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Pacemaker Implantation in Small Animal Practice: Indications, Types of pacing and Implantation Technique

Bhand Akshata[1]*, Ravi Mohan Shukla[2], Chand Tanwar[1], Garima Rathore[1] and Siddharth Chaudhary[1]

[1]Division of Medicine, ICAR-Indian Veterinary Research Institute, Bareilly, Uttar Pradesh, INDIA
[2]Department of Veterinary Pathology, Veterinary College and Research Institute, TANUVAS, Orthanadu, Tamil Nadu, INDIA

**Corresponding author: B Akshata; E-mail: akshatabhand0807@gmail.com*

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ABSTRACT

The implantation of pacemakers is widely accepted as a standard procedure for addressing symptomatic bradycardia in both dogs and cats. The most common rhythm irregularities necessitating pacing for the relief of clinical symptoms or the enhancement of survival rates comprise advanced second- and third-degree atrioventricular blocks, sick sinus syndrome, persistent atrial standstill, and vasovagal syncope. A number of dog breeds, including West Highland White Terriers, Miniature Schnauzers, and Cocker Spaniels, are prone to sinus node disease, whereas Labrador retrievers and German shepherds are prone to atrioventricular block. Since its initial use in 1967 on dogs having third-degree heart blocks, implantation has remained a consistent practice in the field of veterinary medicine. Pacing leads and a pacemaker generator are two components of a modern pacemaker system. The current pacemaker installation technique for dogs uses endocardial leads and is placed intravenously, but for cats, thoracotomies or laparotomy are used to place epicardial leads. Depending on the conduction abnormalities, there are many different ways of pacing, which include atrial pacing, right ventricular apex pacing, interventricular septum pacing, right ventricular outflow tract pacing, etc. Beyond its accomplishments in human medicine, it has attained notable success in veterinary practice, benefiting various animals such as dogs, cats, ferrets, donkeys, and others.

HIGHLIGHTS

- Pacemaker implantation is accepted as a standard procedure for addressing symptomatic bradycardia in both dogs and cats.
- Advanced second- and third-degree atrioventricular blocks, sick sinus syndrome, persistent atrial standstill, and vasovagal syncope are the primary rhythm irregularities requiring pacing.

Keywords: Pacemaker, pacing, atrio-ventricular block, endocardial lead, epicardial lead

The conduction system of hear is made up of sinoatrial node, atrioventricular node, bundle of his and purkinje fiber. It begins and regulates the electrical impulse, resulting in synchronized contraction of the atria and ventricles (Santilli *et al*., 2019). Disruptions in any of these components can result in inter-atrial, atrioventricular, or interventricular dyssynchrony. The initial implantation of a pacemaker in the veterinary domain took place in 1967 on a dog suffering from congestive heart failure (CHF) caused by third-degree atrioventricular block. This procedure involved a thoracotomy and the placement of two leads on the epicardium, enabling a fixed rate pacing of 70 beats per minute (Buchanan *et al*., 2003). After that, several studies have documented the success of implantation in groups of dogs, the largest of which was by Oyama and others of 154 dogs in 2001 (Oyama and others, 2001).

Transvenous lead implants are now used for the majority of pacemaker implantations in veterinary patients, keeping the procedure significantly less invasive

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(Buchanan *et al.,* 2003). The majority of pacemakers (PMs) are transvenously implanted in dogs, employing endocardial leads. Nevertheless, in cats and, under certain circumstances, in dogs as well, there might be a need to use epicardial leads through thoracotomy or laparotomy. Contemporary pacemakers (Fig. 1) consist of a sealed pulse generator housing a lithium iodine battery, which produces electrical impulses and monitors the natural cardiac rhythm through a unipolar or bipolar lead connected to either the endocardial or epicardial surface of the heart. Parameters such as artificial pacing rate, voltage, current, pulse width, and sensitivity can be customized using a telemetry system, facilitating intraoperative and postoperative adjustments. (Wess *et al.*, 2006). Technological progress in the medical device industry has resulted in a diverse range of active and passive transvenous pacing leads designed for human applications. These leads exhibit enhanced characteristics such as smaller profiles, flexible lead bodies, different fixation methods, and insulation materials. Veterinary clinicians can now employ these leads to attend to the specific needs of their patients.

Fig. 1: Pacemaker generator with lead

Breed predisposition

Certain dog breeds, including West Highland White Terriers, Miniature Schnauzers, and Cocker Spaniels, have a higher susceptibility to sinus node disease (Ward *et al*., 2016), whereas breeds such as Labrador retrievers and German shepherds appear predisposed to atrioventricular block (Noszczyk-Nowak *et al.,* 2017). The clinician needs a comprehensive knowledge of the causes, physiological changes, and typical progression of the most common bradyarrhythmias. This understanding is crucial to determine whether a patient is suitable for pacing and to choose the appropriate pacing method. They also need to know what can be accomplished by pacing patients who have different rhythm disturbances.

Indications

In small animal practice, advanced second-degree and third-degree atrioventricular blocks,sick sinus syndrome, persistent atrial standstill, vasovagal syncope are the prevalent rhythm abnormalities that require pacing to either reduce clinical signs or prolong survival rate (Oyama *et al*., 2001; Santilli *et al.*, 2019).

Atrioventricular conduction disturbances

An interruption, whether permanent or temporary, in the conduction of impulses through the atrioventricular (AV) node and/or the His Purkinje system is referred to as an atrioventricular block (Fig. 2a, 2b & 2c). Depending on the anatomical or functional damage along the conduction pathway, atrial impulses may conduct slowly or may be completely blocked(Schrope and Kelch, 2006).It can arise as a consequence of acute or chronic myocardial abnormalities or as a secondary complication of an underlying disorder (Santilli *et al*., 2016).

Fig. 2: First Degree AV Block

Fig. 2a: Mobitz type 1

Fig. 2b: Mobitz type 2

Fig. 2c: Third Degree AV Block

Complete atrioventricular block (AVB) can result from primary or secondary cardiac conditions (whether congenital, acquired, or occurring after traumatic, neoplastic, infiltrative, inflammatory, and systemic disorders) that interfere with the atrioventricular conduction system. Additionally, it has been observed that enteric coronavirus is the causative agent for acute myocarditis and atrioventricular block (AVB) in dogs, with less frequent occurrences of congenital forms or functional issues (such as hyperkalemia, toxicity, antiarrhythmic medications, high vagal tone, and hyperthyroidism).

Sinus node disease

The term "sinus node disease" is commonly used to describe sinus node dysfunction (SND), which is manifested electrocardiographically as severe sinus bradycardia and sinoatrial (SA) block/arrest (Fig. 3). A common electrocardiographic abnormality is the alternation between paroxysmal supraventricular tachycardia and slow atrial and ventricular rates, often followed by recurrent episodes of focal atrial tachycardia, atrial fibrillation (AF), or atrial flutter. While dogs with SND typically do not necessitate treatment, those with SSS often require pacemaker implantation to reduce the frequency of syncope (Estrada *et al*., 2012).

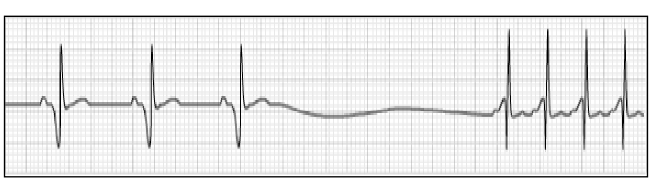

Fig. 3: Sinus node disease

Persistent atrial standstill

Persistent atrial standstill (Fig. 4) is a rare cardiac arrhythmia in both human and veterinary practice. Although myocarditis, neuromuscular disease, and chronic cardiac disease have all been proposed as potential causes of PAS in dogs, atrial myopathy is primarily responsible for this rhythm disturbance. It is important to distinguish between PAS and temporary TAS, which might result from myocardial infarction, hyperkalemia, digitalis toxicity, quinidine toxicity, hypoxia, or hypothermia (Thomason *et al*., 2016; Sanz-Gonzalez *et al.,* 2023)

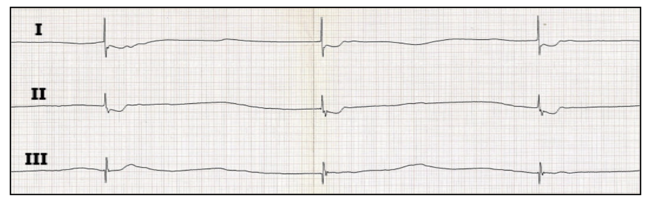

Fig. 4: Persistent atrial standstill

Disruptions within the autonomic nervous system

Disturbances in the autonomic nervous system may cause a decrease in heart rate, a reduction in vascular tone, or both. This can result in temporary cerebral hypo perfusion, eventually leading to brief, self-limited episodes of unconsciousness. Reflex syncope has historically been characterized as a diverse range of conditions in which typically beneficial cardiovascular reflexes momentarily become inappropriate in response to a triggering factor (Chen *et al.,* 2014). Triggering conditions vary widely among individuals, and in most instances, the efferent pathway is not strongly determined by the type of trigger.

Clinical signs

Clinical symptoms are influenced by the severity of the heart block, the rate of the escape rhythm, and the presence or absence of concurrent cardiac conditions. Common signs include weakness, exercise intolerance, temporary loss of consciousness, lethargy, vomiting, diarrhea, and indications of congestive heart failure (ascites or pulmonary edema) (Schrope and Kelch, 2006).

The first implant

In 1958, a Swedish man named Arne Larsson, aged 43, experienced severe Stokes-Adams attacks.He was almost giving up and needed resuscitation virtually every day. His wife had heard of a Swedish doctor in Stockholm who had developed a heart-stimulating device. Dr. Rune Elmqvist, the device's creator, and Dr. Ake Senning, a cardiologist, implanted the device in Mr. Larsson in the autumn of 1958. Although the initial pacemaker only lasted a few hours, a new device was implanted. Mr. Larsson performed admirably well, received 26 devices in total lifespan and died in 2001 (Magjarevic and Ferek-petric, 2010; DeForge W.F., 2019; Verma and Knight, 2019).

The first veterinary implant

The initial permanent cardiac pacemaker was inserted into a 10-year-old male Basenji dog in 1967 (Buchanan *et al.,* 1968). The dog had experienced multiple episodes of heart failure due to complete heart block. This was an epicardial system, and a thoracotomy was needed to implant the fixed-rate device. Ten years later, in 1976, Musselman and co-workers reported the first implantation of a transvenous cardiac pacemaker in a dog.

The transvenous method is considered as less invasive and traumatic compared to epicardial implantation, which frequently requires an abdominal approach and incision in the diaphragm to access the left ventricular epicardial surface.

Components of pacemaker system

The initial pacemakers consisted primarily of a timer and a battery (Mulpuru *et al.,* 2017). They did not possess sensing capabilities, operated at fixed pacing rates, and lacked a means to communicate with the device for programming or retrieving diagnostic data. Compared to today's transvenous method, the surgical process was significantly more complicated. An epicardial lead had to be sewed into the surface of the heart, which required a thoracotomy. The extensive programmability, numerous components, and complete wireless connectivity in modern pacemakers allow physicians to remotely monitor patients' devices without the need for patient involvement. The key elements of a pacemaker system consist of pacing leads and a pacemaker generator.

Pacing leads

Pacemaker leads are tiny wires that link the myocardium to the output circuitry of the pacemaker (Lak and Goyal, 2020). A typical pacemaker lead typically has a diameter ranging from approximately 5 French to 8 French, with a circumference measuring about 5.24 to 8.34 mm. Typical leads are either unipolar (the device serves as the anode) or bipolar (the lead wire serves as both the anode and cathode) (Mulpuru *et al*., 2017). Most modern leads also have a steroid, often dexamethasone, at the tip that elutes with time. The utilization of steroids assists in maintaining stable pacing thresholds over the long term.

The conductor wires typically consist of MP-35N (SPS Technologies, Cleveland), which is a nickel-cobalt-chromium-molybdenum alloy. This material is extremely strong and resistant to corrosion. These conductor wires are coiled in either a cordial or a coaxial arrangement, allowing for more flex generated by myocardium movement during contraction and relaxation of the heart. Each conductor wire strand is individually insulated using ethylene tetrafluoroethylene. These individual strands are subsequently encased in an outer insulating layer crafted from silicone, polyurethane, or a copolymer (DeForge, 2019).

Pacemaker generator

Modern pacemakers are engineered with a sensor circuit, a logic circuit, and an output circuit capable of communication with a pacemaker programmer and a remote monitoring device. Signals enter the pulse generator's circuits from the lead; the sense amplifier is the first section these signals enter.

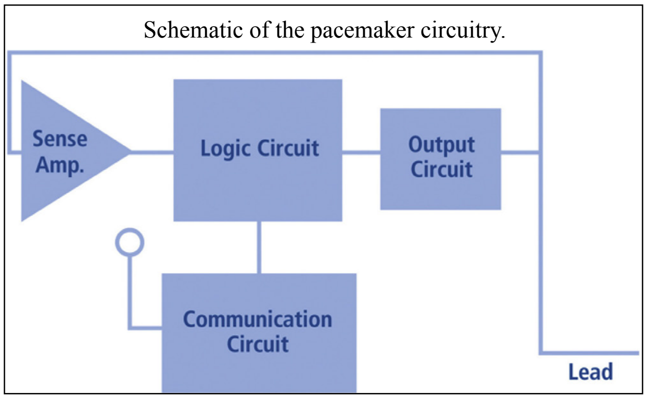

Fig. 5: Component of pacemaker circuit

As the name implies, it multiplies or amplifies small electrical impulses so that the pulse generator can work with them. The signal is then routed to the logic circuit.

The pacemaker's 'brains' are located here (DeForge, 2019). The pacemaker decides whether to send or inhibit an output pulse at this point. If a pacemaker output pulse is required, the output circuit responds by pacing the heart. The communication circuits allows the various circuits to work together. The schematic diagram of pacemaker circuitry is given below (Fig. 5).

Factors to consider when programming pacing rate in dogs (Moise *et al.,* 2021)

Consideration	Comments
Activity level	Younger dogs have more activity with greater demand for rate support
Breed	Low HR in Golden Retriever, Labrador Retriever, West Highland White Terrier
	High HR in Great Dane, Chihuahua, Cavalier King Charles spaniels
Age	Faster HR in less than one year old dogs while adult dog have slow HR
Size	Larger dogs have modestly slow HR but temperament has a dominant influence
Temperament	Mental stress is known to increase HR
Non-Cardiac comorbities	Renal disease, diabetes, systemic hypertension

Types of pacing

Atrial pacing

Dogs with sinus node dysfunction but normal atrioventricular nodal conduction may benefit from atrial pacing, based on certain research (Nielsen *et al*., 2012). The problem lies in accurately fixing atrial leads within the small right atrium of small breed dogs, which are the most usually affected by sick sinus syndrome.

Right ventricular apex pacing

The majority of pacing leads in dogs are set in the right ventricular apex; however, most human patient studies and experimental studies in dogs (Lumens *et al*., 2009) present convincing evidence of the negative consequences of pacing from this location.

Interventricular septum

The optimal location for placing leadless pacemakers, such as Micra by Medtronic, is within the interventricular septum.

Right ventricular outflow tract

Placing it in the right ventricular outflow tract resulted in the narrowest QRS complexes (Garweg*et al*., 2019).

His bundle-Purkinje pacing

This pacing results in a narrow QRS and is now the preferred method in humans (Zhuang *et al*., 2018; Sun *et al*., 2020).

Implantation techniques

Transvenous implantation

When selecting a pacing system, one should carefully consider the diagnosis of bradyarrhythmia, the patient's characteristics (age, size, and concomitant cardiac and systemic disease), the available technology, the associated costs, and the level of expertise required for the insertion (Estrada *et al*., 2019).

Lead placement

Position: For the right jugular vein access during the installation of a permanent transvenous pacemaker, it is recommended that all patients be positioned in left lateral recumbency.

Procedure: To adjust the lead location when setting RV or RA leads, consistently rotate counterclockwise toward yourself and the table/dorsally. When inserting a coronary sinus/left ventricular (LV) lead, if the patient is in right lateral recumbency, the coronary sinus ostium can collapse and close making access difficult. To minimize lead displacement due to activity and neck movement, it is advisable to perform the incision and right jugular venotomy as near to the thoracic inlet as feasible (Estrada *et al*., 2019).

Ventricular-based pacing

Procedure: The RV apex (RVA) is the frequently employed site for the permanent implantation of pacemakers in veterinary patients. Pacing leads often come with various stylets, which may include both curved and straight tips. Straight stylets are equipped with a ball at the tip, enhancing secure locking into the lead and providing greater control during lead guidance. The pacing lead and straight stylet are inserted into the jugular vein, ensuring that the tip of the lead is within the right atrium. To help cross the tricuspid valve, the straight stylet is substituted with a custom-curved stylet. After that, the curved stylet is removed and replaced with a straight stylet to guide the lead to the RVA. (Estrada *et al*., 2019).

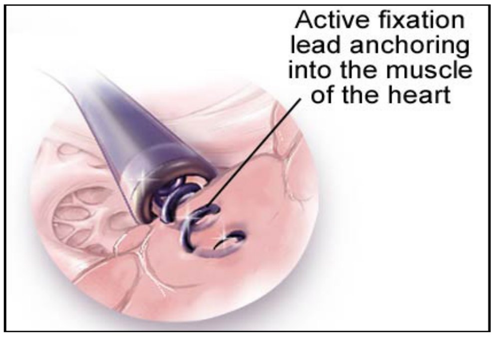

Fig. 6a: Active Fixation of Lead

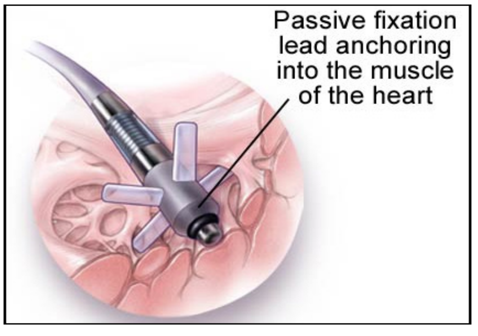

Fig. 6b: Passive Fixation of Lead

To verify the positioning of the lead tip in the right ventricular apex (RVA), orthogonal fluoroscopic or radiographic views, with a preference for left lateral and dorsoventral views, can be beneficial. The lead is correctly positioned in the RVA when the tip is observed at the caudoventral aspect of the cardiac silhouette in a lateral view and slightly deviates toward the midline on the ventrodorsal projection. In order to rotate an active-fixation lead (Fig. 6a) with an extended and retractable helix clockwise, a torque device is positioned at the distal pin of the pacing lead, and the lead is gently pressed against the RVA endocardium. The placement of passive-fixation leads (Fig. 6b) is identical, except that a straight stylet and lead are inserted as deeply into the right ventricular apex (RVA) as possible, without employing a torque device.

Epicardial pacemaker implantation

The implantation of an epicardial pacemaker can be performed independently or concurrently with another thoracic or abdominal procedure. The primary advantage of epicardial pacing lies in its avoidance of contact with intracardiac tissues and blood, thereby mitigating the rare but potentially fatal issues associated with endocardial pacemaker placement. The minimally invasive thoracotomy technique or abdominal Tran's diaphragmatic thoracotomy can be used to perform epicardial pacing as an independent surgery. Epicardial pacing is a suitable choice for small animals with existing infections, those at risk of thrombotic complications, and animals undergoing supplementary thoracic or abdominal surgery (Caluori *et al*., 2019; Orton, 2019).

Generator Fixation

To secure the generator, form a subcutaneous pocket located just dorsal to the jugular venotomy incision. Measure the size of the pocket by attaching and looping the leads underneath the pacemaker generator (PG). To link the leads to the PG, make a second incision in the mid to upper third of the thorax caudal to the shoulder. Once the surgeon is content with the pacemaker generator (PG) pocket, the entire pacing system is taken out, and a single suture is placed deep within the pocket. It is preferably situated within and beneath the thin muscle layer, and then looped into the suture hole on the head of the PG. Subsequently, the pacing system is reintroduced into the pocket, and the suture is securely tied. Prior to closing the incision sites, fluoroscopic evaluation is conducted on the pacemaker generator (PG), lead loops, and lead slack (Orton, 2019).

Temporary pacemaker implantation

It is used to treat life-threatening bradyarrhythmias in an emergency. For the support of heart rate and blood pressure in patients receiving general anesthesia who have sick sinus syndrome or high-grade atrioventricular block, temporary pacemaker implantation is practiced (DeFrancesco *et al.,* 2003).

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