BREATHING PATTERN DYSFUNCTION AMONGST PATIENTS WITH MEDIAN STERNOTOMY POST HOSPITAL DISCHARGE: A CROSS- SECTIONAL STUDY WITHIN A SOUTH AFRICAN CONTEXT

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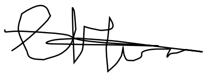
Johannesburg, 13/5/2024

DECLARATION

I, Samantha Hurst, declare that this research report is my own work. It is submitted for a degree in the Master of Science in Physiotherapy at the University of the Witwatersrand in Johannesburg, South Africa. This research report has not been submitted before for any degree or examination at this or any other institution.



Samantha Hurst

Signed in Pretoria on date: 13/5/2024

DEDICATION

"Fear not, for I am with you; be not dismayed, for I am your God; I will strengthen you, I will help you, I will uphold you with my righteous right hand"- Isiah 41:10

To my Yahweh, my constant, thank you for your strength and faithfulness.

"Im not interested in whether you've stood with the great; I'm interested in whether you've sat with the broken"- Sue Fitzmaurice

To my patients, you have taught me more than I could ever teach you.The greatest demonstration of patience and courage during affliction.

"Love is not affectionate feeling, but a steady wish for the loved person's ultimate good as far as it can be obtained.- C.S Lewis

To my family, thank you for showing and teaching me enduring love.

ABSTRACT

Introduction:

Patients following cardiac surgery via median sternotomy surgical approach experience a deficit in chest wall expansion and respiratory muscle strength during hospital stay.
To date, no study has assessed whether there is a long-term breathing pattern dysfunction (BPD) present in patients following cardiac surgery via median sternotomy surgical approach.

Aim: To establish whether patients within the period of three months to one year post cardiac surgery via median sternotomy surgical approach still experience a BPD and, if so, to determine the risk factors to development of such a dysfunction.

Methods:

A cross-sectional observational study was conducted in a private hospital in Pretoria, South Africa from December 2022 - November 2023. Male and female patients between the age of 18-65 years who underwent an elective cardiac procedure via median sternotomy surgical approach were invited to participate. Participants were assessed once within the period of three months to one year post hospital discharge via questionnaires emailed to them and a telephonic video consultation. Outcome measures used included work- and health-related demographic questionnaires, the Physical Activity Vital Sign (PAVS), the Self-Evaluation of Breathing Questionnaire (SEBQ), The Nijmegen Questionnaire (NQ), the Breath Hold Time (BHT) Test, and the measures of upper and lower chest expansion (CE). Data were evaluated using descriptive and inferential statistics. Statistical significance was set at $p<0,05$.

Results:

The study population consisted of 52 participants, of which, most identified as male gender (59,60%, n=31) and underwent coronary artery bypass graft surgery (CABG) (51,90% ,n=27). The median age of participants was 57,00 (IQR 14,00) years and most participants presented with an elevated body mass index (28,90 kg/m², IQR 6,60). Return to work rate was established to have been 61,50% (n=32) with a median return to work time (RTWT) of six (IQR 4,00) weeks. Of the participants who returned to work, the majority (17,30%,n=9) worked in administrative occupations involving prolonged sitting (42,50%, n=17).

The majority of participants scored positive in three of the outcome measures (51,90%, n=27) for BPD. A weak negative correlation existed between age and NQ and between age and SEBQ ($r=-0.32$, $p=0,02$). There was a weak negative correlation between length of

hospital stay and lower CE (r= -0,30, p=0,03). There were weak positive correlations between PAVS aerobic scores and upper CE (r=0,33, p=0,02) ,lower CE (r=0,39,p<0,01) and BHT (r=0,29,p=0,04). There was a weak negative correlation between PAVS aerobic scores and SEBQ scores (r=-0,30,p=0,03).

In terms of predictive values, being identified as male gender reduced the odds of developing a BPD in the psychophysiological dimension by 82%. Participants who underwent the surgery classified as "other" were 21 times more likely to score positive in the psychophysiological dimension of BPD than participants who underwent CABG, valve or mixed CABG and valve surgery. Participants who acquired cardiac complications were 11,67 times more likely to score positive in the psychophysiological dimension of BPD than participants who did not acquire complications or acquired other non-cardiac related complications. The absence of post-operative complications reduced the risk of developing a BPD in the psychophysiological dimension by 77%. Additionally, for every minute a patient partook in weekly aerobic exercise, the odds of developing a BPD in the psychophysiological dimension decreased by 1%. In terms of the biochemical dimension of BPD, participants who returned to work were 4,42 times more likely to score positive for BPD in this dimension.

Conclusion:

There is a high prevalence of long-term BPD amongst patients who underwent cardiac surgery via median sternotomy surgical approach. Factors found to increase the risk of developing BPD in a multidimensional context include the female gender, the type of surgery (particularly thymectomies and atrial septal defect repairs), cardiac post-operative complications and whether a participant has returned to work. Factors found to reduce the risk of developing BPD include the duration of weekly aerobic exercise and the absence of post-operative complications.

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LIST OF ABBREVIATIONS

BHT	-Breath Hold Time
BMI	-Body Mass Index
BPD	-Breathing Pattern Dysfunction
CE	-Chest Expansion
COPD	-Chronic Obstructive Pulmonary Disease
CABG	-Coronary Artery Bypass Grafting
FEV1	-Forced Expiratory Volume in One Second
FVC	-Forced Vital Capacity
ICU	-Intensive Care Unit
NQ	-Nijmegen Questionnaire
PAVS	-Physical Activity Vital Sign
RTWT	-Return to Work Time
SEBQ	-Self Evaluation of Breathing Questionnaire
VAS	-Visual Analogue Scale
VC	-Vital Capacity

CHAPTER 1

This chapter serves as an introduction to establish the need and rationale for the study.

1. BACKGROUND AND NEED

1.1. INTRODUCTION

Breathing pattern dysfunction (BPD) can be broadly defined as a disruption in overall health due to an abnormal pattern of breathing (Courtney, Greenwood, et al., 2011). The precise definition is unclear as it is an umbrella-concept describing various breathing pattern disturbances for example, hyperventilation syndrome, paradoxical breathing, and upper chest breathing (Vidotto et al., 2019). Breathing pattern dysfunction can be classified into “primary dysfunctional breathing” referring to a non-pathological cause such as anxiety while “secondary dysfunctional breathing” refers to an underlying cardiopulmonary or neurological cause (Vidotto et al., 2019).

Currently, there are no gold standard diagnostic tools to define BPD and it is suggested that a multidimensional approach should be used incorporating biomechanical, biochemical, and psychophysiological dimensions when assessing this phenomenon (Courtney, 2011). Biomechanical refers to the actual mechanics of breathing encompassing the movements of the joints of the rib cage and respiratory muscle activity creating a specific breathing pattern (Kiesel et al., 2017). The biomechanical dimension can be assessed by outcome measures such as the Hi Lo test, manual assessment of respiratory motion, rib palpation and measurement of chest wall expansion (Bradley & Esformes, 2014; Tukanova et al., 2020). Biochemical refers to the assessment of an arterial blood gas including pH., carbon dioxide and oxygen levels in the blood (Courtney, Greenwood, et al., 2011; Kiesel et al., 2017). The biochemical dimension can be assessed using capnometry or, a cheaper alternative, that being the Breath Hold Time (BHT) test (Boulding et al., 2016; Courtney et al., 2011). Psychophysiological refers to the body’s ability, or inability, to adapt to changes in the demands of breathing which can result in generalised symptoms (Kiesel et al., 2017). This can be assessed with questionnaires such as the Hospital Anxiety and Depression Scale, the Nijmegen Questionnaire, and the Self-Evaluation of Breathing Questionnaire (Boulding et al., 2016).

A median sternotomy is considered the gold standard of approach amongst cardiothoracic surgeons performing procedures such as coronary artery bypass grafting (CABG), valve replacements and heart transplants. It allows access to the mediastinum and pleural cavities of the thorax via a vertical incision through the sternum dividing the bone into two halves (Reser et al., 2015).

It is noted in the literature that when individuals undergo cardiac surgery via median sternotomy surgical approach, they often present with pulmonary dysfunction post-operatively due to the surgical trauma inflicted onto the thoracic wall thereby affecting chest wall compliance creating an inability to take deep breaths (Urell et al., 2012). This leads to alterations in breathing patterns as confirmed by de Sousa et al. (2016) who concluded that the main characteristics of secondary BPD in the acute stages (within 48 hours post-operatively) include changes in the depth of breathing with a more upper chest breathing pattern, pursed-lip breathing, altered chest expansion (CE) and prolonged exhalation. Gissing (2020) noted a significant change in patients' chest expansion findings from the pre- to post-operative period in a local cohort of patients who underwent median sternotomy procedures. Findings of Gissing's (2020) study could be explained partially due to the significant reductions in the respiratory muscle strength observed in the study participants from their pre- to post-operative period. When reviewing change in lung function, Katiyar et al. (2021) found that there was a mean reduction of 36% and 32% with regards to forced expiratory volume in one second (FEV1) and forced vital capacity (FVC) respectively amongst patients who underwent median sternotomy surgical approach. These measures (FEV1 and FVC) was found to closely correlate with reduced measures of upper CE (Roncada et al.,2015).

The reduction in lung function parameters post-operatively might be due to pulmonary abnormalities such as atelectasis and intra-pleural abnormalities e.g., pleural effusions as highlighted by Gissing (2020) in a South African cohort. Previous studies found that high risk groups associated with post-operative pulmonary complications such as pleural effusions include advanced age (Wang et al., 2014), female gender (Bechtel & Huffmyer, 2020) and abnormal body mass index (BMI) (>35kg/m^2 or <18.535kg/m^2) (Gao et al., 2016).

Literature suggests that the average return to work time (RTWT) for patients who underwent CABG or aortic valve replacement via median sternotomy surgical approach is 30 weeks (±7.5 months). Factors found to delay return to work include older age, female gender, previous diagnosis of depression, low income, and lower education levels (Mortensen et al., 2021). Furthermore, deficits in lung function tests seen in the acute period post-operatively have also been identified after RTWT and these deficits may play a role in delaying or limiting full re-integration into the work force and/or performance in activities of daily living

(Westerdahl et al., 2003, 2016). Previous studies identified that risk factors associated with reduced performance in lung function tests include valve repair type surgeries, higher pain levels post-operatively and increased length of intensive care unit (ICU) stay (Urell et al., 2012).

Westerdahl et al. (2016) in the population of interest outlines the extent of the lung function abnormality over a prolonged period of time, that being one year. Their study showed that pulmonary function measured as vital capacity (VC), FVC, FEV1, FEV1/FVC, peak expiratory flow (PEF), and functional residual capacity (FRC), were significantly reduced compared to pre-operative values (2-5% impairment). Furthermore, within this patient population, Kristjánsdóttir et al. (2004) found an overall restrictive upper chest breathing pattern at three months post-operatively which was yet to be resolved at 12 months following hospital discharge.

Due to the dual role of the diaphragm for ventilation and postural control, disruption of ventilation in the form of BPD can lead to a disruption in postural control (Hodges et al., 2007). Activities performed in daily life such as walking, standing, and handling of objects require a degree of postural control to maintain an upright stance. This translates into the ability to execute tasks in the home and workplace environment particularly for patients who perform multitasking such as carrying e.g., files, walking and talking all at the same time (Haddad et al., 2013). Bradley & Esformes (2014), in their study population of healthy individuals, identified a significant association of the biomechanical (measured using Hi Lo test) and biochemical (measured using capnometry) dimensions of BPD with the Functional Movement Screen (FMS). The authors concluded that participants with diaphragmatic or basal breathing patterns have a higher FMS score than those with apical or "upper chest breathing" further confirming the dual role of respiratory muscles in postural control.

The above-mentioned studies have identified that there is a prolonged deficit in pulmonary function amongst this population group post discharge from hospital which needs further therapeutic intervention. However, no study has assessed whether there is a long-term BPD (involving assessment of biomechanical, biochemical, and psychophysiological dimensions) following cardiac surgery via median sternotomy surgical approach. Furthermore, no study has established how BPD affects, or is affected, by physical activity level and RTWT in this population group. Westerdahl et al. (2016) also describes a need to establish risk factors associated with long-term pulmonary function deficits post cardiac surgery. This leaves gaps in knowledge on which this study is based.

1.2. PROBLEM STATEMENT

As stated above, Gissing (2020) established an alteration in CE and muscle strength (biomechanical dimension of BPD) in the acute phase amongst patients who had undergone cardiac surgery via median sternotomy surgical approach. In South Africa, to date, there is no literature on whether there is a long-term BPD amongst this patient population Furthermore, no study has taken into consideration how health and work related demographics (particularly return to work rate and time) may influence or be influenced by the biomechanical, biochemical, and psychophysiological dimensions of the dysfunction. Also, there are no established risk factors predisposing patients who underwent cardiac surgery via median sternotomy surgical approach to development of a long-term BPD.

1.3. RESEARCH QUESTION

Do patients within the period of three months to one year post cardiac surgery via median sternotomy surgical approach still experience a BPD?

1.4. AIM OF THE STUDY

To establish whether patients within the period of three months to one year post cardiac surgery via median sternotomy surgical approach still experience a BPD and, if so, to determine the risk factors to development of such a dysfunction.

1.4.1. Objectives of the Study

The specific objectives of the study were:

1) To determine the prevalence of BPD of patients within the period of three months to one year post cardiac surgery via median sternotomy surgical approach using CE measurements, BHT test and psychophysiological questionnaires.

2)To determine the work (return to work time, type of work, level of education, income bracket) and health-related (BMI, previous diagnosis of depression, length of hospital stay, pain levels as measured using the Visual Analogue Scale, post-operative complications) demographics of patients within the period of three months to one year post cardiac surgery via median sternotomy surgical approach.

3)To determine the physical activity level of patients within the period of three months to one year post cardiac surgery via median sternotomy surgical approach.

4)To determine the association as well as predictive qualities of work and health related demographics and physical activity level on the prevalence of BPD amongst patients within the period of three months to one year post cardiac surgery via median sternotomy surgical approach.

1.5. SIGNIFICANCE OF THE STUDY

This study may improve our knowledge on whether there is a long-term BPD amongst patients who underwent cardiac surgery via median sternotomy surgical approach. A greater understanding will contribute to early identification and implementation of therapeutic treatment strategies. This study may also identify risk factors predisposing this patient population to development of a long-term BPD further allowing early identification and treatment.

1.6. JUSTIFICATION FOR THE STUDY

To date, within the context of South Africa and globally, there is no literature on whether there is a long-term BPD amongst patients who underwent cardiac surgery via median sternotomy surgical approach. Furthermore, no study has taken into consideration how work and health related demographics may influence or be influenced by the biomechanical, biochemical, and psychophysiological dimensions of the dysfunction. This emphasises the importance of conducting such a study as it may aid clinicians in better understanding the multidimensional nature of BPD within the context of their patients' functional and vocational limitations. Furthermore, a greater understanding and holistic assessment may aid in an improved treatment strategy.

The results may be used by clinicians to identify if there is a greater need of long-term follow-up regarding identification of BPD amongst this patient population as well as to identify the patients who are at a higher risk of developing BPD.

Chapter 2 consists of a review of the literature to familiarise the reader with regards to the concept of BPD; cardiac surgery via median sternotomy surgical approach and the conventional physiotherapy treatment involved; the presence of BPD in the acute stages post-operative median sternotomy, as well as the effect of long-term BPD on return to work and level of function in this patient population.

CHAPTER 2

2: LITERATURE REVIEW

2.1. INTRODUCTION

The following databases were utilised to collect information included in this literature review: Google Scholar, PubMed, EBSCO host, ScienceDirect and Research Gate.

Keywords utilised during the search strategy included: “breathing pattern dysfunction”,” “median sternotomy”, “prevalence South Africa”, “physiotherapy AND median sternotomy”, “long-term breathing pattern dysfunction”, “diaphragm and postural control”.

Additional search terms used included: “secondary breathing pattern dysfunction”, “hyperventilation syndrome”, “dysfunctional breathing”, “functional breathing disorder”, “disproportionate breathlessness”, “behavioural breathlessness”, “psychogenic breathlessness”, “functional breathing pattern dysfunction”, “structural breathing pattern dysfunction”, “classification”, “dimensions of breathing pattern dysfunction”, “signs and symptoms”,” upper chest breathing”, “shoulder breathing”, “breathing mechanics”, “post-operative median sternotomy”, “post-operative complications”, “cardiac surgery”, “pre-operative physiotherapy”, “post-operative physiotherapy”, “sternal precautions”, “acute stages median sternotomy”, “lung volume”, “ hypoxemia”, “mobilisation”, “pain management”, ,return to work time”, “risk factors”, “balance”, “functional status”.

The literature obtained from the sources described above is discussed under the following headings to provide background to the study:

2.2. Breathing pattern dysfunction.

2.3. Median sternotomy surgical approach.

2.4. Breathing pattern dysfunction acute stages post median sternotomy.

2.5 Breathing pattern dysfunction long-term post median sternotomy.

2.6. Effect of long-term BPD on return to work and functional performance.

2.2. BREATHING PATTERN DYSFUNCTION

2.2.1. Dysfunction, not disease

Breathing pattern dysfunction is considered by Magarian (1982, p.733) as a “diagnosis begging for recognition”. As the name suggests, BPD is described as a disorder/dysfunction and not a disease (Boulding et al., 2016). Even though it may co-exist with an underlying pulmonary or neurological disease such as that seen with asthma patients (secondary BPD), it has no underlying organic disease process or related pathology (Clifton Smith & Rowley, 2011). It can therefore be more accurately considered an “adaptation” of the body in response to a physical or psychological stressor (Chaitow et al., 2013).

This, however, does not mean that the effects of BPD on a patients’ overall health and quality of life should be under-estimated as BPD has influences on various aspects of the body’s physiological processes i.e., emotion, circulation, digestion, and musculoskeletal function (Bradley & Esformes, 2014). Furthermore, it can cause deficits in body biochemistry to the extent that it can mimic other diseases including, pseudo-asthma, irritable bowel syndrome and pseudo-angina (Chaitow et al., 2013).

2.2.2. Prevalence of BPD

Breathing pattern dysfunction is frequently under diagnosed amongst various patient populations and is suggested to be as high as 5-11% amongst the general population (Courtney, 2009). Kiesel et al. (2017) argues that it has an even higher prevalence of 50-80% amongst adults. Regarding specific patient populations, it has been approximated to occur in 34% of those suffering with asthma (Boulding et al., 2016). It also occurs more often amongst women than men with a 14% prevalence in women compared to a mere 2% seen in men regarding an asthma study conducted by Thomas et al. (2005). In the post-operative cardiac surgery population, it was found that 23,5% of patients exhibit an altered breathing pattern post-operatively which was deemed ineffective in catering for the physiological demands of the healing body (de Sousa et al., 2016).

The underrepresentation of the prevalence of BPD is suggested to be partly due to a misunderstanding amongst health care professionals about the causes, diagnosis and treatment of this condition which stems from a lack of research regarding the subject (Vidotto et al., 2019). Furthermore, without gold standard methods of testing for BPD, prevalence of this disorder will always be underrepresented (Boulding et al., 2016; Vidotto et al., 2019) and this additionally puts patients at risk of misdiagnosis with deprivation of effective therapies (Barker & Everard, 2015).

2.2.3. Classification of BPD

As previously stated, BPD can be broadly defined as a disruption in overall health due to an abnormal pattern of breathing (Courtney, Greenwood, et al., 2011). In the past, it has also been referred to as "hyperventilation syndrome", "functional breathing disorder", "disproportionate breathlessness", "dysfunctional breathing" and "behavioural or psychogenic breathlessness" (Barker & Everard, 2015; Boulding et al., 2016). Breathing pattern dysfunction has a widespread spectrum with hyperventilation being the most extreme on the scale and normal breathing being on the other end making it generally difficult to identify when the dysfunction is on the lower end of the spectrum (Osborne et al., 2000).

Boulding et al. (2016) states that BPD can occur either in the absence of, or because of an underlying respiratory or cardiac disease. Therefore, BPD can be further classified as "primary BPD" which describes dysfunctional breathing with non-pathological causes such as anxiety and "secondary BPD" which is a physiological response to an underlying cardiopulmonary or neurological disease. Therefore, possible BPD post median sternotomy will be described as "secondary BPD"(Vidotto et al., 2019).

Depiazzi & Everard, (2016) proposed another type of categorization where BPD is classified into "functional" describing alterations in pattern of breathing in reaction to another problem such as stress(Mahut et al., 2014), while "structural" denotes to changes in breathing pattern in response to a physical impairment which can be surgically repaired (Nielsen et al., 2013). The "functional" and "structural "classifications can be further subclassified into "thoracic" (involving structures relating directly to the thorax) and "extra thoracic" (involving conditions affecting the upper airway) (Depiazzi & Everard, 2016). Therefore, in this instance, a BPD seen after cardiac surgery via median sternotomy surgical approach can be classified as thoracic functional BPD.

Boulding et al. (2016) proposed a classification system to describe the various types of dysfunctional breathing patterns.

Table 2.1: Classifying BPD in terms of breathing pattern (Boulding et al.,2016).

Breathing Pattern	Description
Hyperventilation syndrome	Described as increased ventilation or respiratory rate and can be further subclassified into: 1) Exercised-induced hyperventilation (dyspnea during aerobic exercise with associated chest discomfort in the absence of bronchospasm thus distinguishing it from exercise-induced asthma).

	2) Postural hyperventilation (dyspnea with postural changes from a supine position to a standing position). (M. Thomas et al., 2001)
Periodic deep sighing	Described as frequent sighing (up to 15 times within a 15-minute period) in combination with dyspnea (Prys-Picard et al., 2006).
Thoracic dominant breathing	Also known as apical breathing, when an individual utilizes a more upper thoracic movement during inhalation with a diminished lateral thoracic or “bucket-handle” movement. This occurs often in patients suffering from cardiac or respiratory disease or those with reduced abdominal compliance as seen in abdominal obesity or ascites. This however may have an absence of underlying pathology and is then termed “dysfunctional”(Courtney, Van Dixhoorn, et al., 2011).
Forced abdominal expansion	Seen particularly in patients suffering from chronic obstructive pulmonary disease (COPD) where excessive abdominal contraction during exhalation is observed. As these patients usually experience a resistance with exhalation (due to the increased compliance and collapsible nature of the airways), this is considered a normal physiologic adaptation. However, like in thoracic dominant breathing, is termed “dysfunctional” in the absence of underlying pathology (Bianchi et al., 2004).
Thoraco-abdominal asynchrony	Also termed “paradoxical breathing” is described as an incoordination in movement of the rib cage in relation to the abdomen, therefore the abdomen expands outwards during exhalation and inwards during inhalation. This is seen when there is an upper airway obstruction, neuromuscular weakness or in the case of respiratory distress. Again, it is described as “dysfunctional” in the absence of these pathologies (Upton et al., 2012).

As described later in this chapter by Ragnarsdȯttir et al. (2004), an apical breathing pattern is seen post-operatively amongst patients who underwent cardiac surgery via median sternotomy surgical approach and thus the classification amongst this population would be thoracic dominant breathing.

2.2.4. Signs and Symptoms of BPD

Individuals with BPD can present with a variety of signs and symptoms. These symptoms include dyspnea; anxiety; exhaustion; light and sound sensitivity; dizziness; tingling in peripheries; muscle cramps; muscle weakness; pain in shoulders, head, and neck. Signs include apical breathing pattern; tachycardia; cardiac arrhythmia; sweating and hyperventilation causing respiratory alkalosis (CliftonSmith & Rowley, 2011a; McLaughlin et al., 2011). Figure 2.1 outlines the suggested process related to the development of BPD.

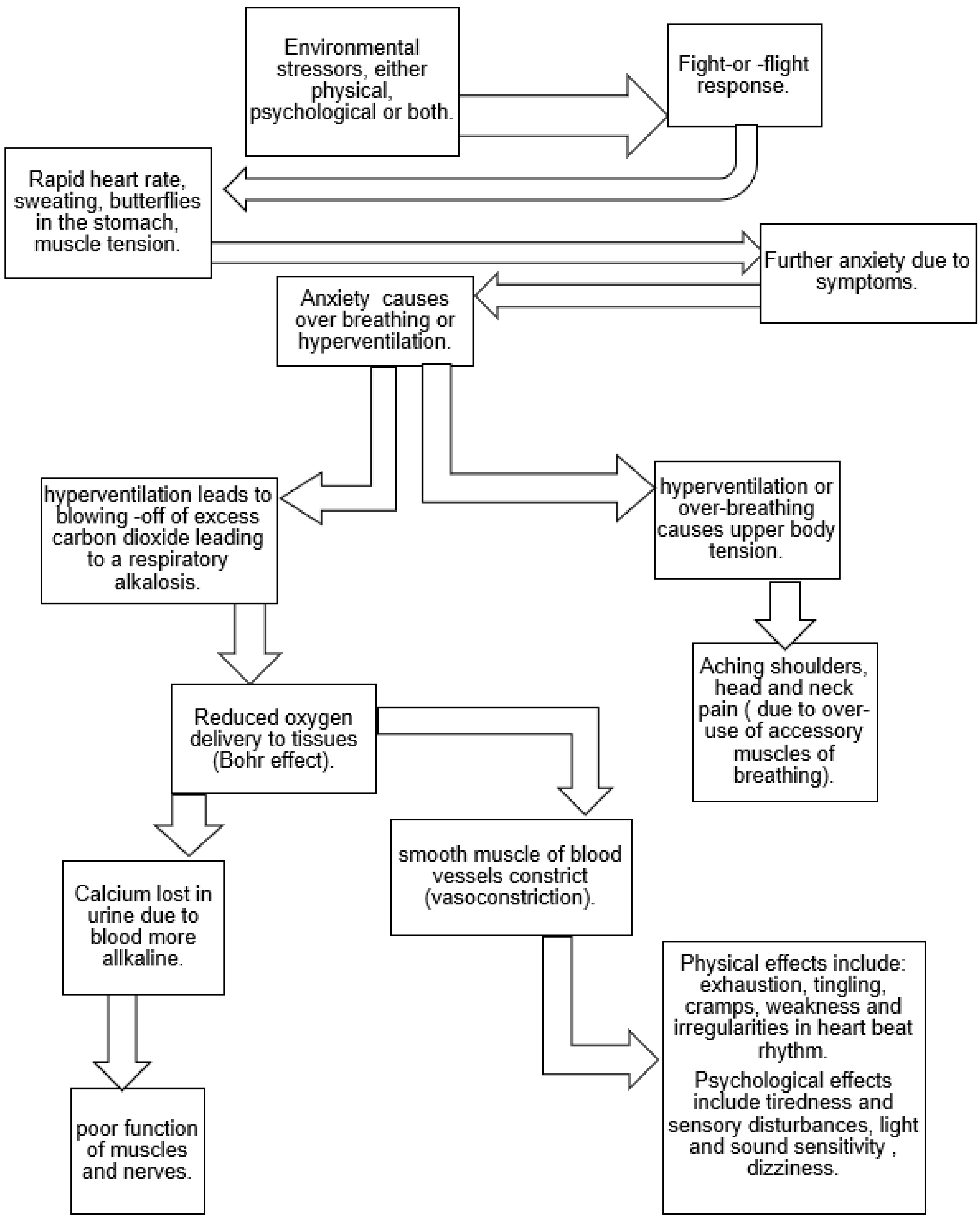

Figure 2.1: Physiological process relating to the development of BPD (Chaitow et al., 2013)

Breathing Pattern dysfunction may stem from a prolonged state of sympathetic activation or arousal (Courtney, 2011). Thus, the patient may exhibit symptoms pertaining to “fight and flight” physiological reactions (Barker & Everard, 2015). This means that BPD can be a symptom of a deeper psychological stress-related problem. Literature concerning battle fatigued soldiers indicated a high prevalence of breathing and cardiovascular problems relating to mental and physical exhaustion following high levels of stress (Courtney, 2011). Interestingly, it has been identified that children and adolescents who exhibit a BPD are often those who are highly driven, perfectionistic individuals who place themselves under excessive amounts of stress to achieve (Barker & Everard, 2015). Amongst the population of patients who underwent cardiac surgery, studies have shown a 15-33% prevalence of depression and anxiety post-operatively (Correa-Rodríguez et al., 2020). Even though these periods of high levels of stress may be periodic, patients fail to return to normal baseline breathing patterns even after the cessation of the stress evoking stimulus has occurred (Courtney, 2009). Thus, BPD can be further defined as breathing which does not adequately balance the states (parasympathetic or “rest and relax” and sympathetic or “fight -or-flight”) of the autonomic nervous system leading to a sympathetic nervous system dominance. In terms of patients post median sternotomy, emotional stress and/or perioperative pain can also lead to a state of sympathetic arousal contributing to a BPD (Courtney, 2011). A constant sympathetic “fight-or-flight” state evokes further anxiety, changes in muscle tone and a lower pain threshold along with other central and peripheral nervous system symptoms (Sueda et al., 2004).

When ventilation is inadequate, accessory respiratory muscles of the upper thoracic cage such as the sternocleidomastoid, scalene and upper fibers of trapezius overcompensate for reduced diaphragm movement resulting in increased vertical displacement of the thoracic cage. This associated shoulder elevation gives a very distinct apical “shoulder breathing” or “upper chest breathing” pattern (Courtney, 2009). The over-use of apical muscles during breathing at rest leads to loss of thoracic mobility and alteration of posture. This further plays a role in limiting diaphragm movement as patients most commonly present with an increased thoracic kyphosis posture and a “poking-chin” position of the cervical spine (CliftonSmith & Rowley, 2011). Zafar et al. (2018) further explained that a deviation of cervical and thoracic spine posture has an almost immediate effect on diaphragm strength and movement thus further promoting shallow breathing. It is important to note that patients with restrictive lung pathologies and end stage COPD display an apical breathing pattern as the best way to compensate for their deficits in lung function (Courtney & van Dixhoorn, 2013). With inadequate ventilation, despite treatment for, or exclusion of other underlying causes, there is no surprise that the key symptom of BPD is feelings of being breathless or dyspnea (sensation of increased work of breathing) (Boulding et al., 2016). Multiple mechanisms contribute to an individual’s perception of dyspnea involving receptors located on the respiratory muscles, lungs, carotid bodies and brainstem coupled with anxiety which further heightens the perception of dyspnea (Barker & Everard, 2015).

Ghannouchi et al. (2016) in their systematic review identified that patients suffering from changes in breathing patterns particularly those seen in COPD and obstructive sleep apnea experience a higher risk of aspiration pneumonia due to the development of swallowing impairment (oropharyngeal dysphagia). Oropharyngeal dysphagia can be caused by multiple factors including the fact that these patient populations have an increased risk of suffering from gastroesophageal reflux (GORD) which can easily cause aspiration (Terada et al., 2010). Patients also show less swallow action during expiration and an increased swallow action during inspiration or during the inspiration-to-expiration transition (swallow-ventilation incoordination). This information should be taken with caution due to the authors (Ghannouchi et al., 2016) identifying a small number of studies (n=28) with absence of randomized controlled trials. Amongst 182 patients post cardiac surgery, Plowman et al., (2023), established that post-extubation, only 11 participants (6%) were classified as safe swallowers while 118 participants (65%) were classified as penetrators to the level of the true vocal folds and a further 53 (29%) were classified as aspirators. The authors further identified that the altered pattern of breathing could be a contributing factor to the ventilation-swallow incoordination.

In the section to follow, information regarding a median sternotomy will be provided to better understand how it might link to the development of BPD in patients following such surgery.

2.3. MEDIAN STERNOTOMY SURGICAL APPROACH

2.3.1. Description of Procedure

A median sternotomy amongst the adult population is the most common approach for various surgical procedures including CABG, cardiac valve surgery (in the presence of stenosis or regurgitation), transplants and resection of mediastinal tumors amongst others (Mohan, 2017). It is a beneficial surgical technique in that it provides direct access to all important mediastinal structures, however, an additional thoracotomy may be required in the case where exposure to the pleural spaces is necessary (Mohan, 2017; Senst et al., 2021).

The approach can be described as a surgical incision made from the midpoint of the manubrium just below the sternal notch of the sternum down to the tip of xiphoid process. After division of subcutaneous tissue, a sternal saw is used to split the sternal bone in two halves to gain access to the thorax (Mohan, 2017; Reser et al., 2015). Once the pericardial sac is opened, the structures of interest are identified, and the appropriate procedure is executed e.g., grafts are harvested from other areas in the body and connected to the coronaries in the case of a CABG or a damaged valve is replaced or repaired. After completion of surgery, the thorax is closed, and the sternum is repaired using surgical wires. Pleural and mediastinal drains are left post-operatively for the first few days (Senst et al., 2021).

The patient is mechanically ventilated during the procedure to artificially control their breathing and is then extubated within the next 24-48 hours post-operatively in the absence of complications (Knapik et al., 2011). Engelman et al. (2019) further adds that to avoid complications associated with prolonged mechanical ventilation, it is safe for patients to be extubated within six hours of arrival in the ICU.

2.3.2. Prevalence of Median Sternotomy in South Africa

In terms of the type of surgery, the most recent statistical analysis amongst patients undergoing cardiac surgeries in a South African context done by the Chris Barnard division of Cardiothoracic Surgery showed that statistics remained constant in terms of CABG (34%), valve replacement (43%) and mixed procedures (8%) over a period from 2003-2014 (University of Cape Town, 2014). They further stated that the need for CABG represents the impact of urbanized lifestyles on the population involving higher incidence of smoking, westernized diet, and stress (University of Cape Town, 2014). This data is unfortunately outdated but it gives an idea of proportions of surgical interventions requiring median sternotomy within a South African context.

A more recent study by Reiche et al. (2021) indicating the overall prevalence of cardiac surgery showed a growing number of coronary artery disease in low- and middle-income countries such as South Africa with CABG to be considered the most beneficial surgical intervention. Their retrospective review was done amongst patients who underwent CABG surgery at a tertiary academic South African hospital from 2000-2017. A total of 1218 patients were included in the statistical analysis (case count was generally under 100 annually) and the mean age of patients was 60 (± 10.1) years. All patients had a median sternotomy surgical approach relevant to the study on which this literature review is based. With the growing trend of coronary artery disease (University of Cape Town, 2014), the surgical case count is likely to increase leaving more scope of research and further learning concerning this patient population. The study by Reiche et al., 2021) does not entirely encompass the whole population of patients undergoing median sternotomy as its focus was only on patients undergoing CABG via median sternotomy technique.

2.3.3. Current physiotherapy treatment post median sternotomy

As stated by Derakhtanjani et al. (2019), the goal of physiotherapy amongst patients undergoing cardiac surgery via median sternotomy surgical approach is to prevent post-operative complications thereby reducing morbidity and mortality as well as reducing length of hospital stay and hospital costs. This may be done by; reducing post-operative pain, reducing secretion retention, and enhancing secretion clearance; maintaining or enhancing lung volume; correcting ventilation perfusion (V/Q) ratio; reducing airway resistance and improving inspiratory as well as global muscle strength (Perelló-Díez & Paz-Lourido, 2018).

2.3.3.1. pre-operative physiotherapy

Pre-operative evaluation and treatment is just as crucial in aiding in the prevention of post-operative pulmonary complications as is post-operative rehabilitation (Valkenet et al., 2013) (level of evidence 4). Inspiratory muscle training (IMT) when used pre-operatively has proven useful in prevention of post-operative atelectasis and pneumonia. This finding was based on the use of IMT for 15-30 minutes, five to seven times per week, for at least two weeks prior to surgery. Recommended loads vary from 10-60% of maximal inspiratory pressure as tolerated.(Katsura et al., 2015) (level of evidence 1a). Cessation of smoking and alcohol consumption one month prior to surgery has also been associated with better surgical outcomes and should be encouraged in the case of elective surgery (Tønnesen et al., 2009) (level of evidence1a). Nakamura et al., (2023) states a need for preoperative orientation to reduce anxiety about the un-known post-operatively. This, amongst patients who underwent cardiovascular surgery, also reduced the incidence of delirium in the ICU (level of evidence 4). Patients should also be educated about the importance of post-operative mobilisation and cough stimulation during preoperative orientation in a further effort to reduce post-operative complications (Castelino et al., 2016; Rodrigues et al., 2021) (both level of evidence 1a)

2.3.3.2. Pain reduction

Non-pharmacological interventions for pain relief post median sternotomy are necessary and are 78% effective when used with pharmacological interventions. The application of ice therapy through gel packs applied over the sternotomy incision for 20 minutes prior to administering breathing exercises with an adjunctive device (spirometer) showed significant reduction in pain levels (Zencir & Eser, 2016) (level of evidence 2a). A randomized controlled trial by Racca et al. (2017) amongst 80 patients post median sternotomy showed that osteopathic manipulative therapy (OMT) administered for 15 minutes, once a day for five successive days after discharge from the ICU led to a significant reduction in pain levels measured via the Visual Analogue Scale (VAS) (median value of one) compared to the control group (median value of three). Furthermore, functional respiratory capacity measured using an incentivator device was significantly greater in those who received OMT intervention. Osteopathic manipulative therapy consisted of gentle manipulations of the thoracic wall over various areas including the anterolateral aspect of the chest at the diaphragmatic level, directly on the sternal area, and the supraclavicular area. Each area lasted five minutes of manipulation (level of evidence 2a). Kinesiology tape, when fan-shaped tape is applied in a star-like pattern below the clavicles and on the lateral surfaces of the chest, has shown to be effective in pain reduction thereby reducing the amount of opioid consumption (Brockmann & Klein, 2018) (level of evidence 2a).

2.3.3.3. Restoring lung volume

Restoration or maintenance of lung volume prevents atelectasis and improves gaseous exchange. Facilitating secretion clearance goes hand-in-hand with restoring gaseous exchange (Lagier et al., 2022) (level of evidence 1b). Current physiotherapy treatment for restoring lung volume amongst this patient population consists mainly of mobilisation, positioning, and deep breathing exercises (with supported huffing and coughing manouvres using a towel or thoracic support device) with or without the use of adjunctive devices such as incentive spirometry (IS), positive expiratory pressure, IMT, intermittent positive pressure breathing (IPPB) and continuous positive airway pressure (CPAP) (Rodrigues et al., 2021) (level of evidence 1a)

Despite its regular use, IS has been shown to have no effect in reducing post-operative pulmonary complications (Eltorai et al., 2018; Freitas et al., 2012) (level of evidence 1b). Positive expiratory pressure (PEP) devices have better evidence with regards to increasing tidal volume thereby reducing post-operative atelectasis. A recent study by Jage & Thakur, (2022) found that oscillatory PEP devices such as the Acapella when used in conjunction with other physiotherapy modalities offers better airway clearance and promotes greater lung volume than conventional physiotherapy (consisting of manual chest clearance techniques, IS and deep breathing exercises) alone amongst patients who underwent CABG via median sternotomy surgical approach. This information should be taken with caution as the study was a pilot consisting of a small sample size (20 participants who underwent CABG surgery via median sternotomy surgical approach of which 11 were in the experimental group and nine were in the control group). The outcome measures included in the study were amount of sputum expectorated, FVC, FEV1, and PEF (level of evidence 2a).

Inspiratory muscle training, when used all days during hospitalization along with conventional physiotherapy (manual chest physiotherapy, deep breathing exercises, postural drainage and suctioning), has been shown to improve maximum Inspiratory pressure (MIP), PEF and tidal volume measures by the time of discharge from the hospital when compared to the use of conventional therapy alone amongst patients who underwent CABG via median sternotomy surgical approach (Barros et al., 2017) (level of evidence 1a).

Although CPAP has been shown to improve oxygenation, it has not been proven superior to other therapeutic techniques (Pasquina et al., 2004) (level of evidence 4). Interestingly there is no evidence that the use of mechanical devices is more effective than breathing exercises alone and it is suggested that there should be a combined use (Urell et al., 2011) (level of evidence 4).

Post-operatively, breathing exercises are recommended to be done once every waking hour particularly with patients whose mobilisation status is restricted. To restore vital capacity, both force and depth should be emphasized with a slow and deep inspiration, a passive expiration and a two-to-five second hold in-between (Bianchi et al., 2004) (level of evidence 3). Breathing exercises should be performed in optimal V/Q matching positioning such as standing, sitting, or leaning forward to enhance effectiveness. A suggested duration of exercise is three sets of ten deep breaths with a 30-60 second rest in between sets (Urell et al., 2011) (level of evidence 1b)..

2.3.3.4. Mobilisation

Mobilisation out of bed needs to occur within the first 48 hours post-operatively. Patients are encouraged to sit in the chair and walk short distances by day two to be able to walk freely by day three post-operatively. Some studies suggest bed exercises as early as one hour after extubation is beneficial (Ramos dos Santos et al., 2017) (level of evidence1a). The use of assistive devices such as a walking frame or rollator is safe and should be implemented to encourage optimal and safe mobilisation (Reeve et al., 2010) (level of evidence 2a) .da Costa Torres et al.(2016) in their randomized controlled trial of 66 patients undergoing CABG via median sternotomy surgical approach, developed a post-operative mobilisation protocol which contributed to less post-operative pulmonary complications, greater functional capacity as well as reduced length of hospital stay as compared to a respiratory exercise program only (level of evidence 2a).

Table 2.2: A mobilisation protocol following CABG via median sternotomy surgical approach (da Costa Torres et al., 2016)

Day 1	•Active upper and lower limb extremity exercises (3 sets of 10 repetitions). •20-minute lower limb cycle ergometer.
Day 2	•Progress to walking on spot for 3 sets of 1 minute duration. •20-minute cycle ergometer.
Day 3	•Progress to walking in ward (7 minutes).

	•Sit in chair for 30 minutes.
Day 4	•Progress walking to 10-minute duration. •Sit in chair for one hour.
Day 5	•Progress to walking for 15 minutes. •Sit in chair for at least two hours.
Day 6	•Progress to walking for 20 minutes. •Step training up and down one step (3 times continuously on a 20 cm heigh step).
Day 7	•Continue walking 20 minutes •Step training up and down one step (6 times continuously on a 20cm heigh step).

From day one post-operatively, patients are also encouraged to perform active shoulder exercises at a slow tempo and within a pain free range. Active mobilisation exercises include shoulder flexion, abduction, and scapular adduction movements (Cahalin et al., 2011) (level of evidence 1b).

2.3.3.5. Post-hospital discharge program

Prior to discharge from hospital, education about sternal precautions is important in preventing complications regarding the sternal wound (Tuyl et al., 2012) (level of evidence 4). The theme of “keep your move in the tube” is appropriate to use by reminding patients to keep their arms close to their bodies as if they were moving in an imaginary tube (Adams et al., 2016) (level of evidence 1b). This strategy minimizes the outward pull on the sternum when performing activities such as getting out of bed, rolling a wheelchair, pushing open a door and lifting items to put on a high shelf (McKenna et al., 2022) (level of evidence 4). However, for activities that require no heavy lifting such as brushing teeth, “out of tube” movements are permitted (Adams et al., 2016). Additionally, patients should be given thoracic mobilisation exercises at discharge to reduce sternal pain and improve patient satisfaction from physiotherapy treatment (Denehy et al., 2018; Sturgess et al., 2014) (level of evidence 2a)

Post discharge, patients are allowed to resume usual activities given that they are pain-free and the principle of “keep your move in the tube” is adhered. Therefore, an activity such as mowing the lawn is doable if a family member is there to assist the patient to pull the cord to start the lawn mower engine (Adams et al., 2016) (level of evidence 1b). Cahalin et al. (2011) reported that, although sternal precautions are necessary, they can easily become restrictions leading to an individual not optimally functioning in the context of their daily lives and work. Restrictions encountered include reduced shoulder range of motion causing an inability to lift, reach, dress or drive oneself. The authors reported that this could be due to the fact that either there is no universally accepted list of precautions; the suggestions given by therapists may be anecdotal and not supported by concrete evidence; precautions are applied uniformly to all patients without taking into consideration an individual's holistic being and how they function in their own personal lives; or the precautions are overly restrictive and lead to fear avoidance behavior (Cahalin et al., 2011; Cohen & Griffin, 2002) (level of evidence 1b). Thus Cahalin et al., (2011) developed a sternal precaution algorithm classifying patients into high risk, moderate risk and low risk of complications. One downside is that they have no clear guidelines as to who is classified into the high, moderate, or low risk groups.

Home use of a thoracic support device such as a "heart-hugger" and thoracic stabilization exercises should also be encouraged. Thoracic stabilization exercises should be performed for 10 minutes, twice daily for six weeks (El-Ansary et al., 2019)(level of evidence 2a). Early enrolment into an outpatient cardiac rehabilitation program less than two weeks post discharge from hospital is recommended (Reeve et al., 2010) (level of evidence 2a). Additionally, Zimmerman et al. (2004), found that a six-week program of daily telehealth consultations where education and positive re-enforcement to promote self-efficacy amongst patients who underwent CABG via median sternotomy surgical approach reduced the influence of symptoms on functioning thus promoting re-integration into daily life (level of evidence 2a).

The section to follow provides information regarding how a possible BPD in the acute stages post cardiac surgery via median sternotomy surgical approach might influence the presentation of symptoms and results of pulmonary function measures.

Key: level of evidence based on hierarchy of evidence fromPolit & Beck, (2010)

2.4. BREATHING PATTERN DYSFUNCTION ACUTE STAGES POST MEDIAN STERNOTOMY

2.4.1. Patient presentation and Pulmonary function measures

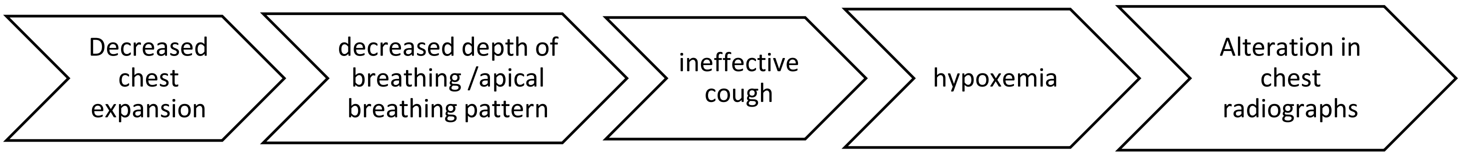

Figure 2.2: Typical presentation of a patient in the acute stages post-operative median sternotomy as described by Wynne & Botti, (2004).

2.4.1.1. Decreased chest expansion measures due to decreased depth of breathing.

In terms or ventilation measures, Gissing, (2020), in addition to CE measures, assessed MIP and Peak Inspiratory Flow (PIF) amongst 61 patients who underwent cardiac surgery via median sternotomy surgical approach. The author conducted a longitudinal study where assessments were made at admission and again at hospital discharge. The results showed that, when comparing pre- and post-operative values, there is an overall decline in both upper and lower thoracic expansion measures, and a lower MIP and PIF upon discharge. The assessments were only conducted until discharge and as stated by the author herself, a need for longer term assessment regarding ventilation kinematics needs to be done.

A diagnostic accuracy study by de Sousa et al. (2016) on 98 patients in a period of 24-48 hours post-operative cardiac surgery (acute period) established that the defining characteristics of BPD amongst this population includes changes in depth of breathing and pursed lip breathing (high sensitivity) as well as asymmetry in chest expansion with prolonged expiration phase greater than a ratio of 1:2 inspiration and expiration time (high specificity). Although this study has a large sample size, it has limitations as analysis of breathing was done by one nurse expert assessing patients individually through physical exam and patient records thus creating a bias.

A much older, outdated study by Ragnarsdȯttir et al. (2004), confirmed that an apical breathing pattern, also known previously as thoracic dominant breathing (Boulding et al., 2016), is seen post-operatively as opposed to a preoperative diaphragmatic breathing pattern. Abdominal movement was found to be 60% of preoperative values while lower thoracic movement was found to be 72% of preoperative values. Respiratory motion was assessed before and after surgery using a Respiratory Movement Measuring Instrument which utilizes sensors placed on each side of the chest at the levels of the fourth and ninth ribs as well as lateral to the umbilicus. Limitations of this study include a small sample size of 20 patients and thoracic cage excursion during breathing was not measured posteriorly therefore changes with expansion of posterior basal lung segments were not assessed. This is because the patients were positioned supine during assessment. Supine is not a functional position, and results could change when the patient is upright due to the role inspiratory muscles (particularly the diaphragm) play in posture control (Katz et al., 2018). This study also did not have a longer follow-up beyond seven days post-operatively where the patients are still in the acute stages of healing.

2.4.1.2. Ineffective cough

An effective cough requires three phases: inspiration, compression, and expulsion. During inspiration, lung volumes increase to 85-95% of their inspiratory capacity to have a total cough volume of 2.3± 0.5 L. During compression, pleural and alveolar pressures rise due to an expiratory force against a closed glottis. During expulsion, the glottis opens, and contraction of abdominal muscles expels secretions and air from the airways. Any alterations to any of these phase's results in an ineffective cough (Schramm, 2000).

Gissing, (2020) in the previously mentioned study, identified a significant difference of median MIP at discharge (30.66 cmH20) compared to admission (55cmH20). According to Kang et al., (2006), although an outdated study, explained that a large amount of air needs to be inspired for an effective cough to take place, and although the expiratory muscles play an important role in cough effort, the lung volume attained prior to the cough is equally as important as it creates an optimal length-tension relationship for the expiratory muscles to contract. Lung volume is determined by the inspiratory muscles during the inspiratory phase of the cough. The authors, in their prospective single center study amongst 40 patients who sustained cervical spinal cord injuries established a more significant correlation between voluntary cough effort and MIP ($r=0.599$, $p<0.001$) compared to voluntary cough effort and Maximal expiratory pressure (MEP) ($r=0.459$, $p<0.005$). Therefore, in the presence of inspiratory muscle weakness, it has been proven that cough effectiveness is diminished despite normal expiratory muscle contraction.

According to Boulding et al., (2016) thoracic dominant breathing (seen amongst patients who underwent cardiac surgery via median sternotomy surgical approach (Ragnarsdóttir et al., 2004)) leads to minimal inspiratory reserve capacity and thus, in this way, BPD can affect cough effectiveness.

2.4.1.3. Hypoxemia

Baobao Li et al., (2022) in their retrospective study on the effectiveness of post-extubation prone positioning amongst patients who underwent cardiac surgery via median sternotomy surgical approach to resolve hypoxemia, found that, the postural adjustment was safe and effective to use. Using a P/F ratio of less than 150 mmHg to identify hypoxemia amongst this population group, the authors found that from August 2018 to August 2020, prone positioning had to be utilized a total of 74 times amongst 22 patients post-extubation.

Gissing, (2020) in her longitudinal observational study found that, amongst 61 participants who underwent cardiac surgery via median sternotomy surgical approach, oxygen saturation levels were significantly lower when compared to admission values ($p=0.001$). She hypothesized that this could be due to the hypermetabolic state because of inflammation following surgical trauma which utilizes more blood oxygen. Other causes could be due to loss of blood during surgery, blood transfusions, fluid overload, hypothermia as well as myocardial dysfunction lowering its contractility therefore affecting output (Parolari et al., 2003). Altered ventilation mechanics as a result of BPD can also play a role due to reduction in lung volume and capacity leading to limitations in appropriate gaseous exchange further contributing to the hypoxemia (Spoelstra-De Man et al., 2015).

2.4.1.4. Alterations in chest radiographs

Multiple studies have shown that chest radiographs taken post-operatively show an increased incidence of atelectasis, pleural effusions and loss of lung volumes seen with elevated hemidiaphragms amongst patients who underwent cardiac surgery via median sternotomy surgical approach (Elkolaly et al., 2018; Gissing, 2020; Kristjánsdóttir et al., 2004). These findings are often not resolved up to a year-post-operatively (Kristjánsdóttir et al., 2004).

The previously described BPD amongst patients who underwent cardiac surgery via median sternotomy surgical approach (thoracic dominant breathing) (Boulding et al., 2016), has been proven to lead to loss of lung volume because of loss of tidal volume due to loss of depth of inspiration (Delgado & Bajaj, 2019). In this way, BPD affects chest radiograph findings.

2.4.1.5. Alterations in pulmonary function tests

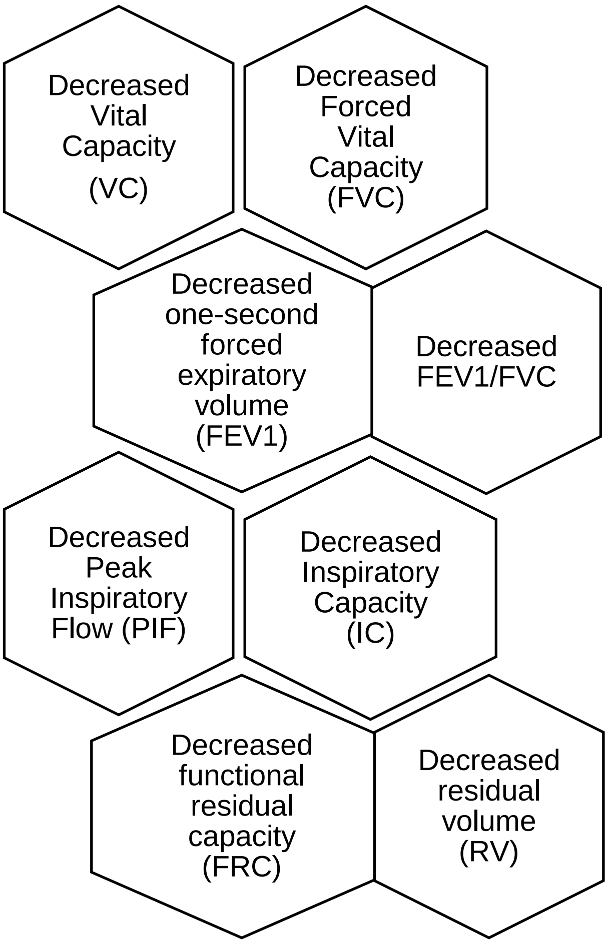

Figure 2.3: Typical alterations seen in pulmonary function tests in the acute stages post-operative median sternotomy.

Previous studies have established significant reductions in pulmonary function tests amongst patients who have underwent cardiac surgery via median sternotomy surgical approach. These tests included: forced vital capacity (FVC); FEV1; FEV1/FVC; forced expiratory flow in 50% and 75% expiration; PEF; maximal voluntary ventilation (Aris et al., 1999; Fayazi et al., 2021; Shenkman et al., 1997); MIP; MEP (Chetta et al., 2006); PIF(Gissing, 2020); inspiratory capacity (Narayanan & Syed Hamid, 2020), and FRC (Calderon et al., 2009).

Furthermore, studies by Fayazi et al., (2021); and Shenkman et al. (1997) found that the results of the pulmonary function tests did not return to pre-operative values several months post-operatively.

Thoracic dominant BPD seen amongst this population group in the acute stages post-operatively (Boulding et al., 2016) causes alterations in the mentioned pulmonary function tests due to its restrictive effects on the mechanics of breathing (Al-Ashkar et al., 2003; Jage & Thakur, 2022; Westerdahl et al., 2003).

2.4.2. Breathing pattern dysfunction and Post-operative pulmonary complications

A median sternotomy surgical technique has been proven to alter breathing pattern from predominantly basal/ diaphragmatic breathing pattern to an upper thoracic breathing pattern thereby predisposing patients to impaired respiratory muscle strength, reduced pulmonary function and atelectasis which can eventually result in pneumonia (Ragnarsdóttir et al., 2004; Roncada et al., 2015). Furthermore, pulmonary measures including VC, IC, FEV1, PEF and total lung capacity (TLC) have been shown to be decreased post-operatively indicating a restrictive pattern of pulmonary function which coincides with the upper thoracic pattern of breathing (Jage & Thakur, 2022; Westerdahl et al., 2003).

Post-operative complications such as pneumonia and atelectasis can lead to increased mortality and morbidity amongst patients with an increase in hospitalization costs and overall length of hospital stay (Mans et al., 2015).

Having established a link between BPD and pulmonary function deficits in the acute stages post cardiac surgery via median sternotomy surgical approach, the following section might establish a lingering long-term BPD in the said population.

2.5. BREATHING PATTERN DYSFUNCTION LONG -TERM POST MEDIAN STERNOTOMY.

2.5.1. Influences of pain

A review done by Zubrzycki et al. (2018) stated that post-operative pain caused by trauma to tissues during cardiac surgery may persist for up to three months. Pain impairs basal thoracic expansion, weakens abdominal and intercostal muscles, and alters pattern of breathing leading to reduced inspiratory capacity thereby decreasing lung volume. This contributes to the incidence of post-operative pulmonary complications (Zencir & Eser, 2016). Furthermore, chronic post-operative pain (pain lasting at least three to six months) has an occurrence rate of 30-50% amongst patients who underwent cardiac surgery. Therefore, if there is persistent pain post-operatively, it is likely there will be restricted deep breathing leading to a persistent BPD (Zubrzycki et al., 2018).

2.5.2. In relation to lung function tests and respiratory movements

An outdated study by Westerdahl et al., (2003), which has a long follow up of four months post CABG via median sternotomy, involved 25 male patients. Patients were assessed three times; before surgery, four days after and four months after that. Pulmonary function tests were done using a Medical Graphis PF/DX Pulmonary Function system. Levels of pain at rest, taking a deep breath and coughing were also assessed using the VAS. Patients presented with normal lung function pre-operatively but displayed a severe restriction in ventilation four days after surgery. Similarly at four months post-operatively, patients still showed a significant reduction in lung function with a deficit of 6-13% preoperative values in VC, IC, FEV1, PEF, FRC and TLC. Contrary to what was found in the studies by Zencir & Eser, (2016) and Zubrzycki et al., (2018) , pain levels were low and not correlated to the restrictive breathing impairment seen four months post-operatively. Authors suggest the cause for the dysfunction to be related to reduced thoracic cage expansion due to alterations in the tissues following opening of the thorax rather than pain. This study proves the need for updated research and therapeutic intervention with longer term follow up as deficits in pulmonary function seem to be long lasting and can become permanent (Westerdahl et al., 2003).

The most recent study on pulmonary dysfunction post cardiac surgery at one year follow-up also noted that long-term evaluation of BPD is lacking. This study showed that pulmonary function measured as VC, forced vital capacity (FVC), FEV1, FEV1/FVC, PEF and FRC was significantly reduced compared to pre-operative values (2-5% impairment). This study has a large sample size of 164 patients who underwent CABG, valve replacement or a combination of two performed via a median sternotomy surgical approach. The authors however did state that there is a need to identify risk factors for the development of long-term breathing dysfunction. Despite their measures of pulmonary function, the authors did not assess actual chest wall breathing pattern or mechanics (Westerdahl et al., 2016).

Unlike Westerdahl et al. (2016), Kristjánsdóttir et al. (2004) in an older study utilized a time frame where they assessed 20 patients before, three months and one year after cardiac surgery via median sternotomy surgical approach. Their aim was to examine alterations in chest wall motion and pulmonary function amongst this population group. Their outcome measures included bilateral respiratory movements using a Respiratory Movement Measuring Instrument (sensors positioned bilaterally at the level of the umbilicus, the ninth and fourth ribs) as well as pulmonary function tests measuring VC, FVC, FEV1 using Pulminet III. Their results showed significant decrease in basal/ abdominal movement as compared to preoperative values which did not normalize by 12 months. Interestingly, the authors noted an increase in chest expansion of the upper and lower thoracic movements which they hypothesize is due to over-stretch injury of the connective tissues of the costovertebral and costotransverse joints of the thoracic cage during surgery as these structures are not able to contract to their original length and remain elongated. They also found that lung volumes did not decrease greatly at three months post-operatively as compared to preoperative measures (volumes decreased 11-14%). This could be because decreased motion of the abdomen during breathing was compensated for by increased upper and lower thoracic motions thereby helping to maintain lung volume. Limitations in this study included a very small sample size as well as the authors did not relate pulmonary deficits to function and thus concentrated only on altered mechanics of breathing and not how it holistically affects the patients in their daily lives.

The section to follow will discuss the prevalence of functional status deficits post cardiac surgery with focus on the diaphragm as a postural control muscle.

2.6. EFFECT OF LONG-TERM BPD ON RETURN TO WORK AND FUNCTIONAL PERFORMANCE

2.6.1. Functional status post cardiac surgery

Although there is a need for newer data, patients who underwent CABG surgery via median sternotomy surgical approach, reported functional deficit when doing home chores two months post-operatively. These patients reported that they either found the activities difficult to perform (56%) or needed assistance to perform (36%) and/or experienced pain during the activity (44%) (LaPier et al., 2008). Furthermore, another, yet outdated study revealed that 36% of patients report dissatisfaction with their functional status one year post-operatively (Falcoz et al., 2003).

Breathing pattern dysfunction, seen in the acute stages post-operatively, has also been proven to have a correlation with poor functional movement levels (Bradley & Esformes, 2014).

2.6.2. The diaphragm

"The diaphragm is one of the most remarkable areas in the body in that it has so much influence and the consequences of its dysfunction can manifest anywhere from the head to the toes" (Stone, 1999, p9)

The zone of apposition (ZOA) describes the area of attachment between the diaphragm and the rib cage. The diaphragm has three ZOA areas namely: fibers attaching onto the posterior surface of the xiphoid process of the sternum; fibers attaching onto the inner surface of the lower six ribs at their costal margins and fibers attaching to the first three lumbar vertebrae (Moore et al., 2014).

Any disruptions to the ZOA eg, damage to the sternal attachments of the diaphragm during a median sternotomy in the case of cardiac surgery, leads to a decreased ability of the diaphragm to contract optimally leading to decreased efficiency in inhalation. Secondary mechanical compensations to this include reduced thoracic expansion, with increased accessory respiratory muscle use and postural alterations. This results in symptoms such as dyspnea, decreased exercise tolerance, increased lumbar lordosis with shortened hamstrings, lumbo-pelvic instability, paraspinal muscle spasm, general low back pain, thoracic outlet syndrome, sacroiliac joint pain and headaches (Kocjan et al., 2017).

2.6.3. Balance and stability

Although the diaphragm has a principle role of respiration particularly that of inspiration, it has a crucial role in balance and postural control as it, along with co-contraction of multifidus, transversus abdominis and pelvic floor muscles, aids in increasing intrabdominal pressure thereby bracing the lumbar spine and allowing for stabilization (Bradley & Esformes, 2014; Kocjan et al., 2018). Stabilization of the trunk involving the contraction of the diaphragm which tenses the thoracoabdominal fascia via its cural fibers happens before initiation of functional movement and is independent of the phase of respiration. This suggests that this is a nonvoluntary response pre-programed by the brain and spinal cord (Kocjan et al., 2018).

Both static and dynamic balance is needed in basic functional movements and postures seen in activities of daily living such as standing, walking, and turning around (Bradley & Esformes, 2014; Kocjan et al., 2018). Any deficits in diaphragm function can lead to reduced balance and stability of the lumbar spine thereby altering motor control. A study done on 34 healthy men and women to determine the relationship between BPD and dysfunctional movement revealed a correlation between low scores on the FMS and upper chest breathing patterns measured with the HiLo Breathing Assessment, Nijmegen Questionnaire, Breath holding Ability and Capnography device (Bradley & Esformes, 2014). As discussed previously by Moreno et al. (2011), phrenic nerve injury has a prevalence of 26% amongst these patients undergoing surgery via median sternotomy surgical approach resulting in diaphragm paresis also resulting in altered breathing patterns. Thus, there is a high likelihood of balance and stability deficit amongst this patient population.

A study by Kocjan et al. (2018) done on 102 participants (group one=62 patients before resection due to lung cancer ; group two= 40 of the previous group assessed three-to-five days after the said surgical procedure ; group three= 40 healthy students enrolled at a University) found better static balance performance (assessed using a Zebris FDM-S platform) amongst participants with greater values of diaphragm muscle thickness, greater index of diaphragmatic thickening (difference in the thickness of the diaphragm at end inspiration and end expiration) and greater diaphragm excursion during quiet breathing, deep breathing and sniff maneuver. Furthermore, the authors established that there is a correlation between reduced static balance ability and diaphragm muscle strength and function amongst patients post thoracic surgery. Although this study is beneficial in establishing the relationship between diaphragmatic function and static balance control, it does not involve assessment of dynamic balance control which is involved in higher order activities such as reaching for a high shelf or climbing up/downstairs.

There is very sparse evidence of the effect of the diaphragm on dynamic balance. A clinical trial with a much smaller sample size (n=13) of healthy university-going adults found that there was a statistically significant relationship between a low error rating in the single leg stance score (SLS) assessing static balance ability, and improvements in diaphragmatic breathing pattern. However, there were no statistically significant correlation scores between improvements in breathing pattern and dynamic balance measured using the OptoGait's "March in Place" protocol, after an eight-week deep breathing exercise program. The authors did state that the dynamic balance testing done could have been flawed due to equipment malfunction with addition to no empirical data to support OptoGait protocol use in research studies (Stephens et al., 2017).

Therefore, early assessment and treatment of BPD will not only aid in breathing but overall performance in activities of daily living thereby improving quality of life (Vidotto et al., 2019).

2.7. CONCLUSION

This literature review concludes the need for further research involving BPD amongst individuals who underwent cardiac surgery via median sternotomy surgical approach due to the under reporting of the prevalence of BPD in various population groups. Also, this literature review has identified certain alterations in pulmonary function tests which have been established to not have been resolved up to one year post-operatively amongst patients who underwent the median sternotomy surgical approach. This links to the possibility of a prolonged BPD due to the already established link between certain measures of BPD (such as chest expansion) and pulmonary function test results. Additionally, as this literature review has related the role of the diaphragm with the ability to execute functional tasks at home and in the workplace, further research is also needed to establish how work-related demographics, such as return to work time and type of work may influence or be influenced by a possible long-term BPD.

CHAPTER 3

3. METHODOLOGY

3.1. INTRODUCTION

This section will discuss the methodology used to address the objectives and aims of the study to answer the research question.

3.2. TYPE OF STUDY

This study was an observational cross-sectional study as each participant was assessed once (Setia, 2016).

3.3. STUDY PARTICIPANTS

3.3.1. Source of Study Participants

Participants were selected based on their admission into a private hospital in Pretoria, South Africa where they underwent an elective cardiac procedure via median sternotomy surgical approach at the cardiothoracic unit of the hospital. Participants were identified by the relevant physiotherapist practices who provided care to the patients during their hospital stay following the surgical procedure.

3.3.2. Sample Selection

Potential study participants were recruited according to the following inclusion and exclusion criteria:

3.3.2.1. Inclusion Criteria

•Male and female patients who underwent cardiac surgery where a median sternotomy surgical approach within a period of three months to one year prior, were used.
•Patients who were able to provide informed consent.
•Patients aged 18-65 years.

3.3.2.2. Exclusion Criteria

•Patients who underwent a median sternotomy due to a non-cardiac origin (e.g., Lung masses or trauma).
•Patients with underlying chronic lung pathologies such as chronic obstructive pulmonary disease.
•Patients who had undergone a surgical re-look.
•Patients who were participating in another clinical trial at the time

3.3.3. Sample size:

Based on advice given by a statistician, total population sampling was used. The total population of patients who had undergone cardiac surgery via median sternotomy surgical approach within a period of one year was selected. In the specific private hospital, a total of 120 patients underwent the above-mentioned surgical procedure the previous year (February 2021-February 2022). Of that population, an estimated 20% demised. Taking into consideration an expected " non-response "rate of up to 30% based on a study by Abrahamsen et al., (2016) as an estimated population size of 60 was expected to be used for the study.

3.4. VARIABLES

3.4.1. Independent Variables:

•Health-related profile of the patients who underwent cardiac surgery via median sternotomy surgical approach (BMI, previous diagnosis of depression, length of hospital stay, pain levels as measured using the Visual Analogue Scale, post-operative complications).
•The median sternotomy approach used by the cardiothoracic surgeon for this chosen patient population.
•Return to work time.

3.4.2. Dependent Variables:

•The presence of BPD as determined by the NQ, SEBQ, BHT, and CE Measurements.

3.4.3. Confounding Variables:

•Age and gender
•Work-related demographics (type of work, level of education, income bracket).
•The physical activity level as determined by the Physical Activity Vital Sign (PAVS).

3.5. OUTCOME MEASURES

As stated in the introduction, there are no gold standard methods to define BPD, but it has been suggested that a multidimensional approach should be used incorporating biomechanical, biochemical, and psychophysiological dimensions when assessing this phenomenon (Courtney, 2011). Therefore, the following outcome measures have been used to enable assessing for BPD within all three dimensions in the current study.

3.5.1. Nijmegen Questionnaire (psychophysiological dimension)

The NQ is a breathing symptom questionnaire originally created to evaluate hyperventilation syndrome, but it has since been used across a variety of medical specialities from pulmonology to otorhinolaryngology to assess BPD (van Dixhoorn & Folgering, 2015). This questionnaire consists of four questions relating to respiratory symptoms while the other 12 relate to stress and anxiety (Courtney, 2011; Van Dixhoorn & Folgering, 2015). A cut-off score of 20 or more denotes a BPD with a sensitivity of 91% and a specificity of 92% (Azizmohammad Looha et al., 2020). It has also been proven to have a strong test-retest reliability (IR=0,98) and a strong correlation with the SEBQ (p=0.0001)(Courtney, Greenwood, et al., 2011).

3.5.2. Self-Evaluation of Breathing Questionnaire (psychophysiological dimension)

The SEBQ is also a breathing symptom questionnaire. This questionnaire offers a greater depth of evaluation than the NQ and differentiates symptoms into two dimensions: "lack of air" relating to increased activity of chemoreceptors and "perception of restricted breathing" which relates to breathing kinematics (Courtney, Greenwood, et al., 2011). To obtain an accurate evaluation, the SEBQ should be used with the NQ as it is still in need of further validation (Courtney, Greenwood, et al., 2011; Mitchell et al., 2016). Scores range from a "0" which denotes "no impairment" while a score of "75" denotes maximal perception of impairment. According to expert opinion, a cut-off score of 25 or more indicates the presence of BPD (Kiesel et al., 2017). It has been established that the SEBQ has a high test-retest reliability (ICC=0.89) and internal consistency (Cronbach's alpha=0.93) within the general population (Mitchell et al., 2016).

3.5.3. Breath Hold Time (biochemical dimension)

Breath Hold Time or BHT test, describes a test where the participant is asked to hold their breath by pinching their nose after a normal exhalation. This test is done in the sitting position and the amount of time the participant can hold their breath is then measured (Kiesel et al., 2017).

Among a general population, BHT has a good inter-rater reliability with ICC=0.88 (0.78-0.93). When used alone without other outcome measures it has a sensitivity of 0.54 (0.49-0.58) and a specificity of 0.60 (0.18-0.92) when a cut-off score of 20 seconds is used. Sensitivity scores only improved to 0.74 (0.69-0.77) with a cut-off score of 25 seconds (Kiesel et al., 2017).

3.5.4. Chest Expansion Measurement (biomechanical dimension)

Measurement of CE is considered the most important measure of breathing patterns at rest and with exercise. Measurement via a non-stretch tape measure is considered affordable, easy to use and non-invasive (Reddy et al., 2019). Measurements of CE are made on two sites; upper CE refers to circumferential measurement with placement at axillary level, while lower CE refers to circumferential measurement with placement at the level of the xiphoid process (Padkao & Boonla, 2020a). Three Measurements are taken at maximal inspiration and maximal expiration for both lower and upper CE and the average difference is noted. This is done in standing and hands at the sides (Debouche et al., 2016) .

In terms of correlation, upper and lower CE measurement demonstrates a significant correlation with lung function tests including FVC, FEV1, FEV1/FVC and VC (p<0,0001) (Reddy et al., 2019). Very good intra rater reliability is established for both upper CE (ICC=0.90 and 0.93) and lower CE (ICC=0.85 and 0.86). Good to very good inter-rater reliability is established for both upper CE (ICC=0.83) and lower CE (ICC=0.84) (Reddy et al., 2019). The mean ranges in healthy non-smokers are 5.6-6.4cm for upper CE and 7-7.5cm for lower CE (Reddy et al., 2019). It is however important to note that gender, age, BMI, pain levels, underlying pulmonary conditions and general level of functioning affect these values (Derasse et al., 2021; Reddy et al., 2019).

3.5.5. Physical Activity Vital Sign

The PAVS, also known as Exercise Vital Sign (EVS) is a questionnaire enquiring of the duration and frequency of moderate to strenuous exercise performed in a week (Ball et al., 2016). The minimum score for adults older than 18 years of age should be 150 minutes over the period of a week. Additionally, adults should do muscle strengthening activities that are moderate to high intensity involving all major muscle groups at least two days a week (Cowan, 2016).

According to Golightly et al. (2017), the PAVS shows a 90% agreeability with the lengthy Modifiable Activity Questionnaire (MAQ) which has a strong correlation with accelerometery.

When identifying the presence of inactivity amongst participants, the PAVS, has a 67% sensitivity and a 68% specificity. The PAVS also shows a low positive correlation with accelerometery (P=0.38, P<0.0001). Therefore, it has proved sufficient criterion validity to be used based on identifying a need for further intervention where additional tests will take place thereafter (Kuntz et al., 2021).

3.5.6. Demographic Questionnaire

The demographic questionnaire is self-compiled based on previous risk factors causing a delay in return to work, described in the literature review by Mortensen et al. (2021). It also takes into consideration risk factors previously associated with pulmonary complications post-operatively as described in the literature review (Bechtel & Huffmyer, 2020; Gao et al., 2016; Kim et al., 2018; Urell et al., 2016; W. Wang et al., 2014). Classification regarding level of education and income bracket (within a South African context) was adapted from Maphupha (2018) and Tuchten (2011) respectively.

Table 3.1: Instrumentation and Outcome Measures

Outcome	Outcome measure	Appendix number
Psychophysiological dimension of BPD	Nijmegen Questionnaire (NQ) and Self-Evaluation of Breathing Questionnaire (SEBQ)	1 and 2
Biochemical dimension of BPD	Breath Hold Time Test (BHT)	Described above under heading 3.5.3
Biomechanical dimension of BPD	Measure of chest expansion (CE) with a non-stretch tape measure	3
Physical activity	Physical Activity Vital Sign (PAVS)	4
Work-related demographics	Self-created questionnaire which includes questions on: •When and whether the participant has returned to work •Type of work •Level of education •Income bracket	5
Health-related demographics	Self-created questionnaire which includes questions on: •Age •Gender •Body Mass Index (BMI) calculated by researcher using height (m) and weight (kg) •Previous diagnosis of depression •Type of surgery •Length of hospital stay •Pain levels during deep breathing and coughing measured using a Visual Analogue Scale (VAS) •Post-operative complications	5

3.6. ETHICAL CONSIDERATIONS

3.6.1. Before the study

Clearance was obtained through the Human Research Ethics Committee of the University of the Witwatersrand (ref no: M220858 available in appendix 6). Approval of title was also given from the Faculty of Health Sciences Post Graduate Office (Appendix 7).

Written permission from the physiotherapy practice owners and cardiothoracic surgeons were also obtained (Appendix 8) . Consent from the chief executive officer of the hospital where the participants underwent the surgery was also given (Appendix 9).

3.6.2. During the study

Ethical considerations in accordance with Protection of Personal Information Act (POPIA) (R. Adams et al., 2021) were made with particular focus on data sharing and re-use. Under Section 12 (2) and (18) of the Act, contact details of possible participants were allowed to be shared by the relevant practice owners on the condition that it is was not shared for any purpose other than this research project. In addition, participants were approached by their treating therapist/ surgeon first (whether telephonically or in person) to gain consent thereby avoiding risk of coercion by the researcher. Prior to the study, the participants and their family member/friend were required to sign consent and were allowed to withdraw from the study at any time with no reason required (Appendix 10). To ensure confidentiality, all study results were stored on a password protected database with anti-virus and anti-malware software installed.

3.6.3. After the study

After analysis of results, each participant was contacted, and their results discussed. If needed, appropriate education and exercises were sent via email and participants were encouraged to contact their individual physiotherapist if their BPD persists. In the write up of the study, details of participants were made as anonymous as possible. With consideration of POPIA, no personal identifiable data was made available for re-use.

3.7. PILOT STUDY

3.7.1. Pilot study aim

•To improve competence and self-efficacy with regards to the use of the outcome measures.

•To establish the ease at which the participants can complete the outcome measures as well as the ease of telephonic consultation between the researcher and participant.

•To adjust, if necessary, the method of data collection and data analysis thereby improving the efficiency of the research process of the main study.

•To establish intra rater reliability of the objective measures (BHT and CE).

3.7.2. Pilot study method

Prior to commencement of data collection, a video example of the physical assessment methods of the CE and BHT were made to be sent with the REDCap online survey to the participants. To make the video, the researcher needed two persons to demonstrate on. Written consent was obtained from both persons and their faces were concealed in the video.

The first seven patients identified by the relevant physiotherapists/ surgeons who underwent cardiac surgery via median sternotomy surgical approach were selected to participate in the pilot study (10% of the anticipated sample size for the main study) (Hertzog, 2008). The method of data collection was the same as the main study except when establishing intra rater reliability of the BHT and CE.

The possible participants were contacted first by the practice owners/surgeons via telephonic/email communication to explain the study and gain consent. If possible participants received therapy during their hospitalisation from the researcher herself, the researcher requested the aid of a colleague to make first contact with the identified patient. If consent was given by the participant, he/she was then contacted by the researcher.
A time and date were arranged amongst the researcher, participant, and family member/ friend for a telehealth video consultation (online since many patients visiting the hospital for surgical interventions were from other provinces or countries e.g., Namibia making it logistically challenging for a face-to face consultation).

Shortly thereafter, an email was sent containing the consent documentation to be signed by the participant and family member/ friend. The demographic questionnaire, PAVS, NQ and the SEBQ (assessed via the REDCap online survey platform) were included in the email along with a video tutorial, made by the researcher on how to conduct the BHT and CE (graphic evidence of the videos are seen in appendix 11). Family members/ friends were not required to be present for that part of the study but were allowed to look at the tutorial videos for the physical assessments. Thereafter, the scheduled video consultation then took place involving the participant, researcher, and family member/ friend. During this consultation, the CE and BHT physical assessments were done:

• The researcher first guided the family member/ friend on how to assess the lower and upper CE (with the participants' back facing the camera) using a non-stretch tape at the level of the axilla (upper CE) and xiphoid process (lower CE). Three measurements at maximal inhalation and maximal exhalation were done at each level.

•Thereafter the researcher guided the family member/friend on how to assess the BHT using their own timer on their phone. The participant stood facing the camera so that the researcher had a view of his/her face and hand movements.
•All measurements were reported during the consultation by the family member/ friend and recorded by the researcher.
•If the demographic questionnaire, PAVS NQ and SEBQ had not yet been completed by the time the video consultation took place, it was then assessed in an interview-like manner by the researcher during the consultation.

To establish intra rater reliability of the CE and BHT, additional measurements were taken. With regards to CE, the average of three measures of upper and lower CE were taken followed by a five-minute rest period (to ensure respiratory muscle recovery and to ensure the initial tests did not have influence on the second part of tests (Portney & Watkins, 2015)) after which, another average of three measures of upper and lower CE were taken. For the BHT, two measures were taken with a five-minute rest in between.

Once results were analysed, the individual participants received their personal feedback via email and appropriate treatment strategies (if needed) were undertaken. This included an email with a home exercise programme and/or referral back to the participants' physiotherapist for further assessment and treatment. This, however, does not form part of the MSc. research project.

3.7.3. Statistical analysis of the results of the pilot study

All data during the video consult were captured on data collection forms and then transferred onto a Microsoft Excel spreadsheet. The questionnaires on REDCap were transferred directly from the platform onto the same Microsoft Excel spreadsheet. The data were then imported into the IBM SPSS 28 statistics analysis program for analysis. A Shapiro Wilk test was done to evaluate whether the data were normally distributed. If data were normally distributed ($p>0.05$), it was expressed as mean and standard deviation (SD). If the data were not normally distributed, it was expressed as a median and inter-quartile range (IQR). Furthermore, a Pearsons correlation test was used for normally distributed data, and a Spearman's rho test was used for not normally distributed data to establish correlation coefficients.

In terms of determining strength of correlation utilising Spearman's rho correlation., Prion & Haerling, (2014) suggests the following interpretation:

0,00-0,20= negligible strength

0,21-0,40=weak strength

0,41-0,60= moderate strength

0,61-0,80= strong strength

0,81-1=very strong strength

In terms of determining strength of correlation utilising Pearsons's correlation, Schober & Schwarte, (2018) suggests the following interpretation:

0,00-0,19=very weak strength

0,20-0,39=weak strength

0,40-0,59=moderate strength

0,60-0,79=strong strength

0,8-1=very strong strength

Lastly the degree of intra-rater reliability utilising the correlation co-efficients from the Pearson and Spearman's rho test were taken from (Koo & Li, 2016):

<0,5=poor intra-rater reliability

0,5-0,75=moderate intra-rater reliability

0,75-0,9=good intra-rater reliability

>0,9=excellent intra-rater reliability

<u>Table 3.2: Intra-rater reliability Scores for the CE and BHT (N=7)</u>

Outcome measure	**Trial**	**N**	**Mean (±SD) /Median (IQR)**	**Shapiro-Wilk Test W (p-value)**	**Correlation R (p-value)**
Upper CE	1	7	1,33 (IQR2.2)	0,718 (0,006)	0,75 (0.52)
	2		2,95 (±1,98)	0,915 (0,432)	
Lower CE	1	7	3,39 (±2,53)	0,877 (0,213)	0,970 (<0,001)
	2		3,2 (±2,17)	0,922 (0,489)	
BHT	1	7	21,86 (±8,34)	0,891 (0,281)	0.947 (0,001)
	2		21,38 (±6,85)	0,967 (0,875)	

*BHT (Breath Hold Time), CE (Chest expansion), IQR (Interquartile range), SD (Standard deviation)

According to the results above, all values except for upper CE trial 1 were normally distributed. Therefore, the scores for upper CE trial 2, lower CE and BHT were represented in mean (±SD) whereas upper CE was represented in median (IQR). In terms of correlation for upper CE, there was a strong positive correlation between trial 1 and 2 (Spearman's rho).

In terms of lower CE and BHT there were very strong positive correlations between trial 1 and 2 (Pearsons's correlation).
Therefore, all objective measures (lower CE, upper CE and BHT) had good to excellent intra-rater reliability (Koo & Li, 2016).

3.7.4. Implications of the pilot study

Firstly, the pilot study proved that the objective outcome measures (lower CE, upper CE and BHT) had good to excellent intra-rater reliability when used by the participants' family members and therefore the main study could be commenced with confidence with regards to producing reliable results.
When commencing the pilot study, there was resistance with regards to some practice owners providing contact details, as they themselves, despite being aware of the research process when signing consent, were not willing to contact the patients themselves to gain consent for the researcher. Therefore, a new agreement had to be made amongst some of the practice owners that they had to first approach the possible participants while they were still in hospital for consent. Thereafter the researcher was allowed to approach the patients in hospital to explain the study and gain consent. The researcher would then make a list to note the participants date of discharge to ensure the participant was contacted telephonically at least three months or more post hospital discharge.

3.8.THE MAIN STUDY

3.8.1. Main study method

The main study followed from the pilot study after determining a sufficient intra-rater reliability of the objective outcome measures (lower CE, upper CE and BHT).Additionally data from the pilot study was also utilised in the main study. The only changes in the main study were that the upper and lower CE were only measured three times each (after which the average of the measurements was determined) as compared to the pilot study where a total of six measurements were taken (three measurements with a five-minute rest before another three measurements). Furthermore, with the BHT, only one measurement was taken compared to the pilot study where two measurements were taken with a five-minute rest in between. In terms of participant recruitment, it was decided that participants would be approached during their hospitalisation first by the practice owner/their treating physiotherapist to ask if they were interested in partaking in the study. Once permission was given, the participants would then be approached by the researcher for further information about the study and to gain consent. The researcher documented the discharge date of the participants to ensure that they would be contacted at least three months or more post hospital discharge. The pilot study took place beginning December 2022 to end January 2023 while the main study commenced beginning February 2023 and concluded end November 2023.

3.8.2. Statistical Analysis of the main study

All data obtained during the video consult as well as the questionnaires were transferred onto the Microsoft Excel Spreadsheet used previously with the pilot study. The Microsoft Excel spreadsheet was then imported into the IBM SPSS 28 statistics program for analysis. For ratio types of data, a Shapiro Wilk test was done to evaluate whether the data were normally distributed ($p>0.05$). Normally distributed data ($p>0.05$) were described as means and standard deviations while data that was not normally distributed, were represented as median and interquartile range (IQR). Table 3.3 below describes the data analysis done in relation to study objectives.

Table 3.3: Statistical analysis of the data obtained from the study:

Objective	Types of Data	Data Source	Descriptive Statistics Used	Test type (purpose)	Statistical Test
To determine the prevalence of BPD	Ratio (not normally distributed)	•Self-Evaluation of Breathing Questionnaire (SEBQ) •Upper Chest wall expansion (CE)	•Median •Interquartile ranges	Presentation of prevalence	Described as percentages of the total population of the sample group used
	Ratio (normally distributed)	•Nijmegen Questionnaire (NQ) •Lower Chest wall expansion (CE) • Breath Hold time (BHT)	•Mean •Standard Deviation	Presentation of prevalence	As above

To determine the work and health-related demographics	Nominal	•Gender •Type of surgery •Previous diagnosis of depression •Post-operative complications •Whether the participant returned to work •Type of work	•Frequencies	Presentation of prevalence	As above
	Ratio (not normally distributed)	•Age •BMI •Pain levels during deep breathing and coughing (VAS) •Length of hospital stay •RTWT	•Median •Interquartile ranges		
	Ordinal	•Level of education •Income bracket	•Frequencies		
To determine the physical activity level	Ratio (not normally distributed)	Physical Activity Vital Sign (PAVS)	•Median •Interquartile ranges	Presentation of prevalence	As above
To determine the association and predictive relationship between the	•Ratio and •Ordinal	All data sources listed above		Correlation and regression tests	•Spearman's rho •Stepwise regression analyses

work and health related demographics, physical activity level and prevalence of BPD				(as able) with nominal data excluded for correlation tests	•Univariate logistic regression analyses

Determining strength of correlation is described underneath statistical analysis of the results of the pilot study.

The results of the main study are presented in chapter 4.

CHAPTER 4

4. RESULTS

4.1. INTRODUCTION

This chapter contains the results of the cross-sectional observational study. The results are presented in accordance with the objectives stated in chapter one of this research report. Therefore, the results will be presented under the following headings:

•Objective 1: Prevalence of BPD
•Objective 2: Work and health-related demographic profiles
•Objective 3: Profile of physical activity level
•Objective 4: Association and predictive qualities for BPD

Figure 4.1 represents a flow diagram of the number of participants reviewed for the study as well as the participation outcome.

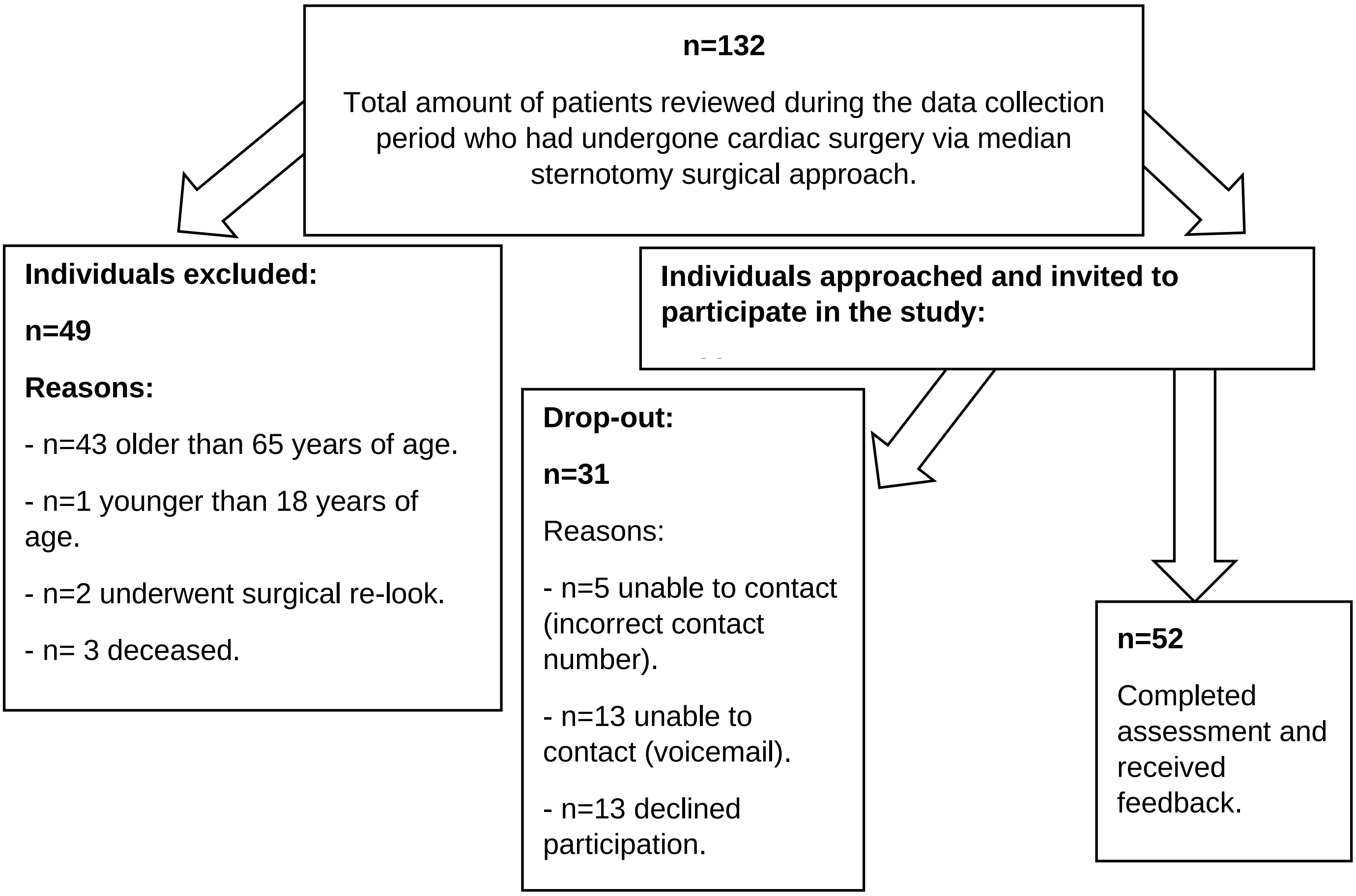

Figure 4.1: A flow diagram illustrating the number of participants reviewed for the study from recruitment to completion and feedback.

Within the total study population of 52 participants, the median (IQR) period assessed post-discharge from the hospital was 158,00 (130,00) days or 5,19 months. The earliest and latest periods of time assessed post discharge from the hospital was found to be 92 (3,03 months) and 363 (11,94 months) days respectively.

Since there was an under estimation of the number of patients who had received cardiac surgery via median sternotomy surgical approach who were over the age of 65 years, the anticipated sample size reduced significantly. Additionally, two of the three original cardiothoracic surgeons performing cardiac surgery via median sternotomy surgical approach left the hospital during the data collection period. This further affected the total number of participants and thus a longer than anticipated data collection period took place (one year instead of seven months). After a years' worth of data collection, a statistician was consulted to determine if effect sizes were adequate. Using a one sample-test (Cohen's d), the effect sizes of the main dependent variables (BHT, NQ, SEBQ, Upper CE and Lower CE) were determined to be adequate by the statistician.

Table 4.1: Effect sizes of the main dependent variables relating to BPD in the study.

BPD outcome measure	**Effect Size (Cohen's D)**
NQ	0,57
SEBQ	0,92
Upper CE	0,92
Lower CE	1,76
BHT	0,66

BHT (Breath Hold Time), BPD (Breathing Pattern Dysfunction), CE (Chest expansion), NQ (Nijmegen Questionnaire), SEBQ (Self-Evaluation of breathing Questionnaire)

Utilizing the lowest effect size (that being from the NQ), it was determined through a G Power calculator, that a sample size of 52 participants would yield a power of 0,98 with an alpha (α) value of 0,05. Literature reports that an α of 0,05 is the standard value used in research (Miller & Ulrich, 2019; Serdar et al., 2021) while a power of at least 0,80 is acceptable in clinical studies (Serdar et al., 2021).

4.2. OBJECTIVE 1: PREVALENCE OF BPD

Within this study population 1,90% (n=1) scored positive on only one of the above tests while 19,20% (n=10) and 51,90% (n=27) scored positive for two and three of these tests respectively. Furthermore, 17,30% (n=9) and 9,60% (n=5) of the population scored positive for four and five of these tests respectively. Table 4.2 reveals statistics specific to the individual outcome measures relating to BPD.

Table 4.2: Breathing Pattern Dysfunction Outcomes:

Outcome Measure	Minimum Score	Maximum Score	% Participants who Scored Positive (n)	Mean (±SD)/Median (IQR) score
NQ	0,00	41,00	38,46 (20)	16,98 (±9,76).
SEBQ	0,00	58,00	15,38 (8)	10,00 (12,00)
Upper CE (cm)	1,00	10,50	86,54 (45)	3,17 (2,67).
Lower CE (cm)	0,67	8,00	98,08 (51)	3,76 (±1,83)
BHT (sec)	10,19	38,30	73,08(38)	21,60 (±5,94)

BHT (Breath Hold Time), BPD (Breathing Pattern Dysfunction), CE (Chest expansion), NQ (Nijmegen Questionnaire), SEBQ (Self-Evaluation of breathing Questionnaire)

Section 4.3 will provide information on the work and health related demographic profile of the study participants.

4.3. OBJECTIVE 2: WORK AND HEALTH-RELATED DEMOGRAPHIC PROFILE

4.3.1. General work and health demographics

According to the table 4.3 below, there was a higher proportion of male participants. Additionally, most participants presented with an elevated BMI which is classified in the overweight category (World Health Organization, 2005). In terms of level of education, most participants had obtained a university or Technical and Vocational Education and Training (TVET) qualification while the majority were categorized in the lowest income bracket.

Table 4.3: Work and health-related demographics of the study population (n=52)

Demographic	Frequencies n (%)	Minimum Value	Maximum Value	Median (IQR) value
Age (years)	N/A	18 ,00	65,00	57,00 (14,00)
Gender (female)	21 (40,40)	N/A	N/A	N/A
Gender (male)	31 (59,60)			
BMI (kg/m²)	N/A	21,00	50,40	28,90 (6,60)
Depression (present)	6 (11,50)	N/A	N/A	N/A
Depression (absent)	46 (88,50)	N/A	N/A	N/A
Level of Education (lower secondary)	4 (7,70)	N/A	N/A	N/A

Level of Education (matric)	16 (30,80)	N/A	N/A	N/A
Level of Education (university or TVET)	32 (61,50)	N/A	N/A	N/A
Income bracket (R0-R54 344)	16 (30,80)	N/A	N/A	N/A
Income bracket (R54 345-R151 727)	4 (7,70)	N/A	N/A	N/A
Income bracket (R151 728-R363 930)	11 (21,20)	N/A	N/A	N/A
Income bracket (R363 931-R631 120)	9 (17,30)	N/A	N/A	N/A
Income bracket (R631 121-R863 906)	6 (11,50)	N/A	N/A	N/A
Income bracket (R863 907-R1 329 844)	4 (7,70)	N/A	N/A	N/A
Income bracket (R1 329 845+)	2 (3,80)	N/A	N/A	N/A
Return to work rate	32 (61,50)	N/A	N/A	N/A
RTWT (weeks)	N/A	1,00	20,00	6 ,00 (4,00)

BMI (Body Mass Index), N/A (Not Applicable), RTWT (Return to Work Time), TVET (Technical and Vocational Education and Training)

4.3.2. Type of surgery

In terms of type of surgery, 51,90% (n=27) underwent a CABG, 32,70% (n=17) underwent valve replacement surgery,1,90% (n=1) underwent a combination of valve replacement and CABG while 13,50% (n=7) underwent surgery considered as “other”. The “other” category consisted of individuals who had removal of cardiac thymus tumors and atrial septal defect repairs. Figure 4.2 is a visual representation of the type of surgeries which required a median sternotomy surgical approach:

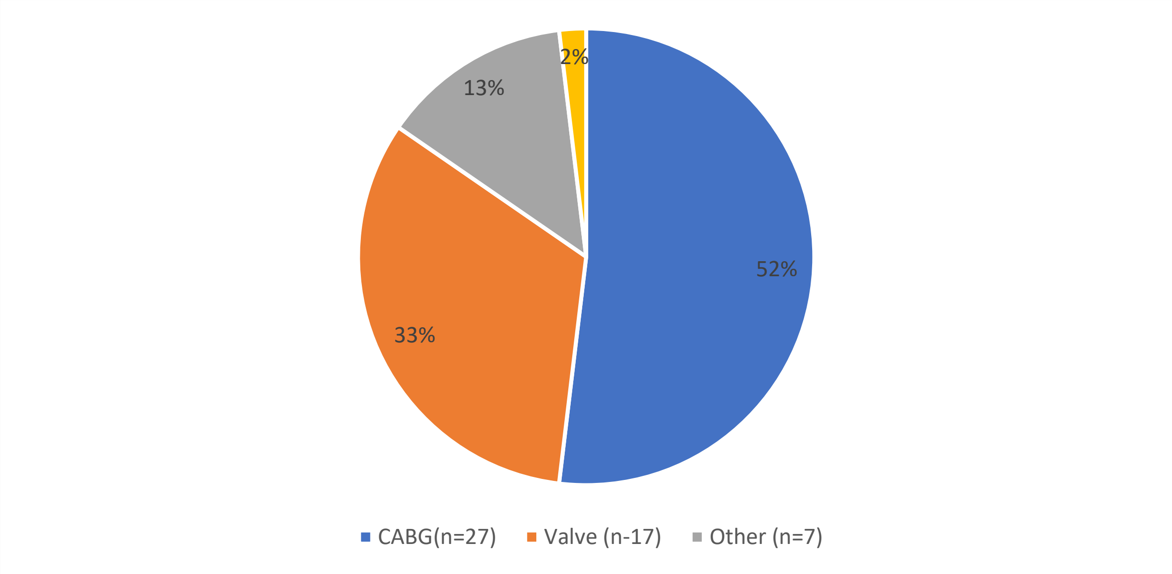

Figure 4.2: A pie chart illustrating the type of surgery requiring a median sternotomy surgical approach (n=52).

4.3.3. Length of hospital stay.

The median length (IQR) of hospital stay for this study population was 7,00 (8,00) days. The minimum length of hospital stay among this study population was 3,00 days, while the maximum length identified was 56,00 days.

4.3.4. Complications

In terms of complications, 55,80% (n=29) of the study population stated that they did not experience any complications following surgery while 44,20% (n=23) stated that they had acquired complications during their hospital stay.

Complications were generalized into five groups which included cardiac, pulmonary, anemia, sternal wound infection, and others. The “other” category revealed small incidences of dialysis requirement, postural changes (increased thoracic kyphosis), delirium, electrolyte disturbances, infection of an arm, sepsis, and stroke. Of those who experienced complications, 30,40% (n=7) experienced complications designated to the “other” category, while 26,10% (n=6) experienced pulmonary complications, 21,70% (n=5) experienced cardiac complications, 8,70% (n=2) experienced anaemia while 13,00% (n=3) contracted a sternal wound infection.

4.3.5. Pain levels

Utilizing the VAS, the median (IQR) pain experienced by participants during deep breathing was found to be 1,00 (5,00) while the median pain level experienced during coughing was 1,50 (5,00). Most participants no longer experienced pain when performing deep breathing or coughing during their recovery period after hospital discharge. Table 4.4 represents the VAS pain scores of participants during coughing and deep breathing.

Table 4.4: VAS Pain Scores of study participants during coughing and deep breathing (n=52)

Score	During coughing n (%)	During deep breathing n (%)
0	22 (42,30)	25 (48,10)
1	4 (7,70)	7 (13,50)
2	1 (1,90)	1 (1,90)
3	4 (7,70)	3 (5,80)
4	3 (5,80)	1 (1,90)
5	7 (13,50)	6 (11,50)
6	4 (7,70)	4 (7.70)
7	0 (0,00)	4 (7,70)
8	4 (7,70)	0 (0,00)
9	2 (3,80)	1 (1,90)
10	1 (1,90)	0 (0,00)
Total	52 (100)	52 (100)

4.3.6. Work-related demographics

Table 4.5 provides information on the occupation types of study participants:

Table 4.5: Occupation types of the study population (n=52).

Occupation Type	Frequencies n (%)
Unemployed/Retired	12 (23,10)
Administration	9 (17,30)
Health Care	4 (7,70)
Agriculture and mining	5 (9,60)
Law Enforcement	5 (9,60)
Manufacturing	5 (9,60)
Sales	4 (7,70)
Education	6 (11,50)
Hospitality	2 (3,80)
Total	52 (100)

In terms of work requirements, of those still involved in the workforce, 42,50% (n=17) stated that their job required mostly sitting, 17,50% (n=7) stated that their job required mostly

physical work while 40,00% (n=16) stated that their job required a mixture of standing and sitting.
Section 4.4 will provide information on the physical activity level of study participants.

4.4. OBJECTIVE 3: PROFILE OF PHYSICAL ACTIVITY LEVEL

Utilising the PAVS as an outcome measure, 88,46%(n=46) of participants stated that they partook in weekly aerobic exercise with a median (IQR) duration of 140,00 (228,00) minutes per week. The minimum duration of weekly aerobic exercise in the study group was 10,00 minutes while the maximum duration was 2100,00 minutes.

In terms of strength training only 21,15% (n=11) stated that they partook in strength training with a median (IQR) of 3,00 (3,00) days per week. The minimum number of weekly strength training days done by this population group was 1,00 and the maximum was 6.,00.

Section 4.5 will provide information on the association and predictive value of the dependent variables on BPD outcomes.

4.5. OBJECTIVE 4: ASSOCIATION AND PREDICTIVE QUALITIES OF THE INDEPENDENT VARIABLES ON THE PREVALENCE OF BPD

4.5.1. Correlation tests

In terms of correlation tests chosen, a Spearman's rank-order correlation test was done as most of the data being compared was not normally distributed.

4.5.1.1. Age and BPD.

Table 4.6: Spearman's correlations between age and BPD dimensions.

Outcome measure	Correlation Coefficient	p-Value
Upper CE	0,06	0,67
Lower CE	0,18	0,19
BHT	0,02	0,90
NQ	-0,25	0,08
SEBQ	-0,32	**0,02***

BHT (Breath Hold Time), CE (Chest expansion), NQ (Nijmegen Questionnaire), SEBQ (Self-Evaluation of breathing Questionnaire) ***Statistically significant (p<0,05)**

A weak negative correlation existed between age and NQ and between age and SEBQ (which was statistically significant). These results can be interpreted as older individuals had lower NQ and SEBQ scores.

4.5.1.2. Level of education and BPD.

Table 4.7: Spearman's correlations between level of education and BPD dimensions.

Outcome measure	**Correlation Coefficient**	**p-Value**
Upper CE	-0,02	0,88
Lower CE	0,06	0,69
BHT	-0,14	0,33
NQ	0,01	0,94
SEBQ	0,05	0,73

BHT (Breath Hold Time), CE (Chest expansion), NQ (Nijmegen Questionnaire), SEBQ (Self-Evaluation of breathing Questionnaire)

There were negligible correlations between level of education and BPD dimensions as highlighted in table 4.7 above. None of these results were statistically significant.

4.5.1.3. Income bracket and BPD.

Table 4.8 Spearman's correlations between income bracket and BPD dimensions.

Outcome measure	**Correlation Coefficient**	**p-Value**
Upper CE	0,05	0,73
Lower CE	-0,03	0,81
BHT	< -0,01	0,99
NQ	0,05	0,74

SEBQ	0,19	0,19

BHT (Breath Hold Time), CE (Chest expansion), NQ (Nijmegen Questionnaire), SEBQ (Self-Evaluation of breathing Questionnaire)

There were negligible correlations between income bracket and BPD dimensions. None of these results were statistically significant.

4.5.1.4. Return to work and BPD.

Table 4.9: Spearman's correlations between return-to-work time and BPD dimensions**.**

Outcome measure	**Correlation Coefficient**	**p-Value**
Upper CE	0,23	0,11
Lower CE	0,09	0,52
BHT	-0,02	0,92
NQ	-0,11	0,42
SEBQ	-0,08	0,60

BHT (Breath Hold Time), CE (Chest expansion), NQ (Nijmegen Questionnaire), SEBQ (Self-Evaluation of breathing Questionnaire)

There were negligible correlations between return-to-work time and BPD dimensions as highlighted in table 4.9 above. None of these results were statistically significant.

4.5.1.5. Body Mass Index and BPD.

Table 4.10: Spearman's correlations between BMI and BPD dimensions.

Outcome measure	**Correlation Coefficient**	**p-Value**
Upper CE	-0,06	0,69
Lower CE	-0,15	0,28
BHT	-0,17	0,22
NQ	-0,07	0,64

SEBQ	-0,11	0,46

BHT (Breath Hold Time), CE (Chest expansion), NQ (Nijmegen Questionnaire), SEBQ (Self-Evaluation of breathing Questionnaire)

A negligible negative correlation existed between BMI and upper and lower CE, BHT, NQ and SEBQ. Furthermore, the results were not statistically significant.

4.5.1.6. Length of hospital stay and BPD.

Table 4.11: Spearman's correlations between length of hospital stay and BPD dimensions.

Outcome measure	**Correlation Coefficient**	**p-Value**
Upper CE	-0,25	0,08
Lower CE	-0,30	**0,03***
BHT	-0,13	0,36
NQ	0,01	0,94
SEBQ	0,19	0,19

BHT (Breath Hold Time), CE (Chest expansion), NQ (Nijmegen Questionnaire), SEBQ (Self-Evaluation of breathing Questionnaire)

***Statistically significant (p<0,05)**

There was a weak negative correlation between length of hospital stay and lower CE (which was statistically significant). The results can be interpreted as, as the length of hospital stay increases, the long-term measure of lower CE decreases.

4.5.1.7. Pain levels and BPD.

Table 4.12 Spearman's correlations between pain levels and BPD dimensions.

Outcome measure	**During deep breathing**		**During coughing**	
	Correlation Coefficient	**p-Value**	**Correlation coefficient**	**p-Value**
Upper CE	0,08	0,56	0,07	0,65
Lower CE	0,04	0,80	0,05	0,72

BHT	0,13	0,35	0,09	0,55
NQ	0,17	0,24	0,17	0,24
SEBQ	0,17	0,24	0,06	0,67

BHT (Breath Hold Time), CE (Chest expansion), NQ (Nijmegen Questionnaire), SEBQ (Self-Evaluation of breathing Questionnaire)

There were negligible correlations between pain levels and BPD dimensions as highlighted in table 4.12 above. None of these results were statistically significant.

4.5.1.8. Physical activity level and BPD.

Table 4.13: Spearman's correlations physical activity vital sign (PAVS) and BPD dimensions.

Outcome measure	**PAVS (aerobic)**		**PAVS (strength)**	
	Correlation Coefficient	**p-Value**	**Correlation coefficient**	**p-Value**
Upper CE	0,33	**0,02***	0,12	0,39
Lower CE	0,39	**<0,01***	0,16	0,26
BHT	0,29	**0,04***	0,18	0,21
NQ	-0,24	0,08	0,04	0,79
SEBQ	-0,30	**0,03***	0,01	0,93

BHT (Breath Hold Time), CE (Chest expansion), NQ (Nijmegen Questionnaire), SEBQ (Self-Evaluation of breathing Questionnaire)

***Statistically significant (p<0,05)**

There were weak positive correlations between PAVS aerobic scores and upper CE, lower CE and BHT (the results were statistically significant). This means that as the duration of weekly aerobic exercise increased, measurements concerning upper CE, lower CE and BHT increased as well.

There was a weak negative correlation between PAVS aerobic scores and SEBQ scores which was statistically significant. Therefore, as the duration of weekly aerobic exercise increased, SEBQ total scores decreased.

There were negligible correlations between PAVS (strength) and BPD dimensions. None of these results were statistically significant.

4.5.2. Prediction value of independent variables

A stepwise regression analysis was performed due to the large number of independent variables to establish the significance of interaction (Helmreich, 2016). Additionally, outliers as well as multicollinearity was taken into consideration. Table 4.14 below shows the outcome in relation to the p-value. A p-value of <0,05 indicates statistical significance which was in keeping with the statistical alpha value.

Table 4.14: Significance of interaction between the independent variables and the dimensions of BPD.

Predictor	**Psychophysiological (p-value)**	**Biomechanical (p-value)**	**Biochemical (p-value)**
Age	0,20	0,92	0,32
Gender	**0,01***	0,86	0,68
BMI	0,08	0,61	0,48
Presence of depression	0,44	1,00	0,19
Surgery type:			
CABG	0,17	0,91	0,87
Valve	0,43	0,21	0,35
Other	**0,01***	0,05	0,43
Mixed	1,00	1,00	1,00
Length of hospital stay	0,85	0,17	0,83

Complications:			
Pulmonary	0,29	0,93	1,00
Cardiac	**0,04***	1,00	0,10
Anemia	1,00	1,00	0,47
Sternal wound infection	0,20	1,00	1,00
Other	0,89	0,93	0,92
Absence of complications	**0,02***	0,25	0,90
Pain coughing	0,38	0,18	0,70
Pain deep breathing	Redundant (variance inflation factor>10)		
Return to work rate	0,08	0,95	**0,03***
Return to work time	0,07	0,88	0,52
Type of occupation:			
Retired/unemployed.	0,62	0,45	0,05
Administration	0,48	0,65	0,59
Health care	0,40	0,59	1,00
Agriculture and mining	0,59	1,00	0,49
Law enforcement	0,64	1,00	0,72
Manufacturing	0,64	0,13	1,00
Sales	1,00	0,59	0,30
Education	0,89	0,93	0,55
hospitality	1,00	1,00	1,00
Type of work			
Mostly sitting (desk-job)	0,08	0,21	0,70
Mostly physical	0,46	0,05	0,92
A mixture of both sitting and physical activity	0,07	0,66	0,13

Level of education			
Lower secondary education (grade 9)	0,80	0,08	0,93
National Senior Certificate (matric)	0,49	0,25	0,08
Higher education (university or TVET)	0,60	0,95	0,10
Income bracket			
R0-R54 344	0,61	1,00	0,73
R54 345-R151 727	0,55	1,00	1,00
R151 728-R363 930	0,91	1,00	0,53
R363 931-R631120	0,66	1,00	0,44
R631 121-R863 906	1,00	1,00	0,68
R863 907-R1329 844	0,55	1,00	1,00
R1 329 845+	0,56	1,00	1,00
PAVS aerobic	**0,02***	0,32	0,27
PAVS strength	0,23	0,48	0,12

BMI (Body Mass Index), PAVS (Physical Activity Vital Sign), TVET (Technical Vocational and Education Training)

***Statistically significant (p<0,05)**

According to table 4.14. the psychophysiological dimension had the most statistically significant interactions with the independent variables, that being; gender, "other" type surgery, cardiac complications, the absence of complications as well PAVS aerobic scores.

The biomechanical dimension of BPD had no significant interactions with the independent variables. This could be since the majority of participants scored positive for this dimension of BPD as the median and mean scores for both upper and lower CE were below population norms.

The biochemical dimension of BPD had significant interactions with return-to-work rate.

Following stepwise regression, univariate logistic regression analyses were done to establish the logistic regression coefficient (B), Wald test (Wald x^2) and odds ratio for each of the statistically significant predictors.

Table 4.15 Logistic regression analyses showing the interaction between the independent variables and the psychophysiological dimension of BPD.

Predictor	**B**	**Wald X^2**	**p**	**Odds ratio**
Gender	-1,74	7,08	0,01	0,18
"Other" surgery	3,05	7,16	0,01	21,00
Cardiac complications	2,46	4,43	0,04	11,67
Absence of complications	-1,48	5,28	0,02	0,23
PAVS (aerobic)	-0,01	5,37	0,02	0,99

PAVS (Physical Activity Vital Sign)

According to table 4.15, males were 0,18 times less likely to develop a BPD in the psychophysiological dimension. Therefore, being identified as male gender reduced the odds of developing a BPD in the psychophysiological dimension by 82% ((0,18-1)*100=82%).

Participants who underwent the surgery classified as "other" were 21 times more likely to score positive in the psychophysiological dimension of BPD than participants who underwent CABG, valve or mixed CABG and valve surgery.

Participants who acquired cardiac complications were 11,67 times more likely to score positive in the psychophysiological dimension of BPD than participants who did not acquire complications or acquired other non-cardiac related complications.

Additionally, and importantly, the absence of complications reduced the likelihood of scoring positive on the psychophysiological dimension of BPD by a factor of 0,23. Therefore, the absence of post-operative complications reduced the risk of developing a BPD in the psychophysiological dimension by 77%((0,23-1)*100=77%).The presence of a complication (cardiac complication) had a much larger predictive relationship to development of a BPD than the absence of such a complication.

Aerobic exercise reduced the likelihood of developing a psychophysiological dimension of BPD by 0,99 times. Therefore, for every minute a patient partook in weekly aerobic exercise, the odds of developing a BPD in the psychophysiological dimension decreased by 1% ((0,99-1) *100=1%).

Table 4.16: A table representing the logistic regression analyses showing the interaction between independent variables and the biochemical dimension of BPD.

Predictor	**B**	**Wald X^2**	**p**	**Odds ratio**
Return to work rate	1,49	5,03	0,03	4,42

Interestingly, participants who returned to work were 4,42 times more likely to score positive for biochemical dimension of BPD than those who had not.

Chapter 5 will present the discussion chapter of this research report.

CHAPTER 5

5. DISCUSSION

5.1. INTRODUCTION

As identified in previous chapters, there is currently no literature on whether a long-term BPD exists amongst patients who underwent cardiac surgery via median sternotomy surgical approach. Furthermore, no studies have established how the multidimensional context of BPD (namely biochemical, biomechanical, and psychophysiological) may influence, or be influenced, by work and health related demographics. Also, there are no established risk factors predisposing patients to development of a long-term BPD in this population group.

The main finding of this study was that all participants scored positive in at least one of the outcome measures relating to BPD testing with the majority scoring positive in at least three outcome measures. Considering that the median period assessed post-discharge from the hospital was approximately five months, a median return to work time of six weeks for this study population shows that the majority of participants commenced reintegration into the workplace with an unresolved BPD. The median assessment time of 5 months is longer than that seen in studies by Westerdahl et al, (2003) and Kristjánsdóttir et al. (2004) with a follow-up of four- and three-months post discharge from hospital respectively. The median assessment period in the current study was also shorter than that seen in a more recent study by Westerdahl et al. (2016) which included a one-year follow-up. It is also important to mention that unlike the current study, the previous mention studies (Westerdahl et al, (2003), Kristjánsdóttir et al. (2004) ,Westerdahl et al. (2016)) were longitudinal studies and thus had more regular time intervals and could thus relate better to how dependent variables change over time.
In this chapter, the results of the current study will be compared to previously published literature to broaden understanding of the presence of long-term BPD amongst patients who underwent cardiac surgery via median sternotomy surgical approach.

The discussion will be presented under the following previously mentioned objectives:

•Objective 1: Prevalence of BPD

•Objective 2: Work and health-related demographic profiles

•Objective 2: Profile of physical activity level

5.2. OBJECTIVE 1: PREVALENCE OF BPD

5.2.1. Nijmegen Questionnaire

In this study population, 38,46%(n=20) of participants presented with a score of 20 or higher and thus scored positive for BPD in this test. Of the total population, the mean (SD) score was 16,98 (±9,76). The prevalence in the current study was higher than that seen amongst 162 Greek patients with stable to moderate asthma (34%) however, the authors used a cut-off score of 17 instead of 20 and the sample size was much larger. Furthermore, it has not been established in the past whether patients who have undergone cardiac surgery via median sternotomy are more prone to develop hyperventilation syndromes over other types of BPD even though hyperventilation syndrome is the most common form of BPD (Courtney, Greenwood, et al., 2011). It should be further noted that even though a cut-off score of 20 or more is generally used, not all populations have the same cut-off scores for the NQ (Azizmohammad Looha et al., 2020) and further research might need to be taken to establish a more accurate cut-off amongst patients who have undergone cardiac surgery via median sternotomy surgical approach (Van Dixhoorn & Folgering, 2015). The prevalence in the current study is however higher than that seen in a study population consisting of 215 university-going students (6-10%) where a mean score was found to be 29,32 (±6,59) amongst the hyperventilation group and 11,42 (±6,14) amongst the non-hyperventilation group utilising a cut-off score of 20 or more (Azizmohammad Looha et al., 2020).

5.2.2. Self-Evaluation of Breathing Questionnaire

With the SEBQ, 15,38% (n=8) of participants presented with a score of 25 or more and therefore scored positive for this test. Of the total population, the median (IQR) score was 10,00 (12,00). The scores of this current study were lower than those seen in an observational study by Mitchell et al., (2016) aimed at determining the reliability of the SEBQ amongst a population of 180 adult participants utilizing online services for study recruitment. The authors found an overall mean score of 15,5 and a mean score of 15,4 amongst those suffering from cardiovascular disease. Furthermore, they compared their overall higher mean scores to another study by Courtney & Greenwood, (2009) which had a mean SEBQ score of 13,4 reasoning that more female participants (74%) were present in their study as females score higher on average. This could explain the low score in the current study with a female prevalence of only 40,40%. Another study by Courtney et al., (2011) done on 83 patients attending general practices and complimentary medicine clinics for a variety of mild medical problems, found a mean score of 12 amongst patients who had normal spirometry values and a mean score of 16 amongst patients who had abnormal spirometry values. This average value is closer to the median value seen in the current study. The authors further attributed their outcome to the fact that the chosen population only presented with signs and symptoms of mild BPD. Furthermore, the actual relationship between the experience of BPD and the breathing pattern itself is not linear. This again highlights the self-reporting nature of the psychophysiological component of BPD (Sharma & Goodwin, 2006; Wang et al., 2014).

5.2.3. Chest Expansion

In this study population 86,54% (n=45) scored below the normal value of 5,6-6,4cm for upper CE with the median (IQR) score being 3,17 cm. Additionally 98,08% (n=51) scored below the normal value of 7-7,5cm for lower CE with the mean (SD) score being 3,76cm.

Various studies such as that done by Gissing, (2020) describe the acute decrease in chest wall expansion measures pre- to post-operatively. The author (Gissing, 2020) showed a significant decrease in median values for upper CE from 104,51cm (12.9) to 102,51cm (12) and a decrease in mean values for lower CE from 100,03cm (±12,04) to 98,70cm (±12,07) when measuring total chest circumference. Another study by de Sousa et al., (2016) reinforced these findings indicating altered chest expansion measures within 24-48 post cardiac surgery however the results were based on subjective observation instead of objective measures. Gissing, (2020) reasoned that these findings in the acute phase post-operatively can be attributed to trauma inflected on the ribs and the joints of the thoracic cage in the presence of pain and reduced respiratory muscle strength. There are, however, scarce resources regarding the long-term outcome of chest expansion measures following cardiac surgery via median sternotomy surgical approach.

Even though chest expansion itself was not measured, a study by Westerdahl et al., (2003), with a follow-up of four months post CABG via median sternotomy, showed a significant reduction on pulmonary function with a deficit of 6-13% of pre-operative values. The authors utilized a Medical Graphis PF/DX Pulmonary Function system to measure VC, RV, IC, FEV1, PEF, FRC and TLC. The results seen in a later study by Westerdahl et al., (2016), done on 164 patients one year following cardiac surgery via median sternotomy surgical approach showed that, even at a longer period post-operatively, lung function measures including VC, FEV1, FVC, FEV1/FVC PEF and FRC were significantly reduced (2-5%).

The authors in both of the above studies suggested that the cause for the dysfunction was related to reduced thoracic cage expansion due to alterations in the tissues following opening of the thorax. Additionally, particularly in the study by Westerdahl et al., (2003), instead of a reduction as with the other measures of lung function, residual volume (RV) showed an increase in relation to other measures. The authors hypothesized that due to airway closure and airflow limitations post-operatively, there is incomplete emptying of air during exhalation. (Shapira et al., 1990; Westerdahl et al., 2003).

This maintenance or increase in RV is similar to that seen in patients with COPD where excessive trapping of air leads to lung hyperinflation (Lofrese et al., 2021). This splinting of the airways leads to loss of full range of motion of the joints of the thoracic cage during breathing which affects the length-tension relationship of the respiratory muscles reducing power and mobility. This results in a reduction in chest expansion measures (Leelarungrayub, 2012; Rehman et al., 2020). The difference in patients with COPD is that the obstruction is caused by changes in lung tissue as a result of chronic inflammation (Lofrese et al., 2021) whereas obstruction in the case of post median sternotomy is caused by surgical trauma afflicted onto the chest wall (Urell et al., 2012).

5.2.4. Breath Hold Time

In this study population 73,08% (n=38) scored below the normal value of at least 25 seconds. The mean (SD) score for this population was 21,60 (±5,94). The results were worse than that seen in a general population of individuals with concerns about their breathing where 41% scored below 20 seconds (Courtney, Greenwood, et al., 2011). Kiesel et al., (2017) in their convenience sample of 51 participants in a general population, had similar results to that of Courtney et al., (2011) with 42% (n=21,4) scoring below 25 seconds.

Comparison with previous literature was challenging as there was no past research available to compare BHT values amongst the same population group (patients who underwent cardiac surgery via median sternotomy surgical approach). Furthermore, no particular cut-off value has been established for this population group. Additionally, different methods in performing BHT have been seen in the literature. One such study is that done by Trembach & Zabolotskikh, (2017) to establish the correlation between BHT single-breath carbon dioxide amongst 43 patients with chronic heart failure. The authors found a mean BHT of 44 seconds however the breath hold was at the end of normal inspiration instead of normal expiration as seen in the current study where methodology on how to conduct the BHT was based on that described by Kiesel et al., (2017).

Apart from being an indicator of end tidal carbon dioxide, the BHT additionally is an indicator of functional residual capacity (Kiesel et al., 2017) which, as described by Westerdahl et al., (2016) in their study on 164 patients one year following cardiac surgery via median sternotomy surgical approach, is decreased (2-5%).Therefore, a reduction in functional residual capacity will lead to a reduction in BHT as less volume leads to less oxygen reserve in the lungs (Hopkins & Sharma, 2019) resulting in activation of the hypoxic chemoreflex. This elicits activation of the sympathetic nervous system as well as hyperventilation (Kara et al., 2003; Mansukhani et al., 2015).Therefore, even if previous literature does not describe long-term BHT measures amongst patients who underwent cardiac surgery via median sternotomy surgical approach, other pulmonary function measures suggest a long-term deficit.

5.3. OBJECTIVE 2: WORK AND HEALTH-RELATED DEMOGRAPHIC PROFILE

5.3.1. Age

Age restrictions were implemented to only include the working population (18-65 years) as outcome measures relating to RTWT, type of work and work requirements were used to establish the influence of BPD on these said outcome measures. There were, of course, exceptions as 23,10% of participants stated that they had retired before the age of 65 years or were unemployed. The median age of 57,00 years for the current study was in keeping with the mean age of 60 (± 10.1) years in a retrospective review by Reiche et al., (2021) involving 1218 patients who underwent CABG surgery at a tertiary academic South African hospital from 2000-2017.Furthermore, a longitudinal observational study conducted in Gauteng by Gissing, (2020) also confirmed a similar median age of 59 years.

In terms of the psychophysiological dimension of BPD, age was found to have a weak negative correlation with SEBQ and NQ scores in this current study. Therefore, as age increased, SEBQ and NQ scores decreased. Due to the self-reporting nature of the outcome measures used, the results could be explained by the fact that older persons have decreased sensation relating to dyspnea and reduced ventilatory responses to hypoxia and hypercapnia by 50% and 40% respectively when compared to their younger counterparts (Sharma & Goodwin, 2006; W. Wang et al., 2014). This is further explained by the fact that efferent neural output to respiratory muscles declines with age (Ketata et al., 2012). Therefore, even though a BPD may have been present, an older patient may not be able to perceive or recognize the symptoms which may affect their scoring on these outcome measures.

5.3.2. Gender

Within this current study, there was a slightly higher proportion of male participants (n=31, 59,60%) compared to female participants (n=21,40,40%). This is in keeping with previous studies such as that done by Gissing, (2020) which consisted of 72,1 % of male participants. The author attributed this to the fact that women, due to the protective effect of endogenous estrogens prior to menopause, have a delay in the onset of atherosclerotic disease. This therefore places men at a higher risk of acquiring atherosclerotic disease which requires surgical intervention at a younger age (Hajar, 2017; Maas & Appelman, 2010).

In terms of predictive effect, being identified as male gender reduced the odds of developing a BPD in the psychophysiological dimension by 82%. As stated previously, the NQ is a breathing symptom questionnaire originally created to evaluate hyperventilation syndrome (Van Dixhoorn & Folgering, 2015). Various studies have identified that females are more at risk of developing hyperventilation syndromes in comparison to males (Azizmohammad Looha et al., 2020; Brat et al., 2019). The authors attribute this to the fact that hyperventilation is associated with mental disorders such as mood and anxiety disorders which has a higher prevalence amongst the female population (Azizmohammad Looha et al., 2020; Steel et al., 2014).

5.3.3. Body Mass Index

The median BMI in the current study population was 28,90 (6,60) kg/m² (classified as the overweight range of 25-29,9kg/m² (World Health Organization, 2005)). This is similar to results represented in a study by Gissing, (2020) done on 61 participants who presented with a mean BMI of 27,79 kg/m² which was also classified as overweight. The results are unsurprising, as obesity, along with other associated comorbidities including diabetes and hypertension, is a major risk factor for acquiring cardiovascular disease which subsequently increases risk of the necessity of cardiac surgery (Ghanta et al., 2017).

It is important to note that BMI assessment as an outcome measure does not differentiate between adipose and muscle tissue and is therefore not a sensitive marker (Jeong et al., 2023). Many athletically fit patients present with elevated BMI since muscle tissue is 22% denser than adipose tissue (Walsh et al., 2018). Apart from the athletic population, an observational study by Svartengren et al., (2020) done on a middle-aged and elderly Swedish population, found that in the absence of central obesity, an increase in BMI has a positive correlation with lung function measures (FEV1 and FVC). The authors explained this phenomenon by stating that participants who had an already elevated BMI during childhood had larger lungs and thus higher outcomes on lung function tests.

5.3.4. Depression

It was necessary to establish whether there was a relationship between depression and the prevalence of BPD amongst patients who underwent cardiac surgery via median sternotomy surgical approach since Correa-Rodríguez et al., (2020) established that 15-33% of patients who underwent CABG surgery acquired post-operative depression which may delay RTWT (Mortensen et al., 2021). Additionally, amongst university-going adults (aged 18 to 54 years), Crockett et al., (2016) found a significant correlation between self-reported symptoms of BPD (utilizing the SEBQ) and depression.

In the current study, most participants stated that they had no history of diagnosed depression (88,50%). This is in keeping with the lower margin of prevalence in the systematic review by Correa-Rodríguez et al.,(2020).The authors determined that depression could either be an underlying condition which increases risk of acquiring cardiovascular disease due to its influence on habits of lifestyle, or it could be a consequence of numerous post-operative complications which can involve a prolonged hospital stay (Elliott et al., 2010; Poole et al., 2014).

The results of the current study should be taken with caution as many participants who may be demonstrating signs and symptoms of depression may not have been diagnosed with depression by a health care professional. A study by Tilahune et al., (2016) on the prevalence of undiagnosed depression amongst 326 patients attending a medical outpatient department at a hospital in Nairobi found that 24,5% of participants displayed significant symptoms of depression which was not detected initially by a clinician.

In the context of BPD, Crockett et al., (2016) established in their observational study on 78 undergraduate and postgraduate students that, although depression had a significant correlation with the self-reporting measures of BPD (SEBQ), there were negligible correlations between depression and rater-observed measures of BPD which was similar to results seen in the current study. Therefore, the presence of depression may only influence the psychophysiological dimension of BPD and not the biomechanical or biochemical dimensions.

5.3.5. Type of surgery

Most participants underwent CABG surgery (51,90%, n=27), followed by valve replacement surgery (32,70%, n=17). The findings are similar to those shown by Gissing, (2020), which revealed that most patients underwent CABG surgery (35%, n=57) followed by valve replacements (23%, n=15).

The results in the above studies contradict those produced in a study by the Chris Barnard division of Cardiothoracic Surgery which demonstrated a higher rate of valve replacement surgeries (43%) compared to CABG surgeries (34%) (University of Cape Town, 2014). This, however, must be taken with caution as this study is at least six years older.

Both the current study and that done by Gissing, (2020) are explained by Reiche et al., (2021) who stated that coronary artery disease is rapidly increasing in prevalence amongst middle- and low-income countries such as Sub-Saharan Africa. This can be linked to evolving habits of lifestyle involving a westernized diet, enhanced stress levels and the increased prevalence of smoking (University of Cape Town, 2014). The increase in incidence of coronary artery disease leads to an increase in the utilization of the most preferred surgical intervention for treating the disease; CABG via median sternotomy surgical approach (Gupta & Wood, 2019).

Interestingly, participants who underwent the surgery classified as “other” were 21 times more likely to score positive in the psychophysiological dimension of BPD than participants who underwent a median sternotomy surgical approach for other reasons. Most of the surgical interventions categorised as “other “involved removal of cardiac thymus tumours also known as thymectomies. Patients diagnosed with tumours, particularly if malignant, often suffer from anxiety and depression (Yang et al., 2013). Additionally, thymomas are associated with a 30% risk in development of myasthenia gravis which has been associated with an increased risk of depression (Li et al., 2022). As stated above, hyperventilation syndrome has been shown to be positively correlated with the presence of depression and other mental disorders (Azizmohammad Looha et al., 2020) which leads to an increased likelihood of scoring high on the NQ and SEBQ.

5.3.6. Length of hospital stay.

The median length (IQR) of hospital stay for this study population was seven (8) days. This was similar to a study done by Osnabrugge et al., (2014) where a mean of 6,9 days was seen post-operatively. A more recent study by Gissing (2020) revealed a slightly higher median length of hospital stay of nine (7) days. Additionally, Osnabrugge et al., (2014) found that the main post-operative reasons for increased length of hospital stay included surgical revisions for reasons that were not cardiac in nature, pneumonia, and sternal wound infections.

There was a weak negative correlation between length of hospital stay and lower CE (which was statistically significant) amongst the patient population of the current study. Additionally, of those who experienced post-operative complications, 26,10% experienced pulmonary complications. As described by Mans et al., (2015), pulmonary complications particularly relating to atelectasis and pneumonia can lead to an increase in the overall length of hospital stay. Naveed et al., (2017) further added that the development of post-operative pulmonary complications post CABG surgery is associated with a greater need for blood transfusion, thereby significantly impacting the required ICU and overall hospital length of stay.

Patients who acquire atelectasis and/or pneumonia present with an apical or “shallow” breathing pattern (Boulding et al., 2016; Brashers & Huether, 2019; Z. G. Wang et al., 2019). An apical breathing pattern leads to inadequate diaphragmatic excursion which correlates with lower CE measures (Srijessadarak et al., 2022; Tanrangka et al., 2018). Amongst patients who underwent cardiac surgery via median sternotomy surgical approach, any deficit in lower CE measures, which could have been exacerbated by post-operative pulmonary complications, did not normalize to pre-operative values at 12 months post-operatively (Kristjánsdóttir et al., 2004). This thereby links the long-term deficit in chest expansion with increased hospital length of stay.

5.3.7. Complications

As stated previously by Derakhtanjani et al. (2019), the goal of physiotherapy amongst patients who underwent cardiac surgery via median sternotomy surgical approach is to reduce the incidence of post-operative complications. In doing so, the rate of mortality and morbidity decreases, and the length of hospital stay shortens. The current study had a post-operative complication incidence of 44,20% (n=23) which was lower than that seen in a cohort by Seese et al., (2020) where there was an incidence rate of 56% for isolated complications. It must be noted however that the sample size in the study by Seese et al., (2020) was much larger (9532 patients over a period of seven years).

In terms of post-operative pulmonary complications, the study by Gissing, (2020), through x-ray evaluation at time of discharge from the hospital, revealed an incidence of 32,8% for minor post-operative atelectasis, and 13,1% for medium post-operative atelectasis. Furthermore, the author found an incidence of 42,6% of minor costophrenic angle filling relating to pleural effusions. Lastly, relating to lung volume changes, the author found an incidence of 26,2% of minor changes of hemidiaphragm height and 1,6% of medium changes of hemidiaphragm height. Therefore, when comparing the study by Gissing, (2020) to the current study, there was a much lower incidence of post-operative pulmonary complications in the current study (26,10% n=6). This however cannot be concluded with full certainty since participants may not have been made fully aware of their pulmonary functioning status at discharge from the hospital and thus the prevalence could have been higher than initially stated. Furthermore, in the current study, x-rays were not made available to the researcher at three months to one year post patient discharge from the hospital and thus, prevalence was based primarily on participant reporting. Additionally, due to the fact that assessment of participants was not done in the acute stages post-operatively and therefore a period of time was given to allow for recovery, it would be expected that any follow-up assessments would show improvement in findings compared to those seen in the study by Gissing, (2020)

The incidence of anaemia was low (8,70%, n=2) post-operatively in the current study compared to a retrospective observational study by de Faria et al., (2021) who found an incidence of 42,9% with a further 29,5% requiring blood transfusion. The authors concluded in their study that even though anaemia is an unfavourable outcome post cardiac surgery, the blood transfusion used to treat such a complication is worse due to its association with both long and short-term mortality post-cardiac surgery (Bhaskar et al., 2012; de Faria et al., 2021). As with post-operative pulmonary complications, the results of the current study should be taken with caution as participants may not have been made aware of the fact that they had anaemia especially since they may not have received blood transfusion to correct it as justified by Bhaskar et al., (2012) and de Faria et al., (2021).

Sternal wound infections also had a low prevalence in the current study (13,00%, n=3) compared to previous literature which suggests an incidence of up to 25% in patients presenting with risk factors (Sharif et al., 2019). Such risk factors include a BMI $\geq$30kg/m², peripheral vascular disease, the need for an intra-aortic ballon pump post-operatively, poor left ventricular ejection fraction, COPD, diabetes mellitus and a bilateral internal thoracic artery harvest (Meszaros et al., 2016). Although underlying diseases and the exact surgical technique was not known in the current study, participants did present with elevated BMIs of which the maximum was 50,40 kg/m².

Cardiac complications (21,70%, n=5) which consisted mostly of arrhythmias, are known to be very common complications post cardiac surgery via median sternotomy surgical approach with an incidence of up to 60% amongst patients who undergo valve surgery (Yadava et al., 2016).Peretto et al., (2014) identified that the most common arrhythmia seen is atrial tachyarrhythmia followed by ventricular arrhythmia and bradyarrhythmia.

Participants who acquired cardiac complications were 11,67 times more likely to score positive in the psychophysiological dimension of BPD than participants who did not acquire complications or acquired complications which were non cardiac in nature. This may be explained by the fact that sleep exaggerates BPD (Choudhary & Choudhary, 2009). In normal breathers, diaphragm activity has been shown to increase by a mean of 11% and 34% during non-REM and REM sleep respectively when compared to wakefulness (Coffee, 2006).Patients with chronic hyperventilation syndromes (which would score high on the SEBQ and NQ for psychophysiological dimension of BPD) are at higher risk for developing sleep apnoea due to them being more reliant on accessory muscles of respiration which leads to loss of diaphragm strength (Coffee, 2006a, 2006b). A much later article by Bordoni et al., (2022) reinforced the fact that patients suffering from obstructive sleep apnoea present with reduced diaphragm muscle strength and endurance, but the authors were not sure whether the impairment is due to inadequate recruitment of peripheral nerves at the neuromuscular junction or alteration of diaphragm muscle fibres. Obstructive sleep apnoea is a common cause of atrial fibrillation; however, it has also been linked with development of arrhythmias at the level of the sinus node, both atrial and ventricular arrhythmias and sudden cardiac death (Laćzay & Faulx, 2021). Additionally obstructive sleep apnoea has been shown to alter the structure of the heart leading to development of hypertension, heart failure and even coronary artery disease which can be treated with CABG surgery(Yoshihisa & Takeishi, 2019).

As described above, the presence of complications (especially cardiac) leads to an increase in the risk of acquiring a BPD post-operatively, therefore, it is not surprising that the absence of such complications will reduce the risk of acquiring a BPD by 77%. However, the absence of post-operative complications did not reduce the risk of acquiring a BPD to the same extent as the presence of a complication would increase the risk. This could be due to the fact that BPD can be classified into having a non-pathological cause "primary dysfunctional breathing" or an underlying cardiopulmonary or neurological cause "secondary dysfunctional breathing" (Vidotto et al., 2019).Therefore, even in the absence of complications, participants could still be at risk of development of a BPD with a non-pathological cause.

5.3.8. Pain levels

Utilizing the VAS, the median (IQR) pain experienced by participants during deep breathing was found to be 1,00 (5,00), while the median pain level experienced during coughing was 1,50 (5,00). This was less than that seen in the acute stages (upon discharge from hospital) where the median score was found to be 4 in a local cohort (Gissing, 2020).

The source of acute pain post-operatively has been extensively described in the literature. These sources have included the site of drain insertions, the site of breastbone incisions, referred pain to the thoracic and lumbar spine, pain from endotracheal intubation and pain from intravenous insertion sites to name a few (Gissing, 2020.; Zubrzycki et al., 2018).The origin of pain can involve ligaments, muscles, tendons and bone from retraction of the sternum during surgical injury (Hamid et al., 2015).

Zubrzycki et al., (2018) stated that post-operative pain can persist for up to six months with an occurrence rate of 30-50% amongst patients who underwent cardiac surgery. This current study further adds that it can persist for even longer than six months (up to one year). Additionally, Kocjan et al., (2018) found that incision and retraction of the sternum during surgery damages the sternal attachments of the diaphragm which disrupts the zone of apposition. This can lead to secondary mechanical compensations which can contribute to long-term conditions such generalized lower back pain, sacroiliac joint pain, headaches.

Pain also influences the ability to execute functional tasks, thus it is no surprise that patients post CABG surgery reported difficulty returning to full functioning un activities of daily living due to pain (44%) (El-Ansary et al., 2019; LaPier et al., 2008).This may be one of the reasons for a sub optimal return to work rate (61,50%) in the current study.

Surprisingly, there were negligible correlations between pain levels and BPD dimensions. This is contradictory to the study done by Zubrzycki et al., (2018) who identified that persistent post-operative pain is likely to have a restrictive effect on breathing thus contributing to BPD. Conversely, the findings of this current study coincide with those of a study by Westerdahl et al., (2003),which, however outdated, found that although there was a persistent restrictive breathing pattern seen amongst patients who underwent CABG surgery via median sternotomy surgical approach at four months post discharge from hospital, pain levels did not correlate with the significant reductions in lung function values.

It is important to take note that, although the current study does not show a correlation between pain levels and the presence of BPD, uncontrolled pain in the acute stages post-operatively may predispose patients to long-term BPD. As suggested by Courtney, (2011), perioperative pain can lead to a constant state of sympathetic arousal. The constant sympathetic “fight-or-flight” state can lower pain threshold and contribute to the formation of a BPD (Sueda et al., 2004,Courtney, 2011). Therefore, in the current study, it could be possible that in the acute stage post-operatively, pain control protocols in the hospital were good.

5.3.9. Work related demographics.

Only 61,50% (n=32) of the population stated that they had returned to work. The median (IQR) RTWT was found to be six (4,00) weeks. This was surprisingly sooner than expected as Mortensen et al., (2021), in their scoping review, identified that the average RTWT for patients who underwent CABG or aortic valve replacements via median sternotomy surgical approach was 30 weeks. The authors found that factors which delay RTWT include age, female gender, previous diagnosis of depression, low income, and lower education levels. This partially relates to the current study, as even though the median age for this current study was 57 years and the largest proportion of the study participants fell within the lower income bracket (30,80%, n=16), there was a more equal distribution in terms of female and male gender as compared to other studies (Johnston et al., 2019; Mortensen et al., 2021). Furthermore, most participants had no history of depression (88,50%, n=46) and more than half (61,50%, n=32) had obtained a higher education qualification. It is also important to note that the study by Mortensen et al., (2021) included resources from developed countries such as Sweden and the USA. South Africa is a developing country where there may be a heightened pressure for patients to return to work post-operatively. The results of the current study coincided with those of an Iranian study by Mehrdad et al., (2016), which showed a return-to-work rate amongst patients who underwent CABG surgery to be 45,1% and 87,1% at two months and six months post-operatively, respectively.

Most of the participants in the current study who returned to work stated that their occupations required sitting (42,50%, n=17) or a mixture of sitting and standing (40,00% (n=16). Furthermore, the largest proportion of those who returned to work had a job in the administration sector linked with desk jobs (17,30%, n=9). Therefore, less physically demanding occupations may allow participants to return to work sooner as they do not interfere with sternal precautions that need to be adhered to allow optimal wound healing. Mehrdad et al., (2016) in their observational study to assess predictors of early RTWT on patients who underwent CABG surgery via median sternotomy surgical approach, further justified the results of the current study. They found that not working “blue-collar occupations” was a predictor of earlier return to work time. Furthermore, those working strenuous jobs had a much lower return to work rate (52%) than those working jobs with light physical demands (72%)

Mehrdad et al., (2016) further explained that participants receiving an income below the poverty threshold had returned to work much later. This could explain the suboptimal return to work rate in the current study as a large portion of participants (30,80%, n=16) fell within the lowest income bracket of R0-R54 344 annual income.

Unlike previously hypothesised, there were negligible correlations between RTWT and BPD dimensions. Due to the dual role of the diaphragm for ventilation and postural control, it was thought that any disruption to it can lead to disruptions in postural control (Hodges et al., 2007). This could affect a person’s ability to execute tasks in the workplace environment thereby limiting full reintegration into the workplace (Haddad et al., 2013).That being said, RTWT and return to work rate does not reflect whether the participants have resumed full functioning in the workplace. Although not assessed in this study, it could be possible that a large portion of these participants may be resuming “light duty” work or reduced working hours. In the study by Mehrdad et al., (2016), 64,8% of participants post CABG had a reduction in their working hours upon return to work.

Unlike RTWT, there was a positive predictive relationship between return-to-work rate and the biochemical dimension of BPD as participants who returned to work were 4,42 times more likely to score positive in the biochemical dimension of BPD than those who had not. An infographic released by Profmed in 2021, showed that 26,0% of South African professionals were highly stressed and 11,11% were extremely stressed. These statistics increased in 2022 to show that 31,90% were highly stressed and 12,52% were extremely stressed in accordance with the stress index. Additionally, work, health and finances were shown to be the biggest contributors to stress levels amongst South African professionals (Profmed, 2022). Chronic Hyperventilation (which would show positive on the biochemical dimension of BPD due to low chemosensitivity to carbon dioxide) can be evoked by stressors found in the workplace (Battaglia, 2017; Tipton et al., 2017). Additionally, a study by Almén, (2021) found that hyperventilation syndrome was seen in most patients presenting with clinical burnout relating to workplace stressors. The authors explained that this chronic hyperventilation response can be avoidant in function and used as a protective mechanism to prepare the person for an unpredicted stressor.

5.3.10. Level of education

In this study population, the majority (61,50%, n=32) of participants had obtained a higher education qualification (university or TVET) even though the return-to-work rate was suboptimal. The results are in keeping with those seen in the study by Mehrdad et al., (2016), who found no significant relationship between higher education levels and early RTWT. However, Mortensen et al., (2021), in their scoping review, identified that lower levels of education were associated with a reduction in return-to-work rate and an increase in RTWT due to the likelihood that blue collar workers, whose jobs were more physically demanding, were most likely to have only acquired a standard education up until matric.

5.4. OBJECTIVE 3: PHYSICAL ACTIVITY LEVEL PROFILE

According to the PAVS score, 88,46%(n=46) of participants stated that they partook in weekly aerobic exercise with a median (IQR) duration of 140 (228) minutes per week. The fact that most participants took part in weekly aerobic exercise seems promising, although the duration of such exercise is very variable as the minimum duration of weekly aerobic exercise in the study group was 10 minutes while the maximum duration was 2100 minutes. Ball et al., (2016) suggests that the minimum duration required for moderate intensity exercise for persons over the age of 28 years is 150 minutes per week, therefore a minimum of 10 minutes seen in this current study is not sufficient.

In the case of cardiac surgery, physiotherapeutic exercise and mobilisation, encouraging aerobic training, commences early in the acute stages post-operatively. Da Costa Torres et al., (2016) in their randomised controlled trial of patients who underwent CABG surgery via median sternotomy surgical approach, developed a post-operative mobilisation protocol where it was planned that patients walk for a duration of 20 minutes by day 7. As described by Doyle et al., (2019) in their meta-analysis, aerobic capacity is related to functional capacity, and a deficit thereof has found to negatively impact functional outcomes post-operatively amongst patients who underwent cardiac surgery. Furthermore, early intervention of high frequency aerobic exercise was found to improve cardiac autonomic function (assessed via heart rate variability) (Doyle et al., 2019), increase peak oxygen consumption (Eder et al., 2010), and enhance distance walked during the 6-minute walk test (Pack et al., 2015).

The results of the current study, due to the high variability, indicate the need for further emphasis on a more standardised community or facility based post-operative exercise program which includes submaximal endurance training progressing to combine resistance training done for three times a week for 12 weeks (Abraham et al., 2021). Counselling to ensure health-related lifestyle changes, which include a long-term exercise plan following the 12-week program should also be implemented (Abraham et al., 2021; Giannuzzi et al., 2003). Furthermore, exercise intervention should begin as early as possible as Zheng & Zhang, (2020) found that a pre-operative exercise program including IMT, aerobic exercise, resistance training and stretching has found to reduce length of hospital stay and improve physical function post-operatively.

There was a positive weak correlation between PAVS aerobic scores and upper CE and lower CE. Reddy et al., (2019) in their observational study amongst healthy non-smokers, healthy smokers, and persons with COPD, found that there was a significant positive correlation between upper CE and lower CE with lung function measures such as FVC, FEVI and FEV1/FVC. Numerous studies that have been done on healthy and special groups such as those suffering from asthma have found that moderate intensity aerobic exercise has been shown to improve pulmonary function measures such as PEF, FEV1 and FVC (Rawashdeh & Alnawaiseh, 2018; Wu et al., 2020). The authors reasoned that aerobic exercise causes greater expansion of the lungs to allow a greater volume of air during exercise to cater for the greater demand of oxygen supply and carbon dioxide removal from exercising tissues.

It has been established that chest wall mobility is related to inspiratory and expiratory muscle strength (Okrzymowska et al., 2019). A study by Padkao & Boonla, (2020) done on 76 healthy male and female participants to evaluate the relationship between respiratory muscle strength, CE and aerobic capacity found that maximum inspiratory pressure (MIP) and maximum expiratory pressure (MEP) had significant positive correlations with middle and lower CE measures. They further added that MEP and MIP had significant correlations with aerobic capacity as measured with the 6MWT.The positive effect of aerobic exercise on

respiratory muscle strength was further established in various population groups including those with cystic fibrosis and COPD (Daabis et al., 2017; Dassios et al., 2013).
Padkao & Boonla, (2020) reasoned that contraction of inspiratory muscles generates force that determines the extent of chest wall and lung expansion. Therefore, respiratory muscles strengthened through aerobic exercise enables greater CE (Mauro & Aliverti, 2016).

In terms of BHT and PAVS aerobic scores, there was a weak positive correlation in the current study indicating that individuals who participated in more aerobic activity were more likely able to hold their breath for longer as assessed with the BHT. Thus, participants who had a longer duration of weekly aerobic exercise had greater tolerance to hypercapnia. This was explained by Thomas et al., (2013) where the chronic exposure to elevated blood carbon dioxide levels amongst people who partake in regular aerobic exercise leads to a desensitisation towards the stimulus thus aerobically fit participants could hold their breaths for longer. Interestingly, a pilot study by Ideguchi et al., (2021) to validate the BHT (at 10, 15 and 20 seconds of breath hold) as a measure of exercise tolerance amongst patients with COPD, found a significant correlation between the minimum oxygen saturation ($Sp0_2$) values in the 15 second BHT test and the 6-minute walk test (6MWT). The authors further added that a cut-off $Sp0_2$ value of <94% after the 15 second BHT test optimally predicts a $Sp0_2$<90% during the 6MWT. Thus, the BHT can be added as a screening tool to predict exercise induced hypoxemia and is therefore an indicator of aerobic fitness. A much older study by Barnai et al., (2005) in patients with cystic fibrosis showed similar results in that BHT had a significant correlation with maximal oxygen uptake (VO_2) (submaximal/maximal index of aerobic fitness) therefore reinforcing the findings by Ideguchi et al., (2021).

There was a weak negative (however significant) correlation between PAVS aerobic scores and SEBQ scores. The weak correlation strength is similar to that seen in an observational study by Mitchell et al., (2016) to determine the reliability and determinants of the SEBQ. The authors estimated physical activity level using energy expenditure tables adapted from the validated Life in New Zealand Questionnaire and found very low correlations with the SEBQ. They reasoned that BPD could affect diverse groups of people and lifestyle may play a very little role in its development. They further added that due to the self-reporting nature of the variables there is a low correlation because of under and over interpretation from the participants. In terms of predictive value however, aerobic exercise reduced the likelihood of developing BPD (particularly in the psychophysiological sense) by 0,99 times. As the psychophysiological dimension links the relationship between mental and emotional stressors with breathing (Courtney, 2016), emotions such as fear and anxiety which was explained previously in the literature review concerning battle fatigued soldiers, can trigger development of a BPD due to sympathetic nervous system arousal (Courtney, 2011). A systematic review by Stonerock et al., (2015) found that, although most studies have methodological limitations affecting the overall quality, the majority of the meta-analyses and randomised controlled trials used in the review concluded that exercise is beneficial in treatment of anxiety and depression in conjunction with other medical and pharmacological therapies. This antidepressive effect of exercise can be explained by the release of “happy hormones” which include increase in noradrenergic and serotonergic levels in the brain with endogenous opioid release(Barnaby, 2015).

Only 21,15% (n=11) of the population stated that they partook in strength training with a median (IQR) of 3,00 (3,00) days per week. The minimum number of weekly strength training days done by this population group was one and the maximum was six. According to Cowan, (2016) adults should do muscle strengthening activities that are moderate to high intensity involving all major muscle groups at least two days a week. Therefore, considering the very low percentage of participants who partook in strength training and the fact that the minimum number of days was only one day per week, this is not sufficient.

As stated previously in the literature review, sternal precautions, although necessary are often overly restrictive due to the lack of a universally established list with many suggestions not supported by scientific evidence (Cahalin et al., 2011; Cohen & Griffin, 2002). Furthermore, sternal precautions take priority over exercise which involves the upper limbs and trunk for the first 8-12 weeks post-operatively. Therefore, patients are generally educated on not lifting more than 1kg until callus formation of the sternal wound is seen (American College of Sports Medicine, 2014). This could indicate why such a low percentage of participants in the current study were engaging in resistance exercise activities. There is, however, no evidence to support the fact that sternal precautions promote wound healing and prevent wound closure complications (Balachandran et al., 2016). Pengelly et al., (2019) in their systematic review on resistance exercise amongst patients who underwent a median sternotomy, found that, the combination of aerobic and resistance training from 12 weeks post -operatively showed greater improvement in physical and functional recovery compared to aerobic exercise alone, although the results were not statistically significant. The authors further argued that resistance training, due to its effect on enhancing insulin sensitivity and reducing inflammation, can have beneficial effects on reducing cognitive decline and sarcopenia. Alater study by Pengelly et al., (2022) found that bilateral upper limb cam-machine resistance training (of moderate resistance) performed as early as two weeks post-operatively did not disrupt sternal healing or resulted in increased pain.

CHAPTER 6

6. CONCLUSIONS, RECOMMENDATIONS AND LIMITATIONS

6.1. CONCLUSION

The aim of this study was to establish whether patients within the period of three months to one year post cardiac surgery via median sternotomy surgical approach still experience a BPD and, if so, to determine the risk factors to developing such a dysfunction.

The main finding of this study was that all participants scored positive in at least one of the outcome measures relating to BPD. Furthermore, the majority of participants scored positive in three of the outcome measures which consisted of the NQ, SEBQ, BHT and measures of upper and lower CE. This therefore confirms the fact that there is a high prevalence of BPD in the long-term post cardiac surgery via median sternotomy surgical approach.

Although this was not directly established in the context of the multidimensional nature of BPD, other measures which correlated strongly with certain measures of BPD, which included various pulmonary function tests, were found to have a long-term deficit in previous literature concerning this study population (Kristjánsdóttir et al., 2004; Westerdahl et al., 2003, 2016). These findings could be related to the acute surgical trauma inflicted onto the chest wall thereby influencing ventilation kinematics particularly relating to the biomechanical dimension of BPD. Other factors found to increase the risk of development of BPD in a multidimensional context include the female gender, the type of surgery (particularly thymectomies and atrial septal defect repairs), cardiac post-operative complications and whether a participant has returned to work.

Furthermore, factors found to reduce the risk of BPD three months to one year post median sternotomy procedure include the amount of weekly aerobic exercise attained in this period and the absence of post-operative complications during acute hospital stay.

Participants’ age had a weak negative correlation with the findings from the NQ and SEBQ which could be explained by the fact that older persons may have decreased sensation relating to dyspnoea and reduced ventilatory responses to hypoxia and hypercapnia. Length of hospital stay had a weak negative correlation with lower CE which was explained by the fact that pulmonary complications not only lead to increased length of hospital stay but also encourage apical breathing which reduces chest wall expansion measures.

However, once outliers were eliminated as done in regression analyses, age and length of hospital stay did not show predictive value in determining the presence of long-term BPD.

Overall, as discussed in the previous chapter, the physical activity level measured using the PAVS of participants three months to one year post-operatively was variable and thus patients were not meeting the weekly aerobic exercise recommendations which was determined by previous literature to be at least 150 minutes per week of moderate intensity exercise (Ball et al.,2016). This indicates that despite needing surgical intervention in the form of cardiac surgery, participants did not make, or made only limited healthy adjustments to their lifestyles which puts them at risk of developing future cardiovascular complications (Tian & Meng, 2019). It is therefore suggested that greater implementation of health promotion counselling strategies (Abraham et al., 2021; Giannuzzi et al., 2003) , and a more standardised community- or facility- based cardiac rehabilitation program done three times a week for 12 weeks combining submaximal aerobic and resistance exercise should take place (Abraham et al., 2021).

6.2. LIMITATIONS

This study was conducted in one private hospital setting in Gauteng, South Africa where patients were admitted to the same cardiothoracic ICU post-operatively with the same nursing protocols. Additionally, the data collection period was much longer to cater for limited sample size due to the fact that two of the three original cardiothoracic surgeons performing cardiac surgery via median sternotomy surgical approach left the hospital during the data collection period. The data collection period was also made longer as there was an under estimation of the number of patients who had received cardiac surgery via median sternotomy surgical approach who were over the age of 65 years and therefore ineligible to partake in the study.

Many of the outcome measures such as the VAS pain scales, the NQ, SEBQ, PAVS aerobic and PAVS strength were self-reporting and therefore based on a participant's perception. Thus, there could possibly be over- or under- reporting concerning these measures which may not give a completely accurate depiction of participants' current condition relating to BPD. Furthermore, most of the outcome measures, apart from the NQ which has previously been translated into European and Asian languages such as Greek, Farsi, Finnish, Norwegian, Swedish, Spanish, Filipino, and Chinese (Van Dixhoorn & Folgering, 2015) are only available in English. This therefore posed a challenge in a South African context as the home language of many of the participants admitted to the private hospital was Afrikaans.

Even though all participants could speak fluent English as a second language, some of the questions, especially those found in the NQ and SEBQ had to be further clarified by the researcher and may therefore have not been culturally relevant. For example, the questions in the SEBQ; “my breathing requires work” and “my breathing requires effort” was interpreted by many participants as the same question phrased differently instead of “effort” interpreted as physical or mental exertion while “work” interpreted as sustained “effort” over a longer period of time.

As the overall multidimensional context of BPD has not been considered before in previous studies concerning patients who have undergone cardiac surgery via median sternotomy surgical approach, certain aspects such as cut-off scores concerning the SEBQ, NQ, BHT and measures of lower and upper CE were based on general healthy population groups. Additionally, no previous literature has identified individual cut-off scores for age groups concerning the SEBQ, NQ, BHT and CE measures. For example, in the case of the BHT, the study by Courtney, Greenwood, et al., (2011) in a population group with a mean age of 49 years, identified a cut-off score of 20 seconds for severe BPD and a cut-off score of 30 seconds for mild BPD. Additionally, the study by Kiesel et al., (2017) identified the BHT cut-off score of 25 seconds amongst a population group of adults in their twenties. Furthermore, as seen in the current study where the age range was large, Reddy et al., (2019) identified normal ranges of upper and lower CE amongst healthy nonsmokers, healthy smokers and patients with COPD of which the age range was from 18 and 70 years therefore reporting of results in the study was not grouped by age but by condition.

Therefore, again, considering that cut-off scores influenced by age and surgical procedures has not been established, the prevalence of BPD could be over- or underestimated in this study.

Given that the chosen period of time was quite broad (three months to one year post-operatively) and participants were only assessed once (as the research aimed to identify prevalence of BPD and not how BPD improves or worsens over time post-operatively) the results are not able to show how the extent of BPD, and other factors such as PAVS scores, may change in relation to time periods post-operatively.

6.3. RECOMMENDATIONS

6.3.1. For Clinical Physiotherapy

As BPD is a multidimensional phenomenon, physiotherapists may take into consideration how the combined biomechanical, biochemical, and psychophysiological dimensions could affect patients post-operatively especially those who undergo cardiac surgery via median sternotomy surgical approach. This is further justified by Courtney, (2016) and Courtney et al., (2011) where they explain that BPD cannot be considered as a single entity but rather that the various dimensions should be assessed individually. Additionally, the outcome measures used to assess the dimensions of BPD are easily attainable and user friendly.

Considering how return to work rate may have an influence particularly on the psychophysiological dimension of BPD, education regarding coping strategies and reintegration into the workplace should take place amongst post-operative cardiac patients. This was justified previously in the literature review by Zimmerman et al. (2004), where a six-week program of daily telehealth consultations involving education and positive re-enforcement to promote self-efficacy amongst patients who underwent CABG surgery reduced the influence of symptoms on functioning thus promoting re-integration into daily life.

As the duration of aerobic exercise positively influenced all dimensions of BPD, post-operative and perhaps pre-operative physiotherapeutic interventions should involve aerobic training which should be recommended to be at least 150 minutes per week of moderate intensity Ball et al., (2016).

As there may be a relationship between BPD and sleep apnoea (Bordoni et al., 2022; Laćzay & Faulx, 2021), especially amongst patients whose primary diagnosis is cardiac in nature, physiotherapy evaluation and treatment should incorporate sleep behaviour and hygiene and relevant referral to a specialist should take place if necessary.

6.3.2. For Further Research

Now that it has been established that there is a high prevalence of BPD in the long-term post operatively amongst patients who underwent cardiac surgery via median sternotomy surgical approach, further research could take place on how the severity of BPD changes over a period. For example, a longitudinal study evaluating the participant group at three-month or six-month intervals post operatively.

It has been confirmed by this study that the assessment of BPD should be multidimensional, which was further justified above by Courtney, (2016) and Courtney et al., (2011). Therefore, this study may provide evidence for the need for further research involving the multidimensional phenomenon of BPD on patients from other post-surgical populations. Additionally further research may need to be done to establish more appropriate cut-off scores regarding outcome measures relating to BPD amongst patients who underwent cardiac surgery via median sternotomy surgical approach.

Additionally, it may be worthwhile to explore the validity of outcome measures such as the NQ, SEBQ and PAVS translated into South African languages and whether the individual questions posed are cross culturally relevant.

Although there may be a link between cardiac complications and the presence of sleep apnoea, further research is needed to confirm this hypothesis. Furthermore, it may be worthwhile to assess how sleep apnoea affects BPD in a multidimensional sense within a more generalised population group.

As there was a limited number of participants who incorporated strength training in their exercise regime, which may be due to fear avoidance because of the overly restrictive precautions given to them post-operatively (Cahalin et al., 2011; Cohen & Griffin, 2002), the data obtained in this study gives limited information. Therefore, further research may be beneficial in assessing how a safe and directed strength training program may impact the long-term outcomes regarding BPD amongst patients who underwent cardiac surgery via median sternotomy surgical approach.

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APPENDICES:

Appendix 1: Nijmegen Questionnaire
Study Code:

Tick the box that best describes your presentation concerning a specific sign or symptom

	Never 0	Rarely 1	Sometimes 2	Often 3	Very Often 4
Chest Pain					
Feeling Tense					
Blurred vision					
Dizzy Spells					
Feeling confused					
Faster or deeper breathing					
Short of breath					
Tight feelings in Chest					
Bloated feeling in stomach					
Tingling fingers					
Unable to breathe deeply					
Stiff fingers or arms					
Tight feelings around mouth					
Cold hands or feet					
Palpitations					
Feeling of anxiety					

<u>Appendix 2: Self-Evaluation of Breathing Questionnaire</u>

Study Code:

Tick the box that best describes your presentation concerning a specific sign or symptom

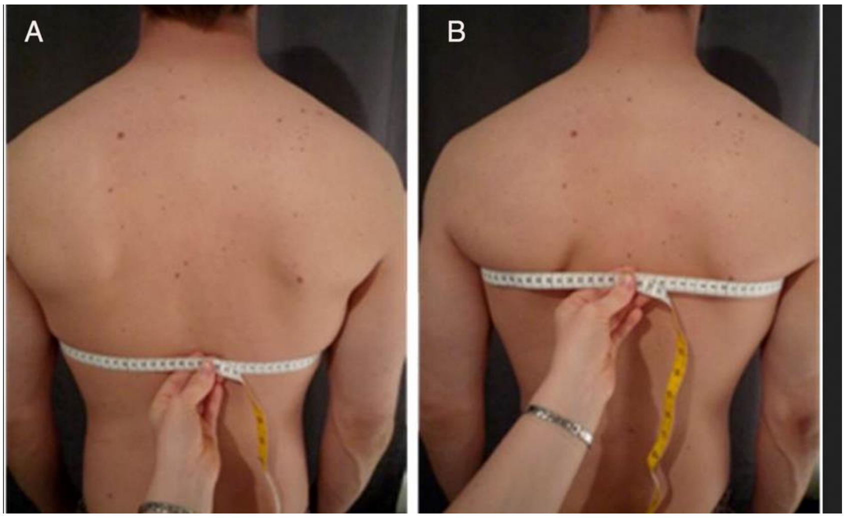
Scoring: (0) never/not true at all; (1) occasionally/a bit true;(2) frequently-mostly true; and (3) very frequently/very true

	0	1	2	3
1 I get easily breathless out of proportion to my fitness				
2 I notice myself breathing shallowly				
3 I get short of breath reading and talking				
4 I notice myself sighing				
5 I notice myself yawning				
6 I feel I cannot get a deep or satisfying breath				
7 I notice that I am breathing irregularly				
8 My breathing feels stuck or restricted				
9 My ribcage feels tight and cannot expand				
10 I notice myself breathing quickly				
11 I get breathless when I am anxious				
12 I find myself holding my breath				
13 I feel breathless in association with other physical symptoms				
14 I have trouble coordinating my breathing when I am speaking				
15 I can't catch my breath				
16 I feel that the air is stuffy, as if not enough air in the room				
17 I get breathless even when I am resting				
18 My breath feels like it does not go in all the way				
19 My breath feels like it does not go out all the way				
20 My breathing is heavy				
21 I feel that I am breathing more				
22 My breathing requires work				
23 My breathing requires effort				
24 I find myself breathing through my mouth during the day				
25 I breathe through my mouth at night while I sleep				
Total				

Appendix 3: Chest Expansion Measurement

Measurement of chest wall expansion (CE) is considered the most important measure of breathing patterns at rest and with exercise. Measurement via a non-stretch tape measure is considered affordable, easy to use and non-invasive(Reddy et al., 2019). Measurements of CE are made on two sites; upper CE refers to circumferential measurement with placement at axillary level, while lower CE refers to circumferential measurement with placement at the level of the xiphoid process(Padkao & Boonla, 2020a). Three Measurements are taken at maximal inspiration and maximal expiration for both lower and upper CE and the average difference is noted. This is done in standing and hands at the sides(Debouche et al., 2016) .

Figure 5: Tape measure placement to assess CE (Debouche et al. (2016))



A-Measurement of lower CE

B-Measurement of upper CE

<u>Appendix 4: Physical Activity Vital Sign</u>
Study Code:

Please answer to the best of your ability giving an approximation:

1)On average, how many days per week do you engage in moderate to strenuous exercise (like a brisk walk): _________________days

2)On average, how many minutes do you engage in exercise at this level?
__________minutes

3)Total minutes per week multiplying question 1 and 2 __________minutes/week

Additional component:

How many days a week do you perform muscle strengthening exercises, such as bodyweight exercises or resistance training? __________days

Key:

Moderate exercise is considered exercising at a level where you will be able to talk but not sing during the activity eg, brisk walking, slow biking, general gardening, ballroom dancing.

Strenuous exercise is considered exercising at a level where you are not able to speak and are somewhat breathless eg, swimming laps in a pool, fast cycling, playing singles tennis.

Appendix 5: Demographic Questionnaire

Study code:

Please answer the following Questionnaire to the best of your ability. Approximate dates are acceptable. If a YES/NO answer is required, please tick the appropriate box.

Health-Related Demographics	
Age	
Gender	
Height	
Weight	
Previous diagnosis of depression	☐ YES ☐ NO
What surgery did you undergo? Please write a description e.g., aortic valve replacement/ coronary artery bypass etc	
How long was your overall hospital stay?	
Did you experience any complications after your operation?	☐ YES ☐ NO
If you ticked "YES" above, please describe what complications you experienced	
Pain levels	
Visual Analogue Scale Place a vertical mark on the line below to indicate how bad you feel your pain when you cough (one mark X) and when you breathe deeply (one mark O) **I---I**	

(No pain)	(worst pain Imaginable)
Work-Related Demographics	
Have you returned to work?	☐ YES ☐ NO
If you ticked “YES” above, please state approximately how many weeks after discharge did you return to work	
Please state your occupation	
What does your work require	☐ N/A (retired, disability etc.) ☐ Mostly sitting (desk-job) ☐ Mostly physical ☐ A mixture of both sitting and physical activity
Please tick your appropriate level of education	☐ Lower secondary education (grade 9) ☐ National Senior Certificate (matric) ☐ Higher education (university or TVET)
Please tick the appropriate income bracket that you fall under (per annum)	☐ R0-R54 344 ☐ R54 345-R151 727 ☐ R151 728-R363 930 ☐ R363 931-R631 120 ☐ R631 121-R863 906 ☐ R863 907-R1 329 844 ☐ R1 329 845+

Appendix 6: Clearance obtained through the Human Research Ethics Committee of the University of the Witwatersrand

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG	HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

Office of the Deputy Vice-Chancellor (Research and Innovation)

TO: Ms S Hurst
School of Therapeutic Sciences
Department of Physiotherapy
Medical School
University

E-mail: sammyleehurst@gmail.com

CC: Supervisor:
<Ronel.Roos@wits.ac.za>
and <HREC-Medical Research Office@wits.ac.za>

FROM: Mr Iain Burns
Human Research Ethics Committee (Medical)
Tel: 011 717 1252

E-mail: Iain.Burns@wits.ac.za

DATE: 2022/10/24

REF: R14/49

PROTOCOL NO: **M220858** (This is your ethics application reference number. Please quote it in all enquiries, oral or written, relating to this study.)

PROJECT TITLE: *Breathing pattern dysfunction amongst patients with median sternotomy post hospital discharge: a cross-sectional study within a South African context*

Please find attached the Clearance Certificate for the above project. I hope it goes well and that an article in a recognized publication comes out of it. This will reflect well on your professional standing and contribute to Government funding of the University.

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

R49 Ms S Hurst

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
CLEARANCE CERTIFICATE NO. M220858

NAME: (Principal Investigator)	Ms S Hurst
DEPARTMENT:	School of Therapeutic Sciences Department of Physiotherapy Medical School University
PROJECT TITLE:	*Breathing pattern dysfunction amongst patients with median sternotomy post hospital discharge: a cross-sectional study within a South African context*
DATE CONSIDERED:	2022/08/26
DECISION:	Approved unconditionally
CONDITIONS:	
NOTE:	If contact information regarding student study participants is required, please contact the Registrar's office - <Nicoleen.Potgieter@wits.ac.za>
SUPERVISOR:	
APPROVED BY:	Dr CB Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	2022/10/24

This Clearance Certificate is valid for 5 years from the date of approval. An extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office secretariat on the 3rd floor, Phillip Tobias Building, Parktown, University of the Witwatersrand, Johannesburg.

I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated from the research protocol as approved, I/we undertake to submit details to the Committee. **I agree to submit a yearly progress report**. When a funder requires annual re-certification, the application date will be one year after the date when the study was initially reviewed. In this case, the study was initially reviewed in **August** and therefore reports and re-certification will be due in the month of **August** each year. Unreported changes to the study may invalidate the clearance given by the HREC (Medical).

Signature of Principal Investigator　　　　Date

Appendix 7: Approval of title given from the faculty of Health Sciences Post Graduate Office

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Private Bag 3 Wits, 2050
Fax: 027117172119
Tel: 02711 7172076

Reference: Mrs Sandra Benn
E-mail: sandra.benn@wits.ac.za

30 September 2022
Person No: 1036655
PAG

Miss SLA Hurst
303 Acornhoek Street
Faerie Glen
0081
South Africa

Dear Miss Samantha Hurst

Master of Science in Physiotherapy: Approval of Title

We have pleasure in advising that your proposal entitled *Breathing Pattern Dysfunction Amongst Patients with Median Sternotomy Post Hospital Discharge: A Cross-Sectional Study Within a South African Context* has been approved. Please note that any amendments to this title have to be endorsed by the Faculty's higher degrees committee and formally approved.

Yours sincerely

Mrs Sandra Benn
Faculty Registrar
Faculty of Health Sciences

100 1922 2022

Appendix 8 : Consent documents signed by surgeons and physiotherapy practice owners.

WITS UNIVERSITY

7.3.4 Consent Document:

Surgeons and physiotherapy practice owners

Having read and understood the information sheet and protocol provided
I hereby give consent for the study to be undertaken by Miss Samantha Hurst on the condition that all terms are abided to.

Name: [redacted]

Title: Physiotherapist

Date: 09/06/2022

Place: Pretoria

Signature

Researcher: Miss Samantha Hurst

Date: 9/6/22

Signature:

7.3.4 Consent Document:

Surgeons and physiotherapy practice owners

WITS UNIVERSITY

Having read and understood the information sheet and protocol provided
I hereby give consent for the study to be undertaken by Miss Samantha Hurst on the condition that all terms are abided to.

Name: [redacted]

Title: Dr.

Date: 07-06-2022.

Place: Zuid Afrikaans Hospital.

Signature

Researcher: Miss Samantha Hurst

Date: 7/6/22

Signature:

7.3.4 Consent Document:

Surgeons and physiotherapy practice owners

Having read and understood the information sheet and protocol provided

I hereby give consent for the study to be undertaken by Miss Samantha Hurst on the condition that all terms are abided to.

Name: [redacted]

Title: Mis

Date: 8/6/2022

Place: ZAil

Signature

Researcher: Miss Samantha Hurst

Date: 8/6/22

Signature:

WITS
UNIVERSITY

***7.3.4 Consent Document*:**

Surgeons and physiotherapy practice owners

Having read and understood the information sheet and protocol provided
I hereby give consent for the study to be undertaken by Miss Samantha Hurst on the condition that all terms are abided to.

Name: [redacted]

Title: Dr (Physiotherapist)

Date: 7 June 2022

Place: Pretoria

Signature

Researcher: Miss Samantha Hurst

Date: 7/6/22

Signature:

***7.3.4 Consent Document*:**

Surgeons and physiotherapy practice owners

WITS UNIVERSITY

Having read and understood the information sheet and protocol provided
I hereby give consent for the study to be undertaken by Miss Samantha Hurst on the condition that all terms are abided to.

Name: [redacted]

Title: Mr

Date: 07/06/2022

Place: Pretoria

Signature

Researcher: Miss Samantha Hurst

Date: 7/6/22

Signature:

WITS
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***7.3.4 Consent Document*:**

Surgeons and physiotherapy practice owners

Having read and understood the information sheet and protocol provided

I hereby give consent for the study to be undertaken by Miss Samantha Hurst on the condition that all terms are abided to.

Name: [redacted]

Title: SENIOR PHYSIOTHERAPIST

Date: 09 06 2022

Place: PRETORIA

Signature ______________________

WITS UNIVERSITY

7.3.4 Consent Document:

Surgeons and physiotherapy practice owners

Having read and understood the information sheet and protocol provided

I hereby give consent for the study to be undertaken by Miss Samantha Hurst on the condition that all terms are abided to.

Name: [redacted]

Title: Physiotherapist

Date: 14 June 2022

Place: Pretoria.

Signature

Researcher: Miss Samantha Hurst

Date: 20/6/22

Signature:

Appendix 9: Consent documents signed by the hospital CEO.

7.3.4 Consent Document:

CEO and HOD

WITS UNIVERSITY

Having read and understood the information sheet and protocol provided
I hereby give consent for the study to be undertaken by Miss Samantha Hurst on the condition that all terms are abided to.

Name: [redacted]

Title: Mnr

Date: 3/10/22

Place: Pretoria Zuid Afrikaans Hospital

Signature

Researcher: Miss Samantha Hurst

Date:

Signature:

Study Title: Breathing Pattern Dysfunction Amongst Patients with Median Sternotomy Post Hospital Discharge: A Cross- Sectional Study Within a South African Context

Dear Sir/Madam

My name is Samantha Hurst, and I am a postgraduate physiotherapy master's student at the University of the Witwatersrand, Johannesburg. As part of the requirements of my degree, I must conduct research in the field of respirology, cardiology and cardiothoracic Surgery.

You are therefore invited to participate in my study on breathing pattern dysfunction post cardiac surgery with median sternotomy surgical approach.

A median sternotomy can be defined as a vertical incision or cut down the breastbone to access the heart and its surrounding structures. In your case, this would have been performed for cardiac surgery.

Even though the surgery is beneficial, your body still recognises the surgery as an injury and therefore adapts to make you most comfortable. This can alter your pattern of breathing making it abnormal or dysfunctional, known as a breathing pattern dysfunction or "BPD".

A breathing pattern dysfunction can be assessed through consideration of multiple dimensions namely:
- "Biomechanical "which describes the actual activity of breathing muscles and the joints of the rib cage
- "Biochemical" which in this context, describes your body's tolerance to carbon dioxide levels in the blood.
- "Psychophysiological" which involves the total body's regaction to your altered breathing pattern which can include factors linking to mental health.

The aim of this study is to establish whether patients within the period of three months to one year post cardiac surgery via median sternotomy surgical approach still experience a BPD.

To determine any risk factors associated with the prevalence of BPD, as well as the effect BPD has on physical activity levels and return to work, measures of physical activity, work-related and health-related demographics will also be used.

To do this, participants who agree to take part in the study will be assessed once through email correspondence and an arranged telephonic consultation.

Assessments sent via email will take approximately 5 minutes to complete and will involve:
•Self-reported questionnaires including details on your work and health-related demographics
•Physical Activity Vital Sign
•the Nijmegen Questionnaire
•the Self-Evaluation of Breathing Questionnaire.
Assessments via a telephonic video call consultation will take approximately 20 minutes and will involve:
-Physical examination including a Breath Hold Time test and a measurement of chest wall expansion

For the chest expansion measurement, please be aware that a family member/ friend would need to be present for this part. The researcher will demonstrate through the video call while your family member/ friend takes your measurements. The family member/ friend only needs to be present for this test and a video demonstration will also be available before the consultation for you and your family member/ friend to look through.
Please note that chest expansion involves measurement of the circumference of your chest with a tape measure at two different places. Please be aware that loose fitting shirts will hinder this. It is thus advisable that female participants can wear and tight strap vest, or if they are comfortable enough, a bra with a towel tucked over it.

If you have not completed the questionnaires before the scheduled consultation, the researcher will go through them with you in an interview-like manner and thus the consultation is expected to take longer.

I would truly appreciate your participation in the study as it would help me as a physiotherapist, and my fellow colleagues in better understanding how median sternotomy can contribute to a prolonged breathing pattern dysfunction and furthermore, how it may affect return to work or return to normal daily life activities.

Who is eligible to take part in the study?

Male and female patients (aged 18-65 years of age) who have undergone cardiac surgery where a median sternotomy surgical approach was used are eligible to partake in the study. Patients who underwent a median sternotomy due to a non-cardiac origin (e.g., Lung masses or trauma), who have underlying lung problems (e.g., Chronic Obstructive Pulmonary Disease or emphysema), have had surgery due to a re-look or who are participating in another study are not eligible to participate.

Are there any risks in taking part in the study?

Due to the non-invasive nature of assessment, there is minimal to no risk other than having to confront symptoms relating to problematic breathing in your questionnaires. Furthermore, you are allowed at any stage of the study to withdraw without giving reason.

What are the benefits of taking part in the study?

Results on your test will be given to you. Based on the results, in the presence of dysfunctional breathing pattern, education will be sent to you as well as referral to an appropriate Health Care Professional.in order to prevent development of a chronic condition You will be compensated 1 GB (± R85) for the data used during your email correspondence and video consultation.

Will information be handled as confidential?

You will be given a study code to ensure that nobody other than the researcher and her supervisor knows your identity. Only your consent form will feature your name which along with your results, will be stored on a password protected database with anti-virus and anti-malware software installed.

A spreadsheet that is only accessible by the researcher will be a key to correlate the study code to your name and email address. Results will be analysed as numbers and levels. Absolute confidentiality however cannot be guaranteed as, if law requires it, the information must be disclosed. All information given will be used solely for the purpose of this study.

For more information, please contact me on 0791527840 or email me at sammyleehurst@gmail.com

For more information on ethical concerns, please contact the Chairperson of the Human Research Ethics Committee of the University of the Witwatersrand, on telephone no. 011 717 2301, or by e-mail at Clement.Penny@wits.ac.za.

Kind regards

Samantha Hurst

Bsc. Physiotherapy (WITS)

Consent Document:

Participant and Family member/friend

Please complete and email back to sender

Having read and understood the information sheet provided.

I hereby give consent for the study to be undertaken by Miss Samantha Hurst on the condition that all terms are abided to.

Participant Name: ______________________________

Date: ______________________________

Signature ______________________________

Family member/friend's name: ______________________________

Date: ______________________________

Signature: ______________________________

Researcher: Miss Samantha Hurst

Date:

Signature:

Appendix 11: Graphic evidence of the video demonstrations

Image from video demonstration BHT

Image from video demonstration lower CE (given to female participants)

Image from video demonstration upper CE (given to female participants)

Image from video demonstration lower CE (given to male participants)

Image from video demonstration upper CE (given to male participants)

Appendix 12: Turnitin Report

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BREATHING PATTERN DYSFUNCTION AMONGST PATIENTS WITH MEDIAN STERNOTOMY POST HOSPITAL DISCHARGE: A CROSS- SECTIONAL STUDY WITHIN A SOUTH AFRICAN CONTEXT