PI Session: 2021.02.10_GRE_Radiology: Pelvis_Preparatory_Marcus John Julius, M.D.

Objectives: At the end of this session, students will be able to:
1. Discuss the limited role of general radiology in imaging of the female reproductive system.
2. Describe the physiologic mechanism essential to the production of a PET scan.
3. Compare and contrast transabdominal and transvaginal pelvic sonography.
4. Differentiate the three different thicknesses of the endometrium seen throughout the menstrual cycle.
5. Explain the difference in the fields of view between pelvic CT imaging and abdominal CT imaging
6. Explain the simplified overview of MR imaging (using terms related to 'low-energy' and 'high-energy' protons)
7. Compare and contrast the concepts of T1 relaxation and T2 relaxation
8. Discuss the advantages and disadvantages of MR imaging
9. Differentiate T1-weighted and T2-weighted images of the male and female pelvis

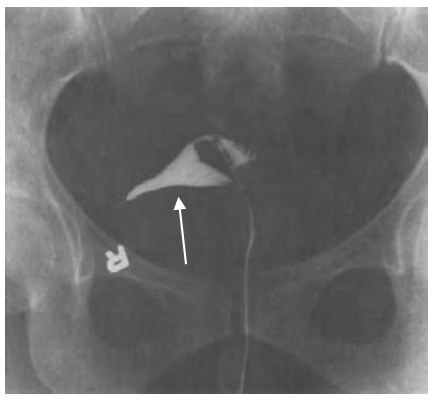
INTRODUCTION: The focus of this PI preparatory session of pelvic imaging is the reproductive system.

General radiology

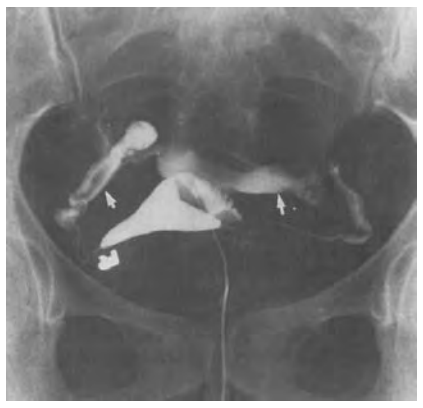
NOTE: Imaging of the musculoskeletal, gastrointestinal, vascular, and genitourinary systems of the male and female pelvis may involve the use of general radiology (and its subdivisions). The scope of general radiographic imaging of the male and female reproductive systems, however, is quite narrow (i.e. to limit exposure of the reproductive systems to ionizing radiation). One exception is the hysterosalpingogram (HSG), an imaging examination of the non-gravid uterus and fallopian tubes.

NORMAL ANATOMY

-*HSG*: Hysterosalpingogram
- -Radiopaque contrast is administered into the uterine cavity via a catheter placed by an OB/GYN physician
- -Imaging is performed under fluoroscopy by radiologist
- -Administered contrast outlines the uterine cavity and lumen of the fallopian tubes
- -Spillage of contrast into the peritoneal cavity from patent fallopian tubes is a normal finding
- -Indications for HSG
  - -Infertility workup
  - -Assessment of uterine anomalies
  - -Documentation of sterility (from prior Essure contraceptive placement)



Normal triangular uterine cavity (arrow)



Arrows demonstrate spillage of contrast from patent fallopian tubes

Nuclear Medicine

NOTE: The role of nuclear medicine imaging of the male and female reproductive systems, however, is quite limited (i.e. to prevent exposure of the reproductive systems to ionizing radiation). One exception is the use of PET imaging (positron emission tomography) is the workup of neoplasia).

INTERACTION WITH MATTER (NUCLEAR MEDICINE

- -*Metabolism*: F^{18} fluorodeoxyglucose (FDG), a positron-emitting isotope (T ½ of F^{18}: 110 minutes)
- -F-18 fluorodeoxyglucose (FDG) is administered via IV
- -Cells with high metabolic rate (i.e. tumor cells) take up and metabolize F-18 FDG
- -FDG is metabolized to FDG-6-phosphate (which cannot be further metabolized by tumor cells)
- -FDG-6-phosphate accumulates in tumor cells (and is detected and quantified)
- -Nuclear medicine images may be 'fused'/merged with CT or MRI images (for more optimal structural/functional assessment)

- Beta plus (B+) decay or positron emission
  - -A proton inside the nucleus is converted into a neutron; a positron (positively-charged electron) is emitted
  - -Positron loses its kinetic energy and annihilates with an electron
  - -Mass of positron and electron (511 keV each) are converted into two 511 keV photons that are emitted in opposite directions (i.e. 180 degrees apart)
  - -Detection/localization of photons allows for creation of PET images

NORMAL ANATOMY:

CT image, left; PET image, center; fused PET-CT image, right (all in coronal plane)

Ultrasonography

NOTE: Sonography, with its lack of ionizing radiation, is an ideal imaging modality for assessment of the male and female reproductive systems. Female pelvic sonography includes imaging of the gravid and non-gravid uterus, the fallopian tubes, and the ovaries. Scrotal and prostate sonography allows for assessment of the male reproductive system.

NORMAL ANATOMY

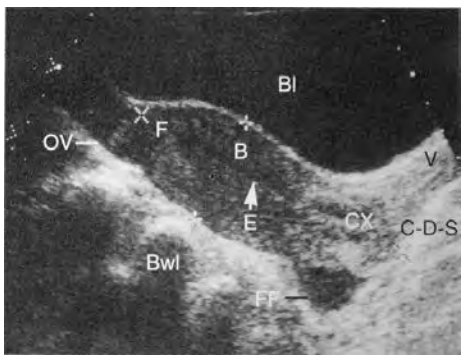
-Female pelvic sonography:

-Transabdominal approach (TA): Transducer is placed on the anterior abdominal wall

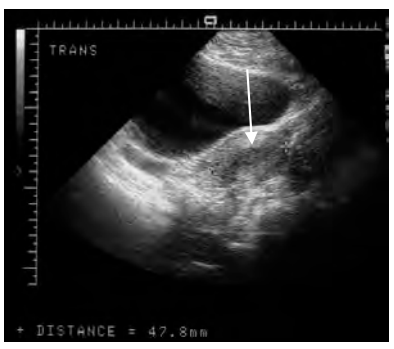
-Imaging through a full urinary bladder ('acoustic window')

-Method of choice is later pregnancy as well as in pre-menarchal (and potentially post-menopausal females)

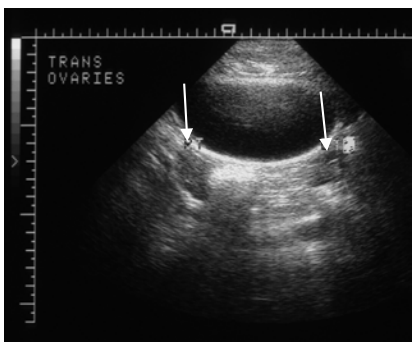
-Image below: Urinary bladder (Bl), Uterine fundus (F), Uterine body (B), Endometrium (E), Cervix (Cx), Ovary (OV) Vagina (V), Cul-de-sac (C-D-S), Bowel (Bwl)



Transabdominal pelvic sonogram: Sagittal image



Transabdominal pelvic sonogram: Transverse image (arrow, uterus)

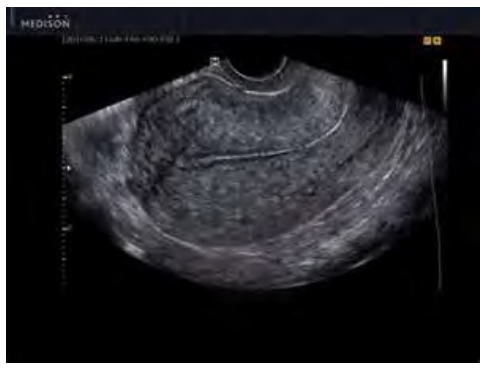


Transabdominal pelvic sonogram: Transverse image (arrows, ovaries)

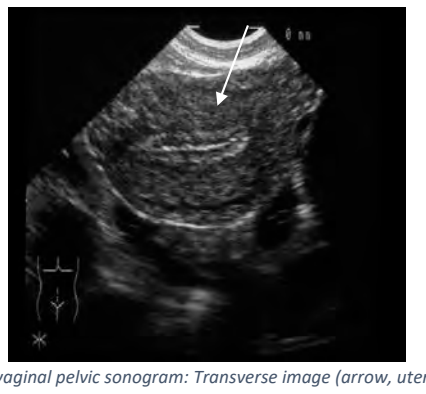
-Transvaginal approach (TV): Transducer is introduced into the vagina (with urinary bladder empty and non-visualized)

-Imaging of the uterus and adnexa (ovaries, fallopian tubes, and blood vessels) is more optimal (i.e. close proximity)

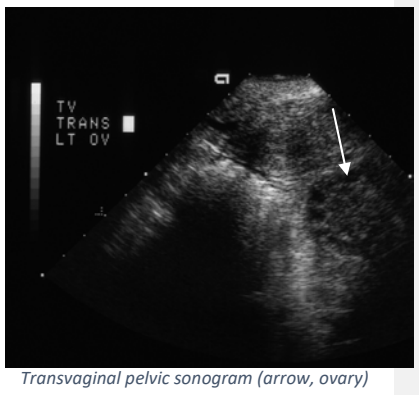
-Method of choice in early pregnancy, potential ectopic pregnancy, potential ovarian torsion



Transvaginal pelvic sonogram: Sagittal image



Transvaginal pelvic sonogram: Transverse image (arrow, uterus)



Transvaginal pelvic sonogram (arrow, ovary)

-Endometrial thickness varies within menstrual cycle

-menstrual phase: <4mm

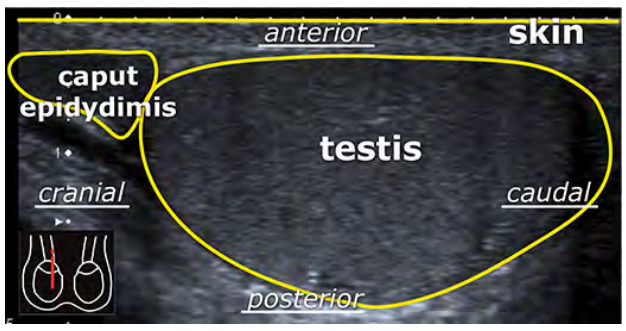
-proliferative phase: 4-8mm (under the influence of estrogen)

-secretory phase: 7-14mm (under the influence of progesterone)

-Ovarian volumes (simple calculation: Length x Width x Height x 0.5)

-premenopausal: <18cc

-postmenopausal: <8c



Scrotal sonogram: Sagittal image

Scrotal sonography

-Assess testicles, epididymi, vasculature, skin

-Clinical indications

-Pain

-Mass

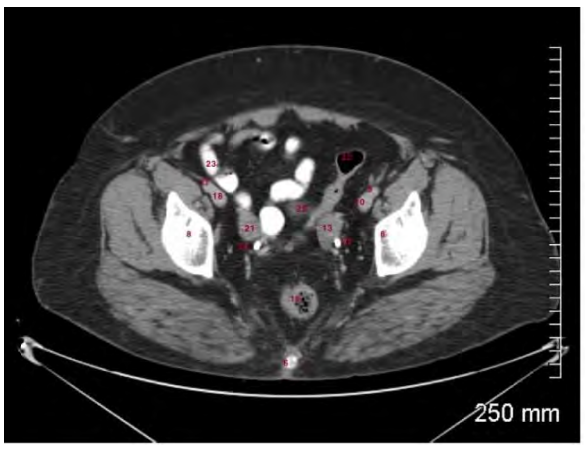
-Trauma

Computerized Axial Tomography

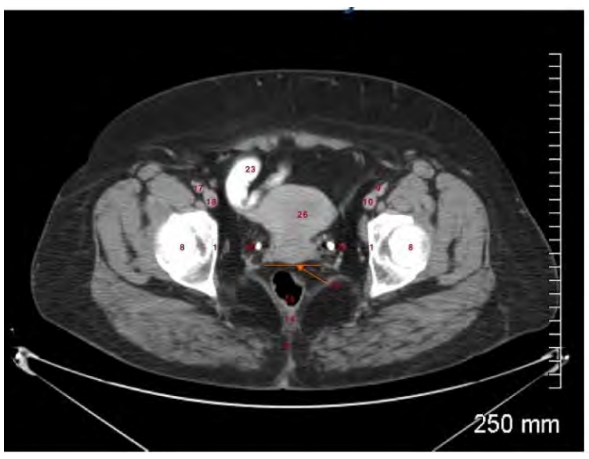
NOTE: The role of CT imaging of the pregnant female is limited (i.e. to reduce exposure of the fetus to ionizing radiation). In the pregnant patient, the workup of *appendicitis* includes sonography and MRI (but may warrant performance of emergent CT examination). In the pregnant patient, the workup of *renal colic* and *urinary tract calculi* includes sonography (but may warrant the performance of emergent CT examination).

CT imaging does play a vital role in diagnosis and monitoring of neoplasia of the male and female reproductive systems (with and without PET). Strictly speaking, the field of view (FOV) of a pelvic CT is from above the level of the iliac crests through the level of the symphysis pubis. Since many disease processes have continuity into the abdomen, abdominal CT (FOV from above the diaphragm through the iliac crests) is often performed in concert with pelvic CT.

NORMAL CT ANATOMY (Female pelvis)

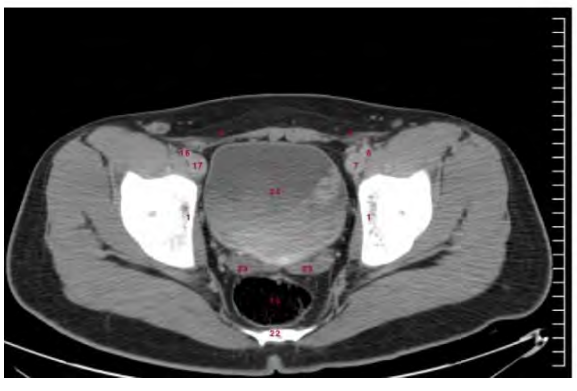


6. Coccyx
8. Ilium
9. Left external iliac artery
10. Left external iliac vein
13. Left ovary
16. Rectum
17. Right external iliac artery
18. Right external iliac vein
21. Right ovary
22. Sigmoid colon
23. Small intestine
25. Ureters
26. Uterus

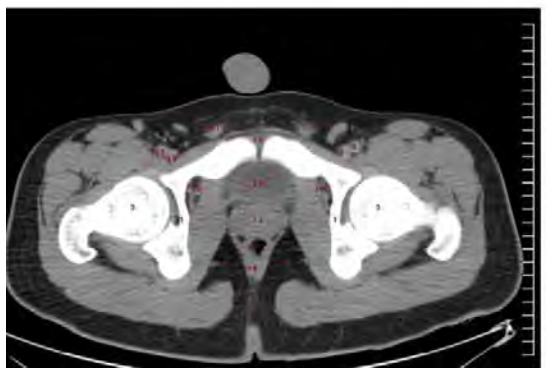


1. Acetabulum
3. Anococcygeal ligament
8. Head of femur
9. Left external iliac artery
10. Left external iliac vein
14. Levator ani
15. Rectouterine pouch
16. Rectum
17. Right external iliac artery
18. Right external iliac vein
23. Small Intestine, radio-opaque and hence not the ovary.
25. Ureters
26. Uterus

NORMAL CT ANATOMY (Male pelvis)



4. Inguinal ligaments and canals
6. Left external iliac artery
7. Left external iliac vein
15. Rectum
16. Right external iliac artery
17. Right external iliac vein
22. Sacrum
23. Seminal vesicles
24. Urinary bladder, distended with urine. (but no contrast fluid)



1. Acetabulum
2. Anal canal
3. Head of femur
5. Ischioanal fossa
8. Left femoral artery
9. Left femoral vein
10. Left obturator vessels and nerve
11. Left spermatic cord
12. Levator ani
13. Prostate gland
14. Pubic symphysis
18. Right femoral artery
19. Right femoral vein
20. Right obturator vessels and nerve
21. Right spermatic cord
24. Urinary bladder

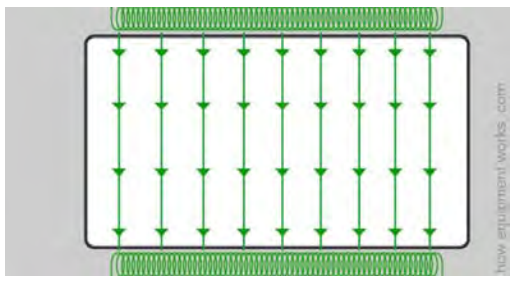
Magnetic Resonance Imaging

-**PHYSICS**:

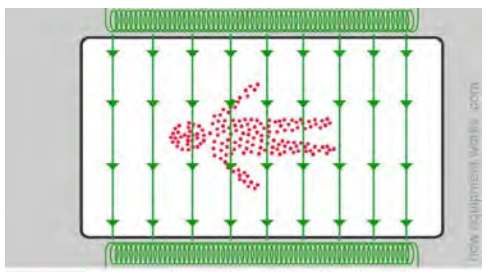
-Protons and neutrons each have a magnetic field called a *magnetic dipole*.
-When neutrons and protons are equal in number within a nucleus, their magnetic moments cancel out
-Nuclei with an *uneven* number of protons and neutrons have a *net* magnetic moment, and act like tiny bar magnets
-Hydrogen nucleus (1 proton; no neutron), therefore, has a large magnetic moment.

-Hydrogen is abundant in the human body and is optimal for MR imaging
-Outside a magnetic field, nuclear spins of hydrogen protons are random (with no net magnetization vector)
-Within an external magnetic field, nuclear spins of hydrogen protons align either *with* or *against* the external field
-A *slight excess* (3/1,000,000) of protons align *with* the magnetic field. (It is this vector that is used in MRI imaging to generate a signal)

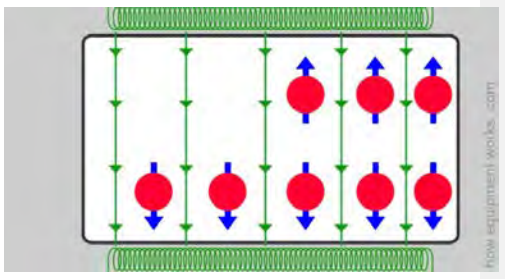
-Simplified overview:
-Subject an individual to a magnetic field
-Align the *net* magnetization vector of the small excess of protons *with* the external field
-Introduce a radiofrequency pulse (RF)
-Perturbing the magnetization vector from its equilibrium position
-Observe the signal generated as the magnetization vector returns to its equilibrium position
-Different tissues (i.e. proteins, water, fat, etc.) generate differing signals. Once analyzed and localized, these signals assist in creating an image



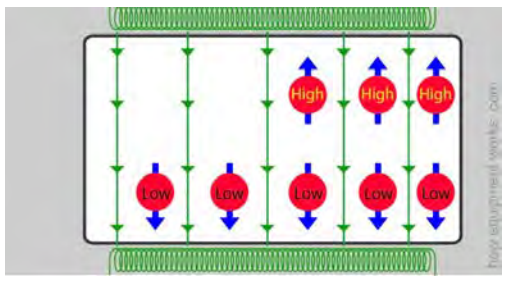
Magnetic field



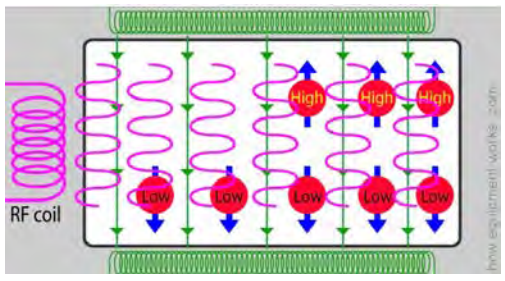
Our patient in magnetic field



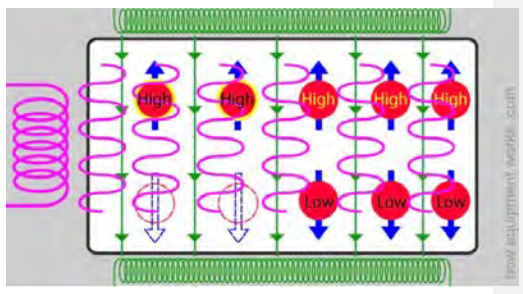
A sample of our patient's protons



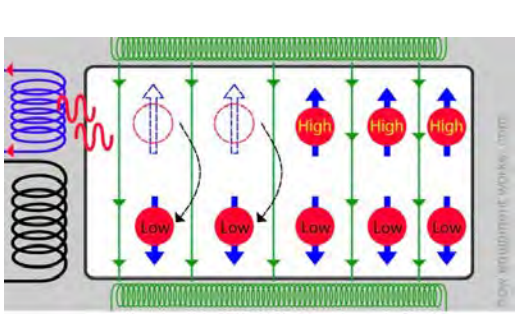
Protons aligned with the external field (Low) and against the external field (High)



RF coil emits energy absorbed by Low-energy protons



Some of the Low-energy protons assume High-energy state



The recently 'energized' high-energy protons prefer to return to their lower energy state. In doing so ('relaxing'), they release energy. This energy, received by 'receiver coils' (in blue), helps to create an MRI image

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-Magnetic nuclei may also be called *magnetic dipoles, spins, or magnetic moments*
-Commonly, texts will illustrate the magnetic nuclei (i.e. protons) as a vector (i.e. magnitude and direction).
-When aligned with the external magnetic field (parallel), the magnetization vector is labelled M_Z
-When the vector is displaced into the orthogonal (XY) plane, it is called $M_{XY.}$

-A certain time after M_Z is displaced, it always eventually returns to the stable (parallel) orientation (through ***T1, 'spin lattice', or longitudinal relaxation)***

-T1 relaxation times are tissue specific (but also vary with strength of external magnetic field)

-The magnetization vector, M_Z, is displaced from its alignment with the external field by the application of radiofrequency (RF)
-Applied radiofrequency (RF) causes the M_Z to rotate through an angle ('flip angle'), proportional to the RF intensity

-A *displaced* vector is often best represented by two vectors (one *perpendicular* to the external field and one *parallel* to the external field)

-The parallel vector is called **longitudinal magnetization (M_Z)**

-The perpendicular vector is called **transverse magnetization (M_{XY})**

-For illustration, let's assume a 90-degree RF pulse which displaces ***all of the net magnetization into the transverse plane (M_{XY}).*** Therefore, ***M_Z is zero.***

-The transverse magnetization vector (M_{XY}) rotates/precesses about the external field.

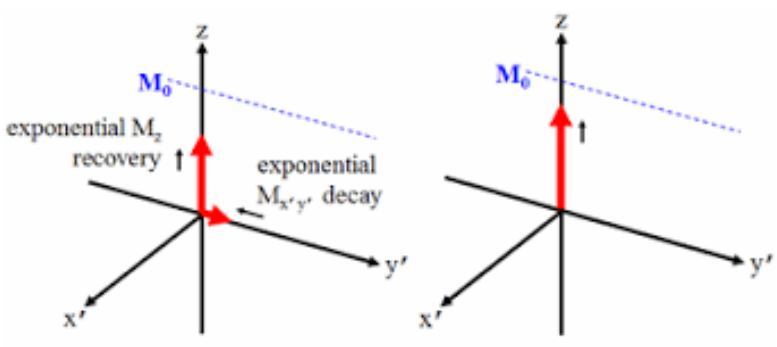
-**Any given transverse magnetization vector, M_{XY},* ***decays *as it interacts with other spins* ***(T2, 'spin-spin', or transverse relaxation).*** *Once spins interact (and dephase), the M_{XY} is irretrievably lost.*

- T2 relaxation times are tissue specific (but independent of the strength of the external magnetic field)

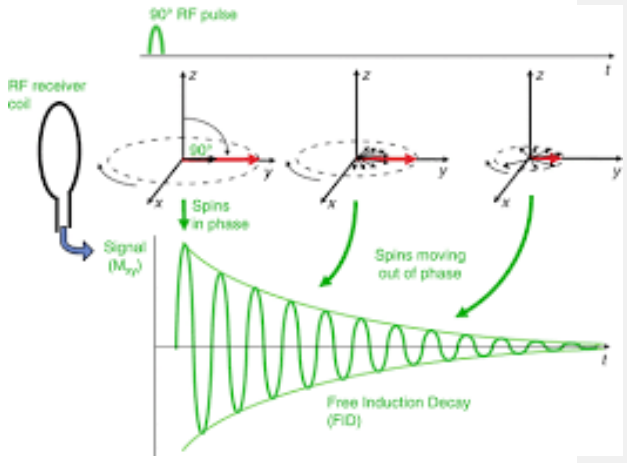
-Note: In addition to spin-spin interaction, M_{XY} may be lost due to external magnet field inhomogeneity, adjacent magnetic tissues, and tissue boundaries. These factors create what is called T2* relaxation (which is faster than T2 relaxation).

-These T2* factors can be offset with the rephasing of spins in order to generate an *echo* for RF receiver detection. *Very simply stated*, this rotating transverse magnetization (after *rephasing* with 180-degree RF pulse) generates an *echo* that can be detected as an induced voltage in a receiver coil, (RF coil placed close to a given body region). With a great deal of processing (beyond the scope of this lecture), an image is created. **Only spins in the XY plane assist in image creation.**

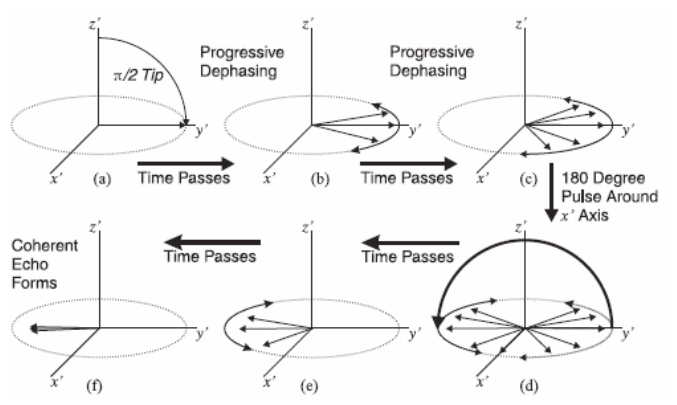
Commented [MJ1]:



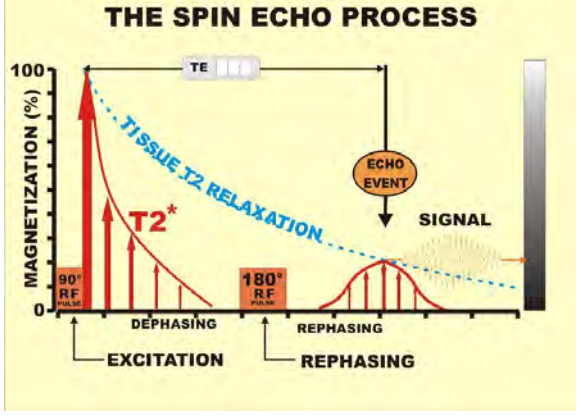
T1 recovery (in M_Z) and T2 decay (in M_{XY})



Dephasing in the transverse plane (with decay over time)

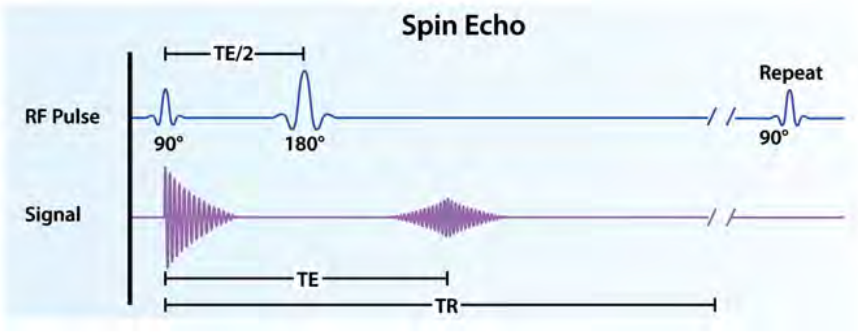


Rephasing with 180-degree pulse (in order to generate an echo for receiver coil detection)



-90 degree RF: initial pulse moves M_Z into $M_{XY;}$
-T2 is dephasing from field inhomogeneity*
-180-degree pulse: 'rephases' the spins in M_{XY} and yields an echo detected by receiver RF coil at TE (echo time)

-Often, the physics behind MR imaging is illustrated by sequences. We have just described the **Spin Echo sequence**. Sequence begins with a 90-degree RF pulse, followed by a 180-degree refocusing RF pulse at time TE/2 (resulting in echo at time TE).
-**Note**: More complex imaging sequences will be discussed in future PI sessions.



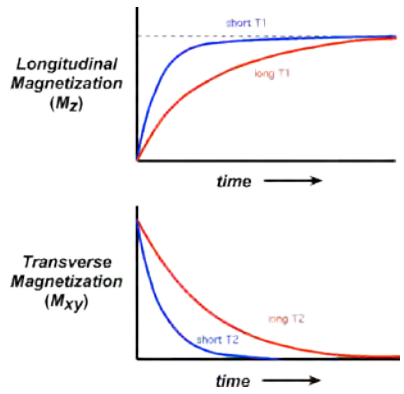
TE: Echo time
TR: Repetition time (time until next 90-degree RF pulse, beginning the process again)
TR and TE can be altered to vary the appearance of tissues

MR IMAGING INTERACTION WITH MATTER

-Different tissues have different inherent T1 and T2 values. As such, multiple MR sequences can be created to demonstrate tissue differences (i.e. 'T1-weighted' and 'T2-weighted' images).

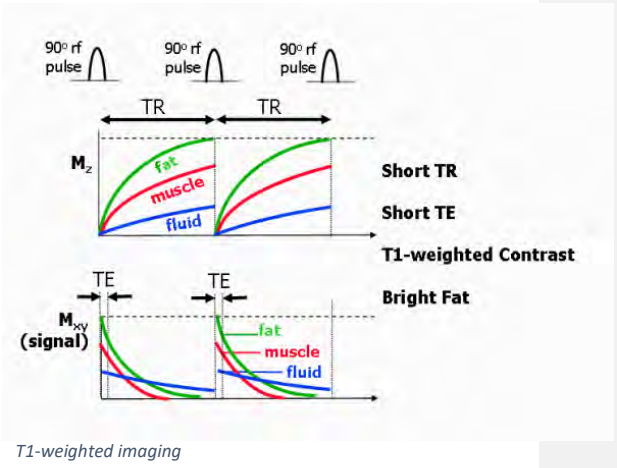
-T1:
- -Longitudinal relaxation time (as a result of spin-lattice interactions)
- -After an RF pulse, longitudinal magnetization ***grows*** exponentially from zero to M_Z, characterized by a time constant T1
  - -At time equal to T1, 63% of M_Z will have formed
  - -After 4 x T1, full net longitudinal magnetization (M_Z) has occurred
- -A tissue with a short T1 time has its M_Z vector reach its maximum value ***faster*** than a tissue with a long T1 time.

-T2:
- -Spin-spin interactions dephase transverse magnetization (M_{XY})
- -Transverse magnetization decays exponentially with time constant T2, resulting in reduction of FID signal
  - At time T2, the FID signal has *decayed* to 37% of its initial value
  - After 4 x T2, the transverse magnetization is zero
- -A tissue with a long T2 time dephases **slower** than a tissue with a short T2 time (leaving more potential to 'rephase' its spins and generate an echo)



Tissue	T1 (msec)	T2 (msec)
Water/CSF	4000	2000
Gray matter	900	90
Muscle	900	50
Liver	500	40
Fat	250	70
Tendon	400	5
Proteins	250	0.1- 1.0
Ice	5000	0.001

-To create a **T1-weighted image**, one maximizes differences in T1 relaxation times (but minimizes T2 relaxation effects)
- -TR: repetition time is kept short (thereby, maximizing the T1 relaxation time differences between tissues)
- -TE: time to echo is also relatively short (thereby minimizing T2 relaxation time differences between tissues)
  - -T1 hyperintense (i.e. bright)
    - -Fat
    - -Contrast
    - -Melanin
    - -Certain blood products (variable)
  - -T1 hypointense (i.e. dark)
    - -Fluid
    - -Cortical bone
    - -Flowing blood
    - -Certain blood products (variable)



T1-weighted imaging

-To create a **T2-weighted image**, one *maximizes* differences in *T2 relaxation times* (but minimizes T1 relaxation effects)

-TR: repetition time is long (thereby, minimizing the T1 relaxation time differences between tissues)

-TE: time to echo is relatively long (thereby maximizing T2 relaxation time differences between tissues)

-T2 hyperintense (bright)

-Fluid

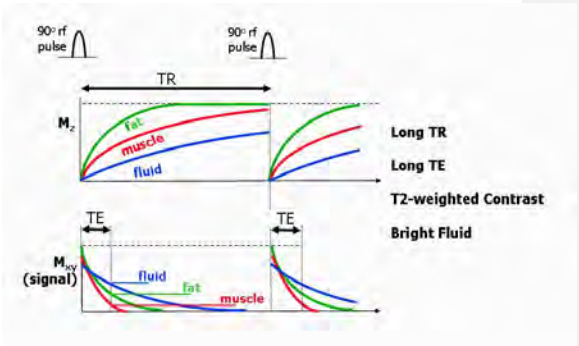
-Certain blood products (variable)

-T2 hypointense (dark)

-Cortical bone

-Flowing blood

-Certain blood products (variable)



T2-weighted imaging

TERMINOLOGY

-**Intensity***:* root word

-*hypointense*: 'darker'

-*hyperintense*: 'brighter'

-**Radiofrequency coils:** Transmit RF signal to the patient (i.e. '*transmitter*')
Receive RF signal from the patient (i.e. '*receiver*')
Both transmit/receive (i.e. '*transceiver*')

-**Gradient coils**: used to produce deliberate variations in main magnetic field

-variations in magnetic field permits localization of:

-slice encoding (i.e. Z-axis)

-frequency encoding (i.e. X-axis)

-phase encoding (i.e. Y-axis).

-All of these gradients assist with assessment of signal from volume elements (i.e. voxels)

-**Voxel**: volume element defined in 3-D space

ADVANTAGES OF MR IMAGING

-No ionizing radiation

-Optimal soft tissue differentiation

-Multiplanar reconstruction

-3-dimensional imaging

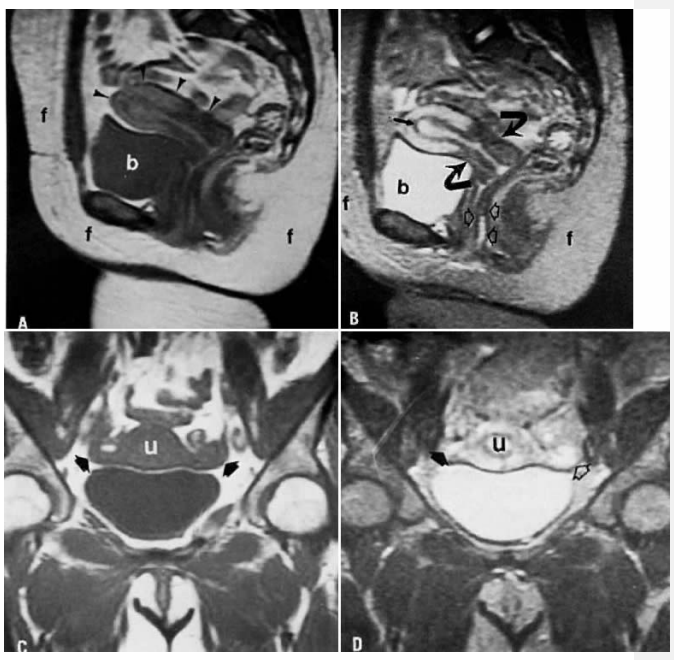
DISADVANTAGES OF MR IMAGING

-Cannot be performed in all patients (i.e. unapproved aneurysm clips, unapproved pacemakers, ferromagnetic metallic foreign bodies, claustrophobia)

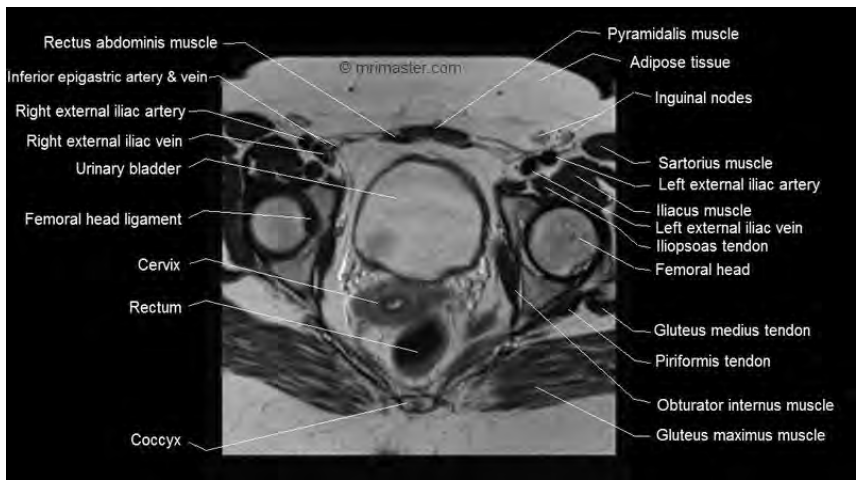
-Cost

EXAMPLES OF NORMAL MR PELVIC ANATOMY

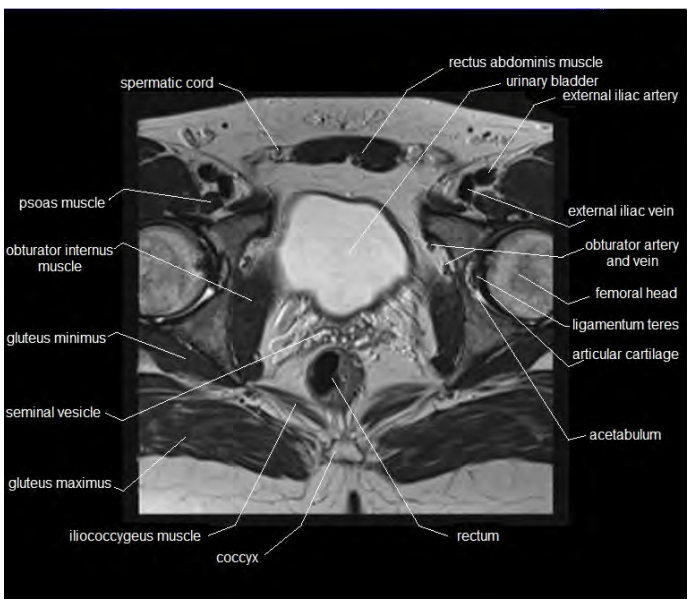
Key:
'f': fat
'b': urinary bladder
'U': uterus
Arrowheads (upper left): uterus
Straight arrow (upper right): endometrium
Curves arrows (upper right): cervix
Short white/black arrows (lower right/left): ovaries/adnexa



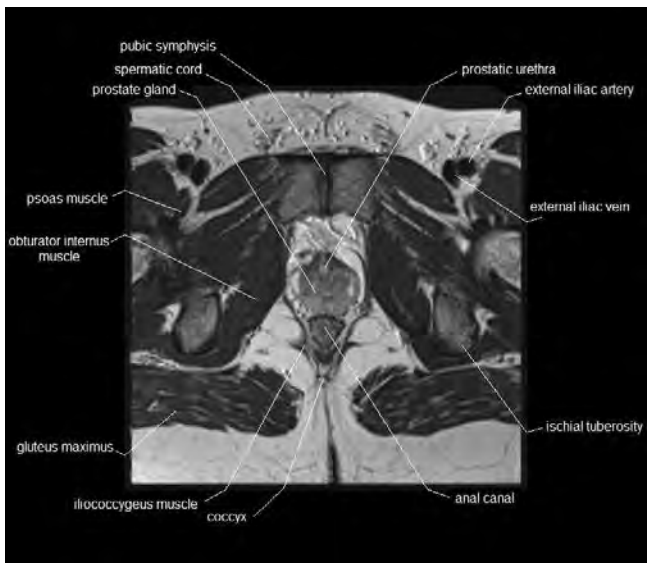
A.T1-weighted sagittal (female) B. T2-weighted sagittal (female)
C.T1-weighted coronal (female) D.T2-weighted coronal (female)



T2-weighted axial image (female pelvis)



T2-weighted axial image (male pelvis)



T2-weighted axial image (male pelvis)

References

-Clinical Radiology: The Essentials. Daffner et al. 4th ed. (Chapters 1, 7, 9,and 10).

-Primer of Diagnostic Imaging. Weissleder et al. 4th ed. (Chapter 4 and 14).

Note: Unless otherwise specified, all graphics are from Review of Radiologic Physics. Huda. Fourth edition.

Note: Medical images are from anonymized patient or online archives.

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