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COMPARATIVE STUDY OF A MODE, B MODE AND M MODE IN ULTRASONOGRAPHY

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ABSTRACT

Ultrasonography (USG) has emerged as an integral diagnostic tool in all fields of medicine due to its non-invasiveness, cost-effectiveness and provision for real-time imaging. It is based on the production and detection of high frequency sound waves that are converted into images by transducers. A-mode (amplitude), B-mode (brightness), and M-mode (motion) are among the first ultrasound modes to have been developed and are widely utilized due to their complementary advantages in clinical applications. This simplest type, A-mode plotting echo amplitude against tissue depth, is still used in ophthalmology and some neurology applications because it gives an accurate representation of linear measurement. B-mode jammed echoes into two-dimensional grayscale images and transformed ultrasonography, thereby providing real-time imaging of internal organs, becoming repeatedly useful abdominal, obstetric, cardiac and musculoskeletal examination. M-mode with its excellent temporal resolution, which captures tissue motion along an acoustic line over time, is still indispensable in cardiological applications (ventricular and valvular assessment, fetal heart monitoring). Comparison reveals their complementary roles: A-mode has the maximum of measurement accuracy, B-mode is specialized in cross-sectional imaging versatility, and M-mode is best for motion analysis. The overall they have decreased dependence on blood invasive procedures; they have provided for earlier diagnostic and they have improved the outcome of patients. Despite being operator-dependent and restricted in comparison to Doppler and modern 3D/4D imaging modes, these have remained at the heart of ultrasound practice. Towards the future, combination with Doppler and contrast imaging as well as volumetric (3D/4D) ultrasound and even artificial intelligence is a theory-to-practice progressive extension to the A-, B- and M-modes for complete diagnostic empowerment. This review highlights their persistent relevance and formative influence on the trajectory of contemporary imaging in medicine, worldwide.

KEYWORDS: Ultrasonography, A-mode, B-mode, M-mode, diagnostic imaging, health care.

1. INTRODUCTION

Ultrasongraphy (USG), a noninvasive imaging technology, also called medical ultrasound or sonography, employs high-frequency sound waves to produce real-time images of the soft tissue structures and organs as well as blood flow, which are occurring within body.[1-3] The transducer generates pulses of ultrasound that are reflected at interfaces of different acoustic properties; the reflected echoes are received and changed to electrical signals, which are subsequently processed and displayed as images.[4–6] Ultrasonography is a point-of-care, dynamic and non-ionizing imaging modality which be carried out relatively easily at the bedside using portable equipment, and constitutes an indispensable cornerstone of modern diagnostic medicine globally.[7-9]

USG is useful in diagnostics and patient care for the following reasons

- Safe and non-invasive: Ultrasound does not use ionizing radiation so it is relatively safe for multiple exams, including but not limited to pregnant women and neonates.[3,7,9]
- Real-time imaging and guidance: Real time means that your using ultrasound at the same time that the images are being taken, so you see moving objects as they move (for example heart valves and fetal motion) absolutely essential for interventional procedures such as needle biopsies, catheter placements and fluid drainage.[1,5,8–11]
- Availability and affordability: Ultrasound machines are cheaper than CT and MRI, portable, and accessible in a variety of clinical settings including resource poor countries.[7,12,13]
- Versatility: USG is used in several clinical domains including obstetrics and gynecology, cardiology

(echocardiography), emergency medicine (point of care ultrasound, POCUS), abdominal imaging, vascular examination, musculo-skeletal analysis among others.[13–15]

Among the various ultrasound imaging modes, **A-mode**, **B-mode**, and **M-mode** remain foundational.[4,12,16]

- **A-mode** (Amplitude mode) visualizes spikes of the intensity of received echoes with respect to a depth (time-of-flight axis.[4,12] Although it is rudimentary, A-mode offers a quantitative measure of the distance to reflectors and was historically one of the first ultrasound techniques developed.[4]
- **B-mode** (Brightness mode) enhances the A-mode echoes by scanning over several lines of sight and then mapping echo amplitude to intensity levels of grayscale "brightness", creating 2D sectional views of anatomy.[4, 8,12] Among various imaging modes, B-mode ultrasonography is most commonly used in clinics.
- **M-mode** (Motion mode) receives echo information from a single scan line on sequences of time, thus creating the one-dimensional representation of motion versus time.[4,12] This mode is very useful for dynamic structure tracking (for example) heart walls or fetal motion in obstetric ultrasound.
  Although newer ultrasound techniques—such as Doppler imaging, color flow, elastography, three-dimensional/ four-dimensional imaging, and contrast-enhanced ultrasound—have expanded the diagnostic utility of the modality, the basic modes of A, B, and M remain central to how ultrasound images are acquired, interpreted, and understood.[12,13,16]

2. PRINCIPLES OF ULTRASONOGRAPHY

2. 1 Basic physics of ultrasound

Ultrasound is sound waves with frequencies above the upper audible limit of human hearing (>20 kHz), yet diagnostic medical ultrasonography generally uses frequency in the range 2–20 MHz.[21] The speed of sound in soft tissue is usually assumed to be 1540 m/s, and the wavelength (λ) is inversely related to frequency (f):

λ=cf\lambda = \frac{c}{f}λ=fc

Where ccc is the speed of sound. The higher the ultrasound frequency, the better the axial resolution; however high frequency ultrasounds attenuate more quickly intro tissue and will not be able to penetrate as deep as lower frequencies (which are conversely less resolvent).[21,22,23]

Ultrasound pulse Oh attenuation Waves that are propagating THE DIMENSIONS OF ATTENUATION into a medium have their amplitudes slowly diminished by the process of attenuation (t = a/x) comprising absorption, scattering and reflection.[22],[24] Boundaries between tissues with differing acoustic impedance (the product of density and speed of sound) generate echoes; the greater the difference in impedance, the stronger is the return echo to the transducer[22,26] Smooth boundaries act as specular reflectors whilst irregular or diverse media may cause diffuse scattering or Rayleigh scattering which are sources for image degradation and artifacts.[22,24,26]

As US pulses traverse the tissue and return as echoes, the returning echoes are processed to give three main pieces of information: its strength (amplitude), time delay (mapping to depth) and in modern systems, direction or angle of arrival after beam forming.[27,28]

2.2 How ultrasonography works

Ultrasound imaging is primarily founded on a pulse-echo approach. Short pulses of high frequency sound are radiated into the body using a piezoelectric transducer.[21,28, and 29] These impulses then propagate through the tissue, reflect from acoustic impedance interfaces at various amplitudes, and are echoed back to the transducer.[21]

The transducer then picks up these echoes, converting the reflected acoustic energy into electrical signals. Timing: The CRT calculator measures the time lapse from pulse emission to echo reception—it is converted (by knowing or assuming the speed of sound in tissue) into a distance, and communicates that information as echoed strength (echogenicity), displayed on a monitor screen as brightness or amplitude.[21,22,27]

With modern scanners, beam forming is possible; i.e., >1 transducer element can both transmit and receive, and the signal can be processed (delayed and summed) to electronically focus the beam to enhance lateral resolution and sensitivity.[30,31] Post-processing can involve image amplification, dynamic compression, filtering and display optimization (the latter often called as "knobology").[26] The echoes obtained can then be shown in several imaging modes (A-, B-mode, M mode, Doppler, etc.) according to how the returning echoes are processed and visualized.[16]

A coupling medium (e.g., ultrasound gel) needs to be used between the transducer and skin in order to fill air gap, because ultrasound waves cannot transmit well through air.[22,24]

2.3. Historical development of A-mode, B-mode, and M-mode

Medical ultrasonography, popularly known as diagnostic sonography or ultrasonic diagnostics, is a diagnostic imaging technique based on the application of ultrasound. Early medical ultrasonography took advantage of industrial and research applications of ultrasound generating techniques. The piezoelectric effect, first discovered in the 19th century, allowed for conversion between electrical and acoustic energy paving a way for early transducers.[32,33]

A-mode (amplitude mode) A-mode was the original ultrasound modality. A single transducer sends out a pulse and listens for echoes coming back. The amplitude of the received echo is plotted as a spike on a graph, where the time of return and depth are shown on the x-axis. And yet this single-dimensional presentation also limited the spatial information about tissue interfaces and distances.[16,24]

The development of B-mode (brightness mode) followed with manual or electronic steering of the transducer (or transducer array) across a plane, acquisition of the various A-mode scans at different angles and/or positions, and conversion of echo amplitude to pixel brightness at corresponding locations in a 2-D image.[32,33] In the 1950s and early 1960s, Ian Donald and others built some of the first contact B-mode scanners for obstetric imaging that contributed to placing MD ultrasound into a routine medical diagnostic tool.[32,33]

M-mode (motion mode) subsequently developed from A-mode. Rather than measuring along a line in space, M-mode locks the ultrasound transducer over a line of sight on the body and echoes are recorded at regular intervals along this path as the transducer is moved across or rotated relative to the patient's body, thereby displaying a representation of movement over time (i.e., motion) as a continuous recording. This modality is most commonly used in cardiology (echocardiography) for observing the movements of heart walls and valves, in obstetrics for fetal motion tracking.[33]

Three basic modes were the basis of the subsequently developed imaging methods. Technological advances in transducer construction, electronic beam steering, real time scanning and digital signal processing have led to the ability for real-time B-mode imaging, Doppler flow analysis, color imaging as well as 3D/4D imaging but the fundamental principles are still based on the early A-modes, B-modes and M-mode capabilities.[33,34]

3. A-MODE ULTRASONOGRAPHY

3. 1. Principle

Amplitude mode (A-mode) ultrasonography is the basic and first type of medical ultrasound examination.[35,36] As sonar 20, in this method only one transducer generates a single pulse of ultrasound along a single line-of-sight. The echoes come back from the interfaces as a series of vertical spikes on a graph, time (or distance derived from time-of flight) being represented along the horizontal axis and echo amplitude along the vertical[37,38]; ii) The interrogated volume is further characterized by means of its contrast with respect to a given background. Each peak represents a reflector; the separation of peaks reflects tissue thickness or spacing between anatomical structures. In contrast to B-mode (which delivers 2D grayscale images), A mode generates a linear echo amplitude trace versus depth.[39]

3.2. Clinical applications

Although largely supplanted by more advanced techniques, A-mode remains clinically relevant in specific fields:

Ophthalmology: A-mode is commonly applied to ocular biometry: the axial length of the eye, which is crucial for IOL power calculations before the cataract surgery.[40,41] It also helps to assess intraocular masses and in distinguishing cystic from solid lesions.[42]

Neurology/neurosurgery: Historically, in echoencephalography, the A-mode was applied to detected midline shifts in patients with suspected intracranial lesions (hematomas, tumors or hydrocephalus).[43],[44] A-mode is 2n inferior to CT and MRI. A-mode has been widely replaced by these two techniques; however it was an important non-invasive screening method in the past.

Other niche uses: A-mode has been used in research, veterinary medicine, tissue characterization and experimental settings as the quantitative depth data that is provided.[45]

3.3. Advantages

- Simplicity: Simple for application specific implementation and interpretation.[37]
- Linear measurements, such as axial length of the eye[46], can be precisely determined.
- Inexpensive and portable; material needs are low in comparison to high-end ultrasound machines.[39]
- One-dimensional data in real-time, obtained without the use of complicated post-processing.[42]

3.4. Limitations

- One-dimensional looking limited on cross-sectional and spatial images of anatomy.[37,39]
- Limited diagnosis: Limited to specialized uses (ophthalmology, some neurology).[43]
- Obsolescence: Replaced in many areas by B-mode, M-mode, and contemporary Doppler imaging.[36,44]
- Operator-dependent: accuracy relies on probe positioning and method.[45]

4. B-MODE ULTRASONOGRAPHY

4.1. Principle

Bright- ness mode (B-mode) ultrasound imaging is the most commonly used technique in diagnostic ultrasound. The returned echoes are used to generate dots of different brightness on a 2D image in B-mode. The x-and y-axes of the display represent dimensions of tissue in space, and each pixel brightness corresponds to echo magnitude.[35,37] Consecutive or simultaneous retrieval of more than one scan line can also be achieved with electronic transducer arrays, enabling a real-time display of cross-sectional grayscale images.[46,47] This principle thus gives spatial presentation of the anatomical structures, which is different from one-dimensional display as in A-mode or M-T mode.

4.2. Applications

B-mode imaging forms the foundation of most clinical ultrasound examinations and is used across virtually all medical specialties:

- Abdominal: Liver, gallbladder, pancreas, kidneys and vascular structures may be examined for mass, stones, hydronephrosis as well as other pathologies.[48-49]
- Obstetrics and gynecology: B-mode is also useful in identifying fetal growth, viability, abnormalities, amniotic fluid volume and placental localisation. It is applied as well for gynecologic assessment of the uterus and adnexa.[50,51]
- Cardiology: M-mode and Doppler provide functional data; B-mode echocardiography offers structural imaging of the chambers, valves (mitral, aortic, pulmonic), pericardium and great vessels.[52]
- Musculoskeletal imaging: Tendons, ligaments, joints and muscles are well-visualised in B-mode for sports medicine and rheumatology.[53]
- Emergency medicine (POCUS): B-mode is the cornerstone of POCUS protocols like FAST, Focused abdominal or thoracic scan at bedside.[54]

4.3. Role in health care systems

B-mode ultrasound is now irreplaceable in today's health care due to safety, ease of access, and cost-effectiveness.[55] It does not involve ionizing radiation, unlike CT or MRI, and it is repeatable as well as appropriate for pregnant subjects and neonates.[56] B-mode portable machines make it possible to perform point-of-care diagnostics in the ER, rural clinic, ambulance and low-resource environment.[54,57]

From a health systems perspective, B-mode contributes to

- Early detection of disease → reducing morbidity and stratifies patients, prompting early paternal / medical intervention.[49,50]
- Fewer use of invasiveness (ultrasound-guided punctures or drainages).[52,53]
- Training and capacity building → core imaging skill for physicians of many disciplines.[55,57]
- Cost reduction relative to advanced modalities (CT/MRI).[56,57]

Therefore, B-mode ultrasound is a fundamental invasive diagnostic modality worldwide connecting highly-sophisticated imaging techniques with real-time bedside assessment.

5. M-MODE ULTRASONOGRAPHY

5. 1. Principle

Motion mode (M-mode) ultrasonography allows to register the movement of structures along a single line of ultrasound beam over time.[35,37] In this method, the transducer sends ultrasonic pulses continuously on a single line of sight. The time–motion graph is presented with echoes returning to the transducer shown on a two-dimensional plot, where the horizontal axis is distance and the vertical axis is depth. The intensity of each point represents echo amplitude.[39,58] This provides high temporal resolution (for example 1000 frames per second) and it well suited particularly for assessment of rapid moving structures such as heart valves and ventricular walls.[59]

5. 2. Applications

M-mode has established clinical value in areas where motion tracking is critical:

Cardiac function (echocardiography)

- Measurement of ventricular wall thickness, chamber dimensions, valve motion, and fractional shortening.[52,60]
- Still considered the gold standard for precise measurement of left ventricular dimensions due to its high temporal resolution.[59,61]

Fetal assessment (obstetrics)

- Used to document fetal heart motion and calculate heart rate, particularly in early pregnancy or when B-mode is inconclusive.[62]
- Recommended over pulsed Doppler in early gestation due to lower energy exposure to the embryo.[63]

Other uses: Evaluation of diaphragmatic motion in neonates or critically ill patients and monitoring of prosthetic valve function.[64]

5.3. Limitations compared to Doppler/3D/4D ultrasound

Despite its utility, M-mode has important limitations:

- One-dimensional: Only a single scan line is used to obtain information; no cross-sectional or volumetric data are obtained.[39,58]
- Angle dependence: the measurement is truly accurate only when the angle of the ultrasound beam relative to the structure being examined is known.[52]
- Superseded by advanced modalities: Blood flow velocities, directionality, and turbulence cannot be obtained on M-mode like Doppler ultrasound.[65,66]
- Three and four dimensional (3D/4D) ultrasound provide increased anatomical detail, as well as dynamic assessment in pregnancy and cardiology.[67,68]
- Operator dependence: Experienced opera-tor should align beam and interpret pattern properly.[59]

6. COMPARATIVE ANALYSIS OF A-, B-, AND M-MODE ULTRASONOGRAPHY

Table 1: Comparison of A-mode, B-mode, and M-mode ultrasound modalities.

Feature	A-mode	B-mode	M-mode
Principle	Echo amplitude vs. depth (1D spikes).[35,36]	2D grayscale image: brightness proportional to echo amplitude.[37,58]	Motion of structures along a single scan line plotted over time (depth vs. time).[59]
Image type	One-dimensional trace.	Two-dimensional cross-sectional grayscale image.	One-dimensional motion-time graph.
Temporal resolution	Low (single measurement).	Moderate (real-time 2D imaging, ~30 fps).	Very high (up to 1000 fps).[59]
Clinical applications	- Ocular biometry (axial length, IOL calculation).[40,41] - Historical neuroimaging (echoencephalography).[44]	- Abdominal imaging (liver, kidneys, gallbladder).[49] - Obstetrics (fetal growth, anomalies).[50] - Cardiology (structural imaging).[52] - Musculoskeletal medicine.[53]	- Cardiac function (ventricular dimensions, valve motion)[59,61] - Fetal heart rate monitoring.[62] - Diaphragmatic motion.[64]
Strengths	- Simple, precise linear measurements. - Low cost, minimal equipment.[6]	- Widely available. - Real-time cross-sectional imaging. - Versatile (many specialties).[49,50]	- Highest temporal resolution. - Accurate motion analysis. - Gold standard for ventricular dimension measurement.[59,61]
Weaknesses	- No anatomical context (1D only). - Largely obsolete except in ophthalmology.[36]	- Limited hemodynamic data (needs Doppler for flow). - Operator-dependent.[49]	- Only 1D motion along one scan line. - Angle dependent. - Lacks volumetric/hemodynamic data.[53]
Current role	Ophthalmology, research, niche use.	Mainstay of diagnostic US across specialties.	Adjunct for motion analysis in cardiology & obstetrics.

6. IMPACT ON THE HEALTH CARE SYSTEM

6.1. Accessibility and cost-effectiveness

Ultrasonography (USG) represents one of the most available and inexpensive imaging modalities at a global level. When compared with CT or MRI, the ultrasound machines are widely available and easier to use for anaesthesiologists.[35,57] Mobile and handheld devices have broadened the reach of diagnostic imaging in low- and middle-income countries (LMICs), rural clinics, emergency care.[70,71] This availability has facilitated USG to be an indispensable primary and point-of-care diagnostic tool that diminished the imaging gap in resource-restricted areas.[55]

6.2. Role in early diagnosis and reducing invasive procedures

Ultrasonography plays an important role in the early diagnosis of disease, especially in obstetrics, cardiology, abdominal imaging and trauma.[49,50] The test facilitates early detection of fetal anomalies, heart malfunction and gallstone, kidney obstruction, and internal bleeding.[52,72] Ultrasound-guided interventions such as biopsy, drainage and vascular access limit the requirement for exploratory surgery or blind procedures, which in turn leads to decreased patient morbidity, length of patient stay and cost.[73,74] The FAST (Focused Assessment with Sonography for Trauma) examination is another common example of how USG has revolutionized emergency medicine by providing prompt detection of internal bleeding without the need for invasive methods.[54]

6.3. Training and skill requirements

Despite its many uses, USG is operator dependent and the efficacy of diagnosis is influenced by the examiner training and experience.[75,76] This leads to differences in diagnostic quality between health care systems. To mitigate this, societies have created formalised training programs in point-of-care ultrasound (POCUS), obstetric ultrasonography and echocardiography.[77,78] Integration of ultrasound into medical school curriculums, and residency training programs has increased diagnostic ability and utilization by diverse fields.[79]

6.4. Integration into modern imaging modalities

While A-mode, B-mode and Mmode sonography continue to be the backbone of US, sono has expanded through the development and use of Doppler-, contrast-enhanced US(elastographyand3D/4Dimaging.[67,80] With these modalities, it is possible to also improve anatomical, functional and hemodynamical assessment thereby increasing clinical use. Moreover, ultrasound is more and more included in hybrid diagnostic process in combination of computed tomography (CT) or magnetic resonance imaging (MRI), but also as a primary test for diagnosing many conditions.[81] New frontiers in artificial intelligence (AI) and machine learning are being put forward for automating image acquisition, interpretation, and triage-tasking that serves to cement ultrasound as an integral part of contemporary health delivery systems.[82]

7. FUTURE DIRECTIONS

7. 1. Advances in ultrasonography

Ultrasound technology is developing rapidly, which increases the sensitivity of diagnosis and extends indications:

- Three-dimensional ultrasonography has the capacity of reconstructing volumetric images from a number of 2D (B-mode) planes, and yields detailed anatomical visualization useful in obstetrics, gynecology and cardiology.[67;83]
- Real-time movement in 3D images (4D ultrasonography) benefits the evaluation of fetal behavior, facial malformations, and heart dynamics.[84]
- Doppler ultrasonography supplements structural imaging, which provides assessment of blood flow velocity and direction and is imperative in vascular, cardiac, and obstetric evaluations.[66,85]
- Introduction of artificial intelligence (AI) /machine learning (ML): AI/ML are increasingly being incorporated into US systems, supporting features such as automated image acquisition, interpretation and decision support.[82,86] Smart technologies also decrease reliance on operator skill and increase reproducibility in different care environments.

7. 2. Building on A-, B-, and M-mode foundations

The new modalities are not replacements but **extensions of traditional ultrasound principles**

- **A-mode** was the basis for quantitative distance and depth measurement that still forms the cornerstone of biometry and tissue characterization algorithms in present (time-gain-compensation) systems.[69]
- **B-mode** is still the essential imaging mode, the fundament of 2D, 3D and 4D reconstruction. Volumetric imaging is obtained by forming a stack of several B-mode slices.[67,83]
- High-frame-rate imaging, similar to **M-mode** but such techniques are introductions in relation to motion tracking; the systems adopted based on this technique can be found in state-of-the-art Echocardiographic applications like speckle-tracking echocardiography.[87]
- **Doppler technologies** enhance these approaches by measuring hemodynamics, with simultaneous B- and M-mode to provide full cardiovascular evaluation.[85]

CONCLUSION

Ultrasonography (USG) has emerged as one of the most versatile, safe and economical imaging modalities in contemporary health care. Each of its cornerstones, A-mode, B-mode and M-mode, has been fundamental in the development of the field. Less popular so far, A-mode has been the principle underlying accurate distance/depth measurements including in ophthalmology and neurology. B-mode brought a revolution in medical imaging with real time two-dimensional gray scale and is today, an indispensable tool for abdominal, obstetric, cardiac and musculoskeletal diagnostics. M-mode, with its superior temporal resolution, it is still essential to study dynamic processes as cardiac movements and fetal heart. Collectively, these modalities have greatly improved early detection, decreased reliance on invasive techniques and facilitated favorable patient outcomes, still while remaining feasibile in a variety of health care environments. Their relative merits emphasize the complementarity of ultrasound technology and the lasting pertinence. In perspective, current developments—such as Doppler imaging, 3D/4D ultrasound and artificial intelligence—are based on the foundations of these fundamental modes which augment their diagnostic capabilities and real-life application. Although newer techniques have now come to the forefront, both the historical roots and current day backbone of global ultrasound applicability resides in A-, B- and M-mode imaging systems, which remain crucial for diagnostic information worldwide alike.

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