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PATIENT-PERCEIVED BARRIERS AND FACILITATORS TO WEIGHT-BEARING WITH A LOWER-LIMB CIRCULAR EXTERNAL FIXATOR

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A Dissertation submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Masters in Physiotherapy by dissertation.

Johannesburg, 2022

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ABSTRACT

Background

External fixators have been used throughout history to immobilise broken bones and correct orthopaedic deformities. The use of circular external fixators has increased owing to the versatility of the fixator and the allowance of early weight-bearing. Early weight-bearing can significantly improve bone growth in most types of fractures. This may result in the earlier removal of the external fixator, less complications and improved patient outcomes.

Purpose

Although literature suggests that patients can fully weight-bear immediately post-operatively, empirical evidence, both globally and locally, shows that many patients do not. As a result, the factors that hinder early weight-bearing need to be addressed. This study aimed to determine the patient-perceived barriers and facilitators to full weight-bearing with a circular external fixator.

Method

A qualitative exploratory study was conducted using semi-structured one-on-one interviews. Patients that had a lower-limb circular external fixator applied in Pretoria, South Africa, and were referred for physiotherapy were invited to participate. Participants were requested to complete a demographic questionnaire prior to the interview. Once the questionnaire had been completed, the interview commenced. The interviews were audio-recorded and transcribed verbatim. Thematic content analysis was used to analyse the data. Codes and categories were identified, and themes were generated. Data saturation was reached after nine interviews.

Results

Four themes were generated from the data that was collected from the interviews. The first deals with the participants' pain, the pain experience, as well as the measures to relieve pain, swelling and injury. Theme 2 presents the participants' state of mind, which has a significant impact on their ability to mobilise and weight-bear. Although a number of participants were negative, there were indeed participants who presented with a positive state of mind. The effects of their surgical history and complications

influenced their current state of mind. The fear of falling or refracturing their leg also had an influence on their attempt to mobilise or weight-bear without their assistive devices. Theme 3 represents the physical factors pertaining to the human body and the external fixator equipment that play a role in the participants' ability to mobilise and weight-bear. Lastly, Theme 4 delves into the medical and non-medical support systems that played a key role in both the physical and psychological state of the participants. Both of these act as facilitators or barriers to weight-bearing. Furthermore, the demographics showed that there are certain factors that increase the participants' chances of developing complications. In fact, with complications, the participants are unable to weight-bear.

Conclusion

The findings are in line with the available literature sources on external fixators. Since the relevant literature sources are few and far-between, the research results add to the limited body of knowledge. They show that there are both physical and psychological factors that are barriers and facilitators to full weight-bearing. Pain was found to be the major influence in weight-bearing. The medical team, as well as the level of support at home, also played a role in this respect.

Clinical Implications

The barriers and facilitators to full weight-bearing with a circular external fixator that were identified in this study should provide for a better understanding among the clinicians managing these patients. With these results as a guideline, further studies should be conducted on the implementation of solutions in the field of general physiotherapy practice around circular external fixators.

ACKNOWLEDGEMENTS

Without the support of the people below, this study would not have been possible. I would like to thank them for their love, expertise, time, and assistance.

Firstly, to all the participants for taking time to participate in my study.

To Mrs Sandy Lord and Mrs Monique Keller, my supervisors, for the guidance and support given.

To my husband, family, and friends for being there for me throughout this process. Without their support, rusks and coffee, and encouragement I would not have completed it.

To Colett Robbertse, my business partner, for providing the support I needed at work, for being there to bounce ideas off and for tackling this adventure with me.

To Dr Mari de Jongh for the transcription of my interviews.

To the South African Society of Physiotherapy for partially contributing to the funding of this research.

Lastly, to the “Walk a Mile” Centre for Advanced Orthopaedics for the referral of the patients.

PRESENTATIONS

The results of this study were presented at, the 21st Century Congress of the South African Society of Physiotherapy in Stellenbosch, September 2022.

The results of this study will be presented at the World Physiotherapy Congress to be staged in Dubai, June 2023.

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List of Abbreviations

Ex-fix: External fixator

TSF: Taylor Spatial Frame

ROM: Range of motion

FWB: Full weight-bearing

NWB: Non-weight-bearing

PWB: Partial weight-bearing

REDCap: Research Electronic Data Capture

SMS: Short message servicE

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CHAPTER 1: INTRODUCTION

A general introduction is presented in this chapter, as are the aims and objectives, and significance of the study. Concluding with an overview of the organisational framework of the study.

1.1 Background

External fixators have been used throughout history to immobilise bone fractures and allow healing. The first external fixators consisted of leather and sticks, and in the 1950s, Gavril Ilizarov, invented the first circular external fixator (ex-fix) (Hernigou, 2016). This technique was only employed in the Western world in the 1980s and has since become an important component of complex orthopaedic practice worldwide (Barker, Burns and Littler, 1999; Green, 1990). Circular external fixators consist of metal rings held in place with pins that run through both soft tissue and bone. These rings are connected to each other with threaded rods and hinges. With this structure, and without having to open the fracture site, surgeons can achieve the rigidity that bone fragments require (Hernigou, 2016). The Taylor Spatial Frame (TSF), designed in 1994, is the most recent version of an Ilizarov-like circular ex-fix. It uses hexagonal rings that are connected by six struts that can manually be lengthened and shortened to change the angles of the rings (Kucukkaya, 2014). In this way, deformities on multiple planes can be corrected, which makes it highly versatile. Circular external fixators, as opposed to uniplanar or multiplanar external fixators, provide for better stability and allow the pressure on the bone to remain even during weight-bearing. As a result, with circular external fixators, full weight-bearing (FWB) can be commenced as soon as the pain allows for it (Amaro et al., 2020; Bhardwaj et al., 2019; Reddy and Radhakrishna, 2019).

Becoming a preferred treatment technique in many situations, external fixators have gained popularity over the past 30 years (Ganadhiepan et al., 2019). They are used to treat comminuted fractures, the non-union of bones, to correct leg length discrepancies and deformities, and in ankle arthrodesis (Barker, Burns and Littler, 1999; Ganadhiepan et al., 2019; Hernigou, 2016; Morasiewicz et al., 2019; Reinke et al., 2021; Siddiqui et al., 2019). External fixators can also be used in osteomyelitis and infection control, and in more recent years, have been used for cosmetic limb

lengthening (Elbatrawy and Ragab, 2015; Ganadhiepan et al., 2019; Hernigou, 2016). Often, the main aim of applying any type of ex-fix is to avoid amputation of a limb (Gubin, Borzunov and Malkova, 2013). External fixators are minimally invasive, offer stability to complex fractures, reduce operation time and in many cases are less expensive (Aziz et al., 2020; Garg et al., 2021). Soft tissue is also able to heal faster, with a diminished risk of major infection developing in the limb (Aziz et al., 2020; Gubin, Borzunov and Malkova, 2013). Most notably, circular external fixators offer a source of indirect fixation, especially in complex fractures, allowing a limb to be used functionally according to the patient's level of pain (Hernigou, 2016). Some authors have noted that external fixators are the only answer for the non-union of long bones, as well as for complex fractures and deformities with surrounding soft tissue damage (Bhardwaj et al., 2019; Gubin, Borzunov and Malkova, 2013).

Complications which may occur because of the application of any ex-fix are contractures, pain,scarring at the pin sites, neurovascular injuries, joint stiffness and muscle weakness (Aziz et al., 2020; Bhardwaj et al., 2019). The most common issue, however, is pin-site infection, which causes an increased level of pain and in turn a decreased level of weight-bearing (Aziz et al., 2020; Bhardwaj et al., 2019; Green, 1990). These infections can easily be treated with pin care and oral antibiotics (Elbatrawy and Ragab, 2015; Naqui et al., 2008; Oh et al., 2013; Reinke et al., 2021; Sengodan and Sengodan, 2012). Further complicating factors may include physical constraints and the inconvenience of a circular ex-fix that adjusts the patient's gait pattern and thus affects their quality of life (Aziz et al., 2020; Barker, Burns and Littler, 1999; Bhardwaj et al., 2019; Gubin, Borzunov and Malkova, 2013; Horas et al., 2015; Naqui et al., 2008; Vitale, Miller and Jimenez, 2006).

Although there are not many published articles regarding physiotherapy and ex-fix rehabilitation, Green (1990) concluded that physiotherapists have an important role to play in the rehabilitation of patients following the application of any ex-fix. This role includes pain control, wound healing, prevention of contractures, maintaining the joint range of motion (ROM), improving muscle strength and length, and gait re-education (Barker, Burns and Littler, 1999; Elbatrawy and Ragab, 2015). Gait re-education is an important part of rehabilitation in patients with any ex-fix (Zhang, 2010). Early rehabilitation and weight-bearing can significantly reduce the level of bone density loss

and improve bone growth in most types of fractured limbs, thus improving function and reducing the chances of re-fracture (Zhang, 2010). This makes gait re-education the most important of the physiotherapy treatment techniques. Physiotherapy interventions should therefore focus on correct weight-bearing (Barker, Burns and Littler, 1999). The percentage of weight-bearing should gradually increase from the first post-operative day in order to promote bone growth, which may result in the earlier removal of the circular ex-fix and fewer complications (Barker, Burns, and Littler, 1999; Barker and Burns, 2001; Green, 1990). Therefore, any issue that hinders early weight-bearing needs to be addressed as soon as possible (Barker and Burns, 2001).

To help achieve FWB, as soon as possible, certain activities need to be initiated. Actively using the limb, walking, stretching, elastic splinting and correct limb positioning while sleeping, all work together to minimise contractures (Bhardwaj et al., 2019; Green, 1990), thus making functional activities of daily living and weight-bearing easier (Bhardwaj et al., 2019). When distraction osteogenesis is taking place, the patients need to make daily adjustments on the struts of the circular ex-fix. This either lengthens the leg by pulling the bone apart at a pseudo fracture site or corrects a deformity by changing the angle of the bone. With bone lengthening and deformity correction through distraction osteogenesis, tight soft tissue, mainly myofascial tissue, resists stretching. Neural structures also have difficulty in adjusting to lengthening which could increase pain and affect mobilisation (Barker, Burns and Littler, 1999). Soft tissue can also be irritated by the ex-fix pins and cause a limitation in joint ROM.

The psychological factors surrounding the wearing of any ex-fix should also be considered (Gubin, Borzunov and Malkova, 2013; Vitale, Miller and Jimenez, 2006). Elbatrawy and Ragab (2015) noted the presence of psychological issues in individuals who received external fixators for the management of their lower limb fractures, but do not say what these issues are. In a study conducted by Naqui et al. (2008), one individual with psychological problems refused to weight-bear and later insisted on the early removal of the ex- fix which resulted in non-healing of the fracture. Furthermore, Siddiqui et al. (2019) found that circular external fixators have a negative impact on self-esteem. Other aspects such as psychosocial, economic

and physical issues also contribute to the general discomfort of patients (Elbatrawy and Ragab, 2015; Naqui et al., 2008; Oh et al., 2013). Psychological factors may affect compliance with regard to mobilisation and weight-bearing, thus resulting in longer bone healing times and an increased risk of complications (Elbatrawy and Ragab, 2015; Naqui et al., 2008; Oh et al., 2013).

1.2 Problem Statement

Early rehabilitation and FWB are important in mitigating the complications and risks associated with circular external fixators (Zhang, 2010). Despite the available evidence about the need for early FWB, patients with circular external fixators are still not FWB up to four weeks post-operatively (Amaro et al., 2020; Barker, Burns, and Littler, 1999; Barker and Burns, 2001; Bhardwaj et al., 2019; Reddy and Radhakrishna, 2019). There is limited literature on the psychological impact of external fixators and these factors may contribute to an individual's ability to weight-bear (Siddiqui et al., 2019). No national or international investigative studies could be found on the barriers and facilitators that respectively challenge and assist patients with circular external fixators. As such, there is little understanding as to why some patients are still not able to FWB on the affected limb, even though circular external facilitators have been shown to improve outcomes.

1.3 Research question

What are the barriers and facilitators to full weight-bearing with a lower-limb circular external fixator?

1.4 Aim of the Study

The aim of this study was to explore patient-perceived barriers and facilitators to full weight-bearing with a lower-limb circular external fixator.

1.5 Objectives of the Study

The objectives of this study were to:

1.5.1 Describe the demographic profile of the participants;

1.5.2 Explore the four-week post-operative barriers to full weight-bearing in patients with lower-limb circular external fixators;

1.5.3 Explore the four-week post-operative facilitators to full weight-bearing in patients with lower-limb circular external fixators;

1.6 Significance of the Study

Aziz et al. (2020) noted that there is a need for future studies to confirm the main complicating factors around external fixators and mobility. Full weight-bearing, without an assistive device, is an important aspect of rehabilitation of patients with circular external fixators. It can improve the quality of life and reduce the time that the circular ex-fix needs to be worn, which reduces the possibility of complications. There have been no reports, nationally or internationally, of studies exploring patient perceptions around weight-bearing with a circular ex-fix. Information in this regard can, therefore, be of value to improve patient treatment regimens and education, thus ensuring improved patient outcomes by better understanding the needs of the patients.

1.7 Organisation of the dissertation

The relevant history of external fixators, their indications, and complications, as well as information on the rehabilitation and weight-bearing of the associated patients is discussed in Chapter 1. The first chapter will also introduce the problem statement, significance of the study, and the aim and objectives of the study. In Chapter 2 the literature review presents the relevant literature with regard to external fixators. The literature sources specifically focused on mobilisation and weight-bearing with a circular ex-fix are minimal, and there are in fact no studies investigating barriers and facilitators to FWB. The methodology of this study is outlined in Chapter 3, with tabular representations of the demographics, and a summary of the interview results is presented in Chapter 4. The results are then discussed and aligned with the relevant available literature in Chapter 5, with conclusions being drawn in Chapter 6. The limitations of this study, as well as recommendations for future studies, follow in Chapter 6. Lastly, the references and appendices are presented.

Figure 1.1 below outlines the layout of this dissertation.

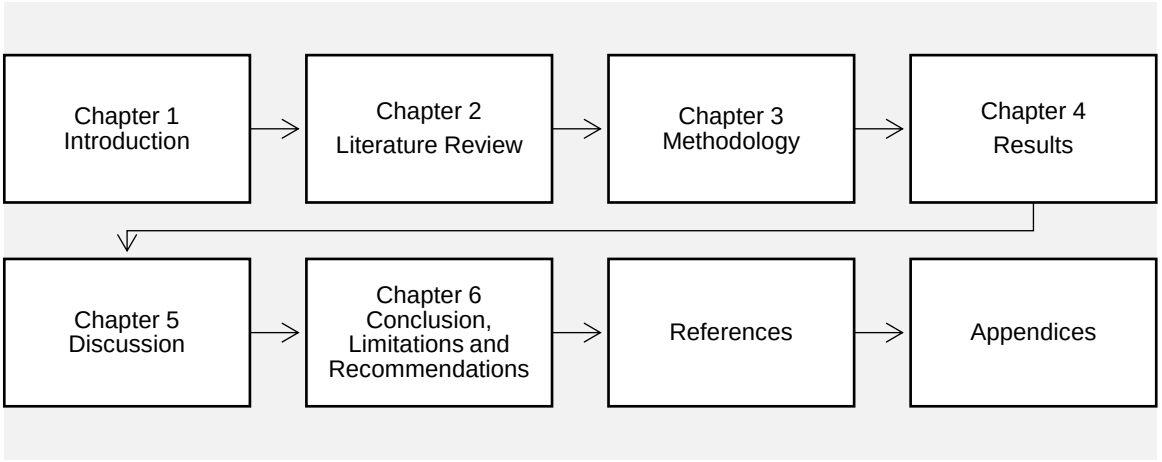


Figure 1.1: Organisational framework of this study

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter discusses the history and evolution of external fixators, their indications, and their advantages. It also presents the demographics of the participants that play a role in the functional outcomes and the possibility of complications. Furthermore, the disadvantages and complications of circular external fixators are noted, as also weight-bearing with a circular ex-fix and its effects on bone growth. These advantages and disadvantages introduce possible facilitators and barriers to weight-bearing with a circular ex-fix. Lastly, the rehabilitation of individuals with external fixators, and the gaps in literature posing potential barriers and facilitators to FWB are discussed.

A search using key words, namely, “external fixator”, “bone healing”, “external fixator and physiotherapy”, “external fixator and physical therapy” and “external fixator and rehabilitation” was conducted from February 2021 until July 2022. The search was performed on Science Direct Journals, CINAHL Complete, SpringerLink, Elsevier, PubMed and Google Scholar. All articles from 1980 to May 2022 were considered for the literature review, as there was more relevant rehabilitation information in older papers than in the recent literature. It is important to take into account the fact that there is no literature on the facilitators and barriers to FWB with a circular ex-fix. With the increase in circular ex-fix use over the last decade, much of the literature conducted is by nature retrospective.

2.2 History and evolution of external fixators

In 400 BC, Hippocrates described external fixators as ideal in immobilising fractures and preserving soft tissue (Hadeed, Werntz and Varacallo, 2022; Hernigou, 2016). The first ex-fix was constructed by Hippocrates with wooden Cornel tree rods and leather rings (Cinthuja, Wijesinghe and Silva, 2022). In 1840, the first practical ex-fix concept, using screws and wires, was introduced (Hernigou, 2016). Almost 40 years later, in 1878, the first true ex-fix, with pins penetrating the bone via a drilled hole and Plaster of Paris was used, and in 1886, these systems had been modified to external

screws and rods that were used for long bone fractures (Hernigou, 2016). In the late 1800s, external fixators became more readily available and their main use by 1898 was for the treatment of the non-union of bones (Cinthuja, Wijesinghe and Silva, 2022; Hernigou, 2016). Albin Lambote created his own version of an ex-fix in 1900, after the invention of a bone clamp system. He noted how simple and rigid it was and that it could also be applied for acute fractures. By 1912, external fixators were the main treatment modality for infected fractures in America (Hernigou, 2016). In 1913, the importance of an indirect fixation, especially for comminuted fractures was noted. The fact that external fixators allowed a limb to be used to mobilise and weight-bear once the patient's pain allowed it, was also of importance. During World War I, the development of external fixators slowed down, and after the war, the use of external fixators increased again (Hernigou, 2016). In Budapest, during the1930s, surgeons lengthened the period of time over which the external fixators were on for. In 1938, it was evident that changes needed to be made to external fixators to make them more clinically relevant. This was when the first truly minimally invasive technique was developed. It involved a guided percutaneous pin placement and is still used widely across Europe today. Researchers started using rods and clamps instead of Plaster of Paris in America in 1939, and in 1943 they realigned bone by piercing both cortices. However, external fixators were subsequently banned in America during World War II, as the period for the ex-fix on the limb was too lengthy and there were too many complications. This caused a delay for many years in ex-fix development (Hernigou, 2016). All external fixators up to this point were mono-planar and not circular by nature and focused on the healing of fractures. The first ex-fix for limb lengthening was used in 1952, but it was so cumbersome that the patient had to remain in bed for months while it was on (Coglianese, Herzenberg and Goulet, 1993). In England, after the war, the Hoffman system, another mono-planar device, was developed, with the importance of rigid fixation being emphasised in 1960. This system was used for primary fracture healing and also for infected areas associated with the non-union of bones (Hernigou, 2016).

Gavril Ilizarov revolutionised external fixators when he created the first circular ex-fix in the Soviet Union in the 1950s. It included a frame made of metal that encircled the limb, with tensioned wires/pins crossing through the bone and soft tissue. Threaded rods then linked the circular frames with hinges, which allowed for the movement of

the bone fragments without having to open the fracture site. This kept the fragments fixed in one position until the bone had completely healed. (Barker, Burns and Littler, 1999; Hernigou, 2016). This Ilizarov technique involving the circular ex-fix was employed in the Western world only in the early 1980s and has since become an important treatment technique in the management of complex orthopaedic procedures in modern medicine (Barker, Burns and Littler, 1999). The circular ex-fix improved with the introduction of the TSF. This frame consists of two rings connected with six struts that can be manually adjusted to change the angles of the rings by changing the length of the struts. It can therefore correct a deformity on multiple planes. The placement of the TSF and the adjustment of the struts are determined using a computer programme (Naqui et al., 2008). The design of the circular ex-fix has evolved to also include circular hexapod external fixators. However, they still follow the Chasles' theorem, with six-axis motion and strut adjustments. This combination, with a supporting computer programme, has made the circular ex-fix an important tool in deformity correction and fracture management (Liu et al., 2021b). Over the decades, and owing to technical advances and evolving orthopaedic requirements, external fixators have gone through many changes (Fernando et al., 2021). The main advances made in external fixators include pin modifications, new configurations, hexapod-style circular external fixators, new surgical techniques, and a change in the materials used (Cinthuja, Wijesinghe and Silva, 2022). Diagram 2.1 below is of a modern circular ex-fix.



Diagram 2.1: Modern circular external fixator

In an engineering review on external fixators, Fernando et al. (2021) were able to determine that the latest versions of circular external fixators are far superior because of their weight-bearing capabilities. In a narrative review on the treatment of Charcot Neuroarthropathy of the ankle and hindfoot with an ex-fix, Martin and Chow (2021) noted that the footplate fitted to the circular ex-fix when the ankle and foot are fixated also offers greater stability to the foot. Owing to the low level of evidence in this narrative review article, this point needs to be further investigated, as no other literature was found in this regard.

In a European article on unilateral three-dimensional external fixation in Serbian traumatology and orthopaedics, Milenkovic et al. (2021) mention that even though external fixators are not new, they have proven themselves important in modern day orthopaedics (Milenkovic et al., 2021). Cinthuja, Wijesinghe and Silva (2022) confirmed this assessment with their short socioeconomic analysis on the use of external fixators in developing countries. Malkova and Borzunov (2021) conducted and summarised a comprehensive systematic review, with level 1a evidence, on current research into external fixators. They noted that external fixators are used all over the world for complex musculoskeletal conditions and are especially important in modern trauma management. As the use of external fixators has increased, more research is being conducted; yet most of the studies are by nature retrospective or narrational. There is still no information on barriers or facilitators to FWB or for physiotherapeutic rehabilitation. The main centres that practise limb reconstruction and conduct clinical research are in India, Egypt, Italy, Russia, China, the United Kingdom and the United States of America.

2.3 Indications for circular external fixator treatment

The different types of external fixators that are still in use today are circular, uniplanar and hybridised. Other terminology used for non-circular, or hybrid external fixators include rail, bilateral, uni/monolateral, multiplanar, biplanar or uniplanar external fixators (Cinthuja, Wijesinghe and Silva, 2022). The different external fixators offer different levels of biomechanical stability which lead to varied healing rates and complication risks (Aziz et al., 2020). This was noted in a study conducted in Malaysia by Aziz et al. (2020), who used a finite element method to evaluate the

biomechanical stability of different ex-fix types. Although this study was conducted on femoral fractures, variable healing rates and complications was noted to be transferrable to other long bones. Thus, the different types of external fixators have different indications for use in fracture and deformity management. An investigation into fracture healing with a circular ex-fix and also into the influence of circular ex-fix configuration, fracture geometry and loading, was conducted by Ganadhiepan et al. (2019). This study, with high Level 1b evidence, showed that although circular external fixators are less convenient, they offer more advantages on account of their versatility in treatment procedures, especially when used in conjunction with the TSF (Ganadhiepan et al., 2019). In a retrospective study on the clinical outcomes of high-energy tibia fractures treated with either a circular ex-fix or a unilateral ex-fix, Liu et al. (2022) found that statistically there is no significant difference between the circular ex-fix and the unilateral ex-fix. The circular ex-fix is, however, deemed superior as, it not only presents with fewer complications, but also allows for better fracture reduction, shorter surgery time and a more stable fixation. The hexapod-style circular external fixators have had many variants over the last 20 years. It has been noted in multiple papers that they have become the preferred technique for deformity correction and fracture healing as a result of their high versatility and their ability to work on multiple planes (Fenton et al., 2021; Ganadhiepan et al., 2019; Liu et al., 2021b; Rao, Jamil and Tasarib, 2021; Robbins, 2021).

A retrospective cohort study of level 2b evidence conducted by Bhardwaj et al. (2019) compared the circular ex-fix to a rail ex-fix in the treatment of the non-union of long bones with infection. This Indian study revealed that a 100% bony union was achieved in both groups. Yet, with regard to the functional outcomes, patient acceptance and complications, the rail ex-fix was better tolerated. However, it was Malkova and Borzunov (2021) who noted the importance of circular external fixators. This article, with a higher (1a) level of evidence, offers valuable information with regard to the indications for circular external fixators. These authors noted that the main indications for circular external fixators are trauma, the non-union of bones, the necessity for plastic surgery, and paediatric orthopaedic conditions. They found that external fixators are especially helpful with reconstructive surgery, deformity correction and limb lengthening, and in fracture management where infection is present, as well as soft tissue damage and/or swelling (Algahtani et al., 2021;

Bhardwaj et al., 2019; Hadeed, Werntz and Varacallo, 2022; Malkova and Borzunov, 2021).

Malkova and Borzunov (2021) also noted that reconstructive surgery and limb lengthening are new subspecialties in orthopaedics that have emerged as a result of the advancements in circular external fixators over the past 50 years. Cosmetic limb lengthening with a circular ex-fix has also become exceedingly popular in recent years (Malkova and Borzunov, 2021).

In a case report and review on anterior knee dislocations by Berliner et al. (2021), it was ascertained that gross instability and vascular injury are indications of external fixators. This is especially true in cases where it is not possible to immobilise the area with a brace. In their comparative study, Bhardwaj et al. (2019) found that it does not matter which type of ex-fix is used; as long as the surrounding soft tissue and vascular structures are damaged, external fixators are the only option for management. Malkova and Borzunov (2021), found that external fixators have been successfully used in attempts to stimulate vascularity in patients with chronic ischemic disease. A retrospective study was conducted by Bhowmick et al. (2021) in Sao Paolo. Spanning over 10 years, it evaluated the benefits of circular external fixators in tibial fractures accompanied by impending or incomplete compartment syndrome. It was found that circular external fixators help in the avoidance of a fasciotomy as they reduce compartment pressure arising from the drainage of serous fluid through the pin sites.

Bone injuries that require reconstructive surgery with a circular ex-fix include congenital and acquired deformities or the non-union of bone. These conditions can be experienced from birth, or arise from infection, osteomyelitis, tumours, or trauma (Ganadhiepan et al. 2019; Malkova and Borzunov, 2021). The main fracture types treated by circular external fixators are complicated comminuted open or closed fractures (Malkova and Borzunov, 2021). Reddy and Radhakrishna (2019) conducted a prospective interventional study on the use of a circular ex-fix in open supracondylar femur fractures. They found circular external fixators to be the best treatment modality for open fractures. Although this study focused on femurs and incorporated level 2b evidence, it is important, and the results were noted to be

transferable to other open fractures. These authors also noted that patient compliance to the management of the ex-fix is important and affects the indication of ex-fix use (Reddy and Radhakrishna, 2019). In their overview of the principles for external fixators, Hadeed, Werntz and Varacallo (2022) agree about the importance of patient compliance with regard to ex-fix care. Patients are required to clean their own pins, adjust their circular ex-fix struts and mobilise, bearing as much weight as what their pain allows (Reddy and Radhakrishna, 2019). Correct care is important as multiple studies note the ability of external fixators to prevent potential amputation where other modalities have failed. The need for an amputation can be due to malformations and infection, especially in the case of diabetic foot ulcers (Berliner et al., 2021; Martin and Chow, 2021; Malkova and Borzunov, 2021; Paola et al., 2021). In their randomised control trial on the comparison of the stiffness characteristics that different circular external fixators have, Fenton et al. (2021) noted that external fixators have been known throughout history for their ability to salvage a limb. In their retrospective cohort study, with level 2b evidence, Jin et al. (2022) also noted this fact when they evaluated the success rate of lower limb salvages using a circular or monolateral ex-fix. In this Chinese study, two separate reviewers reviewed the records of 88 patients from two trauma centres from 2009 until 2018. All the patients had arterial injuries of their lower leg and were being treated with either a monolateral or a circular ex-fix. These researchers collected data on the surgical treatment of these patients, their demographics, and their subsequent outcomes. Using the Enneking score system, they found that pain, quality of life, function, and clinical outcomes improved when the patients were managed with a circular ex-fix.

Malkova and Borzunov (2021) found that another use for external fixators is in ankle arthrodesis procedures. Morasiewicz et al. (2019) evaluated whether the type of stabilisation used for the arthrodesis of the ankle joint affected the patients' activity levels and their ability to engage in sporting activities. In this prospective clinical study, conducted at the orthopaedic clinic of a medical university in Poland from 2007 until 2015, they found that both external fixation and internal fixation techniques were effective. Circular external fixators, however, had better outcomes than internal fixation.

Circular external fixators are most often used for tibial fractures, not only in acute fractures but also in individuals where bony non-union has occurred. This is because external fixators present with a lower chance of serious complications and a high bony union rate in tibial fractures (Bhowmick et al., 2021; Giannoudis et al., 2021; Siddiqui et al., 2019; Sheng et al., 2021). Giannoudis et al. (2021) reviewed the functional and clinical outcomes of 168 patients treated with a circular ex-fix for a distal tibial fracture. This retrospective cohort study, with level 2b evidence, revealed a 98% rate of bony union. Furthermore, a prospective observational study was conducted by Siddiqui et al. (2019) on the impact of a circular ex-fix on the self-esteem of patients and limb functionality with a unilateral tibia fracture. This study, with level 2b evidence, was conducted at a civilian hospital in Pakistan over an 11-year period and specifically evaluated patients with bony non-union emanating from infections of the tibia. They found that although the circular ex-fix improved limb function, it diminished the self-esteem of the patient. Despite this, as evaluated by Sheng et al. (2021) in their retrospective case study on the treatment of tibio-fibular fractures, the circular ex-fix still remains superior in tibial fracture management. Seventy (70) patients with either a circular ex-fix or an internal fixator were evaluated, and it was found that the circular ex-fix was more effective in fracture management and also presented with fewer complications. Bhowmick et al. (2021) noted that external fixators could even be used to avoid further complications. This information is important, as in current times, there are more tibial fractures and therefore, owing to the severity of modern-day injuries, a greater demand for the use of circular external fixators (Giannoudis et al., 2021).

In 2019, there were reports of around 70 million trauma injuries worldwide yearly, and in India alone they noted around 4,5 million open fractures (Bhardwaj et al., 2019; Reddy and Radhakrishna, 2019). Algahtani et al. (2021) noted that external fixators are especially valuable in the case of major trauma injuries. Since such injuries, the resultant defects, as well as the biomechanics of the limb, vary with each person, the adjustability of the ex-fit makes it an ideal device for such rehabilitation measures. In their socioeconomic analysis, Cinthuja, Wijesinghe and Silva (2022) found that around 80% of severe fractures worldwide occur in developing countries. They are mainly due to road accidents, falls from great heights and work-related injuries in industry, transportation, and construction (Cinthuja, Wijesinghe and Silva,

2022). Road accidents are a large problem in developing countries as the condition of the roads is not up to standard, vehicles are overloaded and there are too many vehicles on the roads (Cinthuja, Wijesinghe and Silva, 2022). Numerous authors have noted that major bone trauma is on the rise. This is due to the modern way of life, with traffic accidents, natural disasters, war and gun violence being rife. Major bone trauma causes notable health concerns worldwide, especially in developing countries, and there is a great demand for circular external fixators (Algahtani et al., 2021; Cinthuja, Wijesinghe and Silva, 2022; Milenkovic et al., 2021; Sheng et al., 2021). These authors used a finite element method to evaluate a feasible way to optimise a more patient-specific ex-fix. Cinthuja, Wijesinghe and Silva (2022) noted that owing to the increased demand for circular external fixators in developing countries, external fixators that are clinically acceptable and affordable are required. Further investigation into this problem is necessary.

In their retrospective study on the clinical outcomes of high-energy tibia fractures treated with either a circular ex-fix or a unilateral ex-fix, Liu et al. (2022) noted that the main goal with external fixators is to prevent infection, to obtain union and to allow the patient to return to the normal activities of daily living. Sims et al. (2000) published an article aiming to increase ex-fix awareness in the health care professionals working in hospitals and the community. They noted the importance of encouraging patients to perform their normal functions as much as possible and to avoid isolation and being disgruntled with the ex-fix. In a study conducted by Amaro et al. (2020), the authors found that it is possible to live functionally and continue with activities of daily living with the more modern circular external fixators. These results were obtained in their experimental and numerical study of level 1b evidence, where the use of nylon rods allowed them to evaluate the effect of the configuration of an ex-fix on dynamic compression loads. The fact that circular external fixators allow for normal functioning has led to the increased popularity of circular external fixators.

2.4 Demographics affecting functional outcomes and complications with external fixators

Some factors may positively or negatively influence the functional outcomes and the chance of complications with an ex-fix. Therefore, certain patient demographics and

comorbidities should be investigated. Reid et al. (2022) conducted a retrospective evaluation of the economic and clinical burden and risks, as well as the functional outcomes of a circular ex-fit, subsequent to its application. They evaluated 695 patients in the IBM Marketscan® Research Databases. In this study, they found that females have a lower chance of developing deep infections with circular external fixators than their male counterparts (Reid et al., 2022). The exact reason remains unknown. Oh et al. (2013) conducted a study with 10 individuals aged 16 to 64 years (mean 40.4) on the risks for complications when treating a bony non-union through distraction osteogenesis in conjunction with the use of an ex-fix and locking plate. They found that there is an increased risk for complications in a population younger than 40 years of age. Furthermore, Algahtani et al. (2021) noted that in the light of the reduced risk of surgery, the circular ex-fix is beneficial for an aging population as it is less invasive and patients can weight-bear on their leg. However, they did not note what age they regarded as an indication of being elderly. Berliner et al. (2021) reviewed a case study of an older female with a circular ex-fix, confirming that circular external fixators are beneficial in the elderly. The review was of an 88-year-old female who had received an ex-fix over her knee for a recurrent anterior prosthetic knee dislocation. Berliner et al. (2021) also reviewed similar cases and concluded that external fixators are more beneficial than other forms of fracture management in the elderly. In their prospective longitudinal study, based on level 2c evidence, on the loss of knee ROM in leg lengthening, Barker, Simpson and Lamb (2001) noted that age also influences the loss of knee ROM with lower limb lengthening in patients undergoing deformity correction. This study focused on the loss of ROM in the knee with leg lengthening. The rate at which the bone is distracted, together with age, was found to have the greatest impact on loss of flexion, while age alone had the greatest impact on the loss of knee extension.

In a review of the data for 53 patients who had received a circular ex-fix for the correction of both complex and simple deformities, Naqui et al. (2008) noted that the cause of injury or deformity affected the functional outcomes and complication risks of the patients. They also found that the acute or chronic nature and the location of the fracture also played a role. Similarly, Siddiqui et al. (2019) found that the persistent nature of the injury plays a role in the functional outcomes of the patient. Furthermore, both Naqui et al. (2008) and Siddiqui et al. (2019) noted that operative

records, ex-fix frame constructs, treatment regimes, the length of time that the ex-fix is on for and a follow-up protocol also play a role in both the functional outcomes and the complication risks in patients with tibial fractures. With the lower extremity functional scale applied to determine the functional outcomes, this assessment evaluates, among others, the patients' ability to walk different distances indoors and outdoors. Reid et al. (2022) found that as opposed to patients undergoing external fixation for fracture management, those undergoing deformity correction have the best outcomes. Even though these patients had longer treatment periods with the ex-fix on their limb, they had fewer comorbidities and a better prognosis with a lower risk for deep infection and amputation than patients that had an ex-fix applied for another reason. Lastly, Naqui et al. (2008) and Siddiqui et al. (2019) noted that the number of previous operations, pre-operative deformity parameters, complications, post-treatment deformity and clinical and radiological outcomes also influenced patients who had received a circular ex-fix. However, they did not mention how these factors influenced the patients.

Robbins (2021) conducted a systematic review on the different types of surgical treatments for patients with Blount's disease. With this disease, the growth plates around the knees of children are affected, which causes their legs to grow in a bow shape. Circular external fixators are beneficial in correcting this deformity in childhood or later in life. With a high level 1a of evidence from this review, they noted that the patient's ability to perform basic hygiene and grooming is very important. The patient also needs to comply with and understand ex-fix adjustments and care. This emphasises the importance of evaluating certain demographic attributes of the patient that could affect their ability to do so. They also noted that it is essential for a pre-operative assessment to be conducted to correctly develop a post-operative management plan. Certain post-operative factors should then be considered when developing this plan. Psychosocial factors, such as access to transport for follow-up appointments, need to be evaluated, as do certain physical elements, for example, the patient's ability to mobilise, the stability of the surgical site and the need to prevent joint contractures. In a case study of 16 participants on early weight-bearing problems associated with the use of a percutaneous ex-fix for a calcaneus fracture, Sengodan and Sengodan (2012) noted that certain psychosocial factors may also contribute to the general discomfort of a patient. They did not, however, mention

which psychosocial factors. Jin et al. (2022) mentioned that emotional factors, such as post-traumatic stress disorder or depression could affect the patient's prognosis.

Certain comorbidities may increase a patient's chance of sustaining a complication. Reid et al. (2022) found that obesity, chronic pulmonary disease, depression, diabetes, and hypertension are the top five comorbidities that increase a patient's chance of sustaining a complication. They noted that the main comorbidity to predict deep infection was diabetes and that it should be managed as it can affect bone healing, which can in turn result in a greater risk for amputation. This was also mentioned by Liu et al. (2022) in their retrospective comparison between a circular ex-fix or monolateral ex-fix. Furthermore, Martin and Chow (2021) found that patients with diabetes have a sevenfold increase in the possibility of contracting a post-operative complication. In a review on the importance of external fixators in offloading a diabetic foot ulcer surgically, Paola et al. (2021) mentioned that certain contra-indications to external fixation also exist. These contra-indications are morbid obesity, severe peripheral artery ischemia, neurological disease, or blindness, as well as lack of compliance.

The recent retrospective review published by Jin et al. (2022) describes pin-site infection and the loosening of the pins to be the main complications for external fixators. Therefore, it is important to understand the demographics that could influence these complications. The demographics mentioned in this study are age, gender, mechanism of injury, types of arterial or soft tissue injury, types of skeletal fracture, and time period from injury to surgery. A cohort study, with level 2b evidence, of an ex-fix that spanned the years 2015 to 2019 was conducted by Liu et al. (2021a). This study, using bone transport in conjunction with distraction osteogenensis, considered the potential risk factors for pin-site infection when correcting the non-union of bone. Observations from 12 to 36 months were documented for 91 males and 39 females aged 28-58. The top risk factors for pin-site infections were found to be diabetes, smoking, rural living, being male, doing agricultural work, hypertension, a lower level of education and longer periods of wearing external fixators. The study also found that other factors that contribute to pin-site infections are being older than 60, as well as the use of steroid hormones. It was noted that this study was conducted on a small sample in a single centre and

with a single surgeon. It focused only on the lower limb, but the results were of significance in ex-fix care.

As noted by Bhardwaj et al. (2019), country of residence is also an important demographic factor to consider. In developing countries, the risk of high-speed injuries is elevated owing to the increased need to travel long distances to work on roads of poor quality. In their short socioeconomic analysis on the use of external fixators in developing countries, Cinthuja, Wijesinghe and Silva (2022) found that there are specific barriers to fracture management in these countries. They include family and patient ignorance with regard to the management of external fixators, long-distance travels to healthcare facilities, a lack of medical expertise and equipment, and inadequate hospital theatres and healthcare facilities. These potential barriers to fracture management are important to address as there are multiple cases of complex fractures in developing countries (Cinthuja, Wijesinghe and Silva (2022). In their systematic review, Malkova and Borzunov (2021) found studies conducted by African authors that concluded that instead of amputation, the use of circular external fixators should be the more popular practice in African countries. The costs associated with a patient's inability to work should also be considered, as being the breadwinner often means patients must return to work as soon as possible (Cinthuja, Wijesinghe and Silva, 2022; Sengodan and Sengodan, 2012). Another important point to note is that many developing countries neglect birth defects, leaving them to be corrected with an ex-fix later in life. Furthermore, there is also often a lack of funds for trauma care in developing countries as most of the funds are allocated to non-communicable diseases (Cinthuja, Wijesinghe and Silva 2022).

2.5 Advantages of circular external fixators

With the major advancements in circular ex-fix technology over the last few decades, there has been an increase in the advantages of ex-fix use (Amaro et al., 2020). Amaro et al. (2020) found that newer circular external fixators offer greater stability with fewer complications and therefore allow earlier weight-bearing. Malkova and Borzunov (2021) also noted that all the advantages of circular external fixators are

currently being investigated, yet they have not as yet alluded to any of the advantages.

In their retrospective comparative study, Liu et al. (2022) found that circular external fixators have fewer limitations in terms of deformity correction than those of mono-lateral external fixators. Multiple studies have noted that circular external fixators have been found to be more secure and stable than mono-lateral external fixators (Bayrak et al., 2021; Zein et al., 2021). Comparing circular external fixators and mono-lateral external fixators, Bayrak et al. (2021) evaluated in their retrospective case-control study what the best type of ex-fix was for a tibial fracture from a gunshot wound. They found that compared to patients using mono-lateral external fixators, the surgical and healing times in patients with circular external fixators are shorter. This study, using level 3b evidence, was a retrospective case-control study. The results were confirmed by a study based on higher (2b) evidence that was conducted by Liu et al. (2022), and that noted the same. Another major advantage of the circular ex-fix is that it involves computer-guided placement. This allows for better planning and can take structures such as nerves and vessels into consideration (Naqui et al., 2008). The main advantage of a circular ex-fix would be the ability to adjust to different circumstances (Ganadhiepan et al., 2019). Therefore, as found by Bayrak et al. (2021), there is less malalignment with circular external fixators.

Most notably, in multiple studies of different levels of evidence, including level 1a evidence, the type of fracture or deformity does not matter. The stability of the circular ex-fix allows for early FWB, with minimal disruption to the soft tissue. Furthermore, the technique that is used is minimally invasive (Biz et al., 2021; Malkova and Borzunov, 2021; Meyer et al., 2021; Robbins, 2021; Liu et al., 2021b). Fernando et al. (2021) noted that circular external fixators are known for their superior biomechanical properties and are more effective for multidimensional deformities. Not only do they require less time to the mobilisation stage; they also allow easier wound care without compromising the stability of the fracture (Aziz et al., 2020). Tripathy et al. (2021) conducted a systematic review with a meta-analysis comparing external and internal fixators when treating complex tibia factures. They noted that there is better ROM in the joints when circular external fixators are used. In their turn, Giannoudis et al. (2021) noted that weight-bearing and mobility can

increase joint ROM (Bhardwaj et al., 2019). Also, in their study on surgically offloading a diabetic foot ulcer, Paola et al. (2021) noted that where necessary, a joint can be completely immobilised with a circular ex-fix. One of the main highlights for circular external fixators is that patients can use the limb functionally for the entire time that the ex-fix is on their limb. Numerous authors agree that allowing early return to function gives adequate stimulus for early bone and soft tissue healing and helps to reduce the chances of osteoporosis from disuse (Malkova and Borzunov, 2021; Reddy and Radhakrishna, 2019; Sheng et al., 2021; Zein et al., 2021). Malkova and Borzunov (2021) noted that circular external fixators are, therefore, advantageous. They are more versatile; there is faster bone formation with fewer shear forces; and in some cases, the external fixators are more affordable as they are now manufactured in more countries worldwide. It has also been noted that patients find that external fixators are easy to handle (Milenkovic et al., 2021).

In certain instances, for example in the aged, patients have difficulty complying with the instruction to non-weight-bear (NWB). In these patients, circular external fixators are advantageous, as early weight-bearing is allowed (Martin and Chow, 2021). Therefore, they can be used in the older population to avoid the complications of immobility (Cinthuja, Wijesinghe and Silva, 2022). Furthermore, Sengodan and Sengodan (2012) noted that the ability to weight-bear early is also beneficial among labourers who cannot remain off work for long periods of time. As mentioned by Cinthuja, Wijesinghe and Silva (2022), fractures in developing countries are mostly managed with Plaster of Paris, with considerable complications for the labourers. The specific complications were, however, not mentioned in this article.

Another group of patients that fails to comply with the offloading indications of certain surgical interventions includes those with diabetic foot ulcers. This is usually due to the diminished sensation in their feet. Thus, the ability to weight-bear with a circular ex-fix has been mentioned to be advantageous to them too (Paola et al., 2021). Similarly, although obesity has been mentioned to be one of the top five risk factors for complications with circular external fixators, their allowance for FWB makes external fixators beneficial to obese patients. This is because these patients may also struggle to follow the offloading instructions of other procedures. Martin and Chow (2021) noted that it is possible to provide greater stability to obese patients by

increasing the number of fixation elements in each ring. It is, however, important to note that, owing to the increased circumferential measurement of an obese patient's leg, the circular ex-fix rings do not always allow for a good fit (Hadeed, Werntz and Varacallo, 2022).

Malkova and Borzunov (2021) noted that the indications, cost, and lengthening potential of circular external fixators, as well as their positive effect on bone regeneration make them more beneficial than intermedullary nails. Historically, most bony non-unions were treated with tubular external fixators, internal fixators, or interlocking nails (Bhardwaj et al., 2019). However, recent literature states that distraction osteogenesis with the use of a circular ex-fix is the only solution for the non-union of long bones (Bhardwaj et al., 2019). Bhowmick et al. (2021) and Liu et al. (2022) both mentioned that circular external fixators have a lower chance of infection risk, especially when soft tissue damage and compartment syndrome are present. Literature also reveals that if an internal fixation is carried out when the soft tissue envelope has been injured, it will lead to skin breakdown (Bhowmick et al. 2021). Circular external fixators are more beneficial in that they can be used in cases where there are contra-indications for internal fixation (Martin and Chow, 2021). External fixators can be used especially when there is an active infection, thus obviating the need to wait for surgery (Paola et al., 2021; Sheng et al., 2021). It can, therefore, be noted that, as the insertion is minimally invasive, there are multiple indications for circular external fixators. In their analysis of external fixators in developing countries, Cinthuja, Wijesinghe and Silva (2022) found that external fixators have better success rates and fewer complications in trauma scenarios and offer many more advantages than internal fixators.

Malkova and Borzunov (2021) noted that fractures can effectively be reduced without causing inter-fragmentary compression. They also noted that anatomic alignment is easier to achieve and that the periosteal blood supply is not affected. Therefore, as mentioned by numerous authors, there is less blood loss and also less soft tissue damage. Patients also spend a shorter time in hospital and both the fractures and wounds heal faster, thus reducing the chance of infection and osteomyelitis (Aziz et al., 2020; Cinthuja, Wijesinghe and Silva, 2022; Fernando et al., 2021; Hadeed, Werntz and Varacallo, 2022; Jin et al., 2022; Sheng et al., 2021). Bayrak et al.

(2021) noted that once the circular ex-fix has been applied, further surgeries are usually not necessary. In a case series on circular ex-fix use in the instance of Blount's disease by Zein et al. (2021), it was noted that complete correction can be performed in one setting, which confirms the need for fewer surgeries and less hospitalisation. This is, therefore, more cost effective for the healthcare system and patients themselves. Furthermore, in a review by Biz et al. (2021) on the functional outcomes and complications associated with an ex-fix, their appraisal of studies from 1987 to 2002 noted that after the bone has healed, the ex-fix is removed and there is no implant that is still *in situ*.

A study to assess the advantages of intra-operative distraction and post-operative distraction using Hexapod-type circular external fixators was carried out by Liu et al. (2021b). This study was in a single centre and involved a small sample of patients; yet evidence shows that their results were relevant internationally. This study evaluated the effects of correcting a multiplanar deformity in theatre, as well as the effects of gradually correcting the deformity with strut adjustments post-operatively. Of the patients, 23 that were aged 19 to 64 underwent intra-operative correction and 35 aged 26 to 61 made adjustments to the struts post-operatively. The study found satisfactory clinical outcomes in both the intra-operative and post-operative groups. However, they suggested post-operative adjustments over intra-operative adjustment as this allowed for shorter surgical times and, therefore, less chance of intra-operative risks (Liu et al., 2021b). Robbins (2021) noted that there are multiple advantages of gradual post-operative correction with a circular ex-fix. These include fewer deep infections, a lower risk for neurovascular compromise and the possibility of fine-tuning the adjustments for the correction of deformities. Gradual correction, with an ex-fix requires commitment from the patient, surgeon and family, and takes long. As such, it should be outlined pre-operatively (Robbins, 2021).

Circular external fixators have been mentioned to improve a patient's quality of life. Jin et al. (2022) found that not only do circular external fixators improve the quality of life of the patients; they also reduce the pain in patients with vascular injuries. In their systematic review, Malkova and Borzunov (2021) noted that superior quality of life is observed in patients undergoing deformity correction with an ex-fix. They also mentioned that joint distraction with a circular ex-fix could delay joint replacement

surgery but did not note for how many years. Further studies about the delay in replacement surgery are necessary as Malkova and Borzunov (2021) declared that this study was conducted on a small sample size and with short follow-ups.

2.6 Disadvantages and potential complications of circular external fixators

Despite the vast number of advantages and indications for external fixators, especially circular external fixators, it is evident from literature that during the gradual bone lengthening process, both minor and major complications are possible (Biz et al., 2021). This is because external fixators need to be on for extended periods of time in order to achieve bone consolidation (Algahtani et al., 2021; Biz et al., 2021; Oh et al., 2013). The main complications that may arise are stiffness, weakness and contractures of the muscles and joints, pin-site infections, wire breakage or loosening, as well as pain and discomfort. Oh et al. (2013) noted these complications in their study on distraction osteogenesis with a circular ex-fix and locking plate. Although this was a retrospective review in a single centre with one surgeon and focused on a tibial defect issuing from an infection, these same complications have also been mentioned in other articles (Algahtani et al., 2021; Biz et al.).

Along with pin-site infections, Bhardwaj et al. (2019) listed pain to be one of the most common complications issuing from a circular ex-fix. Pain is a unique complex and subjective experience, as only the individual knows the nature of their pain (Sims et al., 2000). It is very important to recognise the different types of pain throughout the respective stages of ex-fix treatment, they include initial post-operative pain, the pain from tissue tension arising from adjustments and pressure on the pins, or neural tension. Patients need to be educated on the different types of pain and treatment thereof, and they should not cease the use of pain medication and try to manage without it (Sims et al., 2000). Sims et al. (2000) noted that uncontrolled pain in the ex-fix patient could lead to immobility, noncompliance, rejection of the ex-fix and depression. Pin-site infections causing pain can be present at any stage. Pain can also have a psychological effect on the patient, thus resulting in the mental rejection of the ex-fix. Liu et al. (2021b) noted that gradual post-operative deformity correction with strut adjustments can cause pain. They did, however, note that most pain can be managed with oral analgesics. Liu et al. (2022) also noted that pain is

manageable with oral analgesics. Furthermore, Lally, Seligson and Stanwyck (1981) noted that the pain on the pins as a result of the pulling effect on soft tissue subsides once the soft tissue has adapted. This was noted in their article about the challenges to physiotherapy associated with ex-fix use in fracture management.

Zak and Wozasek (2013) conducted a retrospective data analysis, focusing on the impairment of joint ROM and contractures that may be present with bone distraction in limb lengthening with an ex-fix. They found that the use of a circular ex-fix for lower-limb lengthening sometimes results in impaired ankle and knee ROM. It has been noted that muscles that cross two joints are more at risk for shortening, which results in flexion or extension contractures of the joints (Sims et al., 2000). Barker, Simpson and Lamb (2001) found that knee extension is frequently lost and noted that it can be a severe consequence if deformity develops, thus leading to instability of the knee. Several authors have mentioned that the pins that go through the muscles and tendons influence joint mobility and the ability of the muscles to work (Wade, Roberts and Richardson, 1999; Zak and Wozasek, 2013). Cinthuja, Wijesinghe and Silva (2022) found that paresthesia and other nerve injuries, such as nerve palsy from compression on the nerve by the pins, can also affect joint mobility. This neurological damage that could occur with a circular ex-fix can be both permanent or temporary, but Zein et al. (2021) noted that this type of damage can be avoided by surgeons, who should respect safe zones while operating, and dissect carefully.

Owing to the prolonged duration of wearing a circular ex-fix, plantar flexion deformities are common. This was mentioned by Wade, Roberts and Richardson (1999) in their study on the techniques that could be used to prevent a plantar flexion deformity from developing in a patient with an ex-fix. Malkova and Borzunov (2021) noted that other possible reasons for loss of ROM in the early post-operative phase are insufficient pain medication, the fear of moving, psychologically not accepting the ex-fix and psychosocial limitations resulting from having to wear the ex-fix for a long period. Barker, Simpson and Lamb (2001) found that the loss of ROM is worst at the conclusion of the bone lengthening process and is most likely due to the tightness of the tissue (Barker, Simpson and Lamb, 2001). They noted that the soft tissue in deformity correction is pushed to limits that it had not previously reached, whereas in

fractures or the non-union of bones, it is restored to its previous state. Yet, in their narrative article, Green (1990) noted that even when external fixators are applied for fractures or the non-union of bone instead of limb lengthening or deformity correction, the muscles can be irritated enough by the pins to limit joint ROM. Most notably, according to Barker, Burns and Littler (1999) in their survey over 20 years ago of the current practice in physiotherapy for external fixators, the muscles and nerves do not respond well to stretching and lengthening. More recent literature notes that the too rapid lengthening of the bone can cause an increased risk of soft tissue complications, such as contractures and muscle weakness (Zak and Wozasek, 2013). In some instances, however, adjustments need to be sped up or slowed down according to soft tissue tension or early consolidation (Sims et al., 2000). Meyer et al. (2021) conducted a narrative review of circular ex-fix use in clubfoot deformities. They found that soft tissue can get trapped between the components of the ex-fix and can be damaged by distracting too fast. This is important to note when deciding on distraction speed, even though fast distraction has been reported to increase bone healing (Sims et al., 2000). Although a narrative review does not produce a high level of evidence, one can still place a value on the information they have supplied. Meyer et al. (2021) noted that joint subluxation, flexion deformities in the toes, early consolidation and epiphysiolysis are complications that are present when treating a clubfoot deformity by means of a circular ex-fix. They mentioned that stiffness and reduced function are also present. Furthermore, Barker, Simpson and Lamb (2001) found that the risk of knee subluxation is higher with the presence of a fixed flexion deformity. In a study on the effect of mechanical stimulation in bone healing, Augat, Hollensteiner and von Rüden (2020) noted that post-operative stiffness may be due to previous open surgery and not the circular ex-fix.

When the joints are not mobilised through full ROM, the muscles, joints and ligaments increase in tightness, causing scarring of the soft tissue and joint contractures (Reis, 1991). Therefore, stiff joints and muscle contractures have been said to be a common complication associated with a circular ex-fix during limb lengthening (Barker, Simpson and Lamb, 2001). Numerous authors have noted that due to the soft tissue pulling on the pins, swelling, pain and scarring do not only result in stiffness, but also in immobility (Barker, Burns and Littler, 1999; Bayrak et

al., 2021; Biz et al., 2021; Cinthuja, Wijesinghe and Silva, 2022; Hadeed, Werntz and Varacallo, 2022; Martin and Chow, 2021; Reis, 1991). Owing to venous and lymphatic insufficiencies when the muscle isn't being activated, immobility may then augment the swelling (Reis, 1991). Barker, Burns and Littler (1999) mentioned that the physical constraints of the circular ex-fix also contribute to immobility and that the ex-fix influences weight-bearing, proprioception and gait. Furthermore, with pain, gravity and swelling, the patient with a lower limb ex-fix may struggle to dorsiflex their ankle. This in turn also affects their ability to mobilise, and also their gait pattern (Wade, Roberts and Richardson, 1999). Both Barker, Burns and Littler (1999) and Bayrak et al. (2021) mentioned that mobilisation and weight-bearing with a circular ex-fix are very important, and that failure to apply these methods and also non-compliance with regards to ex-fix management could be noted as reasons for complicating the procedure.

Vitale, Miller and Jimenez (2006) reported on the rehabilitation of two cases after intramedullary distractor implantation. They noted that there are not only physical complications with external fixators, but also psychological complications, which may create a serious barrier to ex-fix management. Psychological problems causing rejection of the ex-fix on account of pain can be present at any stage (Sims et al., 2000). In a study conducted by Naqui et al. (2008) on deformity correction, one of the participants with a psychological disorder first refused to weight-bear and then insisted on the removal of their ex-fix before bone consolidation had been achieved. This shows that it is important to understand the needs of the patient, as well as their ability to cooperate or comply with post-operative management in order to restrict complications (Martin and Chow, 2021).

As mentioned above, since external fixators require pins or wires to be inserted through the tissue and bone in order to keep the broken bones in place, one of the most common complications for this treatment modality is pin-site infection. There have, however, been numerous articles stating that the infection is easily resolved with oral antibiotics and pin care (Algahtani et al., 2021; Aziz et al., 2020; Bhardwaj et al., 2019; Jin et al., 2022; Oh et al., 2013; Robbins, 2021; Sengodan and Sengodan, 2012). In their study evaluating the risk factors of pin-site infection, Liu et al. (2021a) noted that literature varies significantly from 6.7% occurrence to 96.6%

occurrence of pin-site infections in external fixators. In their engineering review on external fixators, Fernando et al. (2021) found that too much stress at the pin-bone interface can cause pin-site infection and loosening. The type of ex-fix, joint movement and the location of the pins could also increase the risk of pin-site infection (Liu et al., 2021a). It has been noted that patients need to maintain a high level of hygiene in an attempt to avoid pin-site infections. It is recommended that they should sit on a chair in the shower to stop water from getting onto the pin site (Sims et al., 2000). Owing to the length of time that external fixators are worn, patients need to be able to perform their own pin-site care and it needs to be realised that the education given in this respect is very important (Sims et al., 2000). Liu et al. (2021a) also noted that pin-care education is very important. Green (1990) noted that something as minor as a pin-site infection may cause too much pain to weight-bear. In their article aimed at educating healthcare workers in ex-fix care, Sims et al. (2000) claimed that the signs of pin-site infection are redness, pain and swelling around the pin-site and/or a thick fluid being discharged. Redness and pain were noted to be the first indicators of infection. Sims et al. (2000) also mentioned that an area with increased skin movement, for example, close to a joint, could increase the chances of pin-site infection. In addition, smokers and those with poor nutrition also have a higher chance of infection.

Pathinathan et al. (2021) reviewed two cases and the literature around late onset lower-limb pseudoaneurysms from orthopaedic complications. They noted that if bleeding is present from a pin-site, it may be due to a false/pseudoaneurysm, caused by biological or physical damage to the arteries. Trauma, vascular interventions, and orthopaedic interventions can all cause physical damage to the arteries, while an infection can cause biological damage (Pathinathan et al., 2021). These aneurysms cause bleeding into the surrounding soft tissue and may present as bleeding from the pin-sites. They mostly present as swollen, painful and pulsating, and also possibly as bleeding sites (Pathinathan et al., 2021).

Numerous studies have noted that it is not only the ex-fix pins that cause complications, but also the ex-fix frames. External fixators have been said to be cumbersome, heavy, uncomfortable and bulky. They make day-to-day activities difficult and hinder the patient’s ability to walk, especially when trying to protect the

opposite limb (Algahtani et al., 2021; Hidayat et al., 2022). As circular external fixators are less readily accepted by patients, these difficulties are noted as some of the top complications emanating from this procedure (Aziz et al., 2020; Bhardwaj et al., 2019; Fernando et al., 2021).

When reviewing the literature, other possible major complications that may occur emerged. They include compartment syndrome, osteomyelitis, refractures around the pin, as well as mal-union or non-union of bone. (Barker, Burns and Littler, 1999; Bayrak et al., 2021; Biz et al., 2021; Cinthuja, Wijesinghe and Silva, 2022; Hadeed, Werntz and Varacallo, 2022; Martin and Chow, 2021). Although each of these complications could affect early functioning, many studies show that they rarely affect the outcomes of the procedure (Barker, Burns and Littler, 1999; Bayrak et al., 2021; Biz et al., 2021; Cinthuja, Wijesinghe and Silva, 2022; Hadeed, Werntz and Varacallo, 2022; Martin and Chow, 2021). Biz et al. (2021) found that most studies reveal satisfactory results but there have been some reports of unsatisfactory outcomes. Giannoudis et al. (2021) found that functionality is still impaired at the medium-term follow-up post-ex-fix removal stage, but in this study, functional outcome scoring was conducted only after the removal of the external fixators. This begs the question as to how much of the functionality is impaired while the ex-fix is *in situ* over such a lengthy period of time. In their study, Jin et al. (2022) found that the functional outcome assessment based on the psychological acceptance of the procedure, as well as the degree of the disability, physically improved over time (Jin et al., 2022).

There have also been financial implications mentioned in ex-fix use. In some cases, external fixators have been found to be more expensive, which may be a problem in developing countries. However, according to Cinthuja, Wijesinghe and Silva (2022), circular external fixators are very often reused in developing countries. Literature is non-conclusive on how many times an ex-fix can be reused, but Cinthuja, Wijesinghe and Silva (2022) noted that it has been proven in many studies that reuse is possible, which may lower the cost of treatment. There are studies currently being conducted to minimise the cost of ex-fix use in developing countries. Aimed at improving post-operative mobilisation and functionality, affordable low-profile circular external fixators are currently being investigated (Cinthuja, Wijesinghe and Silva,

2022; Hidayat et al., 2022). There are already many studies introducing low-cost external fixators, but further safety studies need to be conducted before they can be used (Cinthuja, Wijesinghe and Silva, 2022).

Malkova and Borzunov (2021) noted that there have been extensive developments and research to improve circular external fixators in order to mitigate the complications arising from their use. The type of material used has been adapted to reduce infection rates and to make the circular external fixators lighter. Paola et al. (2021) found that in recent years, even in severe cases, as with diabetic foot ulcers, most complications such as local infections are minor. From an engineering perspective, if an ex-fix fails, it may be due to its being either too stiff or too loose (Fernando et al., 2021). Algahtani et al. (2021) noted that fixators that are too rigid result in the non-union or delayed union of bones, while those that are too flexible result in pin-bone interface problems, mal-union or non-union of bone.

Paley's functional assessment tool aims at categorising an issue into one of three categories, namely, a problem, an obstacle or a complication. Each category requires a different approach to rectify it (Bhardwaj et al., 2019). Points to be evaluated are gait, ankle rigidity, soft tissue dystrophy, pain and inactivity with activities of daily living or inability to work (Oh et al., 2013). In a retrospective study evaluating the complications and functional outcomes arising from circular ex-fix treatment in comminuted tibial fractures and deformity corrections, Biz et al. (2021) noted that complications are mostly related to how severe the injury is. This study was conducted from 1987 until 2002 and focused on 15 to 30-year follow ups. Seventy-two (72) participants from a single centre, with one surgeon, were enrolled in the study. Further studies may need to be conducted with participants from a number of centres and operated upon by different surgeons.

2.7 Psychological factors affecting external fixator management

Both Gubin, Borzunov and Malkova (2013) and Vitale, Miller and Jimenez (2006) noted the importance of considering the psychological factors surrounding the wearing of any ex-fix. Elbatrawy and Ragab (2015) also found that there were certain psychological issues present in the individuals who received external fixators for the

management of their lower limb fractures, but do not say what these issues are. A retrospective, observational and transverse study was conducted by Rius-Zavala et al. (2017) on patients treated with an ex-fix from 2005 to 2010. They used clinical records, and statistical analysis to establish whether readmissions, complications in treatment, and reinterventions were related to any specific psychological disturbances. They also wanted to determine if the age of the patients, the type of intervention and time of use were related to these psychological aspects. They found that there was a relationship between the age and the psychological alterations of the patients. There was also a correlation between complications and psychological alterations as well as the prevalence of readmissions. They found less psychological effects in older patients and larger levels of anxiety in patients in the medium age range. There were also larger levels of anxiety in those that had long-term deformities. The psychological abnormalities that they noted were anxiety, irritability, apprehension, restlessness, hyperactivity, anguish and dependence. They noted that all these factors need to be considered when deciding on using an ex-fix for the management of these patients.

2.8 Process of bone healing with an external fixator

Early in the 20th century, it was noted that weight-bearing can stimulate bone healing (Sims et al., 2000). The properties of bone are anisotropic by nature, meaning that they are dependent on the direction of force. The anisotropic behaviour of bones needed at that stage to be evaluated, and only in more recent studies has this been possible with the advancements made in technology (Fernando et al., 2021). These more recent studies, with strong level 1b evidence, have a more robust testing system on the axial torsional and bending loads on the bone. They also focus on *in vitro* studies on actual bone, which was not the case in the past (Fernando et al., 2021). In their engineering review on external fixators, Fernando et al. (2021) were able to determine that circular external fixators can in fact increase the fracture healing time. Heng et al. (2021) statistically analysed the effect of different stresses on an ex-fix limb when treating an open tibial fracture. They found that there is significantly higher callus formation when axial stress is applied to an ex-fix limb and that this will result in a better union of open fractures (Heng et al., 2021). Fenton et al. (2021) found that the hexapod-style circular ex-fix is more rigid with bending and

tortional loads than would be the case with axial loads. In a study conducted by Giannoudis et al. (2021), they found that even though open fractures take longer to heal than closed fractures, 98% of the tibial fractures united with the aid of a circular ex-fix over an average period of 166.5 days. In their retrospective review, Jin et al. (2022) were also able to add substantial information to the current body of research in this regard. They found that the average fracture healing time is five to six (+- 4.3 months), which is in line with the findings of Giannoudis et al. (2021).

After a fracture, new bone is formed through a complex interaction of molecular and cellular processes, whereby bone, cartilage and connective tissue are formed. The tissue is constantly being remodelled, with the structure and the anatomy of the bone being rebuilt, and the functional abilities of the bone being restored (Augat, Hollensteiner and von Rüden, 2020). The most important part of bone healing is to restore strength and the ability of the bone to bear weight (Augat, Hollensteiner and von Rüden, 2020). Bone healing is activated by mechanical signals during loading, namely strain, fluid flow, stress, and streaming potentials, such as shear stress (Augat, Hollensteiner and von Rüden, 2020). Bone formation and fracture site motion have a dynamic relationship and there is a strong connection between inter-fragmentary motion from mechanical stresses over the fracture site and callus formation (Fenton et al., 2021; Fernando et al., 2021). Qi et al. (2021) conducted an *in vivo* test on rats and were able to properly investigate the effect that micro motions have on fracture healing. This study did not, however, thoroughly investigate axial loads. They found that there was an improvement in callus formation with axial loading, but the correct strain range needs to be investigated further (Qi et al., 2021). The early stages of healing are influenced by the three loading forces that occur during gait, namely torsional, bending and axial loading (Fenton et al., 2021). The exact degree of desirable motion across a fracture site has not yet been determined. In fact, literature indicates that the right amount is highly beneficial but that too much movement will have the opposite effect (Fenton et al., 2021). What has been determined is that axial loading is beneficial as it increases bone growth, but shear strains need to be minimised as they can diminish bone growth. There is strong evidence that circular external fixators do this (Augat, Hollensteiner and von Rüden, 2020; Fenton et al., 2021). The main mechanism of action set in place by a circular ex-fix is to reduce the shear strain on the fracture sites, while allowing axial loading,

which promotes the micro motions required to increase fracture healing (Fenton et al., 2021).

The biggest factors that influence inter-fragmentary strain are the amount of loading, the inter-fragmentary gap and the stiffness of the construct for osteosynthesis (Augat, Hollensteiner and von Rüden, 2020). Augat, Hollensteiner and von Rüden, (2020) noted that larger fracture gaps tend to have a delayed healing time, whereas the smaller to middle-sized gaps respond well to axial loading. This was confirmed by Ganadhiepan et al. (2019) in their study on the effect of dynamic loading on bone growth with a circular ex-fix. Therefore, some patients may have to reduce weight-bearing at first as gap size has a big influence on bone growth.

Reconstruction of the bone can also be stimulated by applying distraction or compression forces to the fractured leg, this is done by applying tension to the wires of the circular ex-fix (Malkova and Borzunov, 2021). Should the tension cause the fixation to be either too flexible or too rigid, bone healing would then be delayed (Augat, Hollensteiner and von Rüden, 2020). In leg lengthening and deformity correction, the bone is lengthened or adjusted by cutting it in half and then distracting the two pieces using a circular ex-fix. New bone then forms in this area (Barker, Burns and Littler, 1999). Faster distraction has been shown to increase bone growth (Augat, Hollensteiner and von Rüden, 2020). What is important to note,is that even with this pseudoarthrosis, mechanical stimulation still plays an important role in the ossification process of new bone formation in the distraction gap (Green, 1990).

Early-stage cell differentiation is very important for the overall healing of the bone; therefore, optimal conditions are required from the beginning (Ganadhiepan et al., 2019). In their study on the role that mechanical stimulation plays in bone healing, Augat, Hollensteiner and von Rüden (2020) noted that during the process of bone repair, it is more beneficial to stimulate bone healing earlier than later. In their case series on soft tissue treatment with an ex-fix in open tibial fractures, Hidayat et al. (2022) confirmed that performing functional exercises early accelerates the restoration of tissue structure and function. Healing is also faster in those that mobilise earlier (Wade, Roberts and Richardson, 1999). Therefore, moderate to high strain applied to the fracture during the early healing phases promotes healing.

Augat, Hollensteiner and von Rüden (2020) found that a brisk walk provides for such strain. Furthermore, Coglianese, Herzenberg and Goulet (1993) wrote an article proposing a physiotherapy programme for patients undergoing distraction osteogenesis. Discussing two case studies, they noted that similar to that process in a growing child, functional loading not only increases bone growth but also helps to maintain joint ROM and muscle length. This shows the importance of introducing mobilisation and weight-bearing as soon as possible post-operatively. These facts serve to highlight the main reason for this study, namely, to determine any facilitators and barriers to increasing the load in the early stages of healing. Non-compliance with regard to mobilisation and weight-bearing could result in a longer period being required for bone healing (Naqui et al., 2008). Sims et al. (2000) mentioned that other factors that could affect the bone healing rate are non-steroidal anti-inflammatory drugs, smoking and diet.

2.9 Weight-bearing with an external fixator

Normal functional loading of the limb has been noted to be very important in fracture healing (Barker, Burns and Littler, 1999). Zhang (2010) evaluated the effect of early rehabilitation on bone density in knee joint disorders caused by a fracture of the lower limb. In this experimental study, they found that early rehabilitation and weight-bearing reduce the occurrence of bone density loss, which in turn improves the ability to walk independently and FWB (Zhang, 2010). They also noted that exercise and weight-bearing can significantly reduce the loss of bone density in patients with fractured limbs, thus diminishing the chance of refractures by improving bone mass. Savage and Munjal (2014) presented a case study of a multidisciplinary team approach to limb lengthening using a circular ex-fix. They noted that, where necessary, one could use a weight-bearing prosthesis to facilitate bone growth and repair with a circular ex-fix.

It was originally thought that early weight-bearing should be limited so as not to negatively affect fracture healing. But more recent studies show that early weight-bearing should not only be allowed, but is necessary for fracture healing (Augat, Hollensteiner and von Rüden, 2020). Natural weight-bearing creates a compression load and also bending and sheer forces that together increase bone formation

(Amaro et al., 2020). Using a finite element analysis, Juan et al. (1992) conducted a theoretical analysis of the biomechanical significance of different types of external fixation. They found that even very rigid circular external fixators still allow loading through callus formation over the fracture site. Muscle contractions and weight-bearing are the main processes contributing to fracture site loading (Augat, Hollensteiner and von Rüden, 2020).

Historically, patients with external fixators were not allowed to weight-bear. As such, non-weight-bearing (NWB) gait training was performed, and the awkwardness of the ex-fix made it difficult to walk (Lally, Seligson and Stanwyck, 1981). Later, researchers found that in some cases, for example in fractures, patients needed to remain partially weight-bearing (PWB) or NWB for a period (Barker and Burns, 2001). Yet more recent studies have noted that with circular external fixators PWB is allowed for the first week, and thereafter patients are required to FWB as far as their pain allows (Biz et al., 2021). Patients are therefore asked to perform weight-bearing activities with their crutches one week after surgery (Liu et al., 2021a). Bhardwaj et al. (2019) noted that circular external fixators offer enough stability to allow even loading of the bone during early mobilisation and weight-bearing. Numerous authors have noted that this promotes both bone and soft tissue healing without disrupting the soft tissue, and also helps maintain joint mobility (Hadeed, Werntz and Varacallo, 2022; Liu et al., 2022; Reddy and Radhakrishna, 2019; Zein et al., 2021).

Evidence also shows that early mobilisation exercises of joints and weight-bearing improve muscle function and use (Bayrak et al., 2021). Bayrak et al. (2021) found that the soleus muscle especially benefits from early weight-bearing. Physiotherapists and surgeons should continuously encourage patients to follow a normal gait pattern while at the same time putting as much weight on the ex-fix limb as the pain allows. This weight should gradually increase from the first post-operative day (Green, 1990). It is, however, important to note that in some cases, weight-bearing too early could loosen the pins. Therefore, guidelines from the surgeon are necessary (Jin et al., 2022). Despite the allowance of early FWB, Siddiqui et al. (2019) found the mean time to FWB with a circular ex-fix to be 28.43 +/- 2.55 days. What is important to note is that these participants were in hospital for 4.11 ± 1.23 weeks. More recent literature has shown that the time to FWB with a circular ex-fix

ranges from 65 to 180 days (Sheng et al., 2021). These participants were in hospital for an average of 10.8 days (Sheng et al., 2021). Irrespective of these findings, it is important to note that any factor that causes the patient to reduce their weight-bearing should be addressed immediately (Green, 1990).

Early weight-bearing can also increase the patient's functionality, which may then allow them to return to work earlier (Augat, Hollensteiner and von Rüden, 2020). As noted in a case report by Sengodan and Sengodan (2012), patients that were working as manual labourers were able on average to FWB at 11.6 days. This not only shows the possibility of early weight-bearing, but also the effects of certain barriers, facilitators and demographics.

2.10 Rehabilitation of patients with circular external fixators

Although mention has been made throughout history of the importance of physiotherapy for the rehabilitation of individuals with an ex-fix, there is minimal evidence-based literature in this regard. Furthermore, all physiotherapy guidelines are over 20 years old, and many are not evidence-based Hadeed, Werntz and Varacallo (2022). Because rehabilitation, mobilisation and ultimately weight-bearing are the main responsibility of the physiotherapist, the understanding of the scope of practice is of importance in the rehabilitation of a patient with a circular ex-fix. Physiotherapy is very important to get the patient to mobilise as soon as possible and any change in the patient's condition should be reported to the surgeons immediately. This was noted by Hadeed, Werntz and Varacallo (2022) in their recent overview of ex-fix principles. Reddy and Radhakrishna (2019) conducted a randomised clinical trial on the outcomes for patients that received a circular ex-fix for the main management of an open supracondylar femur fracture. They noted that circular external fixators give the stability needed for early functional rehabilitation and that rehabilitation should be started immediately. Ilizarov made it clear that all conditions with a circular ex-fix share the same principles and that the rehabilitation should, therefore, be the same (Barker and Burns, 2001). He stated that the most basic treatment technique learnt by all physiotherapists working with a patient with a circular ex-fix is to aim for full functional weight-bearing as soon as possible (Barker and Burns, 2001). Barker and Burns (2001) used a consensus technique to try and

develop a physiotherapy clinical guideline for ex-fix patients. They mentioned that some physiotherapists noted that there are times that the patient needs to be PWB or even NWB. As such, one cannot have the same approach for all ex-fix patients. (Barker and Burns, 2001). Barker and Burns (2001) found that prior to 2001, most published circular ex-fix rehabilitation protocols were based on limb lengthening only, and that the protocols and complications mentioned were not, therefore, suitable for the rehabilitation of all procedures.

In the early 80s, Lally, Seligson and Stanwyck (1981) published an expert opinion without any critical appraisal on the challenges for physiotherapists in ex-fix rehabilitation. They noted that physiotherapists were involved in all stages of fracture healing. Initially, it was to help in avoiding secondary complications, such as lung disease or blood clots. Pin-care, ex-fix mechanics and education were the major goals in the sub-acute phase, with the focus also on maintaining ROM and strength in the uninvolved limbs. To avoid stiffening and the degeneration of the joints, physiotherapists focused on active exercises for the uninvolved joints on the affected limb. Isometric muscle activation exercises were also performed over the affected area to prevent muscle atrophy. Lastly, functional rehabilitation was commenced before discharge, with the focus being on stairs, transfers, and correct gait, usually a three-point gait pattern, all within the limitations of the device. A four-point gait pattern with PWB was started when bony union had been achieved, at which point active resistance exercises were given for the involved limbs to improve muscle strength. The focus of end-stage rehabilitation was then to increase weight-bearing to what could be tolerated. However, this article had limitations in that it was based on very old external fixators and not the more current versions that have been adapted and improved; furthermore, it was also based only on case studies. This article is, however, one of the few articles that have produced a physiotherapy rehabilitation regime to follow. The authors felt that it was important at that stage for physiotherapists to know the limitations of the external fixators and the treatment protocols in order to provide the correct care and to prevent complications. They noted that the aim of physiotherapy is to maximise on the benefits allowed by external fixators, namely, early mobilisation and weight-bearing, and to prevent the muscles from atrophying. In so doing, external fixators would then return the patient to the highest possible level of function. These authors also mentioned that

physiotherapists should educate their patients about the care, limitations and mechanics of the device. They should answer the patient's questions, reassuring them in times of doubt. Lastly, they needed to ensure that the patient's joint mobility, circulation and muscle tone would be maintained (Lally, Seligson and Stanwyck, 1981). All these points are still important in modern day ex-fix rehabilitation.

In the early 90's, an article, based on level 5 evidence, was published by Green (1990). This was an article based on expert opinion without any critical appraisal. This article stated what the author felt was important in the rehabilitation of a patient with an ex-fix. The information in this article certainly does offer important information that is still used in treatment today. The main objective was that individuals with external fixators should function as normally as possible for the entire period that the ex-fix is on. Green (1990) was of the opinion that physiotherapy is important in ex-fix management, since during correction, shortened tissue will resist stretching. Therefore, physiotherapists should employ all techniques possible on all their patients who have undergone a circular ex-fix procedure to stretch this tight tissue. This author specifically noted that myofascial tissue resists elongation. Passive stretching, elastic splinting, appropriate night-time positioning and actively using the limb were noted by the author as effective measures for preventing the development of contractures and deformities. The author also mentioned that these techniques were effective in improving functionality (Green, 1990).

Ilizarov noted that weight-bearing and ROM exercises are the main aims set for rehabilitation with a circular ex-fix. However, in 1993, Coglianese, Herzenberg and Goulet (1993) noted that there were no details in the literature as to how this should be done; nor were any rehabilitation criteria or protocols provided. At this stage, there was also no literature documenting the efficacy of interventions used to prevent soft tissue from being restricted in limb lengthening. The best physiotherapy treatment techniques for limb lengthening had not yet been researched at the time. There were, however, literature sources catering for other ex-fix conditions. They stated that strengthening with weight-bearing, prolonged stretching and maintaining a strength *versus* length balance in muscles were beneficial (Coglianese, Herzenberg and Goulet, 1993). Therefore, Coglianese, Herzenberg and Goulet (1993) set out to propose the correct physiotherapy managements for patients that

received distraction osteogenesis for limb lengthening. Around this time, Reis (1991) evaluated the value of ex-fix use during wartime through a randomized control trial conducted from 1973-1983 and they noted that mobilisation and the early movement of all possible joints were important in preventing complications. There was evidence of patients spending six hours a day in group classes, namely, standing doing weight-shifting exercises without assistive devices, and functional loading exercises, such as sit-to-stand-type exercises (Coglianese, Herzenberg and Goulet, 1993). The weight-shifting exercises were performed from side to side and then forwards and backwards, but there were still no exact treatment goals set out. Coglianese, Herzenberg and Goulet (1993), therefore, developed their proposed physiotherapy protocol based on experience. This protocol was divided into phases, stating what they felt were the necessary focus points for each phase. Phase 1 was commenced post-operatively as an inpatient. It focused on bed mobility, walking with crutches, weight-bearing as tolerated, maintaining joint ROM, and making sure that the patient was able to do their home stretching programme, as well as activities for functional loading. In Phase 2, as an outpatient and while distracting, the patient would focus on maintenance and increasing weight-bearing to at least 50%, with functional loading. In Phase 3, as an outpatient and after distracting, the patient needed to aim for optimal joint ROM, and to progress to ambulation and weight-bearing. This progression was towards the use of one crutch when mobilising and towards focusing on advanced functional loading exercises and closed chain strengthening. Lastly, in Phase 4, subsequent to the removal of the ex-fix, the aim was to return to full strength, ROM, and functioning without any assistive devices. Each phase had a goal. Phase 1 was to get the patient out of hospital and able to mobilise independently. They had to be able to weight-bear and gain or maintain joint ROM. In the other phases, the patient needed to be evaluated to decide what the most important need was at the time. It was noted that aggressive and well-informed physiotherapy was needed to maintain joint ROM.

In the late 90s, Barker, Burns and Littler (1999) conducted a survey in current physiotherapy practice at the time. The results of their study noted that 80% of physiotherapists identified the need for better defined protocols and more information for the care of patients with an ex-fix. The physiotherapists felt that communication, leadership in care, patient compliance and resources for extended periods of time

needed to be evaluated in order to better serve the patients and to achieve results. These researchers mentioned that the main objectives were to help overcome psychological barriers, to control pain and to heal wounds, as also to increase the ROM of joints and to improve muscle strength and length. The results of this study showed that this is a specialised field that requires further studies and specialised attention; not just general orthopaedic physiotherapy treatment (Barker, Burns and Littler, 1999).

In 2000, Sims et al. (2000) published an article aiming at increasing the awareness of ex-fix use and implications in the healthcare professionals treating these patients. They noted that expert care from a multidisciplinary team was necessary to provide patients with an ex-fix with all they needed to fulfil their social, physical, and psychological needs. Hadeed, Werntz and Varacallo (2022) also noted that the way the multidisciplinary team works together is what achieves a positive outcome for the patient. It was acknowledged that physiotherapists are important members of the multidisciplinary team when it comes to external fixators (Sims et al., 2000). Physiotherapy is especially important in the prevention of soft tissue complications in these patients (Barker, Simpson and Lamb, 2001). Sims et al. (2000) noted that historically, in cases where intense physiotherapy was necessary, patients were admitted for sufficient pain medication to achieve patient cooperation and compliance before physiotherapy sessions were commenced. They found that allowing the patient to control their pain medication intake had good results. It was also noted that pain medication intake should be coordinated with mobility and strut adjustments (Sims et al., 2000). As mentioned previously, it is sometimes too difficult to contract the muscles when the pins go through the muscle bulk. Sims et al. (2000) found that closed chain and weight-bearing exercises were beneficial in muscle strengthening but not all patients could do them. Therefore, functional exercises such as cycling, or rowing were performed to avoid wasting. Furthermore, these authors felt that the focus should be on the joints that could subluxate, and in some instances, treatment was still needed months after the removal of the ex-fix. Other treatment modalities that they found effective were group sessions and hydrotherapy, and on some occasions the patients needed to see a psychologist. Another important aspect of physiotherapy that they mentioned was education in terms of infections and how they occurred. Where rest and elevation were important,

joint ROM exercises still needed to be continued. Sims et al. (2000) felt that most patients should be mobile on crutches and be able, upon discharge, to climb stairs. They also emphasised the need for the patient to have the contact details of all the necessary providers and be assured that, should they have any further questions, they might call whenever necessary. Their specific physiotherapy programme was also divided into phases. The pre-operative phase focused on the discussions that should be conducted with the patients and specifically their families. This was to familiarise them with the programme, how to manage it, deal with complications and evaluate the patient's expectations and aims. They noted that a stretching programme should be given, and that, if need be, a physiotherapist closer to home be contacted. Arrangements needed to be made for the necessary assistive devices, for example, splints, shoes or wheelchairs. They also noted that the physiotherapist should educate the patients about certain changes that needed to be made, such as clothes having to be adapted with zips, press studs or Velcro, and about finding a way in which to cover the ex-fix frame. Specialised footwear was also proven beneficial in maintaining ankle ROM and helped to reduce knee flexion contractures[1]. Sims et al. (2000) also noted that functionality, ROM, muscle strength and joint stability needed to be assessed pre-operatively. Post-operatively, the focus was on splinting and positioning, as well as on active and active assisted exercises to maintain strength and joint ROM. Stretching exercises, given to keep muscles extended, and correct mobility and ambulation through appropriate assistive devices, were taught. As an outpatient during distraction, follow-up appointments were necessary to monitor muscle strength and ROM. If necessary, adjustments to shoes and splints were made, and active exercises were progressed to increase the loading on the limb. In some instances, if indicated, hydrotherapy was performed. After distraction, as an outpatient and while awaiting consolidation, the patient started to move towards weight-bearing and to focus on closed chain exercises for muscle strength and for improving joint ROM. Finally, once the ex-fix had been removed, the focus was on obtaining full ROM, strength and functionality through the implementation of specific techniques relevant to the required treatment. Massage was recommended to loosen the skin around the pin-sites. Transcutaneous electro-

[1] In recent literature, Donnan et al. (2016) noted that foot protection is a very important part of treatment.

neuro stimulus and relaxation techniques were also used to help reduce pain. These authors felt that education on certain techniques (e.g., watching television, listening to music, pursuing hobbies and going out with friends) to avoid ex-fix preoccupation could also help. Since each patient's pain is unique, they felt that education and adequate pain medication were very important components for complying with the requirements of the programme.

In 2001 Barker, Simpson and Lamb (2001) discussed the loss of knee ROM in patients undergoing leg lengthening in their prospective longitudinal study . In this study of level two evidence, they noted that they felt that the six hours of daily physiotherapy and stretching proposed in literature was impossible for most patients to attain. They therefore set out to present their own treatment protocols. They agreed that a pre-operative session with a physiotherapy programme was necessary, and their in-patient phase was aligned with that of previous literature, focusing on isometric muscle strengthening, education and weight-bearing as tolerated. Their patients were discharged when they were safe to go home and function independently. Outpatient physiotherapy commenced bi-weekly. It was aimed at increasing or maintaining the ROM of the joints above and below the ex-fix. Also, at maintaining the functionality of the limbs, at increasing muscle strength and at mobilising with at least 50% weight on the leg. As distraction continued, the main aim was to regain any joint ROM that had been lost. When the ex-fix was removed, the aim was to return to pre-operative strength, functionality and satisfactory joint ROM. Barker, Simpson and Lamb (2001) emphasised the need to keep complications to a minimum, as patients struggled to keep up with the physiotherapy programme when they developed a complication (e.g., a pin-site infection). The intensity of physiotherapy had to diminish until the infection had subsided. An important complication noted by Barker, Simpson and Lamb (2001) was the early post-operative loss of ROM in the joints. They therefore recommended that physiotherapy should be concentrated on improving joint ROM in the early post-operative phase. This is of importance as it shows that since distraction only starts later, lack of mobility and joint ROM are due to more than just tissue tension (Barker, Simpson and Lamb, 2001). Elbatrawy and Ragab (2015) evaluated the long-term outcomes of patients that underwent cosmetic limb lengthening. In their prospective study with long term follow up, they noted that certain psychological or psychosocial

factors could also affect the patient's general discomfort, ROM and compliance when it comes to correct gait and weight-bearing.

In 2001, one of the only evidence-based physiotherapy studies available was conducted by Barker and Burns (2001). They set out to determine the correct physiotherapy clinical guidelines for the treatment of patients with an ex-fix. Owing to the lack of available relevant research at the time, a Delphi technique was conducted with a panel of experts to establish this guideline. Bias is eliminated with a Delphi technique as the panel members may not discuss the points to reach a consensus; it must be reached separately. This could, however, mean that certain treatment modalities might be missed if the panel member could not explain its importance to other members. Those techniques that were excluded as the role players did not reach a consensus were massage, heat pads, transcutaneous electrical nerve stimulation, slings, pulleys, arterio-venous impulse systems, relaxation, acupuncture, eutrophic stimulation, weights, ultrasound, and accessory mobilisation techniques. The clinicians that participated in this study felt that the guidelines should merely be a starting point and that adaptations were necessary in each case. The results of the study underlined the importance of maintaining muscle strength, joint ROM, and muscle length. This was to reduce contractures and improve functional independence. The authors noted that adequate analgesia was to be given before treatment and that physiotherapists needed to be aware of any psychological problems that might arise and then provide the necessary support. Furthermore, the patients and carers needed to be educated about the home exercise programme and the correct use of splints. The most important treatment technique, however, was noted to be gait education (Barker and Burns, 2001). This was confirmed by Zhang (2010) who evaluated the effects of early weight-bearing on bone mineral density in patients with lower limb fractures. In this clinical trial they found that early weight-bearing due to proper gait education will significantly improve bone growth and reduce the chances of refracture. Barker and Burns (2001) proposed a physiotherapy regime with four phases. The pre-operative phase focused on evaluation, muscle strengthening and joint ROM exercises, as well as instruction on the home exercise programme. The first post-operative phase was as an in-patient activity focusing on muscle strengthening and joint ROM exercises, as well as functional activities focusing on weight-bearing and gait re-education. The second

post-operative phase was an outpatient activity during distraction osteogenesis, and with the same focus as the first post-operative phase, but with the addition of balance and proprioception exercises. The last phase was an outpatient activity during the consolidation phase aiming at regaining the ROM of all joints involved, FWB and proprioception, as well as increasing endurance and cardiovascular fitness.

Although there have not been physiotherapy-specific studies or articles in almost 20 years, there has been some mention of physiotherapy, rehabilitation, and biomechanics in more recent years. Some articles mention that patients generally undergo physiotherapy, but they do not elaborate on their inputs. On the other hand, others merely mention that patients are evaluated by physiotherapists (Martin and Chow, 2021; Zein et al., 2021). It is evident in the case of circular external fixators that a multidisciplinary team approach with specialised staff is still very important in-patient care and rehabilitation (Biz et al., 2021; Martin and Chow, 2021).

In recent years, adolescent deformity correction patients and adult deformity correction and fracture patients were the conditions that received the most physiotherapy (Reid et al., 2022). Biz et al. (2021) conducted a retrospective study on the complications after treatment, as well as the functional outcomes of deformity correction or comminuted tibial fracture patients treated with a circular ex-fix. This study had 15 to 30 year follow ups, and was conducted in a single centre. They found that with proper management, the period that the ex-fix is on for does not affect the functional outcomes (Biz et al., 2021). However, more studies need to be conducted to evaluate both the physical and psychological impacts while the ex-fix is on. In a non-randomised clinical trial by Pawik et al. (2021), they assessed the load distribution of the lower limb in patients that received a circular ex-fix for bony non-unions. They noted that complicated therapy is necessary to improve limb biomechanics and enhance quality of life by improving proprioception, muscle strength and joint mobility and to reduce swelling and pain. These authors also noted that most studies don't really focus on the lower limb biomechanics. Their study was to evaluate the loading on a limb post-ex-fix removal. Although this study showed even load distribution after circular ex-fix treatment, it was tested only on static loading and was not performed with an ex-fix still *in-situ*. This study does, however,

show that once the ex-fix has been removed, normal biomechanics can be restored. This would be true when a circular ex-fix has been used to remedy a case of non-union of the tibia. These authors also noted that impaired joint motion, as well as the weakening of muscles, could impair the function of a lower limb treated with a circular ex-fix. However, they found that rehabilitation helped to improve ankle ROM where a limitation was present. Therefore, as mentioned by Sheng et al. (2021), functional exercises for the knee and ankle should start immediately post-operatively, and also gradual weight-bearing.

Liu et al. (2022) issued an article on their retrospective analysis of the clinical outcomes of circular ex-fix patients compared to monolateral ex-fix patients with tibial fractures. This article mentions the most recent physiotherapy programme available in literature; yet it is not the basis of the article and there is no evidence to support the programme. These authors are of the opinion that the principle of post-operative management is early active rehabilitation with progressive weight-bearing. They recommend isometric exercises from two days post-operatively, as well as early PWB, using crutches. They also recommend that a hard shoe with an elastic band be used to keep the foot in a neutral position and that daily pin-site care with medical alcohol should be performed. This exact protocol was also proposed by Liu et al. (2021b) in their article of the retrospective analysis on the comparison between acute intraoperative correction versus gradual postoperative correction of tibial shaft fractures with posttraumatic multiplanar deformities using a circular ex-fix. Neither of these studies focuses on physiotherapy or rehabilitation and the protocols proposed need further investigation. Kaguku et al. (2004) did, however, note that physiotherapy starting two days after surgery will promote bone healing and reduce the chances of complications such as bed sores, osteoporosis and stiffness of joints. This was found in their retrospective review on the ex-fix management of an open fracture from a gunshot incident in the Democratic Republic of Congo.

Several authors have noted the importance of early weight-bearing in bone growth. Bone growth is achieved through early joint mobilisation and weight-bearing, even with the use of crutches (Malkova and Borzunov, 2021; Zein et al., 2021, Zhang 2010). Both Meyer et al. (2021) and Zein et al. (2021) noted that active knee exercises are encouraged and that stretching should be done throughout the day.

Furthermore, physiotherapeutic exercises may also prevent impairment to the ankle ROM when a circular ex-fix is worn. Zak and Wozasek (2013) were able, through their retrospective data analysis to observe joint ROM and contracture development while distracting bony segments, to come to this conclusion. They noted that physiotherapy in conjunction with functional dynamic splinting is a good way of reducing the chances of developing contractures and muscle weakness while a patient is fitted with a circular ex-fix. These interventions might even prevent or mitigate the limitations associated with joint ROM in their entirety.

Wade, Roberts and Richardson (1999) had already, in the late 90s, noted the importance of dynamic splinting as an alternative to active dorsiflexion. Since dorsiflexion is not always possible, these authors regarded passive dorsiflexion and splinting as very important measures. They proposed that by attaching exercise bands to an ex-fix frame, the resultant mechanism could be used as a dynamic splint. In the light of the difficulties experienced in terms of the ex-fix frame placements and pins, they also noted the need for new techniques to mobilise the ankle. Despite splinting, Zak and Wozasek (2013) found that contractures occurred more often when the patients did not receive physiotherapy. Meyer et al. (2021) noted that physiotherapy and the splinting and strapping of the toes down to the ex-fix footplate are necessary to help prevent the development of deformities. They also noted that, where possible, pre-operative physiotherapy may also be beneficial in cases where there are pre-existing problems with joint ROM that can be addressed. Therefore, as mentioned by Barker and Burns (2001) in the early 20th century, it is important to thoroughly prepare the patients for this surgery. Possessing the knowledge of possible facilitators and barriers to rehabilitation and weight-bearing could indeed help in better preparing the patients for circular ex-fix treatment.

2.11 Potential barriers and facilitators to full weight-bearing with an external fixator

Numerous authors have discussed the advantages of and indications for circular external fixators, and despite the complications that may occur, they rarely affect the outcome (Barker, Burns and Littler, 1999; Bayrak et al., 2021; Biz et al., 2021; Cinthuja, Wijesinghe and Silva, 2022; Hadeed, Werntz and Varacallo, 2022; Martin

and Chow, 2021). Pin-site infection is one of the most common complications and pin-site care is very important. Hadeed, Werntz and Varacallo (2022) noted, however, that there is no literature as to which protocol is the best to follow in this regard. A pin-site infection can be a major barrier to weight-bearing with an ex-fix, as it increases pain. Therefore, it is important to minimise the occurrence of pin-site infections (Aziz et al., 2020; Bhardwaj et al., 2019; Green, 1990).

Although there has been a rise in ex-fix research over the last few years, there has not been anything with regard to physiotherapy and rehabilitation. The research is mainly based on modifications to external fixators, deformity corrections, or case reports on external fixators in fractures (Jin et al., 2022). Many of the studies that have been conducted thus far have been retrospective. As such, they have their limitations. When conducted retrospectively, many ORIF or ex-fix studies are based on different inclusion criteria. Thus, it is difficult to correctly compare these studies (Giannoudis et al., 2021). Most of the literature is also based on Western world cases and conditions, thus resulting in a setting in a socioeconomic milieu that differs from that which prevails in the developing countries. Therefore, there is a need to better evaluate the situation in developing countries where, owing to the high costs, multiple surgeries are not always an option (Sengodan and Sengodan, 2012). In addition, more studies need to be conducted on other materials that can be used to minimise the costs of external fixators (Fernando et al., 2021).

There has been no research on functional recovery in patients with fractures accompanied by vascular injuries (Jin et al., 2022). Research is also needed to understand the association between functional outcomes, radiological findings and patient-reported outcomes (Larsen et al., 2019).

In 1999, with no prospective studies at the time, Barker, Burns and Littler (1999) noted that there was minimal material published with regard to physiotherapy for patients with circular external fixators. There were also no published papers that cited evidence-based physiotherapy practice, even though there were papers describing physiotherapy regimes. In 2001, Barker and Burns (2001) marked the importance of evidence-based practice arising from a thorough systematic review, but which, owing to the lack of literature, was not possible in the case of ex-fix

rehabilitation. Also in 2001 Barker, Simpson and Lamb (2001) noted that research was necessary to evaluate the efficacy of physiotherapy interventions in treating and preventing the loss of joint ROM in patients undergoing limb lengthening. To date, there have not as yet been any studies conducted on this issue. As such, it might be beneficial to include studies on the role that physiotherapy may play in the rehabilitation of patients with circular external fixators and in the investigation into the potential barriers to weight-bearing while mobilising.

More recent studies mention a need to assess the impact of ex-fix treatment on both caregivers and patients (Reid et al., 2022). There is also minimal literature on the psychological impact of external fixators on patients (Siddiqui et al. 2019). Therefore, it is important to evaluate the impact of the ex-fix on the psychology of not only the patients, but also their caregivers. These factors could be facilitators or barriers to mobilisation and weight-bearing.

It is evident that the use of the circular ex-fix is on the rise and proving to be beneficial in many surgical scenarios. Yet there are large gaps in evidence-based literature in the field of physiotherapy and the rehabilitation of patients fitted with the circular ex-fix. The need for a better understanding of what factors might impact circular ex-fix physiotherapy and rehabilitation is uppermost. The main aim for physiotherapy is gait re-education and the avoidance of complications, such as pain and joint contractures. A lack of understanding around the correct rehabilitation of patients that have been fitted with a circular ex-fix may be a major barrier to mobilisation with weight-bearing.

2.12 Conclusion

With the advancements in circular external fixators and their importance in modern medicine, there is a need for a better understanding of the rehabilitation of a patient through the application of this device. The need for FWB to promote bone healing highlights the importance of the correct rehabilitation.

CHAPTER 3: METHODOLOGY

3.1 Introduction

Chapter 3 aims to outline the study design and the sourcing of participants, also including the inclusion and exclusion criteria. The methodology and the tools involved in data collection are discussed. Lastly, the data analysis process and ethical considerations are defined.

3.2 Study Design

This was a qualitative exploratory study using semi-structured in-depth one-on-one interviews and a demographic questionnaire.

3.3 Participants

3.3.1 Source of Participants

The participants were patients that had received a lower-limb circular ex-fix from one of three referring surgeons in Midstream, Pretoria, South Africa. They were referred post-operatively for rehabilitative physiotherapy.

3.3.2 Sample Selection

The participants fitting the inclusion and exclusion criteria were identified on Day 1 after their surgery. Prior to discharge, they were informed about the study and asked whether they would like to participate. Written consent was obtained on that same day and a tentative appointment was made for the interview to take place four weeks later. The inclusion and exclusion criteria were based on the available literature.

Inclusion Criteria

- The participant had been cleared post-operatively by the surgeon for full weight-bearing from Day 1;
- The participant was fitted with a unilateral lower-limb circular ex-fix for trauma, arthrodesis, limb lengthening or deformity correction;

- The participant was an adult of 18 years or older.

Exclusion Criteria

- The participant had an associated pathology or comorbidity that did not allow full weight-bearing;
- An intramedullary nail had been inserted with the circular ex-fix;
- The participant had suffered polytrauma that might have affected their ability to ambulate.

3.3.3 Sample Size

Nine interviews were conducted until the data saturation point was reached. It was determined that the data saturation point was reached when no new information, codes or categories could be developed.

3.4 Data collection tools

Each participant received a printed information document explaining the study, together with a consent form to be signed on their day of discharge from the hospital (Appendices A and B).

3.4.1 Demographic questionnaire

Patient demographics were collected using a self-designed questionnaire (Appendix C) and captured using Research Electronic Data Capture (REDCap) software. The questionnaire was compiled using general demographics from literature and empirical evidence (Barker and Burns, 2001; Bhardwaj et al., 2019; Naqui et al., 2008; Reinke et al., 2021; Rounds et al., 2019; Siddiqui et al., 2019). The data from the questionnaires was used to describe the sampled participants.

3.4.2 Interview guide

Barriers and facilitators to FWB with a lower-limb circular ex-fix were explored on the basis of a semi-structured interview guide. The guide was developed using general and empirical evidence from the literature (Appendix D) (Barker and Burns, 2001;

Bhardwaj et al., 2019; Elbatrawy and Ragab, 2015; Oh et al., 2013; Vitale, Miller and Jimenez, 2006).

3.4.3 Field notes

The researcher took notes during and after the interviews in a reflective journal. These notes were used to confirm the interviewer's understanding of what the participant was saying by relaying the information back to the participant. This information tied in with the transcriptions. Non-verbal clues, such as body language, were also noted in the journal.

3.5 Procedure

3.5.1 Pilot Study

A pilot study was conducted with one participant. Written consent was obtained to conduct the interview and to make an audio recording. This was done on the day of discharge from the hospital where the participant had received surgery to ensure that he/she was no longer under the influence of anaesthetics. The date and time of the interview were tentatively arranged on this day for four weeks later. The date and time were then confirmed via electronic mail in the week following the patient's discharge from the hospital. As a reminder of the interview, a short message service (SMS) was sent out one week before, as well as one day before the agreed-upon time. The questionnaire was filled in, and the interview was conducted four weeks later in the physiotherapy practice of the interviewer. It took place on the same day as the participant's scheduled treatment session. An observer was present to note any negative influences or biases. The observer was a fellow researcher, who had completed a research methodology and ethics course. Said observer noted no potential bias during the interview. He/she felt the interviewer provided open ended questions with sufficient time for the participant to answer, without probing them into a certain direction. The observer mentioned that when there were probing questions, they assisted in the understanding of the questions and not in forcing specific answers. He/she also noticed that the participant seemed to feel at ease and was not uncomfortable with either the interviewer or the questions being asked.

The pilot study was conducted to determine the duration of the interview and to determine whether the participant understood the questions posed in both the questionnaire and the interview. No changes to the syntax of the questions were needed after the pilot study. Therefore, there were no changes made to the demographic questionnaire or the interview guide. As no changes needed to be made, the pilot interview was included in the main study and data analysis.

3.5.2 Main Study

As with the pilot study, written consent was obtained for each participant, and an interview date arranged. On consenting to participate in the study, all participants were orientated as to time and place. As per the pilot study, the demographic questionnaires were filled out four weeks post-operatively on the day of the interview, and prior to its commencement.

The researcher conducted the interviews in the physiotherapy practice, Crouse and Robbertse physiotherapists, in a closed room to allow for privacy. Permission to do so was granted by the researcher's partner (Appendix E). Only the participant and the interviewer were in the room and the interviewer ensured that the participant was comfortable and not overwhelmed. In one interview, a translator was present. The translator had been selected by the participant and was, therefore, a person that the participant felt comfortable with. The decision was made not to include an observer in the main study as the observer noted no bias in the observation of the pilot study. No changes were made to the interview guide (as discussed with the observer) and as such, the interview was included in the data analysis. The researcher felt that, by excluding an observer, the participants could feel more at ease. All Covid-19 protocols were strictly adhered to (Appendix F). The interviews took place before the scheduled treatment session which meant that the participant did not need to travel unnecessarily for the interview. The interviews lasted between four and 30 minutes, with the average being 13 minutes. A digital audio recording of the interview was conducted and was transcribed verbatim. The interviewer made notes in a field journal throughout the interview while the facts emerging from all of the interviews were checked during and subsequent to the interviews. A unique identifier code was

assigned to each participant after the interview and was used during the coding process to ensure anonymity.

3.5.3 Data Analysis

The completed demographic questionnaires were analysed by using descriptive statistics, while the feedback from the semi-structured interviews was analysed in terms of an inductive thematic analysis, as presented by Green et al. (2007). The data analysis process commenced after the first interview and continued until no new information emerged from the interviews. This allowed for a follow-up on new categories that were then developed. It also created an opportunity for the researcher to generate new probing questions for the interviews that arose through the research process. Triangulation was achieved through audio recordings, which were transcribed verbatim, and from the researcher's notes in the field journal. Participant checking was performed after each analysis: this included contacting the participant to ensure that the information had been interpreted correctly. In order to develop an understanding of the information and to establish the relevant codes and categories, the researcher read and re-read the transcripts repeatedly, immersing herself in the data. The initial codes were generated with words and phrases proposed by the researcher and the two supervisors, individually. A meeting was then held to discuss each person's coding and to come to an agreement. As new information was added with each new interview, the meanings were refined, and previous transcripts were re-visited to evaluate whether revision of the previous codes would be necessary. Meetings were held regularly to discuss the codes and categories and to develop themes. A final meeting was held after all interviews had been concluded to finalise the themes. The themes were then linked to the relevant literature until all the descriptive patterns had been developed (Green et al., 2007).

3.5.4 Trustworthiness

To create valid content of a high standard, certain steps were taken to ensure the trustworthiness of this research study. This process was guided by Elo et al. (2014). Before the interviews commenced, the researcher selected certain portions of her interview guide that required additional reflection and removed any phrases showing bias or prejudicial opinions about the population. This was done to create a more

open-minded approach. To ensure that there was no established relationship which could have influenced the information provided by the participant, the researcher did not treat any of the participants prior to the interview. In the consent form, the participants were made aware of the fact that their decision to partake in the study, or not, had no effect on their physiotherapy treatment leading up to and/or after the interview. The way in which the results were established and analysed was accurately documented. Audio recordings, verbatim transcriptions and a field journal were used to document the responses to the interviews. Credibility was achieved through participant checks during the interview to ensure that what the participant was saying was understood and had been interpreted correctly. The results obtained subsequent to the coding process were also verified with the participants. An external audit was conducted by the researcher's supervisors to ensure reliability. Confirmability was achieved by thoroughly documenting all the checking and rechecking procedures. The core research assumptions and the context of the study were thoroughly explained to create transferable results. Lastly, for the sake of authenticity,all data and results were presented in their true form; they have not been adapted to suit an original theory.

3.5.5 Data Management

The demographic questionnaires were completed on REDCap software. The interviews were recorded on a digital audio recording device and transcribed verbatim. Demographic data, codes, categories and themes were analysed and tabulated in Microsoft Excel and all data have been stored safely in a password-protected computer and password-protected cloud-based storage space. Hard copies of the consent forms and the field journal have been stored in a locked drawer in the researcher's work office and will remain there for fifteen years subsequent to the publication of the study. The documents will all be shredded thereafter.

3.5.6 Bias

Multiple measures were implemented to avoid bias. Before starting the interviews, the interviewer performed bracketing to avoid any known bias. This meant that they noted all of their own assumptions and beliefs in order to set them aside to avoid misreading the intended meanings of the participants experiences. The researcher

conducted the initial coding, but two supervisors assessed the coding on the transcripts as well as throughout the data analysis process. Member checking was also implemented, where the results were offered to the participants to review them. The three phases of triangulation were realized. Data triangulation was achieved through audio recordings, which were transcribed verbatim, and from the researcher's notes in the field journal. Investigator triangulation was achieved by the assessment of the coding by the researcher's supervisors. Lastly theory triangulation was executed with literature, to support the data. The interviews were not conducted later than four weeks post ex-fix application as the participants should have been FWB by then. This early date assisted in avoiding the possibility of recall bias. Later interviews may result in participant recall bias as they may not remember the initial postoperative days. Moreover, later interview dates could result in researcher recall bias as they move further away from their bracketing.

3.6 Ethical Considerations

The participants were aware of the voluntary status of the study and gave written consent prior to participation. They knew that they could withdraw at any time without penalty. Confidentiality was maintained by means of a unique identifier code on the questionnaire and no identifying details were indicated on the audio recordings. The study was performed according to the Declaration of Helsinki, while ethical approval was obtained from the University of the Witwatersrand Human Research Ethics Committee (Medical), with the number M210723 (Appendix G)

3.7 Conclusion

The method of this study was followed meticulously throughout. The researcher implemented all the necessary steps to make the participants feel comfortable whilst remaining ethical and providing trustworthy results.

CHAPTER 4: RESULTS

4.1 Introduction

This chapter outlines the results obtained from the nine interviews by analysing the responses to the semi-structured in-depth one-on-one interviews.

The objectives of the study are the following:

1. Describe the demographic profiles of the respective participants;
2. Explore the four-week post-operative barriers to full weight-bearing in patients with lower-limb circular external fixators;
3. Explore the four-week post-operative facilitators to full weight-bearing in patients with lower-limb circular external fixators.

A total of 15 lower-limb circular ex-fix procedures were performed in the timeframe of the study. Of these 15, six possible candidates were excluded as they did not meet the inclusion criteria. Therefore, nine interviews were conducted and the data pertaining to all nine were used. Since no new information emerged from the ninth interview, and data saturation had, therefore been reached. the researcher terminated the data collection process.

4.2 Demographic data of participants

Although all the participants were from a single medical centre in the private sector, this centre was selected on account of the many different types of patients seen. The centre performs non-profit surgery in the community, and as such, allowed for both rural and urban participants. The demographic information of this study was obtained with a questionnaire. The interviewer was present to clarify any questions the patients might have had when completing this questionnaire.

The characteristics of the participants are presented in Table 4.1. For all nine participants, an injury was the original cause of defect. All the injuries were chronic by nature. Two participants (22%) had elected to receive a circular ex-fix to correct a deformity that had developed. On the other hand, the other seven participants (78%)

had to receive one as a result of complications that had resulted in a deformity, infection or the non-union of bone occurring after the original trauma. All but one participant had received multiple previous surgical interventions. Some had received the same interventions multiple times: one had received multiple bone grafts, three had undergone multiple debridement procedures and two had received multiple circular external fixators. (See Table 4.1 for all the previous types of procedure received). None of the participants had received dynamic struts with their current circular ex-fix, but this issue was considered to be irrelevant since they do not affect the weight-bearing instructions or the physiotherapy protocol. All participants, including one who had had no previous surgical intervention, had at least one complication that had led to the need to use a circular ex-fix. (Refer to Table 4.1.)

Table 4.1: Characteristics of participants

Characteristic	**Participants** (n=9)
Gender, male n (%)	5 (56)
Gender, female n (%)	4 (44)
Age in years: mean (SD)	52 (14)
Weight in kg: mean (SD)	82 (18)
Height in cm: mean (SD)	170 (17)
Time from original injury in years: mean (SD)	8 (15)
Foot track fitted: yes n (%)	5 (56)
Foot track fitted: no n (%)	4 (44)
Previous surgical procedure, yes n (%)	8 (89)
Number of previous procedures, mean (SD)	6 (7)
Adjusting struts: yes n (%)	6 (67)
Adjusting struts: no n (%)	3 (33)
Cause of injury, n (%)	
Motor vehicle or motorbike accident	4 (44)
Slips and falls	3 (33)
Gunshot wound	1 (11)
Sports injury	1 (11)
Location of external fixator, n (%)	
Foot, ankle and tibia	5 (56)
Tibia	3 (33)
Knee, tibia and ankle	1 (11)
Types of previous procedures, n (%)	
Internal fixation	5 (56)
Circular external fixator	4 (44)
Multiplanar external fixator	3 (33)
Debridement	3 (33)

Plastic surgery	3 (33)
Ankle fusion	2 (22)
Osteotomy and bone graft	2 (22)
Plaster of Paris	1 (11)
Ankle replacement	1 (11)
Removal of prosthesis	1 (11)
Complication with previous procedures, n (%)	
Non-union of bone	5 (56)
Infection	4 (44)
Delayed wound healing	3 (33)
Deformity of leg	3 (33)
Cyst/abcess formation	2 (22)
Instability of ankle	2 (22)
Pseudoarthrosis	1 (11)
Failed plastic surgery	1 (11)
Loss of limb length	1 (11)
Pin-site infection	1 (11)
Employment status	
Unemployed	3 (33)
Back at work	3 (33)
Awaiting return to work	2 (22)
Working from home	1 (11)
Comorbidities	
Diabetes	2 (22)
Hypertension	1 (11)
Lupus	1 (11)
Spina Bifida	1 (11)

4.3 Themes

Four themes were generated from the data collected from the interviews. These themes were: “Weight-bearing is limited by pain”, “Psychological factors influence weight-bearing”, “Physical factors affect weight-bearing” and “Medical and non-medical support systems”.

4.3.1 Theme 1: Weight-bearing is limited by pain

Pain was found to be one of the main barriers to weight-bearing with a circular ex-fix. This theme outlines the participants’ experience of pain, as well as the measures to relieve pain, swelling and injury. Diagram 4.1 is a schematic representation of Theme 1. The diagram includes, from top to bottom, the subthemes and categories for this theme.

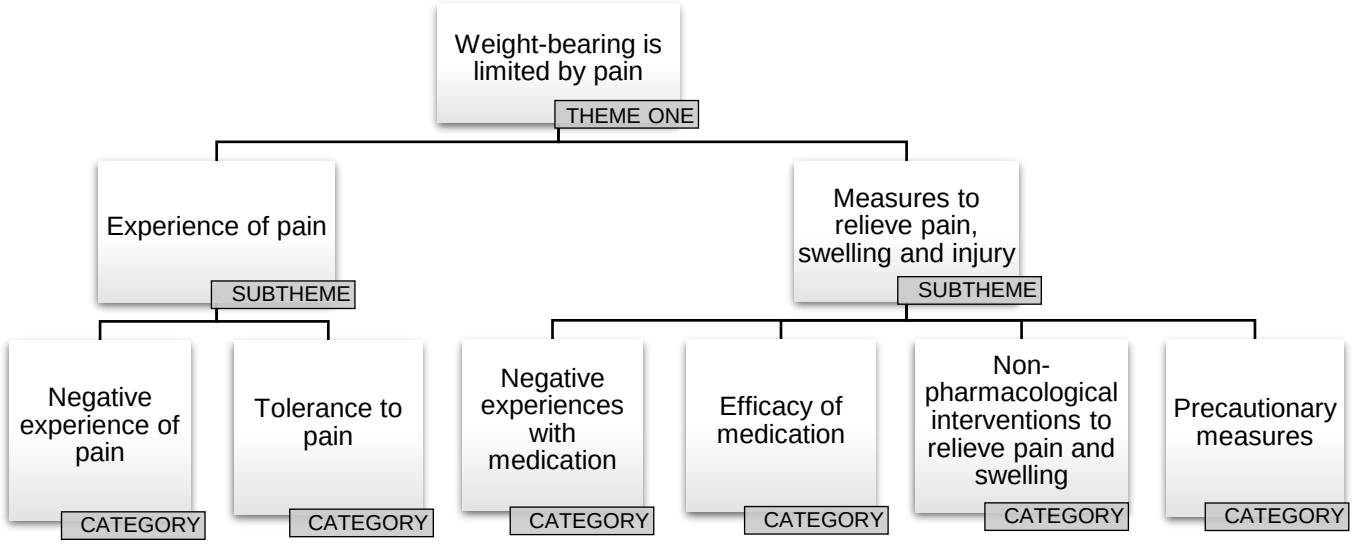


Diagram 4.1 Schematic representation of Theme 1: Weight-bearing is limited by pain

4.3.1.1 Experience of pain

The majority of the participants (89%) experienced pain negatively, especially with weight-bearing and strut adjustments:

> *"When I walk, I want to cry. It's difficult because I feel pain"*
>
> Participant Five

> *"But yes, the adjustments [were] very sore"*
>
> Participant Six

> *"The only time when I feel pain is when I put too much weight on it. Like, if I want to try and walk on it. But then I would just rather not walk on it."*
>
> Participant Four

> *"After the operation, I could have put at least 40 to 50% weight on it. As soon as they started adjusting, realigning, lengthening and all that stuff, then it went down to about 15%. When we were still adjusting, there [were] days that I couldn't put the foot down, because it was just too sore, because it was adjusting and aligning and all that stuff. So, it was just too painful. And then after stopping, slowly, but surely, a little bit more weight, little bit more weight"*
>
> Participant Four

Pain affected sleep in three participants (33%) and daily functionality in five (56%). Four (44%) participants experienced an increased level of pain in the unaffected joints on account of a compensatory gait pattern. According to the participants, this compensatory gait pattern was largely due to the fact that they had to walk with their leg at certain angles to avoid pain caused by the joint limitations in their ex-fix leg. The participants also felt that it was not only their pace that was slow as a result of their high levels of pain, but that their progress was also slow:

> *"I think the pain and all of that keeps one[] awake"*
>
> Participant One

> *"Then every joint is sore because of the way you walk, the way you stand, and everything. It puts pressure on the other joints. So, you don't realize how much pressure you put on them until the day when you would wake up and everything is sore, you know"*
>
> Participant Eight

> *"Let's say I want to try and walk without crutches; it would have been an epic fail. Because of the pain level, but it's only at a certain angle"*
>
> Participant Four

> *"…my progress has been a bit slow because I didn't want to do anything because I was hurting"*
>
> Participant Nine

Other factors that increased the participants' level of pain were swelling in four (44%) participants and pain at the pin-sites in another four (44%) participants. Two (22%) participants mentioned that increased activity levels increased their pain and another two (22%) mentioned that rainy weather increased their pain. Two (22%) participants hurt themselves by slipping and twisting or bumping their leg. The majority (78%) of the participants also felt the need to use an assistive device when walking to reduce their pain:

“The swelling is very sore, when it swells up. So, by the end of the day, it's really very swollen. And then it gets very sore”

Participant Six

“When my leg and my foot swells up, it's like everything is pulling; you can imagine the swelling and this thing is fixed so it doesn't move with it. So that is sore”

Participant Eight

“it’s still a bit sore, where the pins go into the bone or the leg.”

Participant Three

“The only time, if I need pain pills, is when I walk, let’s say, for instance, I have a very active day. And we went out like maybe, shopping, and you know, that type of thing.”

Participant Four

“…some days you get your days that it is sore. And then it's going to rain.”

Participant Eight

Not all the participants, however, had a negative experience of pain. One participant had had a circular ex-fix previously and noted that their pain was less with their current circular ex-fix than what they had experienced previously. Three (33%) participants had been through a large amount of pain with previous procedures and complications over extended periods of time. This had resulted in a desensitisation to pain as they were used to feeling pain and were, therefore, able to do more:

“Less pain. Way less pain than the previous round”

Participant Seven

“...which is a big plus for me, because I've been living with that pain *for the last over a year now. So, constant pain there”*

Participant Eight

4.3.1.2 Measures to relieve pain, swelling and injury

Participants mentioned both pharmaceutical and non-pharmaceutical methods of pain relief. Five (56%) participants had negative experiences with the pain

medication. They mentioned that the medication was not sufficient to reduce the pain or to help them sleep. Two (22%) participants used more medication than prescribed, thus resulting in increased substance use. Side-effects from the medication were also mentioned, namely lower blood pressure and changes in taste affecting eating:

> *"…doctor prescribed pain meds, so I used them more often. Instead of two times a day, I use them three times a day, but hopefully it will get better now."*
>
> Participant Three

> *"…the thing is that in order for her to be better, she has to overdose"*
>
> Participant Four

> *"…the Lyrica® tends to make my blood pressure drop a bit"*
>
> Participant Eight

Although a few participants had negative experiences with the medication, the majority, five (56%), had positive experiences. They mentioned that the medication, especially that for neurological pain, was effective for pain relief:

> "*That's why I used the opioids and I experimented with different ones and then I could [get] through the day."*
>
> Participant One

> *"…if I drink it in the morning and in the evening, I'm actually fine"*
>
> Participant Eight

> *"I was without the Lyrica ® for four days and I don't want to do that again"*
>
> Participant Eight

Pain and swelling were relieved by cycling and general exercises, as well as lying down, elevating, and applying ice to the lower limb. These activities were not only to avoid pain but also to avoid jeopardising the chances of recovery. Two (22%) participants felt it was important to establish precautionary measures to avoid

activities that would put their recovery at risk (e.g. avoiding work in case it caused problems):

"But I am cycling. That helps a lot."

Participant Four

"I mean, if it is swollen, I put it up for an hour, then it is better and I ice it."

Participant Six

"*So it shouldn't be that if I go to work, I put my recovery at risk."*

Participant Two

4.3.2 Theme 2: Psychological factors influence weight-bearing

The participants' state of mind had a large impact on their ability to mobilise and weight-bear. Some participants had a pessimistic state of mind, where others had an optimistic one. What was evident was that the effects of their history, surgeries and complications influenced their current state of mind. Their fear of falling or refracturing their leg also largely influenced their attempt to mobilise or weight-bear without their assistive devices. (See Diagram 4.2 below for a schematic representation of Theme 2). The diagram includes the categories for this theme.

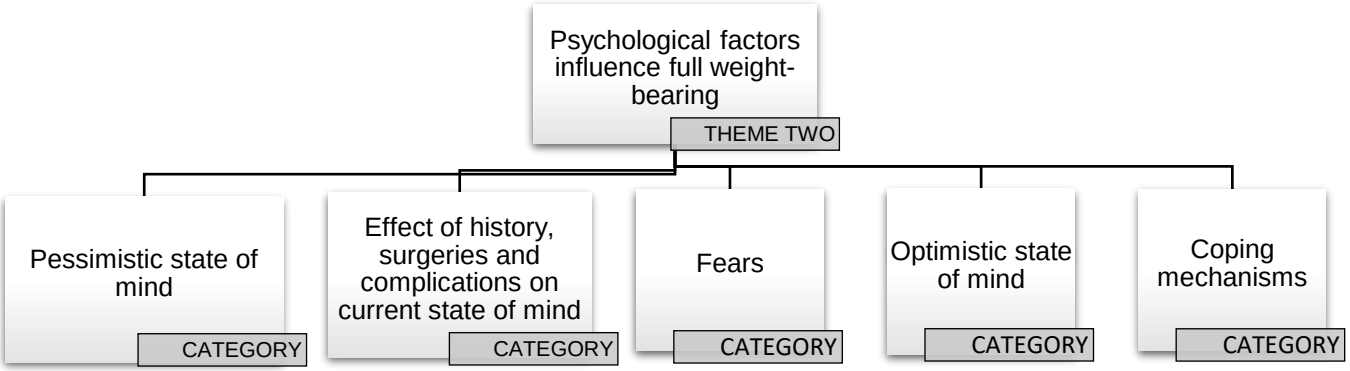


Diagram 4.2 Schematic representation of Theme 2: Psychological factors influence weight-bearing

4.3.2.1 Pessimistic state of mind

Stress, anger, depression, feeling down or upset, frustration, and negativity, are all factors that cause a negative state of mind. For three (33%) participants, other

people's views of their condition also had a negative effect on their mental state. One participant felt that the ex-fix pins also affected them mentally. Two (22%) participants found it difficult to distract themselves from the circular ex-fix, and three (33%) lacked the confidence and trust in the ex-fix to weight-bear:

> *"…it's hindsight that's killing me. To say – "What if?" You know that...[the] What-if situation is killing me mostly. I am quite depressed from that."*
>
> Participant Two

> *"…particularly in the first week or two, very depressed, thinking [what} I've done, made a mistake"*
>
> Participant Nine

> *"…because of the last year, it made me a bit, you know, I was negative for so long…And then you tend to be a bit negative and not feeling well. And you still have to put on a smile, because you can't complain every day."*
>
> Participant Eight

> *"But mentally, you're always aware of it now, with the ex-fix on, you're always aware."*
>
> *Participant Four*

> With regards to weight-bearing, *"I need some confidence."*
>
> *Participant Three*

4.3.2.2 Effect of history, surgeries and complications on current state of mind

The original cause of injury played an important role in the mindset of two (22%) participants. More so, the surgical history and the complications that arose had a negative effect on most (89%) of the participants' mental state. The majority of them had had negative experiences with their previous surgeons. They had also had negative outcomes from the previous procedures that were performed, which resulted in negativity with their current expected outcome:

"So basically, it.... you know, it's not the ex-fix itself. I think it's because of the whole thing that happened, you know, and everything that happened before that tends to catch up with you sometimes."

Participant Eight

"My previous orthopaedic surgeon.... I have proof where he lied to me, he blatantly lied."

Participant One

When asked about their expected outcome: *"…not holding my breath."*

Participant Six

4.3.2.3 Fears

Fear stands out as another influence affecting the weight-bearing possibility of the participants. Three (33%) of the participants had a fear of falling and two (22%) had the fear of refracturing their leg:

"No, I think it's in my head. I'm afraid of falling again, so I normally use something to hold on. Let's say a chair."

Participant Three

"Breaking it again inside the bones. Like I was just nah-ah."

Participant Four

4.3.2.4 Optimistic state of mind

Not all participants had a negative mindset. In fact, five (56%) were positive about their circular ex-fix. One participant noted that they felt a shift to a more positive mindset when they came out of theatre. Five (56%) participants were relieved to be able to weight-bear and could trust that the leg would allow them to stand on it once there was no pain. One participant noted that being mentally strong helped them to push to try to mobilise more. Six participants hoped for a positive outcome, which created a more optimistic mindset:

"There is a hell of a change, you know, even comments I made, when I came out of anaesthesia... My wife said, "You [are] already talking about feeling more positive."

Participant One

"…relieved that I can stand on the leg."

Participant Three

"Well I'm hopeful that the ex-fix fixes it."

Participant Six

"Mentally, I'm full of hope for this op, this ex-fix, so that I can at least walk normal, when they [take] off the frame."

Participant Three

4.3.2.5 Coping mechanisms

The participants mentioned certain activities to help them mentally cope with the idea of the ex-fix. Two (22%) mentioned that distracting themselves about how long the circular ex-fix would be on, helped. One participant mentioned that the focus on a positive expected outcome outweighed the discomfort. Three (33%) participants accepted the possibility of a deformity and one participant even felt that people's reactions to their circular ex-fix were humorous. This same participant felt that researching ways to help get their bone to grow faster helped them to cope:

"Like I said, if I don't think about the amount of time that's still ahead, I'm okay…If I think of the outcome that it can have, that basically outweighs the uncomfortable part of it. Because I know that my leg is going to be healed or well. I am going to have a stiff ankle, but anyway. At least I can walk."

Participant Eight

"I am doing a little count down. I've only got five months to go."

Participant Nine

"People look at you funny in the shopping mall, and that's funny. That's always a fun factor for me."

Participant Four

4.3.3 Theme 3: Physical factors affect weight-bearing

Considerable physical factors pertaining to the human body, as well as the factors pertaining to the circular ex-fix equipment, played a role in the participants' ability to mobilise and weight-bear. Certain biomechanical alterations also needed to be made. (See Diagram 4.3 for a schematic representation of Theme 3.) The diagram includes, from top to bottom, the subthemes and categories for this theme.

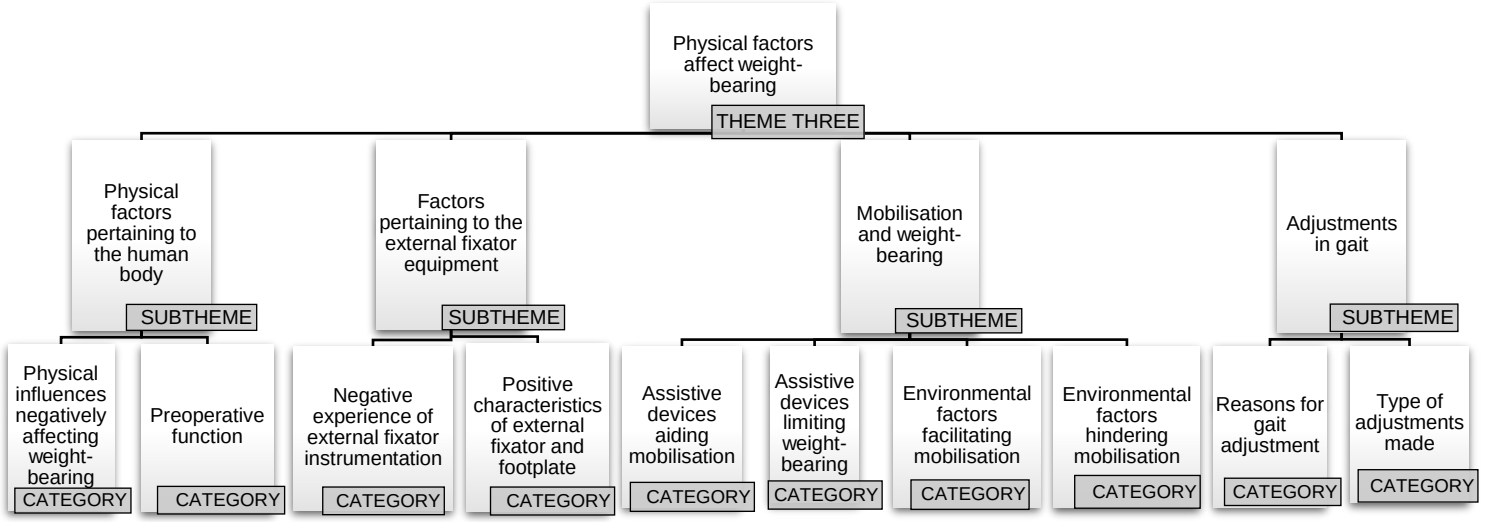


Diagram 4.3 Schematic representation of Theme 3: Physical factors affect weight-bearing

4.3.3.1 Physical factors pertaining to the human body

Certain physical influences negatively affect weight-bearing. Two (22%) participants noted that the presence of wounds and the pulling of the clips on the wounds affected their ability to stand on their leg. One participant felt that their leg was itchy and noted a dead feeling in their toes that affected their ability to feel when walking. Another participant needed to return to theatre for a haematoma. Two (22%) participants struggled to sleep comfortably. They felt that they had to sleep on their back or to use pillows to keep the ex-fix leg straight.

> *"My toes are still dead. So, I can't. I can't feel it."*
>
> Participant Eight

“When you sleep, you don't sleep on the side, you sleep on your back. So it’s now straight.”

Participant Four

The participants also mentioned a negative effect on the musculoskeletal system, namely muscle spasms, muscle atrophy, joint limitations, owing to stiffness, and tension in the leg when trying to weight-bear.

“It's just where the pins are, and then I get these like, it's like, muscle spasms, I don't know... muscle spasm…it makes a knot there between my third toe and this one pin.”

Participant Eight

“I am just losing this calf.”

Participant One

“When you put it down, you can feel there is tension.”

Participant Four

The pre-operative function of the participants also had a positive impact on their post-operative functional outcomes. Two (22%) participants felt that being used to ankle instability and walking with difficulty pre-operatively helped with their post-operative mobilisation. Another participant stated that having had pre-operative strength and balance had also played a role in their ability to mobilise post-operatively:

“....which is a huge plus, because before I couldn't stand on it, [I’d] fall over to my right hand side because [it] just wasn't stable enough.”

Participant Eight

“That's the one thing, that; my ability to balance and the strength of my legs.”

Participant One

4.3.3.2 Factors pertaining to external fixator equipment

Certain aspects of the circular ex-fix instrumentation were mentioned to play a role in weight-bearing. As mentioned above, the pins that pierce the skin caused pain and

had a negative mental effect on four (44%) of the participants. There was also pin-site bleeding present in one participant and pin-site infection present in three (33%) of the participants. One participant even needed help with cleaning their pins.

> *"Just where the entry and exit points are. The infection, the infection caused……caused the pain."*
>
> Participant Six

> *"So, the only thing I've got to clean is the pins, but somebody is gonna help me with that."*
>
> Participant Eight

There were incidents of failure of the circular ex-fix components in two (22%) participants, namely footplates breaking and struts getting stuck. Complications with the circular ex-fix components with their previous surgeries had also caused one of the participants to become wary of weight-bearing with their current circular ex-fix. Five (56%) of the participants felt it was cumbersome and difficult to manoeuvre, especially with the footplate, on uneven surfaces:

> *"No, it's only this foot piece that I break, constantly. I think it's the third time that I'm breaking it."*
>
> Participant Seven

> *"Previously I had one and then when I walked on it, a piece of it broke... actually in my bone. So that is why I'm not walking on it."*
>
> Participant Four

> *"…it's heavy, very heavy, and also, I find that it bashes into my left leg."*
>
> Participant Nine

Two (22%) of the participants, however, felt that the circular ex-fix and the footplate had certain positive characteristics and noted that the size of the circular ex-fix was "*not that bad*". One said that they were better able to mobilise with their footplate and that it improved their balance. They also mentioned that it was easier to walk with the circular ex-fix, while another participant noted that they liked the fact that post-

operatively they could immediately mobilise. One participant mentioned that they were even able to clean their pins themselves:

> *"It's not that difficult. The size is not bad."*
>
> Participant Seven

> *"Because of the....., not just the ex-fix, but because of the....., I call it my shoe, because it's [incomprehensible] tight. You know, in the beginning, it feels like you're gonna fall with it. But as soon as you get used to it, it actually makes standing easier, because, what I can do now.... I can actually stand at the basin and brush my teeth and wash my face without any problems [and] without losing my balance."*
>
> Participant Eight

> *"No, I mean I was up that afternoon, they put it on [in] the morning and I was up and mobile by the afternoon."*
>
> Participant Six

4.3.3.3 Alterations in biomechanics

There were certain biomechanical factors that played a role in mobilisation and weight-bearing. Where assistive devices allowed the participants to mobilise more readily, in seven (78%) cases, these devices resulted in diminished weight-bearing. The participants felt that they could mobilise further with their crutches as they felt safe and that they could protect their other joints from future injuries. They also noted that it was easy to limit weight-bearing with their crutches and wheelchairs, especially when trying to perform activities of daily living:

> *"…you're able to walk more because you feel safer with your crutches."*
>
> Participant One

> *"I do not want to have a hip or a knee replacement…With the help of the crutch or the help of the boot… I can walk without putting stress on any other joint."*
>
> Participant One

"There is weight-bearing on the leg, but with the crutches you can limit it easily."

Participant Four

"But my biggest thing is taking a bath… when I take a bath, I use a skottel [in Afrikaans], because I cannot go to the shower or bath. That's why I use the wheelchair."

Participant Two

"Let's say when I'm making myself a cup of coffee. I can't. How do I walk with the walking frame and the coffee?"

Participant Three

Environmental factors, such as home size and the presence of pets, also play a role. One participant mentioned that their small house made mobilisation safer, whereas the presence of their pets posed the risk of falling:

"Luckily, I don't have a big house…I don't have a big bathroom, so, if I fall back, I'm gonna fall against the washing machine; if I go to the front, it's gonna....., but I don't go sideways."

Participant Eight

"I've got three dogs and my two big dogs [are] a bit of a handful. Especially the one. She's a Pointer.... so, I have to have the crutches. Otherwise, if they bump against me too hard, you know, I [could] fall."

Participant Eight

Seven (78%) of the participants mentioned an adjustment in their gait pattern. This was due to leg-length discrepancies, weakness and an inability to balance. Two (22%) participants noted that the unaffected leg gets injured if the circular ex-fix knocks against it, and six (67%) participants felt it was difficult to function normally. Three (33%) participants lacked the endurance to walk far, and one felt they often lacked the energy needed to mobilise correctly. One participant noted that crutch walking needed to be learnt. Another two (22%) said that owing to the constructs of the circular ex-fix, it remained difficult to walk on uneven surfaces. Clothing

restrictions as a result of the large size of the circular ex-fix also caused discomfort in one participant:

> *"It's only that the one height..... the one [leg]is longer than the other one. That's the only thing."*
>
> Participant Seven

> *"It's not strong enough."*
>
> Participant Four

> *"I don't think it's pain; I just can't balance."*
>
> Participant Two

> *"You knock your good leg against it the whole time and you're full of bruises and stuff."*
>
> Participant Eight

One participant found that wearing a boot to correct their leg length discrepancy and taking longer strides to minimise a limp, assisted in improving their gait pattern:

> *"I put on my boot to make the length of the two legs even… when I['ve] got the boot on, then I can get along without the crutches."*
>
> Participant One

> *"I wasn't really limping..[I] took longer strides… It was kind of easier."*
>
> Participant One

4.3.4 Theme 4: Medical and non-medical support systems

The involvement and lack of involvement from the participants' families, the community and the multidisciplinary medical team had a large influence on the participants. (See Diagram 4.4 for a schematic representation of Theme 4.) The diagram includes, from top to bottom, the subthemes and categories for this theme.

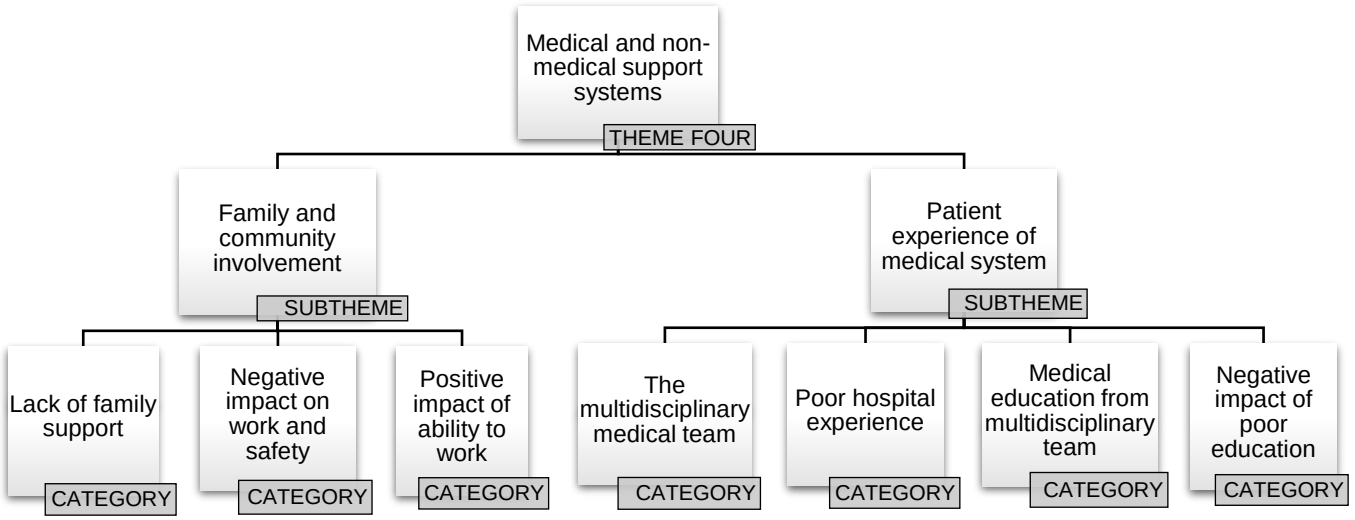


Diagram 4.4 Schematic representation of Theme 4: Medical and non-medical support systems

4.3.4.1 Family and community involvement

The participants' non-medical environment had a negative effect on them. For two (22%) participants, there was a general lack of family support, with their family members no longer wanting to be caregivers. This resulted in a greater need for independence from the participants:

> *"My family structure you know, like, I don't feel that I have sufficient support in [their] hands."*
>
> Participant Two

> *"It makes a huge difference… If you don't have people that support you. My wife gets angry with me because I can't do the stuff that I want [and] that she wants me to do..... because she's not healthy."*
>
> Participant Eight

> *"I want to be independent."*
>
> Participant Two

One participant also mentioned feeling unsafe in the community as they felt they were in a compromised position. They felt that they were being taken advantage of and had to close their business. For three (33%) participants, the unreliable nature of people and the inability to drive were reasons why they struggled to get to work. Two participants, however, did not have difficulty in getting to work, and one participant could carry out their duties from home. Therefore, their ability to work was not affected:

> *"He said: "You know these people are taking advantage of you because they can see that your leg is in pain and you cannot do anything."*
>
> Participant Two

> *"This thing was just expensive for me because now, coming out of my own pocket, and I am not working. I've closed my business, because people are unreliable."*
>
> Participant Two

> *"I can't drive my car, for instance, because I mean, you can imagine you can't drive a car with this thing on. I mean if you get into an accident now, it's your fault."*
>
> Participant Eight

> *"I work on a computer at home. So, I'm like sitting with my leg up. So, workwise, that's not been an issue."*
>
> Participant Nine

4.3.4.2 Patients' experience of the medical system

The multidisciplinary medical team were mentioned as playing an important role in circular ex-fix outcomes. The empathy and honesty of the surgeon were said by four (44%) participants to be important factors, while trust in the surgeon was highlighted. Certain members of the allied health team, for example, the Wound Care sister, were also deemed important. One participant noted that the fast response time of the Wound Care sister reduced the chance of complications:

"And the doctor is caring about what's happening with you and that is very, very..... And that was to me very, very helpful."

Participant One

"I got to the one doctor, before Dr. [FB], and then they just wanted to amputate my leg."

Participant Eight

"So, it took me some time to build trust, now again with Dr [FB], and I think we [have] succeeded in building that trust again."

Participant One

"And within an hour she got a response back. In another hour we got a prescription from the doctor when he came from the theatre…real time and immediacy so that you can take action, before it goes too far."

Participant One

Two (22%) participants mentioned that the professionalism, positivity and support from the multidisciplinary team made them feel positive:

"So when you get to them, and actually they [are] so positive, you know, you just feel like when you go out there, you feel like you [are] positive."

Participant Eight

"In your own mindset, you don't feel left alone. You know we [are] in this together."

Participant One

"Now you have a whole practice that cares about you. And wants to help you, makes the ex-fix itself being not that big a deal."

Participant Eight

One participant had a poor hospital experience and felt the hospital, as well as the nursing support, were not up to standard, and this affected them negatively. They felt that there was a delay in the administration of their medication and a lack of care from the hospital staff:

".....needs serious quality control and updating…the quality of service in the wards is dismal."

Participant One

"You ask for your [a] sleeping tablet and half an hour later they come with it."

Participant One

It was important for the participants to understand how the circular ex-fix worked and one participant mentioned that the way the information is handed over is important. Three (33%) participants felt that the information and education (instruction) on the part of the multidisciplinary team were sufficient. Four (44%) participants felt that they understood the circular ex-fix mechanism of action and that the surgeon explained everything well. One participant mentioned that the recipe for mobilisation from the physiotherapist helped. This recipe is the standard operating procedure taught to physiotherapy students with regards to crutch walking and stairs. It entails the use of the uninjured leg first when going up the stairs and the injured leg going first when going down the stairs. Three (33%) participants were of the opinion that the information on how to avoid injuring themselves was also important, as was the need to follow the doctor's instructions:

So, to have that kind of insight and that's me, you know, I want to understand how something works. If I understand it, then I know what I can do and then [it is] just a matter of starting to do it and trusting it and doing it more and more and you [in Afrikaans] sommer trust."

Participant One

"if [you] can walk, you must also be knowledgeable about how to avoid the inflammation."

Participant Two

"You need to rather do what the doctor says in regard to keeping the alignment and all that stuff."

Participant Four

In three (33%) instances, the participants were poorly instructed and did not understand the methods of distraction with a circular ex-fix. One participant felt that the physiotherapists were unsuccessful in explaining how to mobilise and spoke too fast. Another four (44%) did not follow the doctor's instructions even though they understood what was required of them:

> *"I always know. Now I know there's a gap still, because I saw it on the x-ray; there's still a gap."*
>
> Participant Four

> *"I think that's also with the conversation I had with your physios. It's also an issue where they are too quick."*
>
> Participant One

> *"'Hmm. Look, I don't pump mine up…I don't like it when it's pumped up."*
>
> Participant Seven

4.3.5 Conclusion:

The results above describe the demographic attributes of the participants and the data that were collected from the interviews.

CHAPTER 5: DISCUSSION

5.1 Introduction

This chapter discusses the results of the study in the context of the objectives of the study. They were to describe the demographic profile of the participants and also to explore the four-week post-operative barriers and facilitators for FWB in patients with lower-limb circular external fixators.

5.2 Demographics

Patient demographics played a role in the participant's ability to weight-bear on their leg, as well as in their susceptibility to complications. All participants had a history of injury that caused either a deformity or resulted in the non-union of the bone in their lower limb. All participants' injuries were chronic by nature and circular external fixators were used where other procedures had failed. Circular external fixators have been indicated for the correction of deformities and the non-union of bone, especially where infection is present (Bhowmick et al., 2021; Giannoudis et al., 2021; Siddiqui et al., 2019; Sheng et al., 2021).

Circular external fixators have been said to be the most effective treatment technique for tibia fractures. Literature states an increase in severe tibial fractures in developing countries because of poor road conditions and violent acts, such as gunshots (Algahtani et al., 2021; Cinthuja, Wijesinghe and Silva, 2022; Milenkovic et al., 2021; Sheng et al., 2021). As this study has been performed in a developing country, and circular external fixators are increasingly being used, it is important to better understand the advantages and disadvantages associated with them. Similar to the findings of Cinthuja, Wijesinghe and Silva (2022), most of the traumatic injuries experienced by the participants in this research study resulted from motor vehicle or motorcycle accidents or a gunshot.

Owing to the severity of their injuries, most of the participants had to undergo bone lengthening or deformity correction, achieved by means of distraction osteogenesis. All those who were adjusting their struts, did so post-operatively, and it was at this

stage that they experienced increased pain and therefore, as a result, deliberately reduced their weight-bearing on the affected limb. The pain they experienced could emanate from tissue tension arising from adjustments to and pressure on the pins, or from neural tension (Barker, Burns and Littler, 1999; Sims et al., 2000). Despite this, Liu et al. (2021b) noted that post-operative adjustments are preferred above intra-operative adjustments because in so doing, there is less chance of intra-operative risks.

In a study conducted by Oh et al. (2013) on distraction osteogenesis with a circular ex-fix, these researchers noted that younger patients tend to be more susceptible to complications. In this study, we found that in the case of their previous procedures, most of the participants who had sustained a complication, namely an infection, were also younger. However, most of the participants with a circular ex-fix who had developed a complication were older. Literature states that females are less susceptible to infection, but there were an equal number of infections among the male and female participants in our study (Reid et al., 2022). Diabetes has been mentioned as the main comorbidity to predict deep infections and to affect bone healing (Liu et al., 2022). The two participants with diabetes had a history of a high occurrence of infections and refracturing the leg. The three participants who were obese all struggled with infection and pressure on the rings as a result of their increased leg circumference with the swelling of their lower limbs. This is in line with the findings in literature that state that obesity is one of the top five comorbidities that increase the chances of a complication (Reid et al., 2022). The other comorbidities that presented in the participants were lupus, hypertension and spina bifida. The participants of this study with lupus or hypertension had a higher pre-operative refracture rate. On the other hand, however, the participant with spina bifida did not seem to have any specific complications. In the literature, lupus was not mentioned as a factor playing a role in the prevalence of complications with a circular ex-fix. Hypertension, however, was listed as one of the top five comorbidities that increase a patient's chance of developing a complication (Reid et al., 2022).

The positioning of the circular ex-fix is also of importance. Normal joint mobility is possible when walking with a circular ex-fix as long as it does not cross over the joints (Tripathy et al., 2021). This was evident with most of the participants who had

full ROM of all their joints when the circular ex-fix was not spanned over any joints. However, joints can also be immobilised by fitting a circular ex-fix across a joint (Paola et al., 2021). In fact, owing to the circular ex-fix that was fitted across this joint, the remaining five participants were not able to mobilise their ankles. All of those participants who had the circular ex-fix over their foot, were fitted with a footplate. Only one of these participants felt that the footplate made walking easier; the others felt that it was a hindrance as it lengthened their leg to too great an extent. The footplate is meant to offer more stability and thus to improve mobility (Martin and Chow, 2021).

Most of the participants had undergone more than one surgical procedure previously. The number of previous procedures received by the participants ranged from zero to 25 (a mean of six (6) procedures). In their study about the correction of simple and complex deformities using a TSF, Naqui et al. (2008) found that the ex-fix was superior to other correction techniques as it eliminated the need for multiple procedures. These authors noted that the number of previous procedures a patient had undergone played a role in this respect. However, they did not expand on what role the ex-fix played. Siddiqui et al. (2019) conducted a study on the impact of the Ilizarov fixation technique on the limb's functionality and the self-esteem of patients with unilateral tibial fractures. They also mentioned that the number of previous procedures played a role, but they too did not mention the nature of the role that this factor played. Most previous procedures were ORIFs or monolateral external fixators which have been noted to be less indicated when used for complicated tibial fractures as they are less secure than the circular ex-fix (Bayrak et al., 2021; Bhardwaj et al., 2019; Zein et al., 2021). All the participants who had previously received a circular ex-fix had experienced complications of pin breakage, infections, refracture and deformity development. All these complications are known complications noted in the literature on circular external fixators. (Algahtani et al., 2021; Oh et al., 2013). These complications amplified the fear around developing complications again in two of the participants as their complications had occurred while the circular ex-fix was *in situ*, and their ability to weight-bear declined as a result of this. The other two participants were able to mobilise more successfully with their circular external fixators as having had one before, they were less fearful of this

mechanism. In fact, their complications had arisen only after the ex-fix had been removed.

The participants were also subjected to financial pressure as a result of their vulnerability at having to wear a circular ex-fix. One participant felt the need to close their business as they were situated in the rural sector and felt defenceless with the circular ex-fix being visible. Other participants that were back at work had greater functionality than those that were not working or awaiting their return to work. However, because they were working with the use of a wheelchair, they were weight-bearing less. Various studies have been conducted on the impact of functionality of those that are the breadwinners and have no choice but to return to work. These studies show that the patients who returned to work earlier achieved greater functionality sooner, but also FWB sooner than their non-working counterparts. By six weeks post-operatively, they had all returned to work (Cinthuja, Wijesinghe and Silva, 2022; Sengodan and Sengodan, 2012).

5.3 Factors acting as both barriers and facilitators to full weight-bearing with a circular external fixator

Clinical observations have shown that most patients with a circular ex-fix do not weight-bear early enough. It is therefore important to discuss the barriers and facilitators to FWB as early weight-bearing facilitates bone growth (Augat, Hollensteiner and von Rüden, 2020; Fenton et al., 2021).

5.3.1 Effects of pain and management of pain

Pain stands out as the largest influencing factor to weight-bearing. Pain, along with pin-site infection, is one of the most common complications in a patient with a circular ex-fix (Aziz et al., 2020; Bhardwaj et al., 2019). Most participants experienced pain while weight-bearing. As the main aim for ex-fix rehabilitation is to mobilise FWB as soon as possible, not being able to weight-bear as a result of pain, is a major barrier. (Amaro et al., 2020; Bhardwaj et al., 2019; Hernigou, 2016; Reddy and Radhakrishna, 2019). Literature states that patients need to be educated on the diverse types of pain and what can be done for them (Sims et al., 2000).

Uncontrolled pain in the ex-fix patient could lead to immobility, noncompliance, mentally rejecting the ex-fix, and depression (Sims et al., 2000). As mentioned in the section on the demographic aspects of the patients, pain was also found to be significantly more intense when adjustments are made to the circular ex-fix. This pain resulted in the participants having to reduce the amount of weight that they put on their leg. This was confirmed by Liu et al. (2021b) in their study evaluating the difference between intraoperative and postoperative adjustments for deformity corrections. They found that gradual deformity correction post-operatively with strut changes caused more pain. Ostiak and Koczewski (2009) noted that one of the main features of ex-fix use is the pain occurring during the whole treatment process. They evaluated the level of pain during each stage of treatment. They aimed at defining the connection between the intensity of pain and type and location of the ex-fix. They also evaluated the type of treatments they received, the patients' activity levels and etiology. They analysed 64 patients that had been treated by an ex-fix on their lower limb, aged between 13 to 72 (mean 23.7). They found that there were different pain patterns depending on the type of treatment they had received and their activity levels. Those that underwent lengthening had a quick increase in pain in the initial stages of treatment. Conversely, those that had an ex-fix to stabilize a fracture or for non-union of bone had lower pain levels, as did those that were less active. The area of ex-fix attachment also played a role, with those with a tibial ex-fix having the greatest amount of pain. The findings on the etiological influences on pain intensity were that patients that had the ex-fix for a non-united bone had less pain than the other conditions that required an ex-fix. All these findings were in line with the findings of this study.

It has also been noted that neural structures have difficulty adjusting to lengthening which could also increase pain and affect mobilisation (Barker, Burns and Littler, 1999). Soft tissue can also be irritated enough by the ex-fix pins to limit joint ROM (Barker, Burns and Littler, 1999). However, Lally, Seligson and Stanwyck (1981) found that the pain on the pins caused by pulling on the soft tissue was relieved once the soft tissue had adapted. The participants mentioned that their pain was mainly due to swelling at the pin sites, while other participants felt pain because of injuries sustained by falling or knocking their leg. Others noted that rainy weather increased their pain levels. They also found that they had certain joint limitations owing to their

pain, especially when their feet were at a certain angle. Numerous participants mentioned that the compensatory gait that they had adopted had caused pain in other joints, such as their knees, hips, or backs. They also felt the need to use their assistive devices, such as their walking frames, to help them mobilise. Yet they still experienced a lower level of functionality as a result of their pain. Some participants felt that with regard to mobilisation and weight-bearing, they were not progressing at the pace at which they would have wanted to. Others felt that they were not able to move as fast as what they would have liked to. When participants were more active, there was a definite increase in their level of pain. This was in line with the findings of Ostiak and Koczewski (2009). In some instances, pain even kept the participants awake at night.

Despite this strong negative influence of pain in the majority of the participants, there were some participants that did not experience such high pain levels. It is important to note that pain is a unique, complex and subjective experience, as only the individual knows the nature of his/her pain (Sims et al., 2000). Therefore, each patient will experience pain differently. One participant who had had a circular ex-fix previously mentioned that their pain was less than that experienced with the previous circular ex-fix. Another noted a better level of tolerance to pain as a result of having previously been desensitised to pain in previous experiences with their injury. In their study about circular external fixators with vascular injuries, Jin et al. (2022) found that circular external fixators improve the quality of life and reduce the pain levels in these patients. Therefore, further studies may be necessary to evaluate the full effect of pain on weight-bearing.

Carr (2008) found that patients have a poor understanding of pain management which results in insufficient pain control because of low expectations of pain relief. Pain has been accepted as a foreseeable part of surgery but the nervous system can change in response to long term pain that has not been relieved, which becomes known as chronic pain. Anxiety around surgery has also been found to increase the level of pain. Carr (2008) also noted that deficient education in the health care professionals that work with surgical patients means they lack the necessary skills to correctly treat these patients. They have also noted that this often results in

unnecessary delays in the administration of pain medication in the hospitals. This was mentioned to be a problem by one of the participants.

Most types of pain can be managed with oral analgesics (Liu et al., 2022; Liu et al., 2021b). This was the case with many of the participants, especially those using medication for their neural pain. However, in certain instances, the pain caused the participants to not only use more medication than that prescribed, but to use other forms of medication, such as sleeping tablets or medication for anxiety. They were quick to say that the pain medication they were receiving was insufficient for their level of pain or for assisting them to sleep. Since the doctor did not prescribe this medication, there was, therefore, an increased amount of substance use. As noted by Sims et al. (2000), the intake of patient-controlled pain medication delivers satisfactory results. Although, it may be evident that more control from the doctor is required, some medications, even when prescribed, have adverse effects. Those participants that had a lowered blood pressure caused by their medication could not mobilise as they were afraid they might fall. One participant even felt a change in their taste sensation and as a result went off certain foods. This can be important as diet can affect bone healing (Sims et al., 2000). Despite the factors mentioned above, it is important that patients should not leave their pain medication and try to cope without it (Sims et al., 2000). One of the reasons for loss of ROM in the early post-operative phase is insufficient pain medication (Barker, Simpson and Lamb, 2001; Malkova and Borzunov 2021). Therefore, adequate pain medication is very important for patient compliance (Sims et al., 2000).

5.3.2 Adequacy of education

It is also important to educate patients about the circular ex-fix mechanism of action and post-operative care. Robbins (2021) noted this in their study about deformity correction surgery for Blount's disease and was of the opinion that the patient's ability to comply with and understand circular ex-fix adjustments and care is important (Robbins, 2021). Where the literature states that education is necessary, it is imperative to note that it is not only the surgeon, but also the multidisciplinary team, that needs to inform and give clear instructions to the patient. One participant felt that the physiotherapists that treated him/her were not proficient in their

explanatory technique and talked too fast. Nevertheless, this person did feel that their recipe for mobilisation helped. Education is a particularly important aspect of physiotherapy treatment in the acute and sub-acute phases (Barker, Simpson and Lamb, 2001; Lally, Seligson and Stanwyck, 1981). Therefore, physiotherapists should not only focus on rehabilitation, but also on the delivery of information to their patients. Good rapport needs to be built and physiotherapists should answer all the patient's questions, reassuring them in times of doubt (Lally, Seligson and Stanwyck, 1981). In the late 90s, Barker, Burns and Littler (1999) conducted a survey on current practice in physiotherapy for patients with a circular ex-fix and found that most physiotherapists are of the opinion that this is a specialised field that requires further studies and specialised attention, and not just conventional orthopaedic physiotherapy treatment. In the late 90s, 80% of physiotherapists identified the need for better defined protocols and more information on the care of ex-fix patients (Barker, Burns and Littler, 1999). Although Barker and Burns (2001) conducted a study two years later, with a proposed treatment protocol, there are no recent studies in this regard, and there is still a need to upgrade protocols and update information on physiotherapy in ex-fix care. It is important for physiotherapists to have a detailed knowledge of the limitations of the external fixators, as well as the treatment protocols (Lally, Seligson and Stanwyck, 1981). In this study, the level of education in some instances proved to be adequate, but in others, the participants seemed to be uninformed about the ex-fix mechanism of action and rehabilitation. Some participants understood the mechanics of the circular ex-fix and its method of action and also felt that they were knowledgeable about how to avoid injury. On the other hand, there were others who did not understand the method of distraction, and, because they were worried about damaging the fracture gap created by the distraction osteogenesis, did not, therefore, want to weight-bear. It is, therefore, important that the doctor and multidisciplinary team should correctly explain this information to the patients.

It is also important for the patients to follow the doctor’s instructions. Some of the participants did not do so with regard to their mobilisation, medication regime or the correct use of their footplate. One participant was even seeking other answers for bone growth such as the use of corticosteroids. Patient compliance with regard to ex-fix care is essential (Hadeed, Werntz and Varacallo, 2022). Failure to mobilise and

weight-bear, as well as a general lack of compliance, have for decades been noted to be ex-fix complications (Barker, Burns and Littler, 1999; Bayrak et al., 2021). Therefore, it is also important to understand the patient's ability to cooperate or comply post-operatively to restrict complications (Martin and Chow, 2021).

5.3.3 Functional Outcomes

A few participants did not want to perform certain activities, such as weight-bearing, or even going to work, as they did not want to do anything that they felt could jeopardise their recovery. This in turn affected their level of functionality. Giannoudis et al. (2021) found that functionality was still impaired at the medium-term post ex-fix removal follow-up, but in their study, functional outcome scores were only evaluated after the external fixators had been removed. The participants demonstrated that normal functioning with a circular ex-fix was impaired by their being overly cautious or abusing assistive devices. The main advantage of circular external fixators is that patients can use the limb functionally for the entire treatment time, allowing for early return to function (Malkova and Borzunov, 2021; Reddy and Radhakrishna, 2019; Sheng et al., 2021; Zein et al., 2021). However, in this study there is generally a large dependence on assistive devices to achieve higher functional levels. Literature states that patients should be mobile on crutches (Sims et al., 2000). In fact, patients should start with weight-bearing activities with their crutches one week after surgery (Liu et al., 2021a). However, the use of assistive devices could be both positive and negative. Participants mentioned being able to mobilise more rapidly with their crutches, but in many cases, they were actually limiting their weight-bearing with their crutches. Where being more mobile may seem to be a facilitator, using the crutches to reduce weight-bearing to achieve greater mobilisation is in fact a barrier to weight-bearing. Coglianese, Herzenberg and Goulet (1993) noted the importance of doing weight-shifting exercises without assistive devices to ensure sufficient weight-bearing. Many of the participants were able to mobilise with their crutches or walking frame because they felt safer with these assistive devices. On the other hand, there were others who felt they used their crutches or walking frame to prevent injury, especially to their other joints. Even though they placed less weight on their leg than what was recommended, those that did use their crutches and walking frames were placing more weight on their legs than those using their wheelchairs

most of the time. Several authors have noted the importance of early weight-bearing and the fact that bone growth is achieved by early weight-bearing even with the use of crutches (Malkova and Borzunov, 2021; Zein et al., 2021). Numerous participants used a wheelchair to function more easily and to perform their activities of daily living, such as bathing, cooking, or working. Although one of the main goals with an ex-fix is to return to normal activities of daily living (Liu et al., 2022), using a wheelchair to function is a barrier to weight-bearing. The patient's ability to perform basic hygiene and grooming is, however, very important (Robbins, 2021). Some participants used their crutches or walking frame occasionally but spent most of their time in their wheelchair. Others used their wheelchair when their legs were sore, and they wanted to reduce their weight-bearing.

The environment in which the patient is mobilising also plays a role. One participant felt that they could easily stand and function in their bathroom without any assistive devices, and because it was so small, that if they were to fall, they would fall against something. This facilitated weight-bearing. The same participant stated that they felt safer when moving around the house in their wheelchair because they had dogs which were a fall risk. The work environment is also important to note. Where some individuals were unable to work owing to an unsafe environment or not being able to drive, others could work from home, while sitting in their wheelchair. In both instances the participants were less active, less mobile and therefore weight-bearing less. In their study about the role of mechanical stimulation in the enhancement of bone injury, Augat, Hollensteiner and von Rüden (2020) noted that early weight-bearing is beneficial in the sense that it can increase the patient's functionality and that such patients might then be able to return to work earlier. This has not been the case in this study. Sengodan and Sengodan (2012) found that on average patients that were labourers were already able to FWB at 11.6 days. In most cases, being the breadwinner often means patients must return to work as soon as possible (Cinthuja, Wijesinghe and Silva, 2022; Sengodan and Sengodan, 2012). Where the patients can FWB, returning to work is a facilitator to weight-bearing, but where they are unable to do so, returning to work where they would be using a wheelchair would be a barrier. Furthermore, those participants residing in a rural setting indicated that they felt unsafe in the community, that they were in a compromised position and that people were taking advantage of them because of their physical state. One

participant had to close their business as a result and did not leave their house, as the only way he/she was mobile was with a wheelchair when at home, this proved to be a large barrier to weight-bearing.

5.3.4 Circular external fixator components

There was also a difference in opinion on the circular ex-fix itself. Numerous participants felt that the ex-fix was cumbersome and difficult to manoeuvre. The physical constraints and inconvenience of the circular ex-fix have been frequently mentioned in literature (Aziz et al., 2020; Barker, Burns and Littler, 1999; Bhardwaj et al., 2019; Gubin, Borzunov and Malkova, 2013; Horas et al., 2015; Naqui et al., 2008; Vitale, Miller and Jimenez, 2006). Circular ex-fix frames were said to be cumbersome, heavy, uncomfortable, and bulky; they make day-to-day activities difficult; and hinder the patient's ability to walk (Algahtani et al., 2021; Hidayat et al., 2022). This is especially true of the circular external fixators and noted as one of the top complications, causing them to be less acceptable to patients (Aziz et al., 2020; Bhardwaj et al., 2019; Fernando et al., 2021). The participants also felt that it was difficult to walk with the footplate on uneven surfaces as it did not give way. All of these perceptions make the constructs of the circular ex-fix and the footplate barriers to weight-bearing. Some participants, however, felt that the size of the circular ex-fix was not a problem and that they were better able to mobilise and balance with the footplate. The footplate is meant to offer more stability to the foot (Martin and Chow, 2021).

Some authors noted that external fixators have also been found to be easy to handle (Milenkovic et al., 2021). One participant mentioned that they were able to walk more easily with the circular ex-fix than what they could have managed before the procedure as their leg felt more stable. Another participant was happy about the fact that the circular ex-fix allowed them to mobilise immediately. It is indeed a fact that circular external fixators offer a quicker time to mobilisation than any other method of fracture management (Aziz et al., 2020). As such, the circular ex-fix and footplate could also be facilitators to weight-bearing.

Certain complications with the circular ex-fix equipment have caused a barrier to weight-bearing. One participant, for instance, kept breaking their footplate, while another struggled with the strut of the circular ex-fix getting stuck. Some participants even had a history of complications with their previous circular external fixators; for example, the pins breaking off in their bone. These complications made them cautious to weight-bear out of fear of such a complication arising again. The pins that pierce the skin were also mentioned to be a problem. Other than the pain they caused, as mentioned earlier, the participants struggled with both bleeding and infection at the pin sites. In these instances, the patients could not weight-bear. The presence of bleeding from a pin site may be due to a false/pseudoaneurysm, caused by biological or physical damage to the arteries (Pathinathan et al., 2021). The most recent studies describe pin-site infections and the loosening of pins and wires to be two of the main complications issuing from external fixators (Algahtani et al., 2021; Bhardwaj et al., 2019; Fernando et al., 2021; Jin et al., 2022). These cause an increased level of pain, which reduces the patient's ability to weight-bear (Aziz et al., 2020; Bhardwaj et al., 2019; Green, 1990). These infections can easily be treated with good pin care hygiene and oral antibiotics (Elbatrawy and Ragab, 2015; Naqui et al., 2008; Oh et al., 2013; Reinke et al., 2021; Sengodan and Sengodan, 2012). Owing to the length of the period over which the external fixators are worn, patients need to manage their own pin-site care, and education in this respect is very important (Sims et al., 2000). Some participants could clean their own pins, but others needed help in doing so. The pins that penetrate the muscles and tendons also influence their ability to work and the mobility of their joints (Wade, Roberts and Richardson, 1999; Zak and Wozasek, 2013). Owing to the pulling on the skin by these soft tissue impalements, swelling, pain and scarring can all result in stiffness and immobility (Barker, Burns and Littler, 1999; Bayrak et al., 2021; Biz et al., 2021; Cinthuja, Wijesinghe and Silva, 2022; Hadeed, Werntz and Varacallo, 2022; Martin and Chow, 2021; Reis, 1991). However, Lally, Seligson and Stanwyck (1981) found that the pain issuing from the pulling of the pins on the soft tissue was lessened once the soft tissue had adapted. It is evident that the circular ex-fix and footplate could either be a barrier or a facilitator to weight-bearing. This would depend on the patient and the complications that might arise from the circular ex-fix components.

5.4 Barriers to full weight-bearing with a circular external fixator

Where some elements were a barrier *and* a facilitator to weight-bearing, depending on the participant, their experiences or complications, others were only barriers.

5.4.1 Effects of patient history

The research study found that weight-bearing is influenced by not only previous problems with a circular ex-fix itself, but also the patient's history of surgery and complications. The cause of the injury and previous negative outcomes had a negative effect on participants' mindsets. Several participants felt like victims and this negative mindset affected their ability to mentally recover from the incident; they were more passive and spent more time in a wheelchair. The bad experiences they had had with their previous surgeons made them cautious in trusting their current situation, and some participants were apathetic towards their expected outcome. Literature states that the number of previous operations plays a significant role in the management of an ex-fix but does not mention the effects of previous complications or mismanagement (Naqui et al., 2008; Siddiqui et al., 2019).

5.4.2 Psychological impact of circular external fixator

Multiple authors have mentioned that the psychological factors surrounding wearing an ex-fix should be considered (Gubin, Borzunov and Malkova, 2013; Vitale, Miller and Jimenez, 2006). This is because certain psychological factors may affect compliance with regard to mobilisation and weight-bearing (Elbatrawy and Ragab, 2015; Naqui et al., 2008; Oh et al., 2013). Vitale, Miller and Jimenez (2006) noted that the psychological stresses associated with an ex-fix are a serious complication. There is, however, minimal literature on the psychological impact of external fixators on patients (Siddiqui et al. 2019). A negative state of mind was found to be a large barrier to weight-bearing in the participants as they did not want to do much while feeling that way. They noted feelings of depression, feeling down or upset and were angry and frustrated. Literature states that psychological factors may contribute to the general discomfort of a patient (Sengodan and Sengodan, 2012). More recently, researchers have found that emotional factors such as depression and post-traumatic stress disorder could even affect the patient's prognosis (Jin et al., 2022).

The stressful unresolved personal challenges that participants face with friends and family also need to be addressed. One participant found that what people thought of their ex-fix had a negative effect on them. Indeed, circular external fixators have been found to have a negative impact on self-esteem (Siddiqui et al., 2019). Participants also lacked confidence and trust in their ability to weight-bear. Matters such as the pain caused by the pins had a negative mental effect on the participants, and they expressed their difficulty in distracting themselves from the circular ex-fix. Psychological issues arising from their pain, as well as the psychosocial limitations from having to wear the ex-fix for a long period, resulted in patients not accepting the ex-fix (Barker, Simpson and Lamb, 2001; Liu et al., 2021b; Malkova and Borzunov 2021; Sims et al., 2000). It was noted that the participants should be educated on certain activities (e.g., watching television, listening to music, pursuing hobbies and going out with friends) to avoid ex-fix preoccupation (Sims et al., 2000). Physiotherapists have to be aware of any psychological problems and then provide the necessary support (Barker and Burns, 2001). Fear also stands out as a major barrier to weight-bearing, where most of the participants were found to be afraid of falling or refracturing their leg. Fear of moving could also result in a loss of ROM (Barker, Simpson and Lamb, 2001; Malkova and Borzunov 2021). Patients should be encouraged to live as normally as possible in order to avoid isolation and resentment of the ex-fix (Sims et al. 2000).

5.4.3 Physical barriers to weight-bearing

There are also numerous reasons for an adjustment in gait and in turn, less weight-bearing. As seen above, these include physical constraints and the inconvenience of the circular ex-fix that affects gait pattern and quality of life (Aziz et al., 2020; Barker, Burns and Littler, 1999; Bhardwaj et al., 2019; Gubin, Borzunov and Malkova, 2013; Horas et al., 2015; Naqui et al., 2008; Vitale, Miller and Jimenez, 2006). The participants felt that a lack of strength in the leg and an inability to balance were major barriers to weight-bearing. Pawik et al. (2021) noted that complicated therapy is necessary to improve limb biomechanics and enhance quality of life by improving proprioception and muscle strength. A leg length discrepancy arising from the circular ex-fix leg being longer as a result of the footplate was also mentioned by the

participants as a barrier to weight-bearing. It is not only difficult to mobilise on uneven surfaces but also to function normally.

Most participants could not walk for long periods or distances, and one experienced a lack of energy as a result of dietary changes, as their sense of taste had been affected by the medication. Participants also had to adjust the way they were walking because the circular ex-fix was constantly hitting their other leg and injuring it. Literature mentions the fact that the circular ex-fix hampers the patient's ability to walk when they try to protect the opposite limb (Algahtani et al., 2021; Hidayat et al., 2022). Some participants struggled because crutch walking is a skill that needs to be learnt and, if possible, patients should practice doing so before their procedure. Others felt that they had certain clothing restrictions that caused discomfort. Physiotherapists should educate their patients about certain changes that need to be made, such as clothes needing to be adapted with zips, press studs or Velcro, and the circular ex-fix frame needing to be covered (Sims et al., 2000).

There were also certain negative effects on the musculoskeletal system issuing from the circular ex-fix. Joint stiffness and muscle weakness and spasms made it difficult to fully weight-bear. Owing to a lack of use and atrophy, some participants also noted the fact that the muscles in their legs were disappearing. Impaired joint ROM, as well as the weakening of muscles could impair the function of a lower limb fitted with a circular ex-fix (Pawik et al., 2021). Where the pins pierce muscles and tendons, they influence the joint mobility and the ability of these soft tissue structures to function (Wade, Roberts and Richardson, 1999; Zak and Wozasek, 2013). Joint stiffness and muscle weakness are known circular ex-fix complications (Aziz et al., 2020; Bhardwaj et al., 2019; Green, 1990). Evidence shows that early mobilisation exercises of the joints and weight-bearing improve muscle function and use (Bayrak et al., 2021). It is the role of the physiotherapist to maintain joint ROM, improve muscle strength and length and re-educate gait (Barker, Burns and Littler, 1999; Elbatrawy and Ragab, 2015). Gait re-education is indeed an important part in the rehabilitation of patients with an ex-fix (Zhang, 2010). Physiotherapy and functional dynamic splinting are important in reducing the chances of developing stiff joints and muscle weakness with an ex-fix *in situ*. They may prevent or minimise the limitations in joint ROM all together (Zak and Wozasek, 2013). Pain from tissue tension arising

from adjustments and pressure on the pins, or neural tension, are also all known complications associated with a circular ex-fix, especially when adjustments are being made (Sims et al., 2000). The participants also complained about feeling a general tension in the leg when trying to weight-bear.

Other physical factors affecting weight-bearing negatively are the presence of wounds, as well as pulling on the wound clips. Because circular external fixators allow for easier wound care without compromising fracture stability, they are often accompanied by larger wounds (Aziz et al., 2020). Several participants struggled to find a position in which they could sleep. Correct limb positioning while you are asleep is very important in reducing the occurrence of contractures (Bhardwaj et al., 2019; Green, 1990). Some participants struggled with itchiness in their leg, whereas others experienced diminished sensation. Literature has noted that nerve injury such as paresthesia or nerve palsy and compression of tendons and ligaments can affect mobility (Cinthuja, Wijesinghe and Silva, 2022). The neurological damage that could occur with a circular ex-fix can be both permanent or temporary (Zein et al., 2021). Despite no new orders around weight-bearing, one of the participants even had to return to theatre as a result of a haematoma, which set them back with their mobilisation. On occasion, pseudo-aneurysms from trauma or infection cause bleeding into the surrounding soft tissue (Pathinathan et al., 2021).

5.4.4 Effect of insufficient support structures

Family involvement is also important in the rehabilitation of patients who have been fitted with an ex-fix. This research study found that a general lack of a support structure at home necessitated independence on the part of the participants. This was found to be a barrier to weight-bearing as it forced the participants to mobilise in a wheelchair to achieve more. As most participants had been in and out of hospital and were needing help over a long period of time prior to the fitment of their circular ex-fix, they felt that their significant others had become mere caregivers. In one instance, the participant’s spouse left them, while another one’s partner would no longer drive the patient to their necessary appointments. More recent studies mention a need to assess the impact of ex-fix treatment on both caregivers and patients (Reid et al., 2022). One of the main barriers to fracture management in

developing countries is family ignorance (Cinthuja, Wijesinghe and Silva, 2022). Another barrier is the lack of expertise and inadequate theatres and healthcare facilities (Cinthuja, Wijesinghe and Silva, 2022). One of the participants mentioned their poor hospital experience with regard to the nursing staff and their dissatisfaction with the hospital standards. They felt that the staff did not care and that there was a delay in the administration of their medication. Insufficient pain medication in the early post-operative phase has been linked to possible loss of joint ROM and function. Since these may affect a patient's ability to weight-bear, they are important barriers to note (Barker, Simpson and Lamb, 2001; Malkova and Borzunov 2021).

5.5 Facilitators to full weight-bearing with a circular external fixator

Despite the list of barriers, or facilitators that are also barriers, there are many facilitators that positively impact on weight-bearing with a circular ex-fix.

5.5.1 Methods of improving function and joint range of motion

There are several efficient non-pharmacological ways to relieve pain. Some participants needed to lie down or elevate and place ice on their leg to lessen their pain and swelling. Since the patient may struggle to dorsiflex their ankle with a lower limb ex-fix, it is important to control the pain and swelling. This in turn affects their mobilisation (Wade, Roberts and Richardson, 1999). Furthermore, as a result of a soft tissue impalement pulling on the skin, swelling and pain may also result in stiffness and immobility (Barker, Burns and Littler, 1999; Bayrak et al., 2021; Biz et al., 2021; Cinthuja, Wijesinghe and Silva, 2022; Hadeed, Werntz and Varacallo, 2022; Martin and Chow, 2021; Reis, 1991). Education is especially necessary in cases of infection, where rest and elevation are important, joint ROM exercises should also continue (Sims et al., 2000). Some participants felt that general exercises and cycling diminished their pain and made weight-bearing easier. In an article written by Sims et al. (2000), the authors noted that closed chain and weight-bearing exercises were beneficial in improving function. However, not all patients could do them, with the result that functional exercises such as cycling or rowing were performed instead (Sims et al., 2000). This is helpful since immobility may increase swelling as a result of venous and lymphatic insufficiency when the muscle isn't being contracted (Reis, 1991).

5.5.2 Physical measures to improve gait

In some instances, the participants made certain adjustments to improve their gait and better weight-bear. By wearing a boot on the unaffected leg that corrected their leg length discrepancy and by taking longer strides, they could diminish their limp and transfer more weight onto the circular ex-fix leg. In this respect, literature limits its discussion to a shoe for the circular ex-fix limb. Researchers propose a hard shoe with an elastic band to keep the foot in a neutral position (Liu et al., 2022). Specialised footwear has indeed proven beneficial in maintaining ankle ROM and reducing the number of knee flexion contractures. Furthermore, foot protection is said to be an important part of treatment. (Donnan et al., 2016). As such, it is important for the physiotherapist to arrange for the necessary shoes pre-operatively (Sims et al., 2000). Gait re-education has also been noted to be an important part in the rehabilitation of patients with an ex-fix (Barker, Burns and Littler, 1999; Barker and Burns, 2001; Elbatrawy and Ragab, 2015; Zhang, 2010). Physiotherapists and surgeons should continuously encourage patients to follow a normal gait pattern while putting as much weight on the ex-fix limb as possible (Green, 1990). Participants also mentioned that being used to difficulty in walking pre-operatively made post-operative mobilisation easier. Some of the participants that had elected to have surgery said that their pre-operative strength and ability to balance facilitated their gait and ability to weight-bear post-operatively. As such, certain post-operative factors need to be part of the pre-operative plan. The patient's ability to mobilise pre-operatively should be part of the plan for post-operative preparation (Robbins, 2021). A pre-operative physiotherapy programme should be given where possible (Barker, Simpson and Lamb, 2001; Sims et al., 2000). Furthermore, pre-operative physiotherapy treatment may also be beneficial if there are pre-existing issues in the joint ROM that can be addressed (Zak and Wozasek, 2013).

5.5.3 Psychological variations that facilitate weight-bearing

In the rehabilitation of the ex-fit participants in this research study, not only physical adjustments to facilitate weight-bearing were made. Certain psychological factors were also considered. Psychological factors may indeed contribute to the general wellbeing of a patient (Sengodan and Sengodan, 2012). A change to a positive

mindset and a generally more positive attitude were mentioned as facilitators to weight-bearing, as was the hope for a positive outcome from this surgery. Jin et al. (2022) found that the functional outcome assessment based on the psychological acceptance of the procedure and the degree of the disability, improved the physical aspects of the patient over time. Having an expectation of a positive outcome outweighed the discomfort of the circular ex-fix. Even though malalignment is less likely with circular external fixators (Bayrak et al., 2021), participants even accepted the possibility of a deformity once their bone had healed. Embracing their mental strength allowed the participants to increase their efforts to mobilise despite the pain and to mentally distract themselves from the duration of the circular ex-fix treatment. Thus, they were helped to persevere. This mental distraction has been noted as important in preventing obsessions over the ex-fix (Sims et al., 2000). One participant was relieved that they were able to weight-bear with their circular ex-fix and had more confidence in their ability to weight-bear on the injured leg when their pain was under control. The main advantage of a circular ex-fix is the fact that patients are allowed to use the limb and weight-bear once their pain allows it to (Algahtani et al., 2021; Berliner et al., 2021; Hernigou, 2016; Naqui et al., 2008; Siddiqui et al.,2019). Another participant felt entertained by the reactions of people in the mall to their circular ex-fix and enjoyed walking around with it. Literature notes, however, that circular external fixators have been found to have a negative impact on self-esteem (Siddiqui et al., 2019).

5.5.4 Benefits of the multidisciplinary medical team

The multidisciplinary medical team was mentioned as a largely significant facilitator to weight-bearing. Expert care from a multidisciplinary team is necessary for providing patients who have been fitted with an ex-fix with all they need to fulfil their social, physical, and psychological needs (Sims et al., 2000). Where most of the participants had had a negative experience with their previous surgeons, they all indicated that their experience with their current surgeon was positive. They felt that the surgeon had empathy and was honest with them. This bolstered their trust in the surgeon and their willingness to do what had been recommended, especially regarding weight-bearing. Physiotherapists and surgeons should continuously encourage patients to follow a normal gait pattern while putting as much weight on

the ex-fix limb as possible (Green, 1990). The allied health professionals were perceived as an extension of the surgeon, with the Wound Care sister playing a major role in patient support and care. The fast response time to participant questions and worries was said to diminish the complications, especially regarding infection. It is indeed a fact that the way in which the multidisciplinary team works together is what achieves a positive outcome for the patient (Hadeed, Werntz and Varacallo, 2022). When it comes to external fixators, physiotherapists also play an important role as members of the multidisciplinary team (Sims et al., 2000). The participants felt that the multidisciplinary team was professional, and their positivity and support not only made living with a circular ex-fix easier, but also made them more positive. Support from the multidisciplinary team is necessary in that it provides patients who have been fitted with an ex-fix with all they need to fulfil their social, physical, and psychological needs (Sims et al., 2000). It is evident that a multidisciplinary team approach with specialised staff is very important in-patient care and rehabilitation in respect of circular external fixators (Biz et al., 2021; Martin and Chow, 2021).

5.6 Conclusion

It is therefore evident that there are multiple barriers and facilitators for FWB with a circular ex-fix. However, there are variances for each individual fitted with one of these devices as certain factors can be a barrier for one individual, yet a facilitator for another.

CHAPTER 6: CONCLUSION, LIMITATIONS AND RECOMMENDATIONS

6.1. Introduction

This chapter aims to summarise the findings and to draw conclusions in answering the research question: “What are the barriers and facilitators to FWB with a lower-limb circular ex-fix?”. The limitations of this study and recommendations for the practical implementation of the findings and for future studies are also discussed. Table 6.1 below is a schematic representation of the barriers and facilitators to FWB as well as factors that were a barrier for some participants yet a facilitator in others.

Table 6.1: Barriers and facilitators to full weight-bearing

	BARRIER	FACILITATOR
Pain	√	√
Assistive device use	√	√
Pain medication	√	√
Work and home environment	√	√
Constructs of circular external fixator and footplate	√	√
Adequacy of patient education and understanding	√	√
Need to perform activities of daily living	√	√
History of previous complications and mismanagement	√	
History of injury	√	
Negative mindset	√	
Depression	√	
Impact on self esteem	√	
External fixator preoccupation	√	
Fear of falling or refracture	√	
Muscle weakness and stiffness	√	
Decreased joint range of motion	√	
Decreased balance	√	
Leg length discrepancy	√	

	BARRIER	FACILITATOR
Poor endurance	√	
Pin-site infection	√	
Pin-site swelling	√	
Neural immobility	√	
Change in sensation of leg	√	
Presence of wounds	√	
Lack of family support	√	
Poor hospital standards	√	
Delay in medical administration whilst in hospital	√	
Rest, ice and elevation		√
Cycling and exercise		√
Gait adjustments		√
Decreasing limb length discrepancy with a boot		√
Being accustomed walking with difficulty		√
Preoperative strength and balance		√
Change to a positive mindset		√
Hope for a positive outcome		√
Embracing mental strength		√
Distraction from external fixator treatment time		√
Confidence in being allowed to weight-bear		√
Expert care from multidisciplinary team		√
Trust in the surgeon		√
Fast reaction times to possible complications		√
Support from multidisciplinary team		√

6.2. Conclusion

Despite the known need for weight-bearing with a circular ex-fix to facilitate the bone-healing process, clinical evidence, literature and the findings of this study show that patients are still not FWB up to four weeks post-operatively. Certain demographics

increased participants' chances of developing complications and when there are complications, the participants cannot weight-bear. According to this study, there are multiple physical and psychological factors that are facilitators and barriers to weight-bearing in a patient with a circular ex-fix. The main physical barriers to weight-bearing are pain, leg length discrepancy, difficulty in maneuverability with the circular ex-fix and footplate, and dependence on assistive devices owing to pain, weakness and lack of balance. A lack of family support was also found to be a barrier to mobilisation and weight-bearing. The main psychological barriers are a negative mindset, especially because of the history of the injury, and a fear of falling and refracturing the leg.

Despite none of the participants being FWB at the time of the interview, there were certain facilitators that were mentioned that make the attempt to weight-bear easier. The main physical facilitators to weight-bearing are the ability to cope with pre-operative gait dysfunction as well as pre-operative strength and good balance made it easier to mobilise post-operatively. Wearing a raised boot on the opposite leg and adjusting the gait to avoid pain are other important facilitators.

The participants were also able to relieve their pain with certain non-pharmacological techniques, such as rest and exercise, which could, therefore, also be considered as helpful facilitators. The main psychological facilitators to weight-bearing, however, were a shift to an optimistic mindset, hope for a positive outcome and the positivity of and support from the multidisciplinary medical team.

6.3 Limitations

The limitations of this research study need to be considered when interpreting its findings. Although the data saturation point was reached after interviewing nine participants, a larger sample size over a longer period might have yielded different results. All the participants' injuries were chronic by nature and associated with previous failed interventions, as, owing to polytrauma, acute patients were excluded as potential participants for this study. This study was also limited to a South African private sector context. It is also important to note that none of the participants were

completely FWB at the time of the interview, therefore the facilitators assisted in increasing weight-bearing but were unsuccessful in achieving FWB.

6.4. Recommendations

The research available on this topic is limited, more studies about weight-bearing with circular external fixators, especially with regard to the associated barriers and facilitators, are necessary. This study could form the basis for future studies extending into the international domain. Such studies would help to fully explain all the barriers and facilitators to weight-bearing with a circular ex-fix. The ultimate goal would be to develop clinical practice guidelines and protocols to lead physiotherapists in the correct management of patients who have been fitted with a circular ex-fix. Such endeavours would hopefully contribute to improved weight-bearing and functional outcomes. Further studies on acute patients, as well as patients in other settings, such as the public sector, are also recommended. A longitudinal study could also be done, where interviews with participants are conducted earlier and continue at intervals up to eight weeks. Lastly, studies on the effect of pain catastrophizing in these patients are recommended to truly understand the effect that their pain is having on them. Policies should be put in place to educate and support the family members and medical multidisciplinary team of patients who have been fitted with a circular ex-fix. The multidisciplinary team need to address the barriers and promote facilitators discovered in this study. Surgeons should focus on better pain control and education as well as general rapport with their patients. The wound care sisters need to implement and educate patients in efficient pin care protocols to minimize pin-site infection. The nursing staff ought to have faster reaction times with more empathy. Physiotherapists should also focus on being more proficient in their explanatory technique. There is a need to upgrade protocols and update information on physiotherapy in ex-fix care. It is essential for physiotherapists to have a detailed knowledge of the limitations of the external fixators, as well as the treatment protocols. Orthotists and prosthetists need to minimize the effects of the leg length discrepancy created by the footplate by providing solutions to lengthening the other leg (e.g., with a raised shoe). The psychological wellbeing of the patient is also important, and a psychologist should play a larger role in the multidisciplinary team, particularly with patients that have a long-standing history of injury.

6.5 Summary

Literature reveals that early weight-bearing with a circular ex-fix stimulates bone growth. Clinical evidence shows that patients are not FWB four weeks post operative as confirmed in this study. Numerous barriers and facilitators to FWB with a circular ex-fix were identified. The main barriers to FWB are pain, a negative mindset and fear. The use of assistive devices to decrease pain and perform activities of daily living also created a large barrier to weight-bearing. The main facilitators to FWB were the use of a raised boot on the unaffected limb to decrease a leg length discrepancy and gait adjustments to avoid pain. Fostering a positive mindset also facilitated FWB. Moreover, the surgeon and wound care sister play a large role in the patients' state of mind. Addressing the barriers and implementing a way to promote the facilitators determined in this study, could allow for earlier weight-bearing. This in turn could minimise complications and improve patients' quality of life and functional outcomes. It could also possibly decrease the overall cost of treatment if patients are able to weight bear earlier.

REFERENCES

Alqahtani, M.S., Al-Tamimi, A.A., Hassan, M.H., et al. (2021). Optimization of a Patient-specific External Fixation Device for Lower Limb Injuries, *Polymers (Basel),*13(16), 2661. doi: 10.3390/polym13162661.

Amaro, A., Paulino, M., Roseiro, L., et al. (2020). The effect of external fixator Configurations on the dynamic compression load: an experimental and numerical study, *Applied Sciences (Switzerland),* 10 (1). https://doi.org/10.3390/app10010003.

Augat, P., Hollensteiner, M. and von Rüden, C. (2020). The role of mechanical stimulation in the enhancement of bone healing, *Injury*, 52 (2), S78-S83. https://doi.org/10.1016/j.injury.2020.10.009.

Aziz, A., Umairah, A., Wahab, A., et al. (2020). A finite element study: finding the best configuration between unilateral, hybrid, and Ilizarov in terms of biomechanical point of view, *Journal of Injury*, 51 (11), 2474–78. https://doi.org/10.1016/j.injury.2020.08.001.

Barker, K.L., Burns, M. and Littler, S. (1999). Physiotherapy for patients with an Ilizarov external fixator: a survey of current practice, *Physiotherapy,* 85 (8), 426–32.

Barker, K.l. and Burns, M. (2001). Using consensus techniques to produce clinical guidelines for patients treated with the Ilizarov fixator, *Physiotherapy,* 87 (6),11 289–300. https://doi.org/10.1016/S0031-9406(05)60763-8.

Barker, K.L., Simpson, A.H. and Lamb, S.E. (2001). Loss of knee range of motion in leg lengthening, *Journal of Orthopaedic Sports: Physical Therapy*, 31(5), 238-44; doi: 10.2519/jospt.2001.31.5.238.

Bayrak, A., Polat, Ö., Ursavaş, H.T., et al. (2021). Which external fixation method is better for the treatment of tibial shaft fractures due to gunshot injury? *Orthopaedic Traumatology and Surgical Research*, 108 (5). doi: 10.1016/j.otsr.2021.102948.

Berliner, Z.P., Novikov, D., Ergin, C., et al. (2021). Knee-spanning External Fixation for Recurrent Traumatic Anterior Prosthetic Knee Dislocation with Associated Vascular Injury, *Arthroplast Today*, 10, 160-165. doi:10.1016/j.artd.2021.06.017.

Bhardwaj, R., Singh, J., Kapila, R., et al. (2019). Comparision of Ilizarov ring

fixator and rail fixator in infected nonunion of long bones: a retrospective follow-up study, *Indian Journal of Orthopaedics,* 53 (1), 82–88. https://doi.org/10.4103/ortho.IJOrtho_77_17.

Bhowmick, K., Gunasekaran, C., Kandoth, J.J., et al. (2021). The Role of the Ilizarov Ring External Fixator in the Management of Tibial Fractures with Impending/Incomplete Compartment Syndrome, *Revista Brasileira Ortopedia (Sao Paulo),* 56(5), 579-587. doi: 10.1055/s-0041-1732332.

Biz, C., Crimì, A., Fantoni, I., et al. (2020). Functional outcome and complications after treatment of comminuted tibial fractures or deformities using Ilizarov bone transport: a single-center study at 15- to 30-year follow-up, *Archives of Orthopaedic Trauma Surgery*, (11), 1825-1833. doi: 10.1007/s00402-020-03562-9.

Braun, V., Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research Psychology,* (3), 77–101. doi: 10.1191/1478088706qp063oa.

Carr E. (2007) Barriers to Effective Pain Management, *Journal of Perioperative Practice* · DOI: 10.1177/175045890701700502

Cinthuja, P., Wijesinghe, P.C.I. and Silva, P. (2022). Use of external fixators in developing countries: a short socioeconomic analysis, *Cost Effective Resource Allocation*, 20(1), 14. doi: 10.1186/s12962-022-00353-4.

Coglianese, D.B., Herzenberg, J.E. and Goulet, J.A. (1993). Physical therapy management of patients undergoing limb lengthening by distraction osteogenesis, *Journal of Orthopaedic Sports: Physical Therapy*, 17(3), 124-32. doi: 10.2519/jospt.1993.17.3.124.

Donnan, L.T., Gomes, B., Donnan, A., et al. (2016). Ilizarov tibial lengthening in the skeletally immature patient, *Bone Joint Journal,* 98-B (9),1276-82. doi: 10.1302/0301-620X.98B10.37523. PMID: 27587532.

Elbatrawy, Y. and Ragab, I. (2015). Safe cosmetic leg lengthening for short stature: long-term outcomes, *Orthopedics,* 38 (7), 552–60. https://doi.org/10.3928/01477447-20150701-51.

Elo, S., Kääriäinen, M., Kanste, O., et al. (2014). Qualitative Content Analysis, *SAGE Open*, 4(1), 215824401452263. https://doi.org/10.1177/2158244014522633

Fenton, C., Henderson, D., Samchukov, M., et al. (2021). Comparative Stiffness

Characteristics of Ilizarov- and Hexapod-type External Frame Constructs, *Strategies: Trauma Limb Reconstruction,* 16(3), 138-143. doi: 10.5005/jp-journals-10080-1539.

Fernando, P.L.N., Abeygunawardane, A., Wijesinghe, P., et al. (2021). An engineering review of external fixators. *Medical Engineering Physiotherapy*, 98, 91-103. doi: 10.1016/j.medengphy.2021.11.002.

Ganadhiepan, G., Miramini, S., Patel, M., et al. (2019). Bone fracture healing under Ilizarov fixator: influence of fixator configuration, fracture geometry, and loading, *International Journal for Numerical Methods in Biomedical Engineering,* 35 (6), 3199– 3217. https://doi.org/10.1002/cnm.3199.

Garg, P., Sodha, R., Bin Hamid, F., et al. (2021). Clinical study of functional outcome of external fixator device as a primary definitve treatment of open tibia fracture, *Medico-Legal Update,* 21 (1), 768–71. https://doi.org/10.37506/mlu.v21i1.2408.

Giannoudis, V.P., Ewins, E., Taylor, D.M., et al. (2021). Clinical and Functional Outcomes in Patients with Distal Tibial Fracture treated by Circular External Fixation: A Retrospective Cohort Study, *Strategies: Trauma Limb Reconstruction*, 16(2),86-95. doi: 10.5005/jp-journals-10080-1516.

Green, J., Willis, K., Hughes, E., et al. (2007). Generating best evidence from qualitative research: The role of data analysis, *Australian/New Zealand Journal of Public Health,* 31 (6), 545–50. doi: 10.1111/j.1753-6405.2007.00141.x.

Green, S. (1990). Physiotherapy during Ilizarov fixation, *Techniques in Orthopaedics,* 5 (4), 61–65.

Gubin, A., Borzunov, D. and Malkova, T. (2013). The Ilizarov paradigm: thirty years with the Ilizarov method, current concerns and future research, *International Orthopaedics*, 37(8), 1533-9. https://doi.org/10.1007/s00264-013-1935-0.

Hadeed, A., Werntz, R.L.and Varacallo, M. (2022). External Fixation Principles and Overview, *StatPearls* [Internet] https://www.ncbi.nlm.nih.gov/books/NBK547694/

Heng, D.Z., Li, J., Zhai, J.B., et al. (2021). Application of individualized controllable stress external fixation in open tibial fractures, *Zhongguo Gu Shang*, 34(10), 915-9. Chinese. doi: 10.12200/j.issn.1003-0034.2021.10.006.

Hernigou, P. (2016). History of external fixation for treatment of fractures,

International Orthopaedics (SICOT), 41, 845–853. https://doi.org/10.1007/s00264-016-3324-y.

Hidayat, L., Triangga, A.F.R., Cein, C.R., et al. (2022). Low profile external fixation using locking compression plate as treatment option for management of soft tissue problems in open tibia fracture grade IIIA: A case series, *International Journal of Surgical Case Reports*, 93, 106882. doi: 10.1016/j.ijscr.2022.106882.

Horas, K., Schnettler, R., Maier, G., et al. (2015). The role of soft-tissue traction forces in bone segment transport for callus distraction: a force measurement cadaver study on eight human femora using a novel intramedullary callus distraction system, *Strategies in Trauma and Limb Reconstruction,* 10 (1), 21–26. https://doi.org/10.1007/s11751-015-0220-8.

Jin, L., Zhang, S., Zhang, Y., et al. (2022). Management algorithm of external fixation in lower leg arterial injury for limb salvages, *British Medical Council: Surgery,* 22(1), 79. doi: 10.1186/s12893-022-01486-2.

Juan, J.A., Prat, J., Vera, P., et al. (1992). Biomechanical consequences of callus development in Hoffmann, Wagner, Orthofix and Ilizarov external fixators, *Journal of Biomechanics*, 25(9), 995-1006. doi: 10.1016/0021-9290(92)90035-y.

Kaguku, N., Reinekainnen, V., Luhiriri, et al. (2004). The Use Of External Fixator In the Management of Gunshot-related Open Limb Fractures, *East and Central African Journal of Surgery,* 9 (1),41-43.

Kucukkaya, M. (2009). Correction of Complex Lower Extremity Deformities with the Use of theIlizarov-Taylor Spatial Frame, *Acta Orthopaedica Traumatologica Turcica,* 43 (1), 1-6 https://doi.org/10.3944/AOTT.2009.001.

Lally, P., Seligson, D. and Stanwyck, T.S. (1981). The new challenges of physical therapy for external fixation treatment of fractures*, *Journal of Orthopaedic Sports; Physical Therapy* 2(4), 171-6. doi: 10.2519/jospt.1981.2.4.171.

Larsen, P., Traerup, J., Mikuzis, M., et al. (2019). Patient-reported and Functional Outcomes of Bicondylar Tibial Plateau Fractures managed by Internal Screw Fixation in combination with an Ilizarov Fixator: A Case Series of 22 Patients with Long-term Follow-up. *Strategies: Trauma Limb Reconstruction,* 14(2), 85-91. doi: 10.5005/jp-journals-10080-1432.

Liu, K., Abulaiti, A., Liu, Y., et al. (2021). Risk factors of pin-tract infection during

bone transport using unilateral external fixator in the treatment of bone defects, *Biomedcentral: Surgery,* 21(1), 377. doi: 10.1186/s12893-021-01384-z.

Liu, Y., Cai, F., Liu, K., et al. (2021). Intra-operative acute correction *versus* Post-operative gradual correction for tibial shaft fractures with multiplanar post-traumatic deformities using the hexapod external fixator, *Biomedcentral: Musculoskeletal Disorders,* 22(1), 803. doi: 10.1186/s12891-021-04505-0.

Liu, Y., Liu, K., Cai, F., et al. (2022). Retrospective clinical outcomes in the definitive treatment of high-energy tibial diaphyseal fractures using hexapod external fixator *versus* monolateral external fixator, *Biomedcentral: Musculoskeletal Disorders*, 23(1):330. doi: 10.1186/s12891-022-05257-1.

Malkova, T.A. and Borzunov, D.Y. (2021). International recognition of the Ilizarov bone reconstruction techniques: Current practice and research (dedicated to the 100th birthday of G. A. Ilizarov), *World Journal of Orthopaedics*, 12(8), 515-533. doi: 10.5312/wjo.v12.i8.515.

Martin, B. and Chow, J. (2021). The use of circular-frame external fixation in the treatment of ankle/hindfoot Charcot Neuroarthropathy, *Journal of Clinical Orthopaedic Trauma*, 16, 269-276. doi: 10.1016/j.jcot.2021.02.016.

Meyer, Z., Zide, J.R., Cherkashin, A., et al. (2021). Narrative review of ring fixator management of recurrent club foot deformity, *Annals of Translational Medicine*, 9(13), 1104. doi: 10.21037/atm-20-7621.

Milenkovic, S.S., Mitkovic, M.M., Mitkovic, M.B., et al. (2021). Unilateral 3-D external fixation in Serbian traumatology and orthopaedics, *International Journal of Clinical Medicine,* 75(9). Available at: doi: 10.1111/ijcp.14411.

Morasiewicz, P., Dejnek, M., Kulej, M., et al. (2019). Sport and physical activity after ankle arthrodesis with Ilizarov fixation and internal fixation, *Advances in Clinical and Experimental Medicine,* 28 (5), 609–14. https://doi.org/10.17219/acem/80258.

Naqui, S., Zafar, H., Thiryayi, W., et al. (2008). Correction of simple and complex pediatric deformities using the Taylor Spatial Frame, *Journal of Pediatric Orthopaedics,* 28 (6), 640–47. https://doi.org/10.1097/BPO.0b013e3181831e99.

Oh, C., Apivatthakakul, T., Oh, J., et al. (2013). Bone transport with an external

fixator and a locking plate for segmental tibial defects, *Bone and Joint Journal,* 95 B (12), 1667–72.

Ostiak W., Koczewski P. (2009). Pain intensity in patients treated by the external Fixator. *Chir Narzadow Ruchu Ortop Pol, 74(4):228-32*

Paola, L.D, Carone, A., Valente, M., et al. (2021). Surgical Off-loading of the diabetic foot, *Journal of Clinical Orthopaedic Trauma,* 16:182-188. Doi.org/10.1016/j.jcot.2021.01.005

Pathinathan, K., Sivakumaran, D., Dimantha, W.H.D., et al. (2021). Late-onset pseudoaneurysms of lower limb arteries following late complications of orthopaedic constructs - Two cases and a review of the literature*, International Journal of Surgery: Case Report* 87, 106457. doi: 10.1016/j.ijscr.2021.106457.

Pawik, Ł., Pajchert-Kozłowska, A., Szelerski, Ł., et al. (2021). Assessment of Lower-limb Load Distribution in Patients treated with the Ilizarov Method for Tibial Nonunion, *Medical Science Monitor,* 27, e930849. doi: 10.12659/MSM.930849.

Qi, W., Feng, X., Zhang, T., et al. (2021). Development and validation of a modularized external fixator for generating standardized fracture healing micromotions in rats, *Bone Joint Research,* 10(11), 714-722. doi: 10.1302/2046-3758.1011.BJR-2021-0028.R1.

Rao, M., Jamil, K. and Tasarib, R. (2021). An Alternative Technique to Strut Change in Hexapod Circular External Fixators, *Malaysian Orthopaedic Journal,* 15(3), 157-158. doi: 10.5704/MOJ.2111.029.

Reddy, A. and Radhakrishna, R. (2019). A study of outcomes of open supracondylar fractured femurs treated with the Ilizarov fixator as primary management, *Journal of Evolution of Medical and Dental Sciences,* 8 (40), 3024–27. https://doi.org/10.14260/jemds/2019/657.

Reid, J.S., Vanderkarr, M., Ray, B., et al. (2022). Two-year clinical and economic burden, risk and outcomes following application of software-assisted hexapod ring fixation systems, *Biomedcentral: Musculoskeletal Disorders*, 23(1), 25. doi: 10.1186/s12891-021-04934-x.

Reinke, C., Lotzien, S., Yilmaz, Y., et al. (2021). Tibiocalcaneal arthrodesis using

the Ilizarov fixator in compromisedhosts: an analysis of 19 patients, *Archives of Orthopaedic and Trauma Surgery*, 142(7), 1359-1366. doi: 10.1007/s00402-021-03751-0.

Reis, N.D. (1991). A Philosophy of Limb Salvage in War: Use of the Fixateur Externe, *Military Medicine,* 156 (10), 505.

Rius-Zavala M.M., Orellana-Reta C.A., Fuentes-Figueroa S., et al. (2017) Evaluación sicológica en pacientes tratados con fi jador externo, *Acta Ortopédica Mexicana*, 31(6): Nov.-Dic: 287-291

Robbins, C.A. (2021). Deformity Reconstruction Surgery for Blount's Disease, *Children (Basel),* 8(7), 566. doi: 10.3390/children8070566.

Rounds, A., Burtt, K., Leland, H., et al. (2019). Functional outcomes of traumatic lower extremity reconstruction, *Journal of Clinical Orthopaedics and Trauma,* 10 (1), 178–81. https://doi.org/10.1016/j.jcot.2017.08.013.

Savage, Z. and Munjal, R. (2015). Multidisciplinary team approach to residual limb lengthening using the Ilizarov technique: A case study, *Prosthetic Orthotics International*, 39(5), 414-8. doi: 10.1177/0309364614531011

Sengodan, V. and Sengodan, M. (2012). Early weight-bearing using percutaneous external fixatorfor calcaneal fracture, *Journal of Surgical Techniques and Case Reports,* 4 (2), 98–102. https://doi.org/10.4103/2006-8808.110263.

Sheng, H., Xu, W., Xu, B., et al. (2021). Application of Intelligent Computer-assisted Taylor 3-D External Fixation in the Treatment of Tibiofibular Fracture: Retrospective Case Study, *Journal of MIR Medical Information*, 9(5). 21455. doi: 10.2196/21455.

Siddiqui, A., Siddiqui, F., Bashar, M., et al. (2019). Impact of Ilizarov fixation technique on the limb functionality and self-esteem of patients with unilateral tibial fractures *Cureus,* 11 (10), 1–6. https://doi.org/10.7759/cureus.5923.

Simard, S., Marchant, M. and Mencio, G. (1992). The Ilizarov Procedure: Limb Lengthening and its Implications, *Physical Therapy*, 72 (1),25–34. https://doi.org/10.1093/ptj/72.1.25

Sims, M., Bennett, N., Broadley, L., et al. (2000). External fixation: Part 2, *Journal of Orthopaedic Nursing*, 4 (1), 26-32. https://doi.org/10.1054/joon.2000.0049.

Tripathy, S.K., Varghese, P., Panigrahi, S., et al. (2021). External fixation *versus*

open reduction and internal fixation in the treatment of Complex Tibial Plateau Fractures: A systematic review and meta-analysis, *Acta Orthopaedica Traumatologica Turcica*, 55(5), 444–456.

Vitale, K., Miller, T. and Jimenez, A. (2006). Rehabilitation after intra-medullary skeletal kinetic distractor implantation: a report of two cases and a suggested therapy program, *American Journal of Physical Medicine and Rehabilitation,* 85 (2), 176–80.

Wade, R., Roberts, S. and Richardson, J. (1999). Simple Techniques to prevent Ankle Equinus with External Fixators, *Physiotherapy,* 85 (5), 248-250. https://0-doi-org.innopac.wits.ac.za/10.1016/S0031-9406(05)61438-1.

Zak, L. and Wozasek, G. (2013). Impaired joint motion and contractures in callus distraction and segment transport: a retrospective data analysis, *Wien Klin Wochenschr,* 125, 709-713. https://0-doiorg.innopac.wits.ac.za/10.1007/s00508-013-0432-1

Zein, A.B., Elhalawany, A.S., Ali, M., et al. (2021). Acute correction of severe complex adolescent late-onset tibia vara by minimally invasive osteotomy and simple circular fixation: a case series with a two-year minimum follow-up, *Biomedcentral: Musculoskeletal Disorders*, 22(1), 681. doi: 10.1186/s12891-021-04496-y.

Zhang, L. (2010). Early rehabilitation and bone mineral density in patients with functional disorders of the knee joint caused by lower limb fracture. *Journal of Clinical Rehabilitative Tissue Engineering Research,* 14 (33), 6234–37.

APPENDICES

APPENDIX A – STUDY INFORMATION DOCUMENT

Study title: Patient-perceived barriers and facilitators to full weight-bearing with a lower-limbcircular external fixator

This information booklet is to help you decide whether you would like to participate in this study. Before you respond, you need to fully understand what the procedures are. Therefore, you do not have to give your answer today. The researcher's contact details are on this form, and you are welcome to ask any questions you may have over the next four weeks.

I, Megan Crouse, am doing research on weight-bearing with external fixators. The reason I would like to research this is to seek new knowledge in this regard. In this study, I want to explore why people are or are not able to stand on their leg with a circular external fixator. This is an observational study, which means you would continue with your normal treatment sessions throughout. The treatment and number of treatment sessions necessary are determined by the nature of your condition and need for physiotherapy. They are in no way linked to the study.

This is a qualitative exploratory study conducted using semi-structured in-depth one-on-one interviews and a demographic questionnaire. This means that I would like you to fill out a questionnaire about your injury online while in our physiotherapy practice and participate in a face-to-face interview thereafter. This will be all that is required of you, and only on this one occasion. It will take place on the day of a scheduled treatment session, four weeks after your external fixator was applied. The interview will be conducted before your scheduled treatment and should last about one hour. All Covid protocols will be followed, and your comfort will be ensured.

There are no additional risks to those of normal practice and there will not be an increased chance of adverse reactions if you participate in this study.

There is no direct benefit for you, but the results may improve the quality of life of future patients that have received a lower-limb circular external fixator.

Pertinent information of the study and the results will be made available to you while you are involved.

Participation is voluntary:

Please note that if you refuse to participate, there will be no penalty; you will continue with the usual care for your procedure. You may also discontinue participation at any time without penalty. You do not need to provide a reason for refusal to participate or why you would like to withdraw from the study. All data already collected will, by default, be destroyed unless you specifically consent to its retention.

Confidentiality:

Your personal information will be available only to myself, the principal Investigator, and my research supervisors. It will be treated with the strictest confidentiality, the only exceptions - in the rare occurrence - would be if personal information needs to be disclosed, if required by law, or the Human Research Ethics Committees of the University needs to acquire personal data to respond to a formal complaint or for a compliance audit. An identification number will be given to you to ensure your anonymity. Data and results will be published in a way in which participants remain unidentifiable.

All data collected in the study will be securely kept for six (6) years if there is no scientific publication of the study. If there is a publication, however, it will be kept for two (2) years after publication.Thereafter, it will be disposed of accordingly.

If you need any further information, please feel free to contact myself, Megan Crouse, on 012 942 0827 or email me at 2511810@students.wits.ac.za, or my supervisors, Mrs Sandy Lord on sandy.lord@wits.ac.za, or Mrs Monique Keller on monique.keller@wits.ac.za.

The results of this study will be reported in a dissertation and in a journal article which will be written after the study has been completed. The latter will be made available to you.

This study was structured around the Declaration of Helsinki, which guides doctors in Biomedical Research. It has received ethical approval from the Human Research Ethics Committee (Medical) of the University of the Witwatersrand, Johannesburg ("Committee"). This Committee safeguards the dignity and rights of all humans who agree to participate in a research project, as well as the integrity of the research.

Please contact Professor Clement Penny, the Chairperson of the Committee, if you are not happy with the way the study is being conducted. Contact can be made by phone on 011 717 2301, or by e-mail on Clement.Penny@wits.ac.za. You can contact the Committee secretaries on 011 7172700/1234 or email Zanele.Ndlovu@wits.ac.za and Rhulani.Mukansi@wits.ac.za

Thank you for reading this Study Information Sheet.

APPENDIX B – INFORMED CONSENT DOCUMENT

PARTICIPANT CONSENT FORM FOR STUDY PARTICIPATION AND AUDIO RECORDING

Study title: Patient-perceived barriers and facilitators to full weight-bearing with a lower-limb circular external fixator

If you decide to participate in the study, you will need to sign this document for consent. You may ask for clarification at any stage. Your consent will be to participate in the study, to allow the interview to be recorded and to authorize the use of your data.

I confirm the following by signing these documents:

1. I have been through the Participant Information Sheet, which is attached hereto. It clearly explains the nature of the study, as well as the processes involved.
2. I was given enough time to read through it, or it was read to me in the language that I can understand.
3. I was allowed to ask all the questions I needed to, and I was satisfied with the answers.
4. I fully understand the intended outcomes of the study as to exactly why it is being conducted.
5. I understand that the study will not cost me anything, and that I will not receive any payment should I agree to participate in the study. I also understand that there will not be any immediate benefit to me.
6. I understand that I may say “No” to participation in this study without any reason and without it affecting my normal course of treatment.
7. I understand that I may withdraw from this study at any stage without needing to give a reason. I also understand that any data already collected will be destroyed unless I state that it may be kept. This too will not affect my normal course of treatment.

8. I have been given the contact details listed below and know that I may use them if I would like to know more about the study or if I am unhappy about the way the study is being conducted.

Contact details:
Megan Crouse, Principal Investigator, telephone no. 012 942 0827 or by e-mail at 2511810@students.wits.ac.za.
Mrs Sandy Lord, Supervisor, by email at sandy.lord@wits.ac.za, Mrs Monique Keller,Supervisor, by email at monique.keller@wits.ac.za.

Professor CB Penny, Chairperson of the Human Research Ethics Committee (Medical) at theUniversity of Witwatersrand, on telephone no. 011 717 2301, or by e-mail at Clement.Penny@wits.ac.za.

Ms. Z Ndlovu or Mr Rhulani Mkansi, Committee Secretaries, telephone nos.: 011 717 2700 or 1234, or by e-mail at: Zanele.Ndlovu@wits.ac.za or Rhulani.Mkansi@wits.ac.za

Furthermore, I hereby consent to an audio recording of the interview that will be conducted with me. I understand that:

1. The recording will be stored on a password-protected computer. Access will be limited to the researcher and the supervisors of the researcher.
2. Any information in a verbatim transcription by which I can be identified will be removed.
3. If there is a scientific publication of the research findings, the recordings will be erased within two (2) years of the publication. If no publications arise, the recording will be kept for six (6) years.
4. Approval from the Human Research Ethics Committee (Medical) of the University of the Witwatersrand, Johannesburg will be needed by anyone who would like to access this information in future.
5. If there is no information that could identify me, direct quotes may be cited from my interview and in any write-ups of the research.

Name of Participant: _____

Date: _____

Place: _____

Signature or mark: _____

Witnessed by:

Name of Witness: _____

Signature: _____

Date: _____

APPENDIX C – DEMOGRAPHIC QUESTIONNAIRE

Unique identifier code	
Age	
Sex	
Weight	
Height	
Cause of defect	Born with the Injury
If from an injury	How did the injury occur? Date of injury?
Type of Surgery	Elective ☐ Trauma ☐ Acute ☐ Chronic ☐ Adjustments being made: Yes ☐ No ☐ Location of External fixator: _____ Dynamizers used: Yes ☐ No ☐ Foot track used. Yes ☐ No ☐
Previous procedures	Number of procedures

	_____ Date of procedures _____ Type of procedure _____ Complications _____
Employment status	Unemployed _____ Working from home _____ Back at work _____ Awaiting return to work _____
Any other medical conditions we need to know of	_____ _____
Date of external fixator application	

APPENDIX D – INTERVIEW GUIDE

1. Over the last four weeks, how have you been walking?
   Prompt – were you able to walk without your crutches at all?
   Prompt – did you feel you were walking correctly, without a limp?
   Prompt – why do you think you were walking with a limp?
2. Have there been any changes in your physical or mental condition in these four weeks?
   Prompt – have you become more positive or negative about the ex-fix?
   Prompt - what has happened with your pain levels?
   Prompt - was there something that made standing on your leg easier?
   Prompt – was there anything that held you back from standing on your leg?
   Prompt – have you been able to do your daily tasks and work?
3. Has there been anything with the ex-fix specifically that has made it more difficult or easier for you to stand on it?
   Prompt – how does the footplate affect your ability to properly walk on your leg?
   Prompt – have you had any complications over these four weeks?

APPENDIX E – CONSENT FOR STUDY IN PHYSIOTHERAPY PRACTICE

CROUSE & ROBBERTSE
PHYSIOTHERAPISTS

T:012 942 0827
F: 086 665 3505
reception@myphysio.org.za
www.myphysio.org.za

27 May 2021

To Whom it may concern

I Colett Robbertse, co-owner if Crouse and Robbertse Physiotherapists, give Megan Crouse permission to conduct interviews in our practice. I understand that it will be with the external fixator patients referred to us and that I will treat them prior to the interview. The Patients will have to give consent to partake in her study, for the purpose of collecting data for her Masters in Physiotherapy.

Please feel free to contact me with any questions.

Robbertse

Colett Robbertse
Physiotherapist
012 942 0827

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Megan Crouse
(B.PhysT Tuks) PT 0106224
Colett Robbertse
(BSc Physio Wits) PT 0090263

APPENDIX F – COVID PROTOCOL

This Covid protocol was put together as per recommendations from the National Institute of Communicable Diseases, the information of which is in line with that of the World Health Organization. Standard precautions will be put in place to ensure both patient and interviewer safety.

These precautions are as follows:

Screening: when entering the practice: the participant will be screened for Covid symptoms and their temperature will be checked.

Hand hygiene: both parties will wash their hands and use a 70% alcohol solution to sanitize their hands before entering the room.

Appropriate use of personal protective equipment: masks and/or visors will be worn upon entering the room. There will be no need for physical contact, therefore, no other personal protective equipment is required.

Participant placement: there will be a distance of at least two (2) metres between the interviewer and the participant. This means that masks can be removed during the interview if the participant feels more comfortable seeing the interviewer's face or needs to better hear the questions. The interviewer will still wear a visor. This is purely up to what makes the participant feel more comfortable, and masks can remain on if the participant so wishes. This will be to allow the participant to feel more comfortable: able to read the facial expressions and correctly hear the interviewer.

Respiratory hygiene and cough etiquette will be discussed at the beginning of the session and a window will be opened.

Environmental cleaning: all surfaces will be cleaned before and after the interview with detergent and water and then disinfected using a 70% alcohol solution.

APPENDIX G – ETHICAL CLEARANCE CERTIFICATE

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

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

TO: Ms MD Crouse
School of Therapeutic Sciences
Department of Physiotherapy
Medical School
University

E-mail: 2511810@students.wits.ac.za

CC: Supervisor: Mesdames M Keller and S Lord
<Sandy.Lord@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

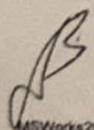
DATE: 2021/09/09

REF: R14/49

PROTOCOL NO: **M210723** (This is your ethics application reference number. Please quote it in all enquiries, oral or written, relating to this study.)

PROJECT TITLE: *Patient perceived barriers and facilitators to weight bearing with a lower limb, circular, external fixator*

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.



MSWorks2000/Iain0007/Clearscan.wps

APPENDIX H – RESULTS TABLES: QUOTES TO SUBTHEMES

Theme 1: Weight-bearing is limited by pain

Quotes	Codes	Categories	Subthemes
“pain would be your indicator to take pressure off.” (*1) “The only time when I feel pain is when I put too much weight on it. Like, if I want to try and walk on it. But then I would just rather not walk on it. “(*4)	Pain with weight-bearing	Negative experience of pain	Experience of pain
“After the operation, I could have put at least 40 to 50% weight on it. As soon as they started adjusting, realigning, lengthening and all that stuff, then it went down to about 15%. … when we were still adjusting there were days that I couldn't put the foot down, because it was just too sore; because it was adjusting and aligning and all that stuff. So, it was just too painful. And then after stopping, slowly, but surely, a little bit more weight, a little bit more weight “(*4)	Pain from adjustment of struts decreases weight-bearing		
“I think the pain and all of that keeps one awake” (*1)	Effect of pain on sleep		
“I think the thing is that she's on and off. The other day she's fine, the pains are better; she can do this; she doesn’t. The other day she is like she's been operated on that same day…like she ....and now the foot is... it’s like there is now the clash between what she wants to do and what she can’t. You know, the mind wants this”(*5 translator)	Inability to sufficiently function due to pain		
“Physically my back is sore, low down, I don’t know if that’s because of the... it must be ...level” (*3) “Then every joint is sore because of the way you walk, the way you stand and everything. It puts pressure on the other joints. So, you don't realize how much pressure you put on them until the day when you would wake up and everything is sore, you know” (*8)	Other joints pain due to compensation of gait		
“Let’s say I want to try and walk without crutches, it would have been an epic fail. Because of the pain level, but it’s only at a certain angle” (*4) “If you walk, put your leg straight down – it’s pain. But if you now try and do it sideways – there is no pain. So, it's an angle thing. “ (*4)	Weight-bearing with ankle at certain angles causes pain		
“I was walking slow, slow, Doctor, because I feel pain” (*5)	Slow pace due to pain		

“my progress has been a bit slow because I didn't want to do anything because I was hurting” (*9)	Slow progress due to pain		
“I feel pain and this becomes really swollen” (*5) “When my leg and my foot swells up, it's like everything is pulling; you can imagine the swelling and this thing is fixed so it doesn't move with it. So that is sore” (*8) “It is a bit sore when I get home at night after work, because it swells a bit” (*8)	Swelling causes pain		
“It’s a little bit sore sometimes where the pins go in” (*8)	Pin sites cause pain		
“Just where the entry and exit points are. The infection, the infection caused……caused the pain.” (*6)	Pin-site infection causes pain		
“No pain pills. The only time, if I need pain pills is when I walk, let’s say for instance, I have a very active day. And we went out like maybe, shopping, and you know, that type of thing. But the pain pill will also just be.... the two pain pills of...., well one pain pill set that I take and that’s it.” (*4) “But that’s from walking too much, I think” (*7)	Activity level affects pain		
“If it’s raining and it’s too cool, she can’t. It’s bad” (*5) “Some days you get your days that it is sore. And then it's going to rain” (*8)	Rainy weather increases pain		
“I was in the bathroom, I slipped, and I bumped the leg and then it was a bit sore.” (*1) “I battled for about the first two weeks because, somehow, I managed to twist my knee” (*9)	Pain due to bumping or twisting leg		
“I think without the pain, she can take steps without the frame. But the pain just takes her back” (*5)	Can’t walk without walking frame due to pain		
“Less pain. Way less pain than the previous round” (*7)	Less pain than with previous circular ex-fix	Tolerance to pain	
“It’s been two and a half years, so.....” (*6) “Which is a big plus for me, because I've been living with that for the last over a year now. So, constant pain there” (*8)	Desensitised to pain because of previous experiences/injuries		
“Maybe we need to ask doctor to give her something advanced on what she gave her.. because she was.... because she was even saying even the injection or something” (*5 translator)	Pain medication not enough for pain	Negative experiences with medication	Measures to relieve pain, swelling and injury
“..but at night I had to take it together with a sleeping tablet to be able to sleep” (*1) “And sometimes even you, if you give her a sleeping pill, she doesn’t sleep still” (*5	Pain medication not sufficient for sleep		

translator)			
“doctor prescribed pain meds, so I used them more often. Instead of two times a day, I use them three times a day, but hopefully it will get better now.” (*3) “the thing is that in order for her to be better, she has to overdose...I have to give her a sleeping pill and this other one, like the anxiety pill, so she can numb whatever is there, because she was crying” (*5 translator)	Pain causes increased substance use		
“the Lyrica® tends to make my blood pressure drop a bit” (*8)	Medication affects blood pressure		
“So, my taste, the change, now I am not sure if it is about all the meds… I am off meat. I am more into salads” (*1)	Change in taste due to medication		
“That's why I used the opioids and I experimented with different ones and then I could go through the day.” (*1) “If I drink it in the morning and in the evening, I'm actually fine” (*8)	Efficacy of pain medication	Efficacy of medication	
“I was without the Lyrica ® for four days and I don't want to do that again” (*8)	Efficacy of medication for nerve pain		
“Now, I've been cycling a lot” (*1) “But I am cycling. That helps a lot.” (*4)	Cycling helps with pain	Non-pharmacological interventions to relieve pain and swelling	
“But exercising helps” (*4) “Obviously not standing, all the exercises are sitting down, just upper body is normal, not with weights. It's just body exercise, your leg and that stuff.”	General exercises help with pain		
“So I lie down and try to… ease the pain.” (*3)	Lying down eases pain		
“I mean, if it is swollen, I put it up for an hour; then it is better and I ice it.” (*6)	Elevation and ice decreases swelling		
“So it shouldn’t be that if I go to work, I put my recovery at risk.” (*2)	Work should not be a risk for recovery	Precautionary measures	
“as long as it does not jeopardize the natural factor, if we can call it that, in the sense of recovery.” (*4)	Nothing should jeopardize natural recovery		

* Denotes participant number

Theme 2: Psychological factors influence full weight-bearing

Quotes	Codes	Categories
"...have got to take care of some matter of the mental stuff about some real stressful issues" (*1)	Stressful personal matters	Pessimistic state of mind
"...have anger and I was preparing myself not to sink him" (*1) "Getting disheartened, getting angry, because of what happened" (*8)	Feeling angry	
"...it's hindsight that's killing me. To say – what if? You know that, the what-if situation, is killing me mostly. I am quite depressed from that" (*2) "As soon as I start thinking about it, I'm getting a bit down" (*8) "... because of the last year it made me a bit, you know, I was negative for so long…And then you tend to be a bit negative and not feeling well. And you still have to put on a smile, because you can't complain every day" (*8)	Feeling depressed, down, and negative	
"It's a bit frustrating." (*2) "So, it's...., it just gets frustrating more than anything else" (*8) "I am just upset that this,.... the only solution" (*2)	Feeling frustrated and upset	
"I just feel somehow when people see me in this condition and also to think that you know I'd be walking with a limp" (*2)	Concern about what people think	
"But the pins, to tell you the truth, the pins drive her crazy." (*5 translator)	Negative mental effect of pins	
"But mentally you're always aware of it now, with the ex-fix on, you're always aware" (*4)	Always aware of ex-fix	
"I don't think it affects my ability to move, but I think it affects my confidence as well" (*2) "I don't have the confidence, let's say to go to the shop at this moment," (*3)	Ex-fix affects confidence	
"I was just caught in the crossfire" (*2) "You know the other guy didn't...., nothing happened to him. He didn't. He wasn't injured or anything." (*8)	Negative effect of being injured as the innocent party	Effect of history, surgeries and complications on current state of mind
"So basically it, you know, it's not the ex-fix itself. I think it's because of the whole thing that happened you know, and everything that happened before that tends to catch up with you sometimes." (*8)	Post-traumatic stress disorder has negative mental health effects	
"Previous orthopaedic surgeon. I have proof where he lied to me, he blatantly lied" (*1)	Bad experience with	

“I had to do everything on my own before. And I had a doctor that didn’t actually care much” (*8)	previous surgeons	
“not holding my breath” (*6)	Not expecting a positive outcome	
“No, I think it’s in my head. I’m afraid of falling again so I normally use something to hold on. Let’s say a chair”(*3) “I am scared that I’m going to fall” (*8)	Fear of falling	Fears
“Breaking it again inside the bones. Like I was just *nah-ah.”* (*4) *“*When I can stand, I can stand alone and maybe they will give us .... and I stand and make so. But I didn’t want to fall and damage [myself] again” (*5)	Fear of refracture	
“There is a hell of a change, you know, even comments I made, when I came out of anaesthesia, my wife said, “You are already talking about feeling more positive.” “(*1) “Well, more positive about it because at least now the leg will be straightened, and I know it's not going to affect me in the long run” (*4)	Feeling positive	Optimistic state of mind
“I think it changed from a kind of a destructive mindset to a constructive mindset and that distinction for me is very critical. And that to me is the core of, I think, what people go through ...this of need-facilitation, which is: I have to get your destructive mindset changed to a constructive one... and mine” (*1)	Change to a constructive mindset	
“relieved that I can stand on the leg” (*3)	Feeling relieved to be able to weight-bear	
“Mentally, I’m full of hope for this op, this ex-fix, so that I can at least walk normal, when they took off the frame” (*3) “Well I’m hopeful that the ex-fix fixes it” (*6)	Hopeful for a good outcome	
“She's a very strong person. She tries. She makes an effort.” (*5)	Increased effort to mobilise due to mental strength	
“Like I said, if I don't think about the amount of time that's still ahead, I’m okay” (*8) “And I am just trying to think of six months down the line… I am doing a little count down. I’ve only got five months to go.” (*9)	Avoiding fixation on external fixator duration	Coping mechanisms
“If I think of the outcome that it can have that basically outweighs the uncomfortable part of it. Because I know that my leg is going to be healed, or well. I am going to have a stiff ankle, but anyway. At least I can walk.” (*8)	The positive expected outcome outweighs the discomfort	
“I think when they cut the bone, it compressed a little, so I have accepted that it is a bit thick.” (*2) “it's fine. It is what it is” (*4)	Acceptance of possible deformity	

“People look at you funny in the shopping mall, and that's funny. That's always a funfactor for me.” (*4)	Humour	
“There's a certain....., they classify it as an anabolic, I think, or a steroid, whatever you want to call it, it is what it is, that they said will help with the bone growth and density of it.” (*4)	Finding other answers for bone growth	

* Denotes participant number

Theme 3: Physical factors affect weight-bearing

Quotes	Codes	Categories	Subthemes
“The ones on the ankle, [are] nearly 1cm, there [are] two of them. And there is one here where the plastic surgery failed. 3cm or something they patched. It looks like it’s getting healed” (*2)	Presence of wounds	Physical influences negatively affecting weight-bearing	Physical factors pertaining to the human body
“Because there [are] clips in, it tends to pull a bit. But that's just one of those things.” (*8)	Pulling of clips on wounds		
“It’s itchy” (*8)	Feelings of itchiness		
“My toes are still dead. So, I can't. I can’t feel it” (*8)	Diminished sensation		
“Then within a day or two I was in the theatre and then, the day hospital, they cleaned it out” (*1)	Return to theatre for haematoma		
“When you sleep, you don't sleep on the side, you sleep on your back. So it’s now straight” (*4)	Have to sleep on back to keep leg straight		
“It's just where the pins are, and then I get these like, it's like, muscle spasms, I don't know muscle spasm…it makes a knot there where between my third toe and then this one pin” (*8)	Muscle spasms		
“I am just losing this calf.” (*1)	Muscle atrophy		
“Sometimes you'll look at your foot and you think [incomprehensible] I can only move my toes. I can’t move anything else. But otherwise, I think if they've done this, from the start I wouldn't have mind[ed] having a stiff ankle.” (*8)	Joint limitations due to stiffness		
“When you put it down, you can feel there is tension,” (*4)	Tension in leg with weight-bearing		

“That's the one thing that.... my ability to balance and the strength of my legs” (*1)	Benefit of pre-operative strength and ability to balance	Preoperative function	
“which is a huge plus, because before I couldn't stand on it, I fall over to my right hand side because it's just wasn't stable enough. (*8)	Being used to instability and difficulty in walking pre-operatively		
“There is a hole now and she is bleeding, non-stop. So, if they can just assist her with that, I think she can be better.” (*5 translator)	Pin-site bleeding	Negative experience of external fixator instrumentation	Factors pertaining to the external fixator equipment
“there were two pins .. this one over here and this one started getting infected” (*1)	Infection in pin site		
“So, the only thing I’ve got to clean is the pins, but somebody is gonna help me with that.” (*8)	Inability to clean pins independently		
“No, it’s only this foot piece that I break, constantly. I think it’s the third time that I’m breaking it” (*7)	Breaking of the footplate		
“Everything works fine. There was one strut that was stuck but the sister at Unitas changed that, so after that everything’s fine” (*3)	Strut getting stuck		
“Previously, I had one and then when I walked on it, a piece of it broke, actually in my bone. So that is why I'm not walking on it” (*4)	Complications with components in previous surgeries causing reduction in current weight-bearing		
“you know it bumps everywhere. It is heavy. It is uncomfortable” (*8) “it’s heavy, very heavy, and I ...also I find that it bashes into my left leg.” (*9)	External fixator is cumbersome		
“You can't take your knee that put it there, because it's not gonna work there. You can't turn it like this, you can't turn it like that. (*8)	Difficult to manoeuvre external fixator		
“It's just when there is unevenness, you know, because this thing doesn't give.” (*8)	Difficult to manoeuvre with footplate on uneven surfaces		
“Hmm. Look I don’t pump mine up…I don't like it when it's pumped up” (*7)	Not liking footplate		

	pumped up		
“It’s not that difficult. The size is not bad” (*7)	Size of external fixator is not bad	Positive characteristics of external fixator and footplate	
“She cleans them. She can clean herself now.“ (*5 translator)	Ability to clean pins independently		
“It made a hell of a difference on my ability to move around. ” (*1)	Improvement in mobility with footplate		
“Because of the,... not just the ex-fix, but because of the, I call it my shoe, because it's [incomprehensible] tight. You know, in the beginning, it feels like you're gonna fall with it. But as soon as you get used to it, it actually makes standing easier, because what I can do now, I can actually stand at the basin and brush my teeth and wash my face without any problems, without losing my balance” (*8)	Improved balance with footplate		
“I don't walk too fast, but it's easier to walk” (*8)	Easier to walk with circular external fixator		
“So I can trust as long as I don’t have pain here, then I can walk.” (*1)	Able to walk if pain free		
“No, I mean I was up that afternoon, they put it on the morning and I was up and mobile by the afternoon” (*6)	Ability to mobilise immediately		
“It’s fine. Without crutches in the house. .... Long distance I walk with crutches” (*7)	Mobilise long distances with crutches	Assistive devices aiding mobilisation	Mobilisation and weight-bearing
“you’re able to walk more because you feel safer with your crutches” (*1)	Feel safe with crutches		
“I do not want to have a hip or a knee replacement…with the help of the crutch or the help of the boot… I can walk without putting stress on any other joint” (*1)	Using assistive devices to prevent future injury		
“There is weight-bearing on the leg, but with the crutches you can limit it easily” (*4)	Easy to limit weight-bearing with crutches	Assistive devices limiting weight-bearing	
“Then I use the wheelchair” (*3)	Using wheelchair to reduce weight-		

	bearing		
“I’ve got a wheelchair at home, so I use the wheelchair as well, to go around, in the house... The frame is difficult. The wheelchair is easier” (*3) “I work in my wheelchair because it's easier. I get around quicker.” (*8)	Easier function with wheelchair at home and work		
“But my biggest thing is taking a bath… when I take a bath I use a *skottel* [in Afrikaans], because I cannot go to the shower or bath.. That’s why I use the wheelchair” (*2) “Let’s say when I’m making myself a cup of coffee. I can’t. How do I walk with the walking frame and the coffee?” (*3)	Need for wheelchair to achieve activities of daily living		
“Luckily, I don't have a big house…I don't have a big bathroom, so, if I fall back, I’m gonna fall against the washing machine, if I go to the front, it’s gonna....., but I don't go sideways.” (*8)	Smaller house size prevents falls	Environmental factors facilitating mobilisation	
“I've got three dogs and my two big dogs [are] a bit of a handful. Especially the one. She’s a Pointer, so, I have to have the crutches. Otherwise, if they bump against me too hard, you know, and I fall” (*8)	Dogs are a fall risk	Environmental factors hindering mobilisation	
“It's only the one[’s] height. The one is longer than the other one. That's the only thing” (*7)	Leg length discrepancy	Reasons for gait adjustment	Adjustments in gait
“It’s not strong enough” (*4)	Lack of strength in leg		
“I think a big issue in the whole process is the ability to balance” (*1) “I don’t think it’s pain.... I just can't balance” (*2)	Inability to balance		
“you knock your good leg against it the whole time and you’re full of bruises and stuff” (*8) “I also I find that it bashes into my left leg.” (*9)	Unaffected leg gets injured		
“It just feels your leg doesn't want to walk with you” (*2) “You can’t just get up and walk outside” (*8)	Unable to function normally		
“15 minutes with the frame and the rest is on the wheelchair, in the house” (*3)	Unable to walk for long		
“At times I am very tired and at times my energy is okay” (*1)	Fluctuating levels of energy		
“people who haven't been walking on crutches, I think the three months before the op… to kind of build-up muscle memory of walking with crutches and you need to almost get into a automatised manner of dealing with crutches.” (*1)	Crutch walking needs to be learnt		
“It's just when there is unevenness, you know, because this thing doesn't give.” (*8)	Difficult to mobilise		

	on uneven surfaces		
“It’s now and then uncomfortable regarding what you can put on to yourself, onto your body.” (*4)	Clothing restrictions cause discomfort		
“I put on my boot to make the length of the two legs even… when I got the boot on then I can get along without the crutches” (*1)	Boot on other foot can correct leg length	Type of adjustments made	
“I wasn’t really limping.... took longer strides… It was kind of easier” (*1)	Longer strides diminish limp		

* Denotes participant number

Theme 4: Medical and non-medical support systems

Quotes	Codes	Categories	Subthemes
“my family structure you know, like, I don't feel that I have sufficient support [at] hand[].” (*2) “It makes a huge difference… If you don't have people that support you. My wife gets angry with me, because I can’t do the stuff that I want [and that] she wants me to do. Because she's not healthy” (*8)	Lack of a support structure at home	Lack of family support	Family and community involvement
“right now is like they are my caregiver” (*2)	Family no longer wants to be caregivers		
“I want to be independent.” (*2) “the sooner I can get it back and get this off, the better” (*4)	Need for independence		
“people can see you are in a compromised position.” (*2)	Compromised position affecting safety	Negative impact on work and safety	
“this thing was just expensive for me because now coming out of my own pocket and I am not working, I’ve closed my business, because people are unreliable” (*2)	Unable to work		
“he said you know these people are taking advantage of you because they can see that your leg is in pain and you cannot do anything” (*2)	Inability to function leads to being taken advantage of		

“I can't drive my car, for instance, because I mean, you can imagine you can't drive a car with this thing on. I mean if you get into accident now, it's your fault.” (*8)	Unable to drive		
“I work on a computer at home. So, I’m like sitting with my leg up. So, workwise that's not been an issue. “ (*9)	Able to work from home	Positive impact of ability to work	
“And the doctor is caring about what's happening with you and that is very, very..... And that was to me very, very helpful.” (*1)	Caring nature of surgeon is helpful	The multidisciplinary medical team	Patients’ experience of medical system
“You know, speaking the truth” (*1)	Honesty of surgeon		
“So, it took me some time to build trust now again with Dr FB and I think we succeeded in building that trust again.” (*1)	Trust in the surgeon		
I've got to the one doctor, before Dr. FB, and then they just wanted to amputate my leg. And when I talked to Dr. FB and them, it was just a total[ly] different scenario. And they never once said anything about that. And they were all just 100% sure that they're gonna fix it, So *ja*, you know, that makes me positive, that makes me believe that everything's gonna be alright.” (*8)	Confidence of surgeon makes patients positive		
“And the role of the wound sister is enormous because [of] her care, her immediacy, her availability, and the manner in which both of them worked with me” (*1)	Role of the Wound Care sister is important		
“And within an hour she got a response back. In another hour we got a prescription from the doctor when he came from the theatre…real time and immediacy so that you can ....you can take action, before it goes too far.” (*1)	Response time of medical team mitigates complications		
“just by doing their job in the proper manner. And a professional manner.” (*1)	Professionalism of multidisciplinary team		
“So when you get to them, and actually they [are] so positive, you know, you just feel like when you go out there you feel like you [are] positive” (*8)	Positivity of multidisciplinary team		
“in your own mindset you don't feel left alone. You know we[‘re] in this together” (*1) “ Now you have a whole practice that cares about you. And wants to help you, makes the ex-fix itself, being not that big a deal.” (*8)	Positive support from multidisciplinary team		
“Needs serious quality control and updating…the quality of service in the wards is dismal.” (*1)	Negative sense of hospital standards	Poor hospital experience	

“You ask for your sleeping tablet and half an hour later they come with it” (*1)	Patient’s perception of delays in administration of medication		
“it is not like a caring way” (*1)	Lack of care from hospital staff		
“So, to have that kind of insight and that's me you know, I want to understand how something works. If I understand it, then I know what I can do and then [it’s] just a matter of starting to do it and trusting it and doing it more and more and you [*in Afrikaans*] *sommer* trust” (*1)	Understanding the external fixator method of action	Medical education from multidisciplinary team	
“he was very good explaining it.” (*1)	Good explanation from surgeon		
“a little recipe for how you walk at steps” (*1)	Recipes for mobilisation help		
“if I can walk, you must also be knowledgeable about how to avoid the inflammation” (*2)	Importance of knowledge as to how to avoid injury		
“You need to rather do what the doctor says in regards to keeping the alignment and all that stuff.“ (*4)	Important to follow Dr’s instructions		
“I always know. Now I know there's a gap still, because I saw it on the x-ray; there’s still a gap.” (*4)	Seeing a bone gap on the X-ray and assuming non-union	Negative impact of poor education	
“I don't want to do it too soon. Because I don't know. I'm feeling my way around. I don't know what I can and can’t do at this stage.” (*9)	Not knowing what is allowed affects mobilisation and weight-bearing		
“I think that's also with the conversation I had with your physios. It’s also a[n] issue where they are too quick.” (*1)	Physiotherapists speak too fast		

* Denotes participant number

TURNITIN REPORT

Full report attached with submission


Megan Crouse Final Report

ORIGINALITY REPORT

3%	2%	1%	0%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS