Review

Phrenic Nerve Injury During Cardiac Surgery: Mechanisms, Management and Prevention

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Phrenic nerve injury is a well-recognised complication of cardiac surgery that can lead to disabling effects from diaphragmatic dysfunction, especially in children and patients with a history of chronic obstructive airway disease. Various mechanisms of injury have been recognised including hypothermia, mechanical trauma and possibly ischaemia. A clear understanding of these mechanisms is important in order to modify surgical techniques to prevent this serious complication of cardiac surgery.

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Introduction

Diaphragmatic dysfunction due to phrenic nerve injury is a well-recognised complication of cardiac surgery. It can lead into a disabling consequences, especially in high risk populations such as children [1] and patients with a history of chronic obstructive airway disease [2]. The true incidence of this complication is unknown, but incidences ranging from 1.2% to 60% have been reported [1,3–8].

Important anatomic relationships between the phrenic nerves and structures in the thorax play a major role in the injury of this nerve during cardiac surgery. The close relationship of the phrenic nerves and the pericardium makes them vulnerable to freezing injury during hypothermic myocardial protection using ice slush [5,9,10]. Also the internal mammary arteries (IMAs) have a very close relationship to the phrenic nerve in the apex of the chest rendering the nerve vulnerable to injury during harvesting of the IMA [11].

Different mechanisms of injury have been recognised. Hypothermic, mechanical and possibly ischaemic injury are well documented and a clear understanding of these is necessary in order to modify usual surgical techniques to prevent damage to the phrenic nerves.

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Anatomy of the Phrenic Nerves

It is important to understand the anatomical course of the phrenic nerves to appreciate their vulnerability to injury during cardiac surgery. The phrenic nerve originates mainly from the fourth cervical nerve root (C4) with contributions from the third and fifth nerve roots (C3 and C5). Formed at the upper part of the lateral border of the scalenus anterior muscle, the nerve passes downwards across the front of that muscle from lateral to medial then to the root of the neck [12–14] (Fig. 1).

Right Phrenic Nerve Thoracic Course

The right phrenic nerve is crossed by the transverse cervical and suprascapular arteries in the root of the neck. At the apex of the thorax, it crosses the right internal mammary artery (RIMA) from lateral to medial (usually anterior to the artery). Further down, it runs along the right side of the innominate vein and the superior vena cava (SVC), and then courses along the pericardium over the right atrium and inferior vena cava (IVC) until it reaches the diaphragm [12,14].

Left Phrenic Nerve Thoracic Course

In the root of the neck, the left phrenic nerve, after leaving the scalenus anterior muscle passes anterior to the left subclavian artery and behind the thoracic duct. It then crosses the left internal mammary artery (LIMA) and then descends in the thorax along the left side of the left subclavian artery, it passes lateral to the aortic arch, and continues down along the left lateral surface of the

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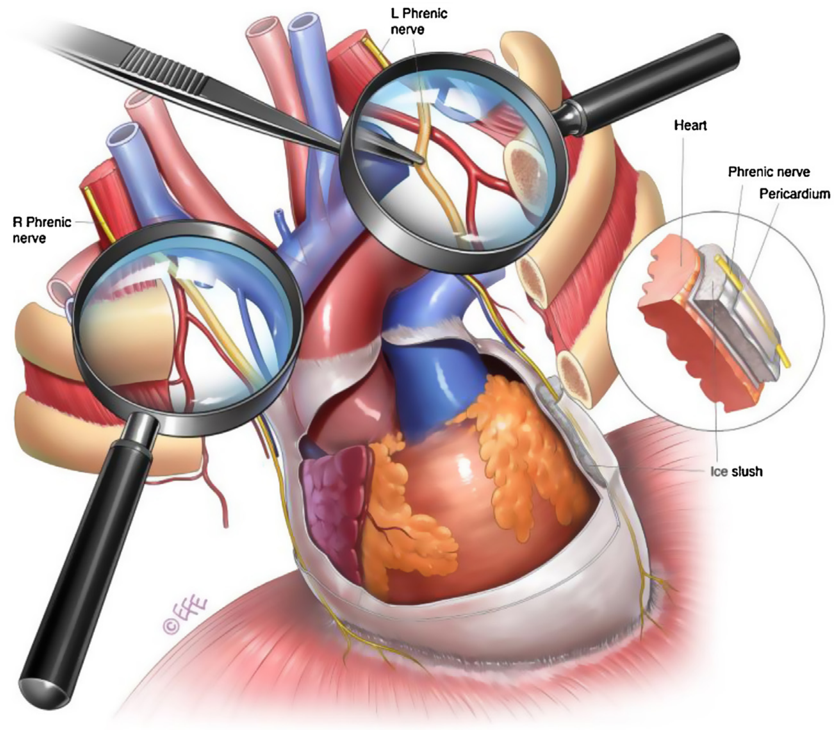

Figure 1. *Relationship of the phrenic nerves to the IMA: the phrenic nerves are at risk during harvesting of the IMA where they cross the IMA (magnifying glasses). The left phrenic nerve is vulnerable to freezing damage from pericardial slush during topical cardiac cooling (inset).*

pericardium, adjacent to the left ventricle, before reaching the diaphragm [14,15].

Phrenic Nerve and Its Anatomical Relationship with the Internal Mammary Artery (IMA)

The IMA is extensively used as a graft in coronary artery bypass graft (CABG) surgery due to its superior long-term patency in comparison to saphenous vein grafts [16]. The IMA has a very close anatomical relation to the phrenic nerve. Henriquez et al. observed that the IMA usually originates as a single trunk directly from the subclavian artery (95% on the right and 92% on the left) but it can originate as a common trunk with other arteries such as the suprascapular, cervical or thyroid arteries [17]. Close to its origin, the IMA is crossed by the phrenic nerve. The left phrenic nerve crosses at an average distance of 1.9 cm (±0.7) and the right an average distance of 1.5 cm (±0.7) from the IMA origin. On the left side, 60% of the phrenic nerves cross the IMA anteriorly and 50% of the right phrenic nerves have the same relationship [14,18] (Fig. 1).

Phrenic Nerve Damage During Cardiac Surgery

Phrenic Nerve Damage Due to Hypothermia-Induced Injury

The intimate relationship of the phrenic nerves with the pericardium makes them vulnerable to freezing injury caused by saline slush instilled into the pericardial cavity [9]. The left phrenic nerve is more vulnerable to cold injury because when ice slush is used it is applied mainly around the left ventricle in the left portion of the pericardial cavity [5,10] (Table 1).

In the 1960s, before the development of cardioplegic solutions, myocardial protection was provided entirely by systemic hypothermia with or without topical cooling. Shumway's original technique of topical cooling consisted of flooding the pericardium with cold (liquid) saline. Phrenic nerve injury was not associated with this original technique. Later on, in order to increase the efficiency of topical cooling, other surgeons replaced cold saline with saline slush at a temperature of −1 °C [19]. During the ice slush era, cold injury was the most commonly reported cause of phrenic nerve injury during cardiac surgery [20]. This phenomenon was shown to be related to the topical cooling which created a demyelination injury to the nerve [21].

Studies done in the late 80s, showed high rates of diaphragmatic paralysis related to cold injury. Two studies reported phrenic nerve paralysis rates of 6.6% and 9.3% due to hypothermic damage [22,23]. Another study using saline slush reported an incidence of 60% of phrenic nerve paralysis [8].

Tissue injury due to hypothermia, such as frostbite occurs when tissues are cooled below their freezing point with the formation of ice crystals in cells. Freezing and thawing induces severe tissue injury. The freezing point of human tissue (around −1 °C) is lower than that of melting ice (0 °C) due to the effect of the electrolytes in the cytoplasm lowering the freezing point. This is the reason