivity of power Doppler vs. Conventional color Doppler
- User Variability – Gain settings
- Grading Scales
  - 1 (absent vascularity – rare w/ modern equipment)
  - 2 (mostly peripheral vascularity)
  - 3 (peripheral greater than intranodular)
  - 4 (predominately intranodular)
How to set gain for power Doppler and color Doppler

- Locate a known avascular area (e.g., larynx)
- Lower or increase gain to enable visualization of occasional artifacts
- Then move the ‘box’ to the target to be studied
- Minimize the size of box to reduce artifacts induced by large pulsatile contiguous vessels
Grade 1 – No flow to nodule
Grade 2 – Peripheral Flow
Grade 3 – Moderate Central Flow
Grade 3 - Moderate Central Flow

Suspicious for cystic papillary carcinoma
Grade 4 – Intense Intranodular Flow
Grade 4 – Intense, internal – high grade Flow
LEFT CYSTIC NODULE WITH VASCULAR MURAL MASS SAG
Does Doppler play a role in the prediction of malignancy?

- 494 consecutive patients with nonpalpable nodules measuring 8 to 15 millimeters. 31 malignant.
  - 87% of cancers were solid and hypoechoic.
  - 77% of cancers had irregular or blurred margins.
  - Intra nodular vascular pattern was seen in 74% of cancers.
  - Microcalcifications were seen in 29 percent of cancers.

- Independent risk factors for malignancy included
  - irregular margins (RR = 16.83)
  - intra nodular flow (RR = 14.29)
  - microcalcifications (RR = 4.97)

- Recommendation for ultrasound guided fine needle aspiration if any of the independent risk factors are present, and if no risk factors are present follow-up with clinical and ultrasound evaluation.

Color Doppler - Follicular Carcinoma
Color Doppler – Benign Nodule
Value of Doppler in prediction of malignancy

- 108 patients with cold thyroid nodules.
  - 54 carcinomas
  - 54 benign nodules
  - 92 correct diagnoses based on color Doppler
  - 6 false negatives, and 10 false positives.

Sensitivity 88.8 percent, specificity 81.5 percent
Positive predictive value 82.7 percent
Negative predictive value 88 percent

- Power Doppler was better than color Doppler.

Does Vascularity play a role in the prediction of malignancy? (2)

- Retrospective evaluation of 1083 nodules in 1024 patients. 814 benign. 269 malignant (97.4% PTC)
- Marked hypoechogenicity, noncircumscribed margins, microcalcifications and taller than wide considered suspicious by gray scale.
- Vascularity graded as none, peripheral or intranodular.

- Vascularity was frequently seen in benign nodules (31%)
- No vascularity was more frequent in malignant nodules (60% vs 43%) (p<.001)

Why the discrepancy? What to do?

- Papillary versus Follicular Cancer
- Power Doppler may be predictive for Follicular cancer.
- In Moon’s study 97.4% were papillary
- Dense fibrosis is seen in 56-89% of papillary carcinoma.
- Consider whether features are suspicious for papillary or follicular.
Value of Doppler in the prediction of malignancy following *follicular* biopsy

- 310 follicular nodules
  - Color Doppler flow mapping prior to surgery
  - Grade 1: No color flow mapping inside the nodule
  - Grade 2: Color flow mapping only in peripheral area; PI index < 1.3
  - Grade 3: Penetrating color flow mapping, vascularity moderate-rich
  - Grade 4: High velocity penetrating color flow mapping, vascular rich; PI index >1.3

- Diagnostic accuracy 81%, sensitivity 86%, specificity 85%.

- Of 177 benign adenomatous nodules, 95 percent were grade 1 or 2 and only five percent were grade 3. Thus, benign Doppler features were highly suggestive of benign pathology. Of 89 follicular adenomas, 66% showed grade 1 or 2 Doppler image, and 34% showed grade 3 or 4. Of the 44 follicular carcinomas, none showed grade 1 Doppler imaging, 13.6% showed grade 2 flow, and 86.4% showed grade 3 or 4 flow.

Bayesian Analysis of Impact of Doppler Flow in Follicular Lesions

• Pre-test probability of malignancy 15% for a “suspicious for follicular neoplasm” biopsy
  • Sensitivity of 86
  • Specificity of 85*
• The post-test probabilities change to:
  • 49% if intra-nodular flow (grade 3,4)
  • 3% if no intra-nodular flow (grade 1,2)

*Levine R, Value of Doppler Ultrasonography in Management of Patients with Follicular Thyroid Biopsy Specimens. Endo Practice, 2006; 12(3)270-274.
US Features of Follicular Neoplasm

- 165 of 3106 cases FN cytology
- 25 cancers of 114 who had surgery (21.9%)
- Male sex, Age >45 & Size >4cm tended to be higher rate of cancer but not statistically significant
  - Other studies suggest these are helpful predictors
- Internal blood flow was the only US feature predictive of cancer (p = 0.03)

Doppler in SRINs
(Solid Round Isoechoic Nodules)

DW Kim et al. Thyroid. April 2013, 23(4): 472-476
Doppler in SRINs

- Sonographically Indeterminate Nodules
- 727 consecutive patients underwent US-FNAs
- 27 patients who had SRINs > 5mm enrolled
  - 7 were cancer (25.9%) – 4 FVPTC, 3 PTC
- The color Doppler pattern of each nodule was classified into one of four categories: scant, peripheral, central, or mixed type (grade 1-4)
- There was no significant correlation between the color Doppler pattern and the malignancy rate of SRINs.
Doppler in Follicular Neoplasms

- 47 Consecutive patients w/ FNA of FN
  - 17% malignant at surgery
- Doppler was not predictive of cancer
- Irregular margins was the only single variable significantly associated with malignancy

Value of Doppler in Prediction of Malignancy

Conclusions

• Doppler analysis may provide useful information regarding malignant potential.
• Power Doppler has greater sensitivity and is able to detect lower degrees of internal flow.
• The negative predictive value of Doppler is not sufficient to obviate the need for FNAB, but Doppler information can be interpreted along with other ultrasonographic characteristics including echogenicity, edge definition, calcifications, etc.
Amiodarone-induced Thyrotoxicosis
Color Doppler (1)

- **Type 1** – Preexisting Thyroid abnormality
  - “Graves-like”
  - Treatment with thionamides and perchlorate
  - Normal or increased vascularity
- **Type 2** – Normal Thyroid
  - “Destructive thyroiditis-like”
  - Treatment with glucocorticoids
  - Absent vascularity
  - Often elevated Interleukin 6
Amiodarone-induced Thyrotoxicosis Color Doppler (2)

- Flow Absent (CFDS 0)
  - 58% Prednisolone response rate
- Flow Present (CFDS 1-3)
  - 14% Prednisolone response rate

- Treatment Algorithm
  - CFDS 0: Prednisolone
  - CFDS 1-3: Thionomides and perchlorate
  - Combined therapy/surgery if unresponsive
Doppler Graves and Thyroiditis

- **Graves**
  - “Thyroid inferno”
  - Peak systolic velocity (PSV) 8-20 cm/sec
- **Thyroiditis**
  - Micronodulation in Hashimoto’s
  - Various vascular patterns – absent to hypervascular
  - Subacute thyroiditis – focally may appear as suspicious nodule
- **Thyrotoxicosis Factitia**
  - Minimal intrathyroidal vascular flow
  - Peak systolic velocity (PSV) 3-5 cm/sec
Graves Disease
Thyroid Inferno
Thyroiditis - Not always hypovascular
Post-partum thyroiditis – Hypo phase
Graves Disease versus Destructive Thyroiditis.

- Multiple studies have attempted to separate Graves from thyroiditis using variety of Doppler techniques.
  - Power Doppler Images
  - Thyroid blood flow area
  - Thyroid artery velocity
Thyroid Blood Flow

Ota H et al., Clin Endocrinol (Oxf) 67:41 2007
Thyroid Blood Flow Area

Kurita S et al. Thyroid. 2005;15(11) 1249
Intraparenchymal Vascularity

Fig. 1. Intraparenchymal vascularity of the thyroid gland in 31 patients with destructive thyrotoxicosis and in 34 patients with Graves disease.

Kumar H et. al., Endocrine Practice 15(1) 6-9, 2009
Inferior Thyroid Artery Peak Velocity

Fig. 2. Mean peak systolic velocity of the inferior thyroid artery (ITA) in 31 patients with destructive thyrotoxicosis and in 34 patients with Graves disease. Each dot represents a patient. The horizontal lines represent the means.

Kumar H et. al., Endocrine Practice 15(1) 6-9, 2009
Differential Diagnosis of Thyrotoxicosis  Conclusions

- The distinction between Graves’ Disease and thyroiditis can be based on a combination of clinical features, RAI uptake, Tslg levels, and ultrasound features.
- RAI uptake remains the “gold standard” but the behavior over time is often the final determinant.
- Recognize the limitation of Doppler techniques and do not use in isolation.
Doppler - Clarification of Interpretation
Doppler - Clarification of Interpretation
Doppler - Clarification of Interpretation
Clarification of Interpretation

Biopsy Needle
Node
Jugular vein
Clarification of interpretation – Central Nodes?

Blood Vessels, Not Nodes
Clarification of Interpretation - Cyst?
Doppler Before Biopsy
In normal nodes vessels enter centrally at the hilus, and spread along the long axis. In malignant nodes aberrant vessels enter peripherally in the node capsule. Increased (disordered) vascularity may be seen peripherally and centrally.
Doppler of Nodes

- Demonstration of Chaotic or peripheral vascularity in malignant nodes
  - Can be seen in reactive nodes
- Normal vascularity is reassuring
- Power Doppler for high sensitivity
- Use low wall filter
- Use PRF < 800
  - Low wall filter and low PRF both increase the sensitivity for detection of low flow.

DOPPLER PATTERN IN NODES MORE PREDICTIVE THAN IN NODULES
MTC surgery – 2014, serum Calcitonin 50, FNA LYMPHNODE calcitonin – 50,000

Doppler – Indentation of great vessel by LN

Note subtle abnormality in vessel in CT
Doppler – Parathyroid Glands
Doppler for predicting successful alcohol ablation
‘pruning’ of the vascular pedicle
Doppler: Conclusions and summary

- Color Doppler facilitates decision making during FNA of nodules and lymphnodes
- The negative predictive value of Doppler is not sufficient to obviate the need for FNAB
- Doppler information must be interpreted along with other ultrasonographic characteristics including echogenicity, edge definition, calcifications, etc.
- Power Doppler has greater sensitivity over color doppler and is able to detect lower degrees of internal flow
- Lack of flow in a follicular lesion makes malignancy less likely
- RAI imaging is still the mainstay rather than doppler to determine etiology of hyperthyroidism
- Vascularity may be low in lesions suspicious for papillary carcinoma
- Doppler provides details regarding vascular pedicle and during and after ETOH injections