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THE BIOMECHANICAL ROLE OF PAPILLARY MUSCLE ANGULATION IN CARDIAC FUNCTION AND WELL-BEING AND ITS REHABILITATION STRATEGIES: A REVIEW

KILANI KUSUMA
FACULTY OF PHYSIOTHERAPY MEENAKSHI ACADEMY OF HIGHER EDUCATION AND RESEARCH, TAMIL NADU, INDIA

P.V.HARI HARA SUBRAMANIAN*
FACULTY OF PHYSIOTHERAPY
MEENAKSHI ACADEMY OF HIGHER EDUCATION AND RESEARCH, TAMIL NADU, INDIA.

Abstract
Aim and Objective of the Study This review investigates the biomechanical function of papillary muscle (PM) angulation in heart health and function. It explores rehabilitation techniques, including pharmacological therapies and exercise regimens, to optimize PM function, enhance cardiac rehabilitation, and improve patient outcomes.
Methodology A comprehensive review of literature from scholarly articles, books, and reputable sources was conducted in the fields of cardiac biomechanics, exercise physiology, and rehabilitation protocols. This analysis provides insight into PM angulation's impact on cardiac efficiency and potential interventions.
Discussion PM Angulation influences mitral valve function, ventricular contraction, and overall cardiac efficiency. Abnormal angulation can contribute to mitral regurgitation, left ventricular remodelling, and heart failure by disrupting uniform tension distribution and increasing ventricular stress. This impairs cardiac output and exercise tolerance, leading to fatigue, dyspnoea, and reduced aerobic capacity.
Cardiac rehabilitation incorporating aerobic training, resistance exercise, inspiratory muscle training (IMT), and postural correction can improve PM function and cardiovascular health. Supervised aerobic training enhances cardiac output, reduces ventricular remodelling, and improves stroke volume. Resistance training strengthens myocardial efficiency and prevents ventricular dilatation. IMT boosts respiratory function and lowers cardiac workload, while postural training enhances heart efficiency by improving vagal tone and respiratory mechanics. These interventions optimize PM alignment, mitigate mitral regurgitation, and enhance cardiac function.
Conclusion PM mal-angulation adversely affects exercise physiology and heart function, necessitating targeted interventions. Advanced imaging, surgical procedures, and rehabilitation strategies are crucial in optimizing cardiac efficiency. Future research should focus on personalized treatments integrating biomechanics, pharmacological therapies, and exercise-based rehabilitation to improve cardiac outcomes.
Keywords: Papillary muscle angulation, cardiac biomechanics, cardiac well-being and rehabilitation strategies.

INTRODUCTION

Papillary muscles are cone-shaped muscles in the ventricles of the heart that anchor the chordae tendineae to prevent valve prolapse. The left ventricle's papillary muscles (PMs) are essential anatomical elements that have a major impact on ventricular contraction, mitral valve function, and overall cardiac efficiency. By keeping the chordae tendineae taut during systole, they function as mechanical stabilizers and stop mitral valve prolapse (Nishino et al., 2020)[1]. The biomechanics of the left ventricle are influenced by the angulation and spatial location of the papillary muscles, which have an impact on hemodynamic efficiency, stroke volume, and ventricular wall stress (He et al., 2019).[2]

Mitral regurgitation (MR), left ventricular remodelling, and heart failure are among the cardiac conditions linked to abnormal papillary muscle angulation. Variations in angulation can cause valvular insufficiency, volume overload, and decreased cardiac output by interfering with the mitral valve's ability to distribute tension uniformly (Wang et al., 2021)[3]. Furthermore, the progression of heart failure may be exacerbated by ventricular dilatation and systolic dysfunction brought on by PM displacement or misalignment (Hamada et al., 2019)[4].

Comprehending the biomechanical function of papillary muscle angulation is crucial from a clinical standpoint in order to enhance the precision of diagnostic procedures and therapeutic measures. Developments in computational modelling, cardiac MRI, and echocardiography have improved our capacity to evaluate PM orientation and its effect on heart function (Sakaguchi et al., 2022)[5]. In order to improve patient outcomes, surgical techniques such mitral valve replacement and papillary muscle repositioning seek to restore ideal angulation (Opolski et al., 2018)[6]. Papillary muscle angulation's biomechanical effects, its function in the heart, and its influence on general health are all intended to be thoroughly examined in this paper. In order to improve heart biomechanics, we will examine the physiological and pathological impacts of PM angulation, current developments in diagnostic imaging, and possible treatment approaches and rehabilitation strategies.

Aim of the study

The purpose of this review is to investigate the biomechanical function of papillary muscle angulation in heart health and function. Additionally, the study looks at rehabilitation techniques that can maximize the function of papillary muscles, emphasizing medicinal therapies and exercise regimens. In order to improve cardiac rehabilitation and patient outcomes, this study attempts to offer insights into possible clinical applications by summarizing current research.

METHODOLOGY

The body of knowledge in the domains of exercise physiology, cardiac biomechanics, and rehabilitation protocols was thoroughly examined. A basis for understanding the function of papillary muscles and their angulation in maximizing health will be built by examining books, scholarly articles, and trustworthy sources.

Synthesis of review

The Effects of Papillary Muscle Mal-Angulation on Exercise Physiology

Exercise physiology is greatly impacted by papillary muscle (PM) mal-angulation, which alters cardiac output, myocardial efficiency, and hemodynamic response to physical activity. According to Nishino et al. (2020)[1], PMs in a healthy heart maintain appropriate mitral valve function, guaranteeing ideal ventricular filling and effective stroke volume at elevated metabolic demand. However, improper positioning or misalignment of PMs results in aberrant pressure distribution, decreased ventricular contraction, and mitral regurgitation (MR), which eventually lowers cardiac reserve during exercise (He et al., 2019)[2].

The heart must increase its ejection fraction and stroke volume during physical exercise in order to supply the oxygen-demanding muscles. The inefficiency of left ventricular (LV) contractility in people with PM mal-angulation results in decreased diastolic filling, inadequate cardiac output, and intolerance to exercise (Wang et al., 2021)[3]. According to Hamada et al. (2019)[4], compensatory hyper contractility brought on by the changed angulation may also raise myocardial oxygen consumption (MVO_2), which may contribute to early tiredness and dyspnoea. Decreased peak oxygen uptake (VO_2 max) during exercise and arrhythmias can result from PM dysfunction's disruption of cardiac synchronization, which also increases afterload and mechanical inefficiency (Sakaguchi et al., 2022)[5].

Because of their increased myocardial remodelling and compensatory hemodynamic responses, athletes and people with high levels of physical activity have been shown to respond to PM dysfunction better (Opolski et al., 2018)[6]. PM mal-angulation, however, is associated with poorer exercise capacity, a worse prognosis, and a higher incidence of exertion-induced symptoms such palpitations, light-headedness, and angina-like chest pain in patients with heart failure (Wang et al., 2021)[3].

It has been demonstrated that pharmacological treatments including beta-blockers and ACE inhibitors, as well as therapeutic approaches aimed at PM relocation and mitral valve replacement, improve cardiac function and exercise tolerance (Hamada et al., 2019)[4]. Furthermore, for those with PM mal-angulation, cardiac rehabilitation programs emphasizing strength training and aerobic fitness may enhance hemodynamic efficiency and quality of life (Sakaguchi et al., 2022)[5]. Optimizing training plans, therapeutic interventions, and general cardiovascular health requires an understanding of the interaction between PM mal-angulation and exercise physiology.

Enhancing Papillary Muscle Mal-angulation and Cardiac Function via Exercise Therapy and Cardiac Rehabilitation

In order to improve ventricular function, decrease remodelling, and increase overall circulatory efficiency, cardiac rehabilitation is essential. Targeted exercise therapy can enhance mitral valve function, restore myocardial efficiency, and lessen heart failure symptoms in patients with papillary muscle mal-angulation.

1. **Benefits and Mechanism of Supervised Aerobic Training:** By improving cardiac output, myocardial oxygen utilization, and left ventricular (LV) function, supervised aerobic training lowers maladaptive ventricular remodelling, which may be a factor in papillary muscle mal-angulation. By improving endothelial function, increasing mitochondrial efficiency, and promoting angiogenesis (the development of new blood vessels), aerobic exercise can assist in optimizing ventricular mechanics.

Aerobic training has been repeatedly demonstrated to improve heart function and lower cardiovascular mortality. According to a study by Mandsager et al. (2018), patients with heart disease who had better levels of cardiorespiratory fitness also had a considerably decreased risk of cardiovascular death[7]. Furthermore, a thorough analysis of 22 randomized controlled trials (RCTs) by Taylor et al. (2021) showed that supervised aerobic training significantly decreased left ventricular dilatation and increased ejection fraction (EF), both of which are linked to improve positioning of the papillary muscles and increased cardiac efficiency[8]. Additionally, Lavie et al. (2019) emphasized that LV fibrosis can be reduced by moderate-intensity aerobic activity, which helps stop further declines in mitral valve function and promotes long-term cardiovascular health[9].

It is important to properly plan aerobic exercise for cardiac rehabilitation in order to optimize advantages and minimize hazards. Walking, cycling, swimming, and rowing on a treadmill are all suggested forms of exercise because they improve cardiovascular endurance without putting undue strain on the heart. For the best cardiovascular adaptation, the intensity should be kept between 40 and 70% of VO_2 max using the Karvonen formula. Heart output and left ventricular function can be consistently improved by scheduling three to five sessions per week, each lasting 20 to 45 minutes. Monitoring blood pressure and heart rate during the session is crucial, nevertheless, in order to avoid undue strain and lower the chance of unfavourable cardiovascular events, guaranteeing safe and efficient recovery[10].

2. Benefits & Mechanism of Strength Training: By strengthening skeletal muscles and enhancing muscular pump function overall, resistance exercise can improve the regulation of cardiac preload and afterload. This encourages better papillary muscle angulation over time and lessens the stress on the left ventricle. Furthermore, sarcopenia, which is frequently seen in heart failure patients and can impair circulatory efficiency, is avoided by resistance exercise.

Research indicates that resistance exercise is essential for enhancing heart health, especially in those with left ventricular (LV) dysfunction. Resistance training dramatically increased cardiac efficiency and stroke volume, which enhanced total cardiovascular performance, as shown by Hollings et al. (2020)[11]. Furthermore, progressive resistance training improved left ventricular end-diastolic diameter (LVEDD) and prevented additional ventricular remodelling, which is crucial for preserving ideal cardiac structure, according to Corneli's et al. (2022)[12]. Additionally, a meta-analysis by O'Connor et al. (2018) demonstrated that resistance training and aerobic exercise together significantly decreased the severity of mitral regurgitation, underscoring the complementary role that both training modalities play in improving mitral valve function and heart health in general[13].

Carefully planning resistance exercise for cardiac rehabilitation will improve myocardial function without overtaxing the heart. Light-to-moderate resistance training using bodyweight exercises, resistance bands, and free weights is advised as it enhances cardiovascular health and muscle strength. Keep the intensity between 30 and 50 % of your one-repetition maximum (1RM) to guarantee safe and efficient muscle activation. To allow for proper recovery and cardiovascular adaptation, each set should include 12–15 repetitions, be completed at a moderate pace, and be done two–three times a week. A safe and long-lasting approach to resistance training in cardiac rehabilitation requires that patients refrain from excessive straining and the valsalva manoeuvre, which can cause abrupt spikes in blood pressure and needless cardiac stress[14].

3. Benefits & Mechanism of Inspiratory muscle training: The diaphragm and intercostal muscles are strengthened with IMT, improving lung function and lowering dyspnoea (shortness of breath). This results in increased pulmonary compliance, which lowers cardiac workload and directly improves cardiopulmonary endurance. Additionally, it has been demonstrated that IMT calms the overactive sympathetic nervous system, improving heart rate variability (HRV).

The efficiency of Inspiratory Muscle Training (IMT) in enhancing cardiopulmonary function and lowering cardiac workload is supported by research. According to Charususin et al. (2018), an 8-week IMT program dramatically increased heart failure patients' peak oxygen uptake (VO_2 max) and decreased their left ventricular end-diastolic pressure, which improved their ventricular efficiency[15]. Furthermore, IMT has been shown to alleviate dyspnoea in patients with chronic heart disease by reducing dyspnoea scores and producing significant improvements in mitral valve function (Dall'Ago et al., 2019)[16]. Additionally, IMT improved diaphragmatic efficiency, which in turn improved cardiac function, according to Winkelmann et al. (2021), highlighting its significance as a non-pharmacological intervention for cardiovascular-health[17].

Inspiratory muscle training is a successful non-pharmacological strategy for enhancing cardiac and respiratory performance. It uses inspiratory muscle trainers, like Power Breathe or Threshold IMT, to strengthen the intercostal and diaphragm muscles, which lowers cardiac workload and dyspnoea. The ideal adaptation without undue strain can be achieved by setting the training intensity between 30 and 60% of maximum inspiratory pressure (MIP). To get the most out of each session, it is advised to do so every day or at least five times a week. Each session should last 5 to 15 minutes. A safe and controlled advance in IMT is ensured by patients being careful not to experience excessive hyperventilation, which can cause dizziness or respiratory discomfort[18].

4. Benefits &Mechanism of Postural Training and Stretching: An increase in intra-abdominal pressure due to poor posture might change diaphragmatic mobility and thoracic expansion, which can impair heart function and

ventricular compliance.
Enhancing vagal tone, lowering intra-thoracic pressure, and improving spinal alignment through stretching and postural correction all contribute to increased heart efficiency.

Studies show that stretching exercises and posture correction have a major effect on respiratory efficiency and heart function. In order to maximize cardiac output, Shamsi et al. (2017) showed that postural correction exercises enhanced stroke volume and diastolic function in patients with postural kyphosis[19]. Furthermore, Barbosa et al. (2020) discovered that stretching exercises, in patients with chronic cardiac problems, increased heart rate variability and respiratory mechanics, which helped the heart's autonomic regulation[20]. Additionally, yoga-based posture correction was found to dramatically enhance mitral valve function and minimize heart failure symptoms by Hale et al. (2022), highlighting the need of including flexibility and postural exercises in cardiac rehabilitation programs.[21]

Stretching and postural training are essential for enhancing respiratory mechanics, heart function, and general cardiovascular health. Yoga, Tai Chi, Pilates, and thoracic extension exercises are suggested forms of exercise that improve spinal alignment, flexibility, and thoracic expansion. To guarantee steady adaptation without undue strain, these exercises should be done at a low-to-moderate intensity. To encourage steady changes in posture, respiratory efficiency, and heart function, sessions should be held three to five times a week and last 10 to 20 minutes each. In order to provide a safe and controlled approach to postural training, it is imperative to prevent excessive spinal hyperextension, as this may result in vertebral stress and discomfort[22].

Thus, Inhibitory muscle training, resistance training, postural training, and aerobic training can all be included in cardiac rehabilitation programs to maximize papillary muscle alignment, decrease mitral regurgitation, and improve ventricular function. These treatments ought to be customized for every patient's requirements and regularly assessed for efficacy and safety.

CONCLUSION

Reduced cardiac output and tolerance result from mal-angulation of the papillary muscles (PM), which also affects exercise physiology, ventricular mechanics, and mitral valve function. In order to maximize heart function and enhance patient outcomes, advanced imaging, surgical procedures, and rehabilitation initiatives are used. Future studies should concentrate on tailored treatments that use targeted medications, biomechanics, and exercise-based interventions to improve cardiac health.

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