Understanding biological systems using ultrasound: complex dynamical systems view

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There have been many dramatic achievements in medical ultrasound since its first application as a diagnostic tool. These include gray-scale display (B mode), Doppler method, and real-time three-dimensional sonography (so-called real-time 3D, or 4D). All of these techniques provide us with great benefits in understanding human physiology and pathology. Yet, as an obstetrician specializing in fetal diagnosis, I feel that it is time to utilize this sophisticated ultrasound technology for understanding complex biological systems.

The development of the theory of nonlinear dynamics in the past several years has provided the scientific world with a rich variety of theoretical methods for investigating dynamical systems. The principal understanding of the mechanisms in such systems was associated with the creation of diverse means for the description and analysis of nonlinear processes. The new view of the world attracted more and more interest from those in various sciences dealing with nonlinear dynamics. A nonlinear system may give rise to chaos where long-term predictability is impossible, and small perturbations may result in radically new behavior in the measured variable. Nonlinear dynamics theory has emerged as the new form of analysis for studying complex biological systems.

I always wonder what life is. What type of system is life? How can we understand living systems? Since the famous publication of *What is Life?* by Schrödinger, it seems to me that we have not yet reached satisfactory

answers to those questions in spite of the remarkable success of molecular biology. As Kaneko mentioned [1], such basic questions about a life system itself cannot be answered by the mainstream approach of current biology “reductionism” that elucidates molecules and genes. We need some alternative approach, that is, complex systems biology based on a dynamic systems approach, to understand the basic features of a biological system. These features include heredity, reproduction, morphogenesis, and development, all of which are concerned with fetal medicine. I feel that recent advances in ultrasound technology have expanded the possibilities of obtaining information on a fetus developing complex biological systems in utero.

For example, 3D ultrasound has been available for more than 10 years. There are some definite situations in which 3D is advantageous [2]: (1) when it is difficult to integrate a 3D impression of the anatomy of a developing fetus, especially for curved structures or (2) when there are complex structures not usually encountered that can be difficult to understand with 2D sonography alone, e.g., complex fetal anomalies. Along with surface images and volume measurement, 3D sonography overcomes these problems. I am convinced that this technique will highlight the normal and abnormal morphogenesis of a fetus in more detail in the future.

In addition, 3D ultrasound enhances the visualization of various fetal behaviors. For instance, before 3D ultrasound was introduced for fetal examinations, we had already known of fetal facial movements: yawning, sucking, and swallowing. The use of 3D ultrasound made us aware of the presence of various fetal facial expressions: smiling, crying, and grimacing [3]. Thus, 3D ultrasound presents a new possibility of comprehensive analysis of fetal neurological development. Moreover, spatiotemporal image

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correlation (STIC) gives us 3D moving images of the fetal heart, enhancing our understanding of the characteristics of the fetal circulatory system with the Doppler method.

I hope that by using sophisticated fetal ultrasound techniques we will move onto the next stage where we can understand the mysteries of the beginning of the living system of an individual.

References

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