



Echocardiographic imaging options in ovine research subjects

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Abstract Objectives: To determine the feasibility of acquiring quality transesophageal (TEE), epicardial (EE), and intracardiac (ICE) echocardiographic images in ovine subjects and to discuss the merits of each technique with a focus on ICE image acquisition.

Animals: Eleven male castrated Dorset adult sheep.

Methods: Transesophageal echocardiography was performed under general anesthesia. Epicardial echocardiography was performed as part of an open chest (thoracotomy or sternotomy) experiment. Subjects were recovered with permanent jugular vein indwelling catheter and ICE from this approach was described. Feasibility of each technique was qualitatively assessed based on subjective image quality from three images for each image plane in each sheep.

Results: Transesophageal echocardiography was technically challenging and did not provide adequate image quality for consistent interpretation. Epicardial echocardiography and ICE had more favorable results with ICE demonstrating unique benefits for post-operative serial monitoring.

Conclusions: Epicardial echocardiography and ICE were effective imaging techniques. Epicardial echocardiography required the least specialized training but was

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considered to have limited feasibility due to its requirement for an open chest procedure. Even with the necessity for permanent indwelling jugular cannulation, ICE was the least invasive of the three imaging techniques and potentially the most practical approach for chronic studies by minimizing post-operative stress. Transeosophageal echocardiography was not a feasible technique in this study.

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Abbreviations

Ao	aorta
ECG	electrocardiogram
EE	epicardial echocardiography
ICE	intracardiac echocardiography
LA	left atrium
LV	left ventricle
MV	mitral valve
RA	right atrium
RV	right ventricle
RVOT	right ventricular outflow tract
TEE	transeosophageal echocardiography
TTE	transthoracic echocardiography
TV	tricuspid valve

Introduction

Echocardiography has expanded beyond the traditional transthoracic approach in both clinical and research investigations; transeosophageal (TEE), epicardial (EE), and intracardiac (ICE) examinations are each with their own merits and challenges in regard to image quality and invasiveness. Awareness of available imaging options is vital in the development of studies looking to optimize both image quality and animal welfare, particularly for ovine subjects due to their high prevalence as established models for cardiac research [1].

Transthoracic echocardiography (TTE) is a non-invasive imaging modality ubiquitous in clinical practice and research in both humans and animals. Requiring little to no sedation and no equipment beyond a standard ultrasound machine and transducer, this approach is widely documented in ovine models [2–4]. Transthoracic echocardiographic image acquisition is feasible in ovine models [1] but can be challenging under certain study conditions such as in post-operative animals [5]; depending on a study's methodology, other modes of echocardiography may be more effective at achieving high quality images for reliable interpretation.

Transeosophageal echocardiography has become increasingly common in the last twenty years in animal and human research and in clinical practice. The value of TEE arises from the transducer proximity to the desired structures which allows for reduced loss of ultrasound signal, providing higher quality images than traditional TTE [6]. However, TEE is technically challenging, requiring specialized equipment and training; a range of medical doctors undergo training for clinical implementation based on published guidelines for TEE in humans [7]. There is heightened risk for complications to the subject with TEE than TTE, particularly in animals where general anesthesia is necessary and where small body size may even preclude certain animals from TEE. In veterinary clinical practice, the most common indications for TEE include pre- or intraoperative evaluation for interventional procedures, and less commonly for characterization of complex heart disease [8]. While not present in every veterinary cardiology office, TEE is increasingly accessible for pet owners [9,10].

Epicardial echocardiography is valued for its superior image quality while still not significantly raising patient risk beyond the inherent invasiveness of the associated open chest procedure [11]. For this reason, EE is used primarily in human medicine in perioperative scenarios where a sternotomy/thoracotomy is already indicated [12]. The transducer's direct contact (sterile sleeves are present to maintain asepsis) with the epicardium allows for excellent ultrasound beam transmission and access to nearly unencumbered anatomic windows [13]. Obstacles to EE can arise from the procedure's sterility requirements, potential surgical disruption, and spatial/personnel limitations within the thoracic cavity and around the operating table [12]. In ovine models, EE has been used to investigate prosthetic valve implantation [14], tricuspid valve (TV) annulus functional anatomy [15], and right ventricular outflow tract (RVOT) reconstruction [16]. To the authors' knowledge and relevant literature search, EE is not widely performed in clinical veterinary medicine due to procedural invasiveness and limited need during

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