Returning Female Athletes to Running Following a Tibial Bone Stress Injury

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Abstract

Tibial bone stress injuries (BSIs) are common in female athletes, particularly among distance runners. They have a high recurrence rate in females, and complexity emerges in the wider management and successful return to running. Following a tibial BSI, a critical component to complete rehabilitation is the successful return to running, and there is a lack of consistency or strong evidence to guide this process in female athletes. Therefore, the primary aim of this thesis was to investigate what criteria should be used prior to allowing the introduction of running, and how the process of returning female athletes to running following a tibial BSI should be navigated. Firstly, a scoping review of the literature was conducted to outline the criteria used prior to resuming running and to establish evidence-based guidelines for the return to running process following a tibial BSI in females. Forty-eight studies met the inclusion criteria. The recommendations surmised from the scoping review are based largely on level IV evidence. Five components were identified as important to address prior to introducing running, these being: 1. The resolution of bony tenderness; 2. Pain-free walking; 3. Evidence of radiological healing in high-risk BSIs; 4. Strength, functional and loading tests; 5. The identification of contributing factors. An individualised graduated return to running programme should be instigated, often starting with walk-run intervals, progressing running distance, ahead of speed and intensity, with symptom provocation a key consideration. Contributing factors to the initial injury, in particular energy availability and menstrual health, should be addressed throughout the return to run process. Secondly, ten experienced sport medicine clinicians were interviewed to establish how females with tibial BSIs are returned to running clinically, and to determine the critical components of management. Reflective thematic analysis was conducted to establish the themes and subthemes. When returning female athletes to running following a tibial BSI in a NZ context, their health should first be optimised, with nutritional status, and psychological and hormonal health particularly important. Symptom resolution and functional movement testing should be utilised to assess readiness to return to running. Progression of running load should be gradual, and guided by pain and physical assessment findings, as opposed to the generic 10% rule for running distance progression. Running gait retraining and modification of running surface should be individualised, but may include increasing running cadence and avoiding hard surfaces initially. In order to improve bone health, plyometric

training may be a beneficial addition in the advanced stages of progression. There is a need to individualise the return to running process and utilise a multi-disciplinary management approach. There are many facets involved in the return to running process following a tibial BSI in female athletes. All components are essential to address, but the size and influence of those components will be different for every individual. This thesis combines clinical reasoning with a comprehensive evidence synthesis to guide clinicians and researchers who seek to implement and evaluate return to running guidelines following a tibial BSI in female athletes.

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List of Abbreviations

BSI	Bone Stress Injury
RED-S	Relative Energy Deficiency in Sport
MRI	Magnetic Resonance Imaging
RTS	Return to Sport
ACLR	Anterior Cruciate Ligament Reconstruction
NLM	National Library of Medicine
RCT	Randomised Controlled Trial
MDT	Multi-disciplinary Team

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made.

Chapters 2 and 3 of this thesis represent two separate papers that have been or will be submitted to peer-reviewed journals for consideration for publication. My contribution and the contribution of the various co-authors to each of these papers are outlined at the beginning of this thesis. All co-authors have approved the inclusion of the joint work in this Master's thesis.

Esther George	**Dr Kelly Sheerin**	**Professor Duncan Reid**

Candidate Contribution of Co-authored Papers

Chapter 2: Criteria and guidelines for returning females to running following a tibial bone stress injury: A scoping review. Submitted to *Sports Medicine.*	George 80% Sheerin 10% Reid 10%
Chapter 3: Experienced sport medicine clinicians and returning females to running following a tibial bone stress injury. To be submitted to *Qualitative Research in Sport, Exercise and Health.*	George 80% Sheerin 10% Reid 10%

List of Co-Authored Works Arising from the Master's Thesis

Manuscripts submitted for publication

1. George, E., Sheerin, K., Reid, D. Criteria and guidelines for returning females to running following a tibial bone stress injury: A scoping review. Submitted to *Sports Medicine.*

Manuscripts formatted for submission

George, E., Sheerin, K., Reid, D. Experienced sports medicine clinicians and returning females to running following a tibial bone stress injury. To be submitted to *Qualitative Research in Sport, Exercise and Health.*

Peer-reviewed conference presentations

1. George, E. Sheerin, K., Reid, D. Guidelines for returning females to running following a tibial bone stress injury. *Sports Medicine New Zealand Conference.* Wellington; 2022. p. 14. (Appendix 2)
2. George, E. Sheerin, K., Reid, D. The return to run process for females following a tibial bone stress injury: a scoping review. *The International Society of Biomechanics in Sport Conference*. Milwaukee, USA; 2023. (Appendix 3)

3. George, E. Sheerin, K., Reid, D. Returning females to running following a tibial bone stress injury: Expert Interviews. *New Zealand Manipulative Physiotherapists Association Conference*. Rotorua, 2023. (Appendix 4)

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Thank you to the experienced sports medicine clinicians who participated in this research. Your time and expertise in the interviews were greatly appreciated. This research would never have been possible without you all being so generous with your time and knowledge. You are all very inspirational to me as sports medicine clinicians and I hope to work alongside some of you in the future.

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Finally thank you to my parents Chris and Jude, your unwavering love, encouragement and support through this whole process has been pivotal and so greatly appreciated. You have done so much for me over the past two years to allow me time to work on this thesis, from cooking endless meals, renovating my house and garden, being a constant listening ear, and helping me find work/life balance. You probably know far more about returning to running after tibial bone stress injuries than you ever wanted.

Ethical Approval

Ethical approval for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC). The AUTEC reference was 21/411, with approval granted in December 2021 (Appendix 1).

Chapter 1: Introduction

1.1 Background

1.1.1 Defining the Issue

Participation in running events worldwide has increased by 57% over the past 10 years, with an increase in female participation from under 20% in 1986 to just above 50% in 2018 (1). Running has many health benefits (2), however, there is also an inherent risk of musculoskeletal injury (3). A meta-analysis has reported running-related injury incidence ranged from 2.5 – 33 injuries per 1000 hours of running in a study of novice runners (3).

Bone stress injury (BSI) is a holistic term that encompasses low-grade bony stress reactions, to actual fractures (4). BSIs are fundamentally due to an inability of normal bone to withstand repetitive loads (5, 6), and there is a growing consensus BSIs occur due to an accumulation of load-induced microdamage, that exceeds the ability for bone remodelling (7). Although not common in the general population, BSIs account for 29 injuries per 100000 athlete exposures among collegiate cross-country runners, and in this population overall, BSI rates are over double in female athletes compared to males (8).

BSIs more commonly occur in the lower extremities (6, 9), with the tibia the most common location, particularly in female runners (8-17). Lower extremity BSIs are common among female distance runners due to the repetitive loading of the sport, with more than one-third of cross-country runners experiencing lower extremity BSIs (18). There is evidence that females are at increased risk of lower extremity BSIs (19-24). A systematic review of BSI incidence in military and athletic populations has reported an overall incidence of 9.7% in female athletes, compared to 6.5% in male athletes (19). Barrack et al. (22) cite a BSI prevalence of 8-52% in female endurance runners and track and field athletes and reported endurance running was the sport with the highest risk of BSI in females. Tenforde et al. (17) also found that tibial BSIs were the most common overuse injury sustained among competitive high school runners (41% of females and 34% of males).

1.1.2 Risk Factors for Tibial BSIs

The greatest predictor of developing a BSI is a history of prior BSI (20, 23), and BSIs have one of the highest recurrence rates of all running-related injuries (13, 20, 23). Prior BSI has been shown to increase the recurrence rate 5-6 times among female runners (18, 20, 23), therefore it is critical that contributing factors of the initial BSI are addressed during the return to running process to prevent the risk of recurrence.

There are many contributing factors associated with increased incidence and recurrence rates of BSIs, with Relative Energy Deficiency in Sport (RED-S) a major one in female athletes (25). According to Mountjoy et al. (26) "the syndrome of RED-S refers to impaired physiological function including, but not limited to, metabolic rate, menstrual function, bone health, immunity, protein synthesis, cardiovascular health caused by relative energy deficiency". RED-S is more common among female athletes (27), and it is established that low energy availability contributes to impaired bone health and the risk of BSIs particularly in female athletes (22, 25, 26, 28). The relative risk of BSI has been shown to increase by 4 and 5.7 times in female athletes, scoring 'moderate-' and 'high-risk' on the RED-S Risk Assessment Scale respectively, when compared to those scoring as low-risk (29). Furthermore, amenorrhea, defined as "the absence or abnormal cessation of the menses" (30), and indicating chronic energy conservation, was found in a relatively high proportion (37%) of elite female distance athletes (31) and 57% of female cross-country runners reported a history of menstrual irregularity (18). Several biomechanical factors during running have also been shown to be associated with an increased risk of tibial BSIs specifically in female athletes, such as increased rearfoot eversion angles, increased peak hip adduction angles and increased vertical loading rates (32-34). It would be valuable to establish a consensus regarding important contributing factors in female runners with tibial BSIs to address in clinical practice during the return to running process and to prevent injury recurrence.

1.1.3 Classifying Tibial BSIs

Tibial BSIs can be classified based on the grade of injury, as well as risk based on the location in the tibia. Several Magnetic Resonance Imaging (MRI) BSI scales have been proposed, mostly grading injuries from 1 to 4 (35-37). For most classification systems, the first three grades are considered 'stress reactions', and when there is a visible fracture line, the injury is considered a 'stress fracture', and typically classified as grade 4 (35-38).

BSIs can also be clinically classified as 'low-risk' or 'high-risk' injuries by anatomic location, which has implications for treatment and healing (5, 39-41). In the tibia, the most common location especially among runners is the posteromedial tibial shaft, which is considered a low-risk injury. These typically heal without major complications, and a gradual return to running can be initiated earlier (5, 41). In contrast, high-risk injuries involving the anterior tibial cortex may require surgical fixation or prolonged non-weight bearing, have a higher risk of complications, and likely require a longer timeline for returning to running (40). Differences in the grade of BSI, or risk of location will result in differing recovery times to the point of starting the return to running process.

1.1.4 Current Management of Tibial BSIs

Regarding the decision of when to return an athlete to sport, the 2016 Consensus Statement on Return to Sport (RTS) identified that this decision should be shared among all members of the rehabilitation team (42). Important elements to include in the RTS decision include a battery of physical tests replicating the reactive elements and the decision-making steps athletes use in real sporting situations, assessment of psychological readiness to RTS, and workload must be taken into consideration (42). However, this consensus statement did not specifically discuss BSIs, and the authors recognised that consensus is needed regarding the RTS criteria for common sporting injuries (42). While there are certain injuries, such as anterior cruciate ligament reconstruction (ACLR), where substantial research has been undertaken to create return to sport and running criteria (42-45), with some emerging evidence specific to menstrual cycle phased training (46), no criteria have been established regarding when a female athlete is safe to return to running following a tibial BSI.

Specific to the process of returning to running, Warden and colleagues have presented a management protocol for non-specific BSIs (7), and a loading protocol specific to tibial and metatarsal BSIs (47), in long-distance runners. While collectively these publications provide a degree of clinical guidance, the only female-specific guidelines relate to taking a detailed menstrual history in females with a BSI, and providing appropriate multidisciplinary management where RED-S is indicated (7, 47). The authors advocate that an important component of treatment is addressing contributing risk factors including running biomechanics, muscle strength and endurance, training structure, running surface and footwear (7, 47). Warden et al. (7) present an example of graduated return to running progression, beginning with one minute of running on alternate days, and progressing to 30 minutes of continuous running before increases in speed or frequency are introduced. Chen et al. (48) published an update on general BSI treatment in female athletes, however the only guidelines provided on the return to running process included resuming running at half pace and distance on alternate days one week after the resolution of focal bony tenderness. The authors emphasised important factors in the treatment of female athletes were identifying and correcting energy imbalance and monitoring menstrual function. They also discussed the potential influence of biomechanical factors such as increased loading rates, and nutritional deficiencies such as calcium and vitamin D deficiencies (48). While not specific to BSIs, Hegedus, et al. (49) also proposed a comprehensive six-phase progression to guide the successful return to competitive distance running following lower extremity injury. The authors advocate for starting with cross-training, which is gradually replaced with running, and interval sessions are not introduced until 50% of the normal running distance has been achieved. The importance of individualising the process, and monitoring physical and psychosocial measures were highlighted, however, no sex-specific guidelines were proposed.

1.2 Rationale and Significance of the Research

Tibial BSIs can result in not only considerable pain, but can cause disruption to training and competition, considerable financial burden in elite athletes, and substantial reductions in cardiovascular and muscular function (13, 50, 51). The recurrence rate of tibial BSIs is high especially in female athletes (18, 20, 23), therefore it is important management is optimised.

I myself am a female runner as well as a practising Musculoskeletal Physiotherapist. In both these realms I see the increased rates of BSIs in female runners, the high recurrence rates especially in a female running population, and the negative implications on these athletes. As such I see the importance of undertaking research to try to optimise the return to running process and prevent the recurrence of tibial BSIs in female athletes.

Following a tibial BSI, a critical component to complete rehabilitation is the successful return to running. However, there is a lack of information regarding when female athletes should begin this process, and a lack of consistency or strong evidence to guide the process of returning female athletes to running. Despite the number of women participating in sports continually rising (52), particularly distance running, there is a dearth of sports science research focused on females (53). More specifically, the increased incidence and recurrence of BSIs in female athletes indicate there are female-specific factors that increase risk and justify female-specific treatment responses. It is therefore highly valuable to establish evidence-based clinical guidelines for the process of returning female athletes to running to reduce the recurrence rates of tibial BSIs in female runners. The practice of evidence-based medicine means integrating individual clinical expertise with the best available external clinical evidence from systematic research (54).

1.3 Aim and Research Questions

1.3.1 Aim

To investigate criteria prior to introducing running and the process of returning female athletes to running following a tibial bone stress injury.

1.3.2 Research Questions

What is the evidence for criteria prior to introducing running, as well as the process of returning to running, following a tibial bone stress injury in female athletes?

How do experienced sport medicine clinicians return female athletes to running following low-risk tibial BSIs, and what do they consider as critical components of management?

1.4 Thesis Structure

The thesis is presented in a pathway two format and consists of four chapters to address the thesis aim and objectives (Figure 1). In accordance with the Auckland University of Technology's pathway two format, the thesis contains two chapters (two and three) developed for journal publication. The manuscripts in these chapters are presented in the format as they have been, or will be, submitted to target journals, and as such there is repetition of some information. Each chapter begins with a prelude, which serves to demonstrate the link between chapters and brings together the thesis as a cohesive whole.

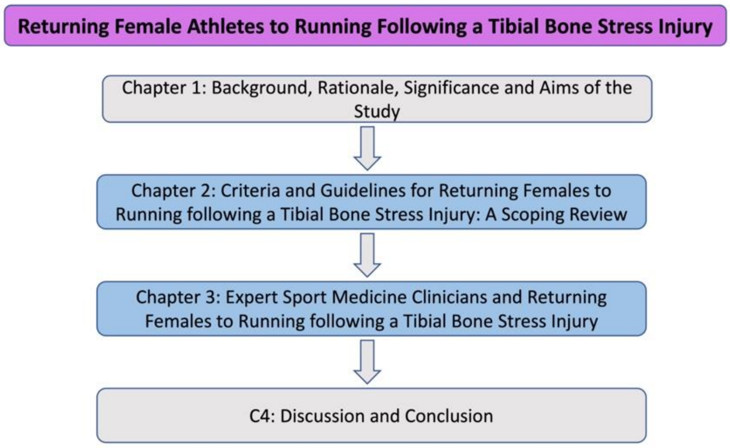

Figure 1: Thesis Structure and Chapters

Chapter 1 provides the background context, rationale for the thesis and the thesis aims. Chapter 2 is a scoping review of the literature which was conducted to establish what the current literature recommends regarding the criteria prior to resuming running and guidelines for the return to running process for female athletes following a tibial BSI. Chapter 3 is a qualitative study involving semi-structured interviews investigating how experienced sports medicine clinicians return female athletes to running, and what clinicians deem to be the critical components of management. Chapter 4 is then an overall discussion integrating the findings from the scoping review and the findings from the interviews with the experienced sport medicine clinicians to develop practical guidelines for the process of returning females to running following a tibial BSI. Practical implications are presented through an infographic. Study strengths, limitations, and directions for further research are also discussed. The thesis has been referenced in National Library of Medicine (NLM) style, with a single reference list at the end.

A mixed methodology research paradigm was chosen as the most beneficial design for this thesis to address the research questions. Mixed methods research as defined by Johnson et al. (55) "combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purposes of breadth and depth of understanding and corroboration". Mixed methodology enhances knowledge of a topic and allows strong conclusions to be made (56). It is particularly well-suited to health research, and through the integration of both quantitative and qualitative methods can address multifaceted research questions in depth(57). In the case of this thesis, the mixed methodology approach of the quantitative component (scoping review) informed the development of the question guide for the semi-structured interviews in the qualitative component. Furthermore, the qualitative component then assists to strengthen the quantitative research on this topic.

Prelude to Chapter 2

In order to optimise the return to running process for female athletes following a tibial bone stress injury, there must first be a clear understanding of what the literature recommends regarding criteria prior to introducing running, and for the process of returning to running following a tibial bone stress injury. This Chapter takes the form of a scoping review to outline the criteria used in clinical decision-making prior to resuming running, and to establish evidence-based guidelines for the return to running process following a tibial BSI in females. A scoping review was deemed most appropriate to map the current literature in this area, identify gaps in the literature and determine areas for future research (58). This manuscript has been formatted for publication in *Sports Medicine* and has been accepted for publication subject to final approval.

Chapter 2: Criteria and Guidelines for Returning Females to Running following a Tibial Bone Stress Injury: A Scoping Review

2.1 Abstract

Tibial bone stress injuries (BSIs) are common among female long-distance runners. They have a high recurrence rate in females, and complexity emerges in the wider management and successful return to running. Following a tibial BSI, a critical component to complete rehabilitation is the successful return to running, and there is a lack of consistency or strong evidence to guide this process in female athletes. The objectives of this review were to outline the criteria used in clinical decision-making prior to resuming running, and to establish evidence-based guidelines for the return to running process following a tibial BSI in females. Electronic databases including MEDLINE, CINAHL, Scopus, SPORTDiscus and AMED were searched for studies that stated criteria or provided guidelines on the objectives above. Forty-eight studies met the inclusion criteria and were included. Thirty-nine were reviews or clinical commentaries, three were retrospective cohort studies, two were randomised controlled trials (RCTs), two were pilot studies, one was a prospective observational study, and one case series. Therefore, the recommendations that have been surmised are based on level IV evidence. Decisions on when a female athlete should return to running should be shared between clinicians, coaches and the athlete. There are five important components to address prior to introducing running, these are: the resolution of bony tenderness, pain-free walking, evidence of radiological healing in high-risk BSIs, strength, functional and loading tests, and the identification of contributing factors. Effective return to running planning should address the athlete's risk profile and manage the risk by balancing the athlete's interests and reinjury prevention. An individualised graduated return to running programme should be instigated, often starting with walk-run intervals, progressing running distance ahead of speed and intensity, with symptom provocation a key consideration. Contributing factors to the initial injury, in particular energy availability and menstrual health in the female athlete, should be addressed throughout the return to run process.

2.2 Key Points

The overall recommendations are as follows:

1. The decision on when to start the return to running process in female athletes following a tibial BSI should be purposeful and based on defined criteria.
2. The return to run process following a tibial BSI needs to be individualised and based on multiple factors including the severity of injury and experience of the runner. While widely cited, the 10% rule of graduated loading is not generalisable to all runners.
3. It is important to acknowledge and address mechanical loading issues, and other contributing factors including biomechanical, nutritional, and specifically hormonal factors in the female athlete.

2.3 Introduction

Bone stress injuries (BSIs) predominantly occur in physically active individuals and are fundamentally due to an inability of normal bone to withstand repetitive loading (5). There is a growing consensus BSIs occur due to an accumulation of load-induced microdamage that exceeds bone remodelling (7). BSI is a holistic term that encompasses low-grade stress reactions through to fractures of the bone (4).

Up to 95% of BSIs in athletes occur in the lower extremities, with the tibia the most common location, particularly in female runners (10-14, 17). Lower extremity BSIs are common among female distance runners due to the repetitive loading of the sport, with more than one-third of cross-country runners experiencing lower extremity BSIs (18). Female athletes are at increased risk of lower extremity BSIs (19-23), with a systematic review of BSI incidence in military and athletic populations reporting an overall incidence of 9.7% in female athletes, compared to 6.5% in male athletes (19). Tenforde et al. (17) also found that tibial BSIs were the most common overuse injury sustained among competitive high school runners (41% of females and 34% of males). Additionally, BSIs have one of the highest recurrence rates of all running-related injuries (13, 20, 23). Prior BSI has been shown to increase the recurrence rate 5-6 times among female runners (18, 20, 23).

Relative energy deficiency in sport (RED-S) is more common among female athletes (27), and it is established that low energy availability contributes to impaired bone health and risk of BSIs particularly in female athletes (22, 25, 26, 28). The relative risk of BSI has been shown to be increased by 4 and 5.7 times in female athletes, scoring 'moderate-' and 'high-risk' on the RED-S Risk Assessment Scale respectively, when compared to those scoring as low-risk (29). Sports such as cross-country running had more athletes within the moderate- to high-risk category (29).

Tibial BSIs can be classified based on the grade of injury, as well as the risk associated with the tibial location. Several MRI BSI grading scales have been proposed, mostly grading injuries from 1–4 (35-37). For most classification systems, the first three grades are considered 'stress reactions', and when there is a visible fracture line, the injury is considered a 'stress fracture', and typically classified as grade 4 (35-38). BSIs can also be clinically classified as 'low-risk' or 'high-risk' injuries by anatomic location which will guide treatment (5, 39-41). In the tibia, the most common location especially among runners is the posteromedial tibial shaft, which is considered a low-risk injury. These typically heal without major complications, and a gradual return to running can be initiated earlier (5, 41). In contrast, high-risk injuries involving the anterior tibial cortex may require surgical fixation or prolonged non-weight bearing, have a higher complication risk, and likely require a longer timeline for returning to running (40). Differences in the grade of BSI or risk associated with tibial location will result in differing recovery times to the point of starting the return to running process.

Tibial BSIs can result in not only considerable pain, but can cause disruption to training and competition, a considerable financial burden in elite athletes, and substantial reductions in cardiovascular and muscular function (13, 50, 51). Therefore it is important management of these injuries is optimised. Following a tibial BSI, a critical component to complete rehabilitation is the successful return to running. However, there is a lack of information regarding when the athletes should begin this process, and a lack of consistency or strong evidence to guide the process of return to running. While existing reviews have explored the general concepts of BSI management (14, 19, 33, 42, 48, 59-85), these have not been specific to females. While there are certain injuries, such as anterior cruciate ligament reconstruction (ACLR), where substantial research has been undertaken to create return to sport and running criteria (43-45), with some emerging evidence specific to menstrual cycle phased training (46), no criteria have been established regarding when a female athlete is safe to return to running following a tibial BSI.

The increased incidence and recurrence of BSIs in female athletes indicate there are female-specific factors that increase risk, and justifies that treatment response needs to be female-specific. General sport science papers have highlighted the dearth of female research (53), therefore with tibial BSIs where there are obvious female-specific factors, there needs to be female-specific research. Therefore it would be highly valuable to establish evidence-based clinical guidelines for the process of returning female athletes to running, and to reduce the recurrence rates of tibial BSIs in female runners.

The specific aims of this scoping review are:

1) To outline the criteria used in clinical decision-making prior to resuming running for females following a tibial bony stress injury.
2) To establish evidence-based guidelines to support clinicians in the return to running process following a tibial bony stress injury in females.

2.4 Methods

The methodological framework proposed by Arksey and O'Malley (86) and the Joanna Briggs Institute Evidence Synthesis (87) were followed for the design and reporting of this scoping review: step 1, identify the research question; step 2, identify relevant studies; step 3, study selection; step 4, charting the data; and step 5, collating, summarising and reporting the results.

Initial literature searches revealed no studies specific to tibial BSIs in female runners, and as such the search scope was widened to include lower extremity BSIs, and any return to running-based activities. Studies included sources of information as recommended in the manual 'Methodology for JBI Scoping Reviews' (87) that provided guidelines for the process of returning to running related activities or stated criteria prior to introducing running related loads. Only full-text studies published in English were included. Keywords and constructs (i.e., Medical subject headings, Boolean phrases) used to execute each search were developed from a preliminary search (Table 1), and the full search strategies for all databases can be found in Appendix 5. The reference lists of included studies and the reference lists of key reviews were also screened, and a forward citation tracking Google Scholar was conducted to identify any potentially relevant studies that may have been missed in the database search (75). Studies were included if they outlined specific criteria prior to the introduction of running-related loads, or provided guidance on the process of returning to running-related activities, following a tibial or lower extremity BSI (Table 2).

Table 1: Scoping Review Search Terms

Search 1	**Search 2**
"Bon* Stress Injur*" OR "Stress fracture*" OR "Stress reaction*"	"Bon* Stress Injur*" OR "Stress fracture*" OR "Stress reaction*"
"lower extremit*" OR "lower limb*" OR leg* OR knee OR tibia*	"lower extremit*" OR "lower limb*" OR leg* OR knee OR tibia*
(return*) n3 (sport* OR play OR training OR activit*)	(Run*)

Table 2: Inclusion and Exclusion Criteria

Inclusion Criteria	**Exclusion Criteria**
Human participants	Animal models or cadavers
Articles referring to bone stress injuries in the tibia or a non-specific location in the lower extremity	Articles focusing on bone stress injuries in a specific location that was not the tibia
Females and males	Specific focus on males
Describes the activities, process, or criteria prior to beginning the process of returning or running-related activities	No description of the return to running-related activities, process, or criteria prior to beginning running-related activities
Specific detail of bone stress injury management	No specific mention of bone stress injury management

The lead author (EG) screened titles and abstracts, and EG and KS then independently screened the full-text articles to determine the final study selection (Figure 2). Any discrepancies were resolved during a consensus meeting. A third reviewer (DR) was available if needed, but was not required. Data were extracted into a spreadsheet by EG and independently verified by KS. Disagreements were resolved via consensus or discussion with DR. An inductive thematic analysis was used to identify patterns, summarise consistent findings across studies, and generate common themes (88). Regular meetings were held to discuss and agree on emerging themes and interpretations.

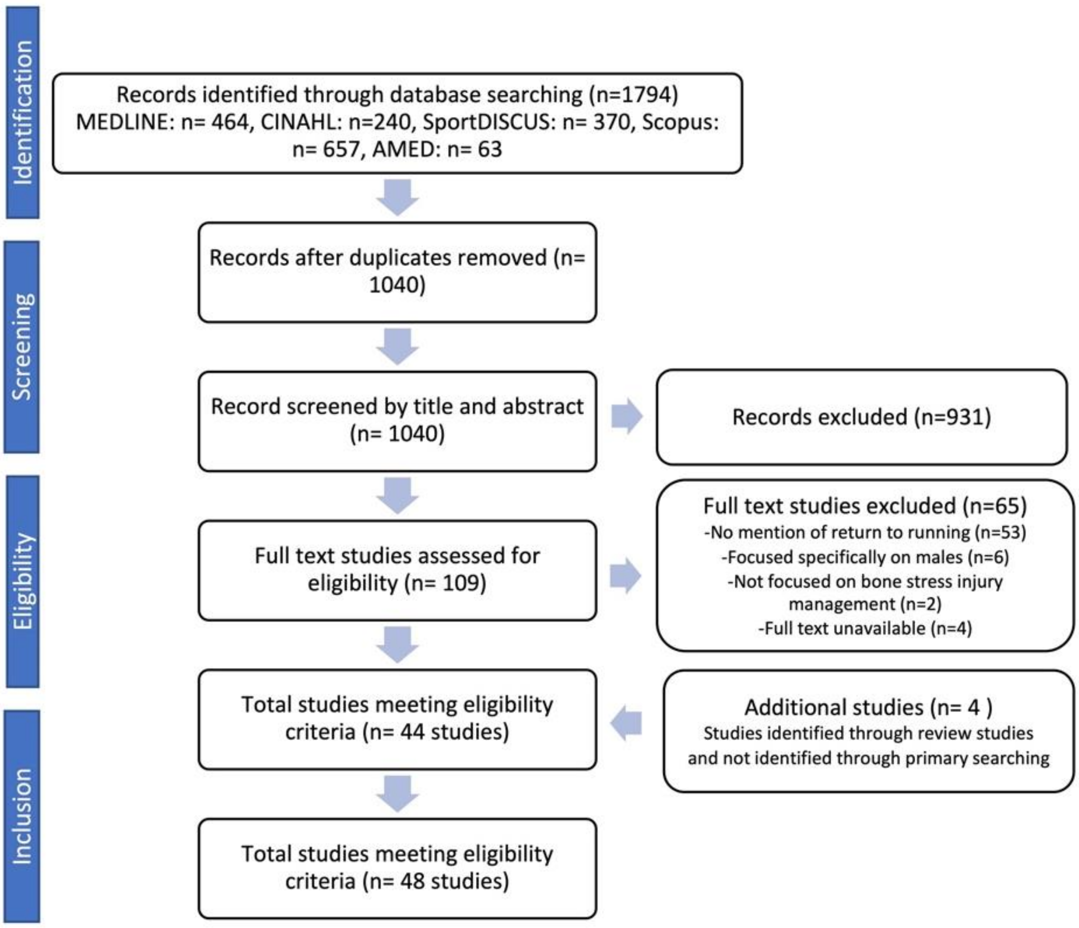

Figure 2: Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram

2.5 Results

The initial search identified 1040 studies, of which 48 studies met the inclusion criteria (Figure 2). Of these, 39 were reviews or clinical commentaries, three were retrospective cohort studies, two were randomised controlled trials (RCTs), two were pilot studies, one was a prospective observational study, and one was a case series. The variation in the quality of these studies further justified that a scoping review was appropriate rather than a systematic review. Of the 48 studies, 46 provided criteria prior to introducing running-related loads, and four themes of criteria were identified: Symptom Resolution, Radiology, Strength, Functional and Loading Tests, and Addressing Contributing Factors. All studies provided guidance on the return-to-run process, and three themes were identified: Graduated Running Progression, Running Surface, and Biomechanics and Strength Training.

2.5.1 Return to Run Criteria

2.5.1.1 Symptom Resolution

All studies that identified criteria indicated that the athlete must first be pain-free, and their symptoms resolved with ambulation and activities of daily living for a period ranging from 2-14 days prior to the introduction of running-related loads (7, 11, 35, 40, 41, 47, 48, 60, 61, 64, 67, 69, 71, 74, 77-80, 89-110) (Table 3). Thirty-five percent of reviewed studies recommended a certain walking distance or duration ranging from 1 mile to 45 minutes as presented in Table 3 (7, 47, 60, 79, 90, 92, 94-96, 100, 105, 109, 111, 112). Two reviewed studies recommended completing this walking distance three times (96, 109), however the number of repetitions was not specified in any other studies.

Forty-eight percent of reviewed studies stated that bony tenderness should have resolved before introducing running-related loads (7, 61, 67, 69, 80, 92-96, 98, 101-107, 110). Three studies, which were either clinical commentaries or reviews, specified this should be for at least one week (48, 77, 97), while a RCT and case series presented contrasting recommendations, indicating that persistent localised tenderness did not influence initiation or completion of the running progression with participants (11, 79).

2.5.1.2 Radiology

Differing recommendations were provided regarding the requirement for radiologic healing prior to introducing running-related loads (Table 3). Eighty percent of studies either did not state imaging as a criterion prior to introducing running, or specified that evidence of radiological healing was not required prior to introducing running-related loads, due to the lack of consistency between clinical and radiological healing and the limited sensitivity of radiographs (11, 41, 60, 61, 92, 94, 96, 106, 108, 111). All of these studies indicated this regarding BSIs in low-risk locations such as posteromedial tibia. In the case of a high-risk BSI, such as anterior tibial cortex BSI, 22% of studies specified imaging as important to confirm healing and prevent complications such as progression to full fracture before the athlete returns to running (40, 48, 71, 77, 92, 94, 96, 101, 103, 108). The studies providing recommendations on the inclusion of imaging were all either clinical commentaries, reviews or case series.

2.5.1.3 Strength, Functional and Loading Tests

Thirty-three percent of studies indicated lower extremity functional movements should be assessed prior to introducing running-related loads (7, 35, 47, 48, 64, 77, 79, 90, 97, 98, 100, 101, 110, 111, 113) (Table 3). Only a small number of specific movements were recommended, with a single leg vertical hop test to indicate preparedness for return to running-related activities reported by only 8% of studies (47, 62, 79, 90). An RCT by Swenson et al. (79) reported that the single leg vertical hop test for pain was strongly correlated with functional progression, and was the most sensitive test for predicting the return to unrestricted pain-free activity. The remainder of the studies were clinical commentaries or review studies. Nine studies indicated lower extremity strength should be assessed and addressed prior to introducing running-related loads (7, 35, 67, 78, 97, 101, 104, 111, 114). Harmon et al. (67) specified 75–80% of lower extremity strength of the injured, compared to the non-injured side, should be achieved prior to introducing running-related loads.

2.5.1.4 Addressing Contributing Factors

All studies that stated return to running criteria agreed that a key component of management is to identify and address contributing factors involved in the initial development of the BSI (7, 11, 35, 40, 41, 47, 48, 60, 61, 64, 67, 69, 71, 74, 77, 78, 80, 89, 91-111, 113-116). These factors will be individual to the athlete, but important factors identified included menstrual health, nutritional deficiencies, energy availability, running biomechanics, muscle strength and flexibility deficits, mechanical loading issues (commonly referred to as 'training errors') and footwear to prevent the risk of recurrence (Table 3). Seventy percent of studies identified the importance of assessing menstrual health and RED-S risk when treating a female athlete (7, 35, 40, 41, 47, 48, 60, 61, 64, 71, 74, 77, 78, 80, 89, 91-94, 96-98, 100-104, 106, 108, 110, 111, 116). It is indicated that these contributing factors should be addressed prior to a return to full training.

2.5.2 Return to Running Process

2.5.2.1 Graduated Running Progression

The athlete's goals and previous running level should guide the return to running process (60, 61, 67, 92, 97, 98, 105, 109). A walk-run progression, gradually substituting walking with increasing time increments of running was recommended by 31% of reviewed studies that provided guidance to return to running (7, 60, 79, 89, 90, 92, 94-96, 101, 109, 111, 112). Two RCTs and one pilot study presented walk-run programmes and the rest of these recommendations came from review studies or clinical commentaries. The length of running increments ranged from 100 metres (m) to 5 minutes, and the progression of these increments ranged from 100m to 5 minutes (see Table 4). The initial speed of these running increments will be dependent on the pre-injury level of the runner, but 48% of studies recommended beginning at a slower pace, with specific recommendations presented in Table 4 (7, 47, 48, 60, 64, 69, 71, 77, 79, 89, 90, 92, 94-97, 101, 107, 109, 111, 112, 114).

Of the studies that stated a frequency of initial runs, 63% recommended starting with alternate days (7, 11, 35, 47, 48, 71, 77, 78, 80, 89, 96-98, 100, 105, 107, 109, 112-114), with several studies specifying this should be maintained for times ranging from 2- (48, 97, 98) to 4-weeks (7, 89) (Table 4). Other studies indicated the athlete could start at an increased frequency depending on symptoms (60, 79, 90, 92, 94, 95, 111).

Progressively increasing running distance by 10% per week, often referred to as 'the 10% rule', is a common recommendation to prevent injury during normal training (96, 104), but is also widely cited as a method of returning to running following a lower extremity BSI (47, 61, 64, 67, 69, 71, 80, 81, 101, 102, 105, 107, 110, 116) (Table 4). A small number of these clinical commentaries or reviews highlighted that this approach is not generalisable, and individual runners may tolerate different rates of progression (7, 67, 109), but provided no more specific guidance. Pain or symptom provocation are the main indicators used in the reviewed studies to guide the progression through the return to running process following a tibial BSI (7, 11, 35, 47, 48, 60, 64, 67, 69, 71, 78, 79, 89, 90, 92, 94-96, 98-102, 104-106, 108-116), with several studies specifying the importance of being pain-free, both during and following activity (7, 47, 71, 102). If symptoms were provoked at the injury site whilst running, it was recommended that athletes rest until symptoms resolved, and then resume at a lower level (7, 35, 60, 67, 89, 92, 94-96, 98, 100, 101, 110-113, 115, 116).

It is widely cited that distance should be progressed prior to increasing speed when returning to running following a tibial or lower extremity BSI (7, 47, 60, 61, 71, 79, 89, 92, 94, 95, 97, 98, 105, 109, 111, 112, 115) (Table 4), with 11 studies suggesting a specific running distance or duration that should be achieved before speed changes, ranging from 1 mile to 45 minutes (7, 60, 79, 89, 90, 92, 94, 95, 98, 111, 112). Similar to the progression of distance, five studies suggested 'the 10% rule' as a guideline to progress running speed (7, 64, 69, 101, 110). Other recommendations regarding the progression of speed are presented in Table 4.

2.5.2.2 Running Surface

While a number of studies provided specific recommendations to initiate running on either a treadmill (60, 61, 92, 94, 95, 111, 116) or a running track (79, 90, 112), there are conflicting recommendations regarding return to running and surfaces (Table 4). Other recommendations included starting on a level surface or limiting hills during recovery (7, 64, 69, 77, 91, 97, 101), and avoiding hard (7, 48, 77, 80, 89, 97, 98, 100, 103, 104, 106, 108, 109, 116) or uneven (7, 64, 91, 100, 101, 104, 106) surfaces. Some studies suggested avoiding multiple terrains during the initial recovery (7, 69, 89, 109), while others recommended varying terrain once back to normal training (64, 89, 91, 111, 115). Two RCTs and one pilot study recommended introducing running-related loads on the running track.

The remainder of the studies providing recommendations were review studies or clinical commentaries.

2.5.2.3 Biomechanics and Strength Training

An important component of the return to running process recognised by 63% of reviewed studies was to address lower extremity biomechanical abnormalities thought to contribute to the initial injury (7, 35, 47, 48, 60, 61, 64, 67, 69, 71, 74, 77, 78, 89, 91-94, 96-102, 105, 108, 111, 113, 115). Additionally, multiple biomechanical risk factors for tibial BSIs in females were acknowledged. In particular, peak hip adduction (48, 69, 77, 98, 102) and rearfoot eversion (48, 61, 69, 77, 98, 102) were identified as important risk factors among female runners.

Furthermore, muscle strengthening was identified as important by 75% of studies to correct muscle imbalances and improve biomechanics following a tibial BSI (7, 11, 35, 47, 60, 61, 64, 67, 69, 71, 77, 78, 80, 89, 91-97, 100-105, 107-111, 113-116). Strengthening of local muscles including the calf and tibialis anterior (7, 11, 47, 60, 64, 69, 71, 77, 80, 89, 95, 101, 109, 116), as well as proximal strength including the core and pelvic muscles (7, 47, 69, 71, 89, 101, 104, 105), were recommended (Table 4). Ten studies acknowledged the importance of progressing to plyometric strengthening in this process (47, 60, 67, 71, 89, 92, 94, 105, 109, 111). It was suggested that these recommendations were more specific once athletes could sprint (60, 92, 94, 111), or squat one and a half times their body weight (109). Lastly, 29% of studies identified addressing muscle flexibility as an important component (11, 60, 61, 64, 69, 71, 78, 80, 89, 91, 101, 104, 110, 117), in particular calf and hamstring flexibility in the case of a tibial BSI. The majority of the studies providing recommendations on biomechanics and muscle strengthening were clinical commentaries, case studies, or reviews.

Table 3: Return to Running Criteria Themes

Recommendation	Detail	References
Resolution of bony local tenderness	Timeframe not specified	(7, 61, 67, 69, 80, 92-96, 98, 101-107, 110)
	For 1 week	(48, 77, 97)
	Not required	(11, 79)
Pain-free with ambulation and activities of daily living	Timeframe not specified	(40, 41, 60, 64, 80, 91-96, 99-105, 108)
	2 day pain-free duration	(90)
	3-5 day pain-free duration	(7, 35, 47, 79, 89, 113)
	10-14 day pain-free duration	(11, 48, 61, 67, 69, 71, 74, 77, 78, 97, 98, 109, 110)
Pain-free walking	30 minutes	(7, 47, 109)
	45 minutes	(111)
	2 x 20 minutes	(112) (pain less than 3 on visual analogue scale)
	1 mile	(79, 90)
	1.5 miles	(96)
	3 x weekly	(96, 109)
Evidence of radiological healing	Not necessary for low-risk locations (posteromedial tibial)	(11, 41, 48, 60, 61, 71, 77, 92, 94, 96, 101, 106, 108, 111)
	Only necessary in high-risk locations (anterior tibial cortex)	(40, 48, 71, 77, 92, 94, 96, 101, 103, 108)
	Necessary	(78, 104, 110)
	Referral for imaging if return of symptoms	(69)
Functional movements assessed	Yes	(7, 35, 64, 77, 97, 98, 100, 101, 110, 111, 113)
	Single leg vertical hop	(47, 48, 79, 90)
	Single leg squat	(7)

Lower extremity strength assessed	Yes	(7, 35, 78, 97, 101, 104, 111, 114)
	75-85% strength	(67)
Contributing factors	Nutritional factors	(7, 40, 41, 47, 48, 60, 61, 64, 69, 71, 74, 77, 78, 80, 89, 92-94, 96-98, 100-104, 106, 108, 110, 115, 116)
	Menstrual health	(7, 35, 40, 41, 47, 48, 60, 61, 64, 71, 74, 77, 78, 80, 89, 91-94, 96-98, 100-104, 106, 108, 110, 111, 116)
	Footwear	(7, 11, 40, 41, 47, 60, 61, 64, 69, 71, 74, 78, 80, 89, 92-94, 97, 98, 100, 101, 103-105, 108-110, 116)
	Training errors	(7, 11, 35, 40, 41, 47, 60, 61, 64, 69, 71, 74, 78, 80, 89, 92-94, 96-98, 100-102, 104, 105, 108, 111, 113, 114, 116)
	Psychological factors	(97, 103, 115)
	Biomechanical factors	(7, 11, 40, 41, 47, 48, 60, 61, 64, 67, 69, 71, 77, 78, 80, 89, 91-105, 107-111, 113-117)

Table 4: Return to Running Process Themes

Component of process	Recommendation	Detail	References
Introduction of running load	Walk-run	Length not specified	(101)
		Start with 30 second running increments	(105)
		Start with 100 metre running increments	(79, 109, 112)
		Start with 1 minute running intervals	(7, 89, 96)
		Start with 400 metre running increments	(90)
		Start with 5 minute running increments	(60, 92, 94, 95, 98, 111)
		Progress running increments by 1-2 minutes	(7, 89, 96)
		Progress running increments by 100-400 metres	(79, 90)
		Progress running increments by 5 minutes	(60, 92, 94, 95, 98, 111)
		Progress total distance but keep the same running increments length	(109, 112)
	Gradual progression		(11, 40, 41, 48, 69, 74, 77, 91, 93, 97, 99, 100, 103, 104, 108, 114-116)
	Alternate days		(11, 35, 47, 71, 77, 78, 80, 96, 100, 105, 107, 109, 112-114)
		For first 4 weeks	(7, 89)
		For first 2 weeks	(48, 97, 98)
	Rest days included	During progression	(91, 101, 108)
		During normal training	(40, 41)

	Daily depending on symptoms		(60, 79, 90, 92, 94, 95, 111)
	10% progression		(47, 61, 64, 67, 69, 71, 80, 81, 101, 102, 105, 107, 110, 116)
		As part of usual training/for injury prevention	(96, 104)
		Acknowledges lack of evidence	(81, 102, 105)
		Not generalisable, runners may tolerate different rates of progression	(7, 67, 109)
	15-20% progression		(109)
	Progression guided by pain		(11, 48, 64, 69, 77, 78, 80, 95, 98, 99, 104-109, 114)
		If pain rest and resume at a lower level	(7, 35, 47, 60, 67, 79, 89, 90, 92, 94, 96, 100, 101, 110, 111, 113, 115, 116)
		If pain less than 3/10 at rest and resume at lower level	(112)
		Specify the athlete should be pain-free during and following	(7, 47, 71, 102)
	Progression guided by goals and previous running level		(35, 40, 41, 60, 61, 67, 74, 92, 94, 97, 98, 105, 106, 109-111, 113)
	Progression guided by whether location is low-risk (posteromedial) or high-risk (anterior tibial cortex)		(7, 40, 41, 47, 48, 60, 61, 67, 71, 77, 78, 93, 95-98, 100-103, 106, 108, 116)
	Progression guided by grade/ severity of injury		(7, 35, 47, 60, 61, 69, 77, 89, 94, 97, 101, 103, 105, 106, 108, 110, 112, 113, 115)
Running speed	Start 30-50% usual pace		(7, 47, 48, 64, 69, 71, 77, 97, 101)
	Start at a slower pace		(60, 79, 90, 92, 94-96, 107, 109, 111, 112, 114, 115)
	Pace reduced by 1metre/second		(89)

Progression of speed	Progress from jogging to running	(67, 93)
	Progress from walk-jog to jog-run	(79, 112)
	Increase intensity by 10% weekly	(7, 64, 69, 101, 110)
	Progress to half pace strides then gradually Progress to full pace striding	(60, 92, 94, 111)
	Increase distance prior to speed	(7, 47, 60, 61, 71, 79, 89, 92, 94, 95, 97, 98, 105, 109, 111, 112, 115)
Criteria prior to speed changes	45 minutes	(60, 92, 94, 95, 98, 111)
	40 minutes	(89)
	6 track laps walk/ 6 laps jogging (1.5 miles total)	(112)
	30 minutes	(7)
	1 mile	(79, 90)
	Temporarily reduce running volume when increasing speed	(47, 112)
	Hold distance steady when increasing speed	(7, 60, 79, 92, 94, 111)
Running surface	Start on level asphalt	(91)
	Start on running track	(79, 90, 112)
	Track may increase strain	(97)
	Start on treadmill	(60, 61, 92, 94, 95, 111, 116)
	Start on level surface	(64, 77, 91, 101)
	Start on moderate firmness surface	(64)
	Hard surfaces risk factor/ avoid	(7, 48, 77, 80, 89, 97, 98, 100, 103, 104, 106, 108, 109, 116)
	Start on softer surfaces initially	(98)
	Hills can increase strain/risk	(7, 64, 69, 97)
	Irregular/uneven/soft surfaces can increase strain/risk	(7, 64, 91, 100, 101, 104, 106)
	Limit multiple terrains initially	(7, 69, 89, 109)

	Vary terrain once back to normal training		(64, 89, 91, 111, 115)
Biomechanics	Address lower extremity biomechanics		(35, 40, 60, 61, 64, 78, 80, 91, 92, 94, 103, 105, 108, 111, 113, 115)
	Gait retraining		(7, 47, 48, 67, 69, 71, 89, 91, 98, 100, 101, 103, 105, 113)
		Reduce stride length/ increase cadence	(7, 47, 89, 101)
		To reduce vertical loading rates	(7, 71)
		Modify initial foot contact	(7)
	Risk factors	Excessively supinated or pronated feet	(11, 48, 60, 61, 77, 92, 94, 97, 99, 100)
		Reduced dorsiflexion range	(61, 97)
		Increased peak hip adduction angle	(48, 69, 77, 98, 102)
		Increased rear foot eversion angle	(48, 61, 69, 77, 98, 102)
		Increased vertical loading rates	(48, 71, 77, 98)
		Increased rearfoot striking	(48, 71)
	Orthotics		(47, 65-67, 75, 95, 112, 118-127)
Strengthening	Include strengthening		(7, 11, 35, 47, 60, 61, 64, 67, 69, 71, 78, 80, 91-97, 100, 102-105, 107-111, 113-116)
		Calf strength	(7, 11, 47, 60, 69, 71, 77, 80, 89, 95, 101, 109, 116)
		Hip strength	(7, 47, 71, 89)
		Dorsiflexor/ intrinsic foot muscle strengthening	(7, 64)
		Core strengthening	(7, 69, 71, 104)
	Include balance		(69, 109)
	Plyometrics/ running drills		(47, 60, 67, 71, 89, 92, 94, 105, 109, 111)

		Include 3 x weekly	(47)
		Introduce once athlete can squat 1.5 times body weight	(109)
		Introduce once able to fully sprint	(60, 92, 94, 111)
Flexibility	Include flexibility		(11, 64, 69, 80, 89, 91, 101, 104, 110, 117)
		Calf stretching	(60, 61, 64, 71, 80, 89, 91)
		Hamstring stretching	(89, 117)

2.6 Discussion

The main objectives of this scoping review were to summarise and make recommendations regarding, firstly the return to running criteria currently used to safely return females to running, and secondly the guidelines for the process of returning females to running following a tibial BSI. Specific to the running criteria, five important components have been identified to address prior to returning females to running. These include the resolution of local bony tenderness, pain-free walking, evidence of radiological healing only in the case of a high-risk BSI, assessment of strength, functional and loading movements, and identification of contributing factors. There are then four important considerations in the return to running process. These include walk-run progression, progression of running load, running surface, and addressing biomechanical and strength factors. There is clearly some information that is non-sex specific, and could relate to both males and females, however as part of this review there has been a focus on literature that is particularly of relevance to females.

2.6.1 Return to Run Criteria

2.6.1.1 Resolution of Localised Tibial Tenderness

Tibial tenderness should be assessed by a medical professional, and then monitored by the athlete during daily activities, ambulation and rehabilitation (7, 61, 69, 92-94, 96, 98, 101, 110). However, the weight placed on resolution should be guided by the severity of the injury and the level of the runner.

Localised tibial tenderness has been found to correlate with more involved marrow and cortical abnormalities findings on MRI (36), and therefore once bony tenderness has resolved a significant degree of healing should have occurred. There was not complete consensus between scoping review articles on whether complete resolution is required. A number of reviews have suggested that resolution of bony tenderness is required prior to introducing running-related loads (7, 48, 61, 67, 69, 77, 80, 92-98, 102-107, 110), however there is a lack of scientific evidence to support these statements. Conversely, an RCT and a large case series reported that persistent localised tibial tenderness did not influence initiation or successful completion of the functional progression among their participants (11, 79). Those that began the return-to-run process with bony tenderness still successfully completed the functional progressions (79). Therefore, waiting for complete resolution of bony tenderness may unnecessarily prolong the return to running process following a low-risk tibial BSI. Ensuring complete resolution of bony tenderness prior to returning to running is a logical criterion following a high-risk tibial BSI, considering the increased risk of complications. Following a low-risk BSI, a logical approach may be to assess bony tenderness and monitor for any increases throughout the process of increasing running load.

2.6.1.2 Pain-free Walking

The second step is to ensure athletes progress their walking tolerance prior to initiating running. There is consensus from all studies that the athlete should be pain-free with walking. This is also a logical criterion, as bone pain generally indicates mechanical or chemical irritation and overload to the bone (7, 36, 63, 128). Walking between 1 mile and 45 minutes has been suggested by a number of studies (7, 60, 79, 89, 90, 92, 94, 95, 98, 111, 112), however there is a lack of evidence to support this, and minimal guidelines have been provided on the frequency of walks. A similar criterion of increasing walking to 60-90 minutes daily for 3 weeks has been suggested following a sacral stress fracture in a female runner (129). Tibial stress has been shown to significantly increase during running compared with walking, more so in females, highlighting the need to gradually expose bone to load to ensure bone adaptation and prepare for running-related loads (122). Clinically increasing pain-free walking tolerance makes sense to ensure positive bone adaption, however further evidence and clarification on this point is required and specific walking distances should be individualised based on the runner.

2.6.1.3 *Evidence of Radiological Healing*

The results of this scoping review indicate that evidence of radiological healing is not required except in the case of a high-risk BSI, such as an anterior tibial cortex. It is well-established that early presentation and low-grade BSIs are often missed on plain radiographs and findings on imaging often lag behind clinical healing (12, 37, 70, 121, 130, 131). Wright et al. (131) carried out a systematic review to determine the diagnostic accuracy of imaging modalities used to diagnose lower extremity stress fractures. The findings indicated that radiographs are limited by low sensitivity, particularly in the early stages of stress fracture, and in some cases may not reveal an existing stress fracture at any time (131). Therefore clinical, as opposed to radiological, signs of healing should guide the decision to introduce running related loads in low-risk BSIs, such as posteromedial tibial BSIs. However in the case of an anterior tibial cortex BSI, an X-Ray should be completed despite the low sensitivity. Further imaging may then follow if required to confirm complete healing prior to returning to running. This is in line with other BSI management recommendations discussing low-risk and high-risk BSIs, as there is an elevated risk of complications at high-risk locations including fracture progression, refracture, delayed union and non-union (12, 39).

2.6.1.4 *Assessment of Lower Extremity Strength and Functional Pain Provocation Loading Tests*

The initial phase prior to returning to running can be utilised to strengthen local and proximal muscles. Only a relatively small number of studies specified assessing lower extremity strength prior to introducing running related loads, with one study recommending achieving 75-80% lower extremity strength symmetry (67). However almost all reviewed studies recommended addressing biomechanical abnormalities and muscle imbalances thought to contribute to the initial injury. This is likely an important component as lower lean body mass, smaller calf girth and reduced leg press strength have been identified as risk factors for tibial BSIs in females (18, 118, 132, 133). The plantar flexors are one of the main muscle groups acting directly on the tibia and have the potential to alter tibial stress therefore assessing calf strength may be potentially valuable (134, 135). Isometric muscle tests where hamstring and quadriceps strength is 70-80% of the unaffected side has been recommended in return to running criteria following ACLR (43-45). However further research is required in female athletes to identify specific strength criteria prior to returning to running following a tibial BSI.

Functional tests replicating some of the physical requirements of running may determine whether the athlete is ready to return to running. Although only one-third of studies indicated functional movements should be assessed, almost all reviewed studies recommended addressing biomechanical abnormalities and muscle imbalances thought to contribute to the initial injury. The single leg vertical hop test replicates the loading and unloading components of running, and could assess the capacity of the tibia to withstand stress and readiness to return to running in conjunction with other components of the clinical examination (124, 136). The single leg vertical hop test for pain is cited as a highly sensitive test for predicting the return to unrestricted pain-free activity, and is strongly correlated with functional progression following a tibial BSI in both female and male runners (79). Similarly the single leg vertical hop test has been used following femoral and sacral stress fractures to guide progression through the rehabilitation process (68, 137).

The 2016 Return to Sport Consensus Statement recommends that a battery of tests are used to mimic the demands of the sport when making a decision regarding return to sport (42). Therefore, based on the scoping review findings, along with other lower extremity BSI case studies, and ACLR return to running research, clinicians could consider a battery of strength, functional and loading tests prior to introducing running-related loads. Assessments could include the single leg vertical hop test, lower extremity strength testing particularly focused on calf strength, and lower extremity biomechanical assessments. However further research is needed in female athletes following a tibial BSI before clear guidelines can be provided.

2.6.1.5 Identification of Contributing Factors

The need to identify and address contributing factors such as menstrual health, nutritional factors, biomechanical factors, mechanical loading issues and footwear was acknowledged by reviewed studies. It is beyond the scope of this scoping review to systematically review these risk factors, but these recommendations are in line with the intrinsic and extrinsic risk factors identified by Abbott et al. (13), as well as other reviews in this area (138, 139).

Fundamentally all overuse injuries in runners are linked to mechanical loading issues (7, 48, 92, 97, 140, 141). As such it is important that these are not repeated during the return to running process, or when full training eventually resumes. Alongside mechanical loading issues, it is particularly important that female athletes are screened for RED-S to optimise return to run outcomes, and to prevent long-term health consequences. RED-S has a well-established effect on menstrual function and bone health in female athletes (25). RED-S may be accompanied by low bone density, menstrual dysfunction, disordered eating and low body mass index, and these factors put female athletes at higher risk for BSIs (22, 23, 25, 28). The RED-S Risk Assessment Model classifies athletes into low, moderate and high-risk categories depending on subjective and objective examination and aids return to sport decision-making. If an athlete is classified as high-risk they should not be cleared for participation, and if they are classified as moderate risk they should have a medical treatment plan implemented during the return to run process (26).

2.6.2 Return to Run Process

2.6.2.1 Consideration 1: Walk-run Progression

The initial introduction of running-related loads following a tibial BSI should be achieved through the progressive application of load to promote tissue adaption, whilst preventing injury reoccurrence. Typically, this is achieved via a walk-run progression on alternate days, gradually substituting walking with increasing time increments of running at a slower pace (7, 89, 112). Several studies (60, 92, 94, 95, 111) all provide the same walk–run progression with no further evidence added since the initial proposition of this idea in the study by Brukner et al. (92). The specific length of running increments varied considerably among reviewed studies, however starting with 30-60 second increments, and progressing by 1-2 minutes, or equivalent distance was suggested by half of the studies. These recommendations were based on expert opinion, and although three of the reviewed studies started with 100-400m running increments and found participants made rehabilitative progress, the aim of these studies was not necessarily to compare a walk run progression to another approach for increasing running distance (79, 90, 112). Beginning with two 30-60 second running increments, interspersed with walking, has been recommended in recent return to competitive distance running guidelines (49). As little as a few minutes of impact exercise will stimulate bone formation, however bone cells become desensitised to prolonged mechanical stimulation (142). Bone is a living tissue that can fatigue quickly so incorporating rest intervals to prevent bone fatigue is important (82, 140, 142-144). Mechanical fatigue tests support that bone is better able to withstand mechanical loads when applied over shorter durations (140). Also the need for a gradual progression from walking to running is particularly important in females as tibial stress has been shown to significantly increase during running compared with walking, more so in females (122).

These points support the inclusion of a walk-run progression consisting of short-duration running periods initially, with adequate recovery interspersed throughout. Introducing running related loads on alternate days, or at a reduced frequency, also has a scientific basis, as periods of relative rest enable the bone cells to regain mechanosensitivity to support further bone adaptation (139, 145). After 24 hours of rest, 98% of bone mechanosensitivity returns (145). Muscular fatigue is thought to increase bone stress, and therefore it is important to utilise rest breaks during return to running (73, 127, 146). Therefore individualisation of this walk-run process is important and should take into account the pre-injury training status of the athlete and the severity of the injury.

There is evidence from studies involving female athletes to suggest that increased running speed can lead to significantly higher vertical tibial acceleration (147), and increases in anterior and posterior tibial stress (148, 149). Rice et al. (149) found that peak posterior stress was 14% higher during level running at 3.5 m/s than 2.5 m/s. Similarly Meardon et al. (122) found that increasing running speed by 10-20% has resulted in up to 9% increased tibial compression and tension, and up to 26% increased shear stress. The greater magnitudes of tibial acceleration and stresses at faster speeds may increase the risk of BSI. However it should be acknowledged that those experiencing high impacts may not always develop injury (150). Further controlled trials are required in female athletes to assess the effect of walk-run progressions following a tibial BSI.

2.6.2.2 Consideration 2: Progression of Load

Regarding the progression of load, it was consistently recommended that pain should guide progression. There should be no pain during or following running. If pain is present then athletes should rest until symptoms have resolved, then resume at a lower level (7, 35, 47, 60, 67, 79, 89, 90, 92, 94, 96, 100, 101, 110, 111, 113, 115, 116). Pain is a complex phenomenon, it is not always closely linked to musculoskeletal damage, and is mediated by numerous individual factors (151). More precise means of monitoring patient responses are needed, but at this point, pain is the only metric available to guide progression of running load following a tibial BSI.

It is recommended that running distance should be progressed before speed following a tibial BSI, which is in agreement with the six-phase *Return to Running Programme for Competitive Runners* that also recommends running distance is built to 50% of pre-injury level, before interval sessions are introduced (49). Mechanical fatigue tests indicate that BSI risk increases more rapidly with progressions in running velocity than running distance (47, 139, 140).

While the ‘10% rule’ that guides the progression of running load in the return to running following a BSI is widely cited (47, 61, 64, 67, 69, 71, 80, 81, 101, 102, 105, 107, 110, 116), the origins of this principle are unclear. The principle appears to have originated as a progression of distance (107), but has been extrapolated across different variable domains, including time and intensity, still without supporting evidence (7, 64, 69, 101, 110). From an injury perspective, the 10% rule appears to have originated in the space of training progression of mechanical load to prevent injury (152) and then it has been translated across to the return to sport domain across various injuries (153, 154). It would seem that this principle is largely based on expert opinion, as there is no empirical research providing validation. Buist et al. (155) found no difference in running injury prevalence in novice runners who followed a 10% average progression in weekly running distance, compared to those whose weekly progression was greater than this. Specific running BSI studies cite this principle as a methodology for progression of distance, as well as time and intensity, following injury, yet there is minimal evidence to support it as a guide for return to sport in general, let alone from a BSI perspective. Further to this, Nielsen et al. (156) found that tibial stress fractures were not linked to the '10% rule', instead proposing they may be related to other training errors. As with many other injury- and training-related variables, runners are likely to tolerate the progression of distance, time and speed differently (139), and based on this and the evidence available, the rate of progression should be individualised, and should take into account the pre-injury training status and the severity of the injury. Inadequate management of training parameters such as distance, duration, frequency, and intensity, as well as the interrelationship of these parameters, could contribute to the high recurrence rate of tibial BSIs. While the majority of the reviewed studies mentioned one or two of these parameters, the evidence across them all is lacking, and more empirical research is required to help guide the return to running process for females following tibial BSIs (120, 126, 157).

The rate of progression should be individualised based on risk and grade of the tibial BSI as well as the level of the athlete, this is in agreement with a meta-analysis by Hoenig et al (39), and the return to competitive running guidelines (49). Where progressions are too fast, the risk of recurrence is amplified (49). While this is generally not a factor with low-risk locations (such as posteromedial tibial BSIs) or in recreational athletes, it is an important consideration for high-risk locations (such as anterior tibial cortex BSIs) due to the increased risk of complications, or in elite athletes that are keen to return to sport as quickly as possible. Rehabilitation should also be modified according to MRI-based injury severity if available, with a slower progression for higher grade BSIs (38).

2.6.2.3 Consideration 3: Running Surface

With regard to surface characteristics, a quarter of studies recommended starting on a treadmill (60, 61, 92, 94, 95, 111, 116) due to the more compliant surface, and several other studies recommended avoiding hard surfaces (98, 104, 108, 109, 116). Three studies involving female participants provide supporting evidence for this recommendation, reporting that running on a treadmill resulted in a reduced peak tibial acceleration (123, 158) and lower tibial in vivo strains and strain rates (159) compared with running overground. Additionally, Milner et al. (158) reported peak tibial acceleration was lower running on the treadmill compared to grass. Conflictingly, some reviewed studies provided example return to running programmes on a running track (79, 90, 112), which is generally a hard surface. These studies were RCTs and a pilot study, and therefore the surface recommendation may simply have been to control this, as opposed to a logical or even practical solution for running.

Tibial acceleration, foot pressure and ground reaction forces have all been used as a surrogates of lower extremity loading in runners, and a number of studies have assessed changes in these variables on different surfaces. However, there is conflicting evidence regarding the influence of running surface on these metrics and tibial BSI risk. Harder running surfaces such as concrete have been shown by some studies to result in higher tibial acceleration (147), plantar pressures (160, 161) and ground reaction forces (72). Significantly lower vertical tibial acceleration has been shown during running on the woodchip trail in comparison with synthetic running track and concrete, at least at some running velocities (147). Similarly, lower peak plantar pressures were produced when running on grass compared to running on asphalt and concrete (160, 161). However Waite et al. (162) found higher tibial acceleration on grass than concrete when running on level ground and further studies found no difference in tibial acceleration between grass and sidewalk (158) or between dirt, gravel and paved surfaces (163). The relationship between surface hardness and injury risk is complex as some runners compensate for different running surfaces by altering leg stiffness depending on the surface compliance (164-166). Potthast et al. (125) concluded that surface compliance explained less than 10% of tibial acceleration variance, instead knee joint angle and muscle pre-activation changes had greater effects on the severity of tibial acceleration. This research has been completed in healthy individuals, and it is not BSI specific or specifically measured in only female athletes. Therefore, at this point, the influence of surfaces in the process of returning to running post-injury is conflicting and unclear.

In the initial stages post-injury, several reviewed studies have recommended it may be beneficial to avoid hills (7, 64, 69, 97). However, once again there is conflicting evidence in the literature regarding the influence of surface incline grade. Rice et al. (149) found that running uphill at 10% and 15% inclines resulted in greater tibial stress than level running, however Waite et al. (162) reported no difference in peak tibial acceleration between running on an incline grade compared to a level grade. In regards to running downhill, several studies found downhill surfaces to result in lower tibial stresses than level or uphill running (149, 167). However, Waite et al. (162) found a significant increase in peak tibial acceleration on downhill surfaces compared to uphill surfaces. Further research is needed in female athletes following a tibial BSI to make clear recommendations regarding the influence of different running surfaces.

2.6.2.4 Consideration 4: Addressing Biomechanical and Strength Factors

An important component of the return to running process acknowledged by almost all of the reviewed studies was the need to address biomechanical factors and muscle imbalances potentially contributing to the initial injury. With regard to running gait parameters, there is some evidence to suggest that greater peak hip adduction and rearfoot eversion angles (33, 34, 83), and increased tibial acceleration (32, 66, 84, 168-171) are associated with the development of tibial BSIs in female runners. A recent study has found that women with a history of BSIs experience greater increases in vertical average loading rate, vertical instantaneous loading rate, vertical stiffness, and tibial shock with exertion compared to women without a history of BSI (172). Therefore, screening for, and where appropriate, interventions aimed at addressing these variables could be beneficial during the return to running process. Running gait analysis and retraining was recommended by a number of reviewed studies (7, 47, 48, 67, 69, 71, 89, 91, 98, 100, 101, 103, 105, 113), and while several potentially beneficial adjustments were suggested, including reducing stride length or increasing cadence (7, 47, 89, 101) (Table 4) to reduce tibial stresses, it is beyond the scope of this review to detail all potential solutions.

Reduced lower extremity muscle size and strength have been shown to be related to BSI risk in females (18, 118, 132, 133). It is hypothesised that muscle provides a protective mechanism with respect to tibial BSIs by attenuating shock and reducing loads (139). Additionally, resistance training has shown positive effects on bone health in premenopausal women (173). If muscular activity produces dynamic mechanical signals of significant magnitudes and significant rates, it is hypothesised osteogenesis will occur (174), therefore resistance training should be an important component of the return to running process. Addressing core and proximal strength, as recommended by reviewed studies, is also important to optimise lower extremity biomechanics. Excessive hip adduction during the running gait has been shown as a predictor of tibial BSIs in female runners (34), indicating the need to address this in an individual with an increased adduction moment. There is inconclusive evidence regarding the effects of hip strengthening on kinematic variables, but it may improve eccentric control and could be beneficial in certain athletes (71, 175).

Although only 21% of reviewed studies recommended progressing to plyometric strengthening, there is evidence from other related studies that running does not subject the body to high enough impacts to produce osteogenic effects (142).

Bilateral bone loss peaks around 12 weeks post-injury, which often coincides with a progressive return to activity (176). There is a body of evidence from related studies that would suggest the addition of plyometric training is an area that needs attention, both practically and from a research perspective. High-impact training (defined as loads greater than four times body weight) (177) such as jumping or hopping can be highly osteogenic and energy efficient and therefore is likely to be beneficial for improving lower extremity bone mass during advanced stages of the return to running process (178-180). Structured exercise programmes that combine high-impact loading with resistance training are effective at significantly improving bone mineral density at the lumbar spine and femoral neck in premenopausal women (181). For the tibia specifically, zig-zag hopping has been shown to produce higher strain and strain rates compared with other plyometric movements, jogging and walking, and consequently could be a beneficial tibial bone-strengthening exercise (182). Two to four short exercise sessions per week (30 min/day or less) over a prolonged period are required to maintain or improve bone health (179). Therefore, this evidence suggests that plyometric loading would be a beneficial addition in female athletes during advanced stages of the return to running process once adequate healing has occurred, so long as the increase in bone loading is accounted for and running loads are reduced accordingly (139). However, further female tibial BSI-specific controlled trials are needed in this area in order to provide guidelines on its addition in the return to running process in this population.

2.6.3 Limitations:

While evaluation of the risk of bias is not mandatory for scoping reviews, 81% of studies included in this scoping review were clinical commentaries or reviews, so will inherently have a high risk of bias. Studies looking at general lower extremity BSIs, as well as studies not specifying sex, were also included in this scoping review due to the lack of studies assessing tibial BSIs in females. The proposed continuum from medial tibial stress syndrome into lower grade bone stress reactions is still lacking evidence. For the purpose of this review, we set the line at lower grade stress reactions. All included studies provided some guidance in terms of criteria prior to introducing running-related loads, or on the process of returning to running, following a tibial or lower extremity BSI, however no studies in this review specifically compared return to running approaches. This scoping review reported criteria and guidelines for the return to run process based on what is recommended in published research. Other innovative and potentially useful tests and guidelines for the process of returning females to running following a tibial BSI may be used in practice, but not reflected in this review.

2.7 Conclusion and Further Recommendations:

The literature has been grouped into five themes regarding the components involved in the decision on when it is appropriate to introduce running-related loads in female athletes following a tibial BSI. These components include resolution of localised tibial tenderness, pain-free walking, evidence of radiological healing, assessment of lower extremity strength and pain provocation tests, and identification of contributing factors. The literature has then been grouped into four considerations involved in the process of returning a female to running following a tibial BSI. These considerations include beginning with a walk-run progression; individualising progression of load based on pain, risk of location, grade and level of the runner; running surface; and addressing biomechanics and strength. One component that has been identified as vital for a successful return to running and to prevent injury recurrence in the female athlete is assessing and addressing RED-S. Gait retraining and strength training, to address poor biomechanics, may also be beneficial for the female athlete. While the focus was on females it is appreciated that a lot of this information is relevant regardless of sex. These components and considerations are based on level IV papers, and therefore randomised control trials are sorely needed in the area of returning females to running post tibial BSI.

Prelude to Chapter 3

A scoping review of the literature reported criteria and guidelines for the return to run process based on what is recommended in published research (Chapter 2). The majority of the studies included in the scoping review were clinical commentaries or reviews, so will inherently have a high risk of bias. Although all included studies provided some guidance in terms of criteria prior to introducing running-related loads, or on the process of returning to running, following a tibial or lower extremity BSI, no studies in this review specifically compared return to running approaches. The scoping review identified there are a lack of studies specifically assessing tibial BSIs in females. It is possible that how experienced sport medicine clinicians manage tibial BSIs may differ from what is documented in empirical evidence. Other innovative and potentially useful tests and guidelines for the process of returning females to running following a tibial BSI may be used in practice, but not reflected in the scoping review. The practice of evidence-based medicine means integrating individual clinical expertise with the best available external clinical evidence from systematic research (54). However, given the minimal evidence available to clinicians to help practically guide the implementation of return to running programmes following tibial BSIs in female athletes, consultation with clinicians experienced in working with female athletes is warranted and could be highly beneficial (54). This chapter takes the form of a qualitative study to determine how experienced sport medicine clinicians return female athletes to running following low-risk tibial BSIs, and what they consider as critical components of management. This manuscript has been formatted for submission to *Qualitative Research in Sport, Exercise, and Health*.

Chapter 3: Experienced Sport Medicine Clinicians and Returning Females to Running following a Tibial Bone Stress Injury.

3.1 Abstract

Tibial bone stress injuries (BSIs) commonly affect female runners and have a high rate of recurrence. Although there have been reviews published on the general management of BSIs, there is much less available documenting the clinical reasoning and management of the return to running process following a tibial BSI from the perspective of experienced sport medicine practitioners. This study explored different experienced sport medicine clinicians' perspectives and practices regarding how they return female athletes to running following low-risk tibial BSIs and what they determine as critical components of management. Ten semi-structured interviews were conducted with experienced sports medicine clinicians (five Sports Physicians, four Physiotherapists and one Physiologist). Reflective thematic analysis revealed three key themes. The first theme 'Health and Wellness' reflects the importance clinicians placed on first optimising a female athlete's health, with nutritional status, and psychological and hormonal health particularly important in the female athlete. The second theme 'Bone Healing' reflects the components required to ensure and promote bone healing. Clinicians discussed using clinical as opposed to radiological signs to indicate bone healing, ensuring symptom resolution, and ensuring optimal load management. The third theme 'Functional Return' describes clinicians' approach to progressively returning athletes to running. Progression of running load is recommended to be gradual and guided by physical assessment findings. Finally a notable thread that stretched across all three themes, was the importance of establishing a multi-disciplinary management approach, reflecting the many facets involved in tibial BSIs in female athletes. All components are essential to address, but the size and influence of those components will be different for every individual. This study highlights the need to veer away from a 'one size fits all approach' and individualise the return to running process in female athletes following a tibial BSI.

3.2 Introduction:

Tibial bone stress injuries (BSIs) are common among female runners (10, 13, 18, 23, 133) and have one of the highest recurrence rates of all running-related injuries (13, 20, 23). Prior BSI has been shown to increase the recurrence rate by 5-6 times among female runners (18, 20, 23). Following a tibial BSI, a critical component of complete rehabilitation is the successful return to running. Whilst a number of studies and reviews have assessed the quantitative elements of return to running programmes (48, 61, 71, 77, 89, 94, 97, 98, 101, 111), there is much less available documenting the clinical reasoning and management of return to running from the perspective of experienced medical practitioners (7, 47). It is possible that how experienced clinicians manage tibial BSIs differs from what is documented in empirical evidence.

Relative energy deficiency in sport (RED-S) results from a mismatch between energy intake and expenditure during exercise (25), and is more common among female athletes (27). In particular, RED-S has a negative effect on menstrual function (183), bone health (184), and consequently BSI risk in female athletes (29, 185, 186). The relative risk of BSI has been shown to be increased between 4 and 5.7 times in female athletes, scoring moderate- and high-risk on the RED-S Risk Assessment Scale respectively, compared to those scoring as low-risk (26, 29). Sports such as cross-country running, are associated with higher scores on RED-S risk assessment scale (29). Furthermore, amenorrhea, indicating chronic energy conservation, was found in a relatively high proportion (37%) of elite female distance athletes (31). It has been highlighted that in general there is a dearth of sports science research focused on females (53). More specifically, the increased incidence and recurrence of BSIs in female athletes indicate there are female-specific factors that increase risk, and justify female-specific treatment responses.

Warden and colleagues (7) have presented a management protocol for non-specific BSIs, and a loading protocol specific to tibial and metatarsal BSIs (47), in long-distance runners. While collectively these publications provide a degree of clinical guidance, the only female-specific guidelines relate to taking a detailed menstrual history in females with a BSI and providing appropriate multidisciplinary management where RED-S is indicated (7, 47). The authors advocate that an important component of treatment is addressing contributing risk factors including running biomechanics, muscle strength and endurance, training structure, running surface and footwear (7, 47). Warden et al. (7) present an example of graduated return to running progression, beginning with 1-minute running increments on alternate days, and progressing to 30 minutes of continuous running, before increases in speed or frequency are introduced. While not specific to BSIs, Hegedus, et al. (49) propose a comprehensive six-phase progression to guide the successful return to competitive distance running following lower extremity injury. The authors advocate for starting with cross training, which is gradually replaced with running, and interval sessions are not introduced until 50% of normal running distance has been achieved. The importance of individualising the process, and monitoring physical and psychosocial measures was highlighted, however no sex-specific guidelines were proposed.

The practice of evidence-based medicine means integrating individual clinical expertise with the best available external clinical evidence from systematic research (54). However, given the minimal evidence available to clinicians to help practically guide the implementation of return to running programmes following tibial BSIs in female athletes, consultation with clinicians experienced in working with female athletes is warranted. The aim of this study was to establish how experienced sport medicine clinicians return female athletes to running following low-risk tibial BSIs, while determining critical components of management.

3.3 Methods:

Semi-structured interviews involving open-ended questions were used to explore clinicians' knowledge and practices on the return to running process following a tibial BSI in female athletes (187). This approach was chosen to facilitate a comfortable situation where clinicians could articulate their individual experiences, knowledge and opinions. This study was approved by the Auckland University of

Technology Ethics Committee (# 21/411) (Appendix 1). It is important to note that the three researchers involved in the analysis process were Physiotherapists and the primary researcher is a female practising Physiotherapist herself. This will inevitability have influenced the creation of questions, interviews, interpretation of what the clinicians said, and consequently the analysis process.

3.3.1 Participants:

Sports medicine clinicians (Physiotherapists, Sports Physicians, Physiologists) with at least five years' experience working with females with tibial BSIs, and who were regularly involved in the process of returning them to running, were invited to participate. A purposive and snowball sampling approach was implemented to attain variation in professional background and to ensure a full spectrum of expertise on the topic was covered (188). Individuals who could offer an experienced opinion were identified through the authors' collective networks. Fourteen potential participants were approached between March and October 2022, and recruitment ceased when the target of 10 participants consented to be interviewed (189, 190). A range of clinicians, working across community and high-performance environments were included (Table 5).

Table 5: Participant Demographics and Experience

	Gender	**Area of Work**	**Relevant Experience**
Physiotherapist 1 (PT1)	Female	Private Practice Physiotherapist	40 years
Physiotherapist 2 (PT2)	Female	Sports Physiotherapy Specialist currently practising in high performance sport.	22 years
Physiotherapist 3 (PT3)	Female	Sports Physiotherapy Specialist currently practising in high performance sport.	23 years
Physiotherapist 4 (PT4)	Female	High performance sport Physiotherapist	30 years
Sports Doctor 1 (SD1)	Male	General Practitioner Doctor specialising in sports medicine	30 years
Sports Doctor 2 (SD2)	Female	Sport and Exercise Physician Doctor with a special interest in female and youth athletes	7 years
Sports Doctor 3 (SD3)	Female	Sport and Exercise Physician Doctor	9 years
Sports Doctor 4 (SD4)	Female	Sport and Exercise Physician Doctor	19 years
Sports Doctor 5 (SD5)	Male	Sport and Exercise Physician Doctor currently practising in high performance sport.	21 years
Physiologist 1 (PH1)	Female	Sport and Exercise Physiologist specialising as a female health physiology researcher	6 years

3.3.2 Data Collection:

Semi-structured interviews of 45 to 65 minutes in duration were carried out by the primary researcher (EG). The interviews were conducted and recorded using Microsoft Teams virtual conferencing application. A sample of open-ended questions to help guide the interviews were developed through author collaboration, and subsequently adapted after piloting and feedback with an experienced Physiotherapist. A compendium of the questions is provided in Appendix 6. Initial notes were taken during each interview, and then fully verbatim by the primary researcher at a later date. Participants were offered the opportunity to check transcripts for accuracy. In presented extracts, […] indicates that some text has been removed.

3.3.3 Data Analysis:

Braun and Clarke's six-phase framework for reflexive thematic analysis was used for the analysis of data (88) (Figure 3). An inductive, semantic and critical realist approach was used, focused on identifying and discussing the salient themes repeated across, and within, transcripts (88, 191). Reflexive thematic analysis is a flexible process in which a researcher identifies, analyses and reports patterns within the data (192). Reflexive thematic analysis was selected as it allows insights into participants' thoughts, beliefs, and experiences to be identified, whilst also recognising the researcher's role in constructing the findings from the information shared by the participants(192). The research question that guided the analysis at every phase was: How do experienced sport medicine clinicians return female athletes to running following low-risk tibial BSIs, and what do they consider as critical components of management?

The primary researcher (EG) repeatedly reviewed the transcripts and accompanying notes to appreciate the breadth and detail of the data. Relevant codes were developed by EG, and the data were coded into broad themes by EG, in consultation with KS and DR, and in reference to the original transcripts. An example of the thematic analysis coding is provided in Appendix 7. Themes and subthemes were then reviewed and refined by EG, DR and KS. A candidate thematic map was then applied to the entire data set to ensure it accurately reflected the meanings evident in the data set. It is important to note that the interviewed clinicians each had different professional backgrounds and experience levels, and as such some refrained from commenting on areas they felt didn't align with their area of expertise.

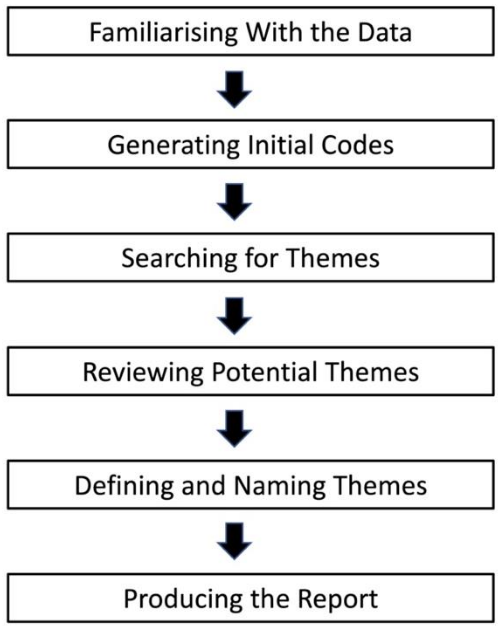

Figure 3: Thematic Analysis Six-phase Framework

3.4 Results:

The analysis resulted in three key themes and two or three sub-themes under each theme (Figure 4). Within the first theme 'Health and Wellness' clinicians emphasised the importance of addressing the initial underlying reason(s) for the tibial BSI occurring. Under the second theme 'Bone Healing' clinicians described the components required to ensure and promote bone healing. The third theme 'Functional Return' describes clinicians' approach to progressively returning athletes to running, and the important steps to cover. The importance of a multi-disciplinary team (MDT) approach was a common and notable thread reflected across all three main themes. It was presented as an overarching message to emphasise the many facets that clinicians raised that needed to be addressed as part of the comprehensive management of returning to running. It is important to note that although the themes are presented separately, returning females to running following a tibial BSI is a multi-faceted process, and therefore there is considerable overlap between themes.

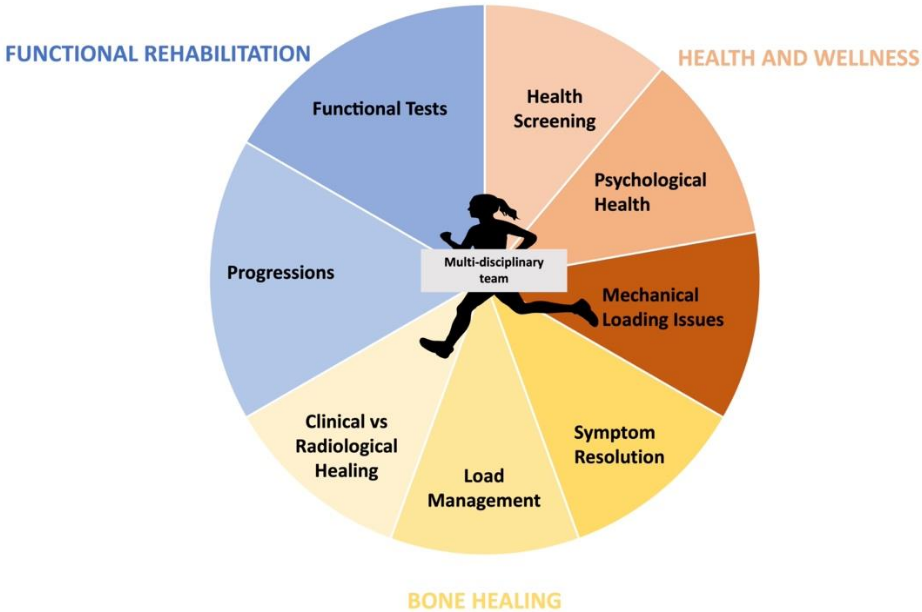

Figure 4: Themes and Subthemes

3.4.1 Theme 1: Health and Wellness

Addressing the factors that contributed to the initial occurrence of the tibial BSI was a key consideration in successful management according to interviewed clinicians. All clinicians spoke of the need to identify the cause in order to be successful with returning female athletes to running. Three subthemes were identified including assessing and addressing mechanical loading errors, health screening for any issues that may impact bone healing and assessing and addressing psychological health (Figure 5).

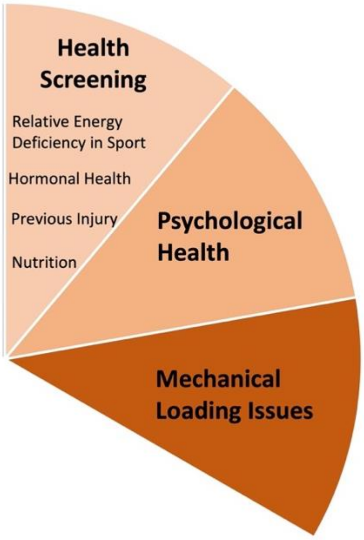

Figure 5: Health and Wellness Theme

3.4.1.1 Subtheme 1: Assessing and Addressing Mechanical Loading Issues

Mechanical loading issues are often associated with the occurrence of BSIs, and this was acknowledged by all clinicians. A thorough review of an athlete's training history to identify any recent changes to running frequency, intensity, or distance was recognised as an important exercise by all the Sports Doctors and three Physiotherapists. Adequate recovery between sessions was also an important component of the training load highlighted by PT4 and SD4:

> *"It could be a young hockey player who's in three teams and just has way too much load and they've got no prep and recovery strategies… So being able to grow the athlete during that time, especially with prep and recovery strategies as well." (PT4)*

Potential mechanical loading issues should be highlighted, and education provided to prevent further injury when athletes are returned to their usual running training as explained by SD2:

> *"Their training load leading up to the injury, so that's something we try and look through in a reasonable amount of detail as well just to look for where whether there were and where there might have been any having any training errors, um and how we could again try and prevent this from happening again."*

Clinicians explained the importance of also involving the athlete's coach if applicable when addressing mechanical loading errors. The thought processes of the coach must be addressed to ensure lasting changes are achieved, as explained by SD5:

> *"The coach is key right in all of this. Because if at certainly at this level, we work out, if you're not addressing that, then in terms of some of the thought processes and stuff and some of the thinking that they brought in, then actually you're often just banging head against brick wall."*

The importance of not only assessing for mechanical loading errors, but ensuring these errors are addressed and not repeated to prevent reinjury, was also highlighted by all clinicians.

3.4.1.2 Subtheme 2: Health Screening:

Clinicians highlighted the importance of optimising the female athlete's health and physiology to enable them to manage the return to running process and prevent reinjury. Athletes should be screened for factors influencing their health in the period prior to resuming running. All clinicians spoke of the importance of a nutritional review, especially where low energy availability is suspected, as described by PH1:

> *"Usually the first point of call, even with the return to running, is to get nutritional support and make sure that they've gone through that nutritional review and that they're setting themselves up in the process of returning to running."*

Within nutrition, three Sports Doctors and one Physiotherapist highlighted the importance of identifying vitamin D and calcium deficiencies, as these are key for bone health and are beneficial to optimise to prevent further injury (193). SD3 highlighted the importance of this screening:

> *"The other things that we're thinking about are kind of nutritional deficiencies, if they've been energy deficient, if they got a diet that's not containing adequate calcium and Vitamin D."*

Clinicians were all aware of the relationship between low energy availability and impaired bone health particularly in female athletes (25) , and highlighted the critical importance of screening for RED-S, as demonstrated by PH1:

> *"All of the RED-S and the women's health stuff sits in behind all of this. And so and in this environment, you know, as soon as you mentioned female runner that becomes you know number one on your on your radar."*

The relationship between RED-S and menstrual disturbances, and consequently the importance of screening menstrual health to identify any current or previous irregularities, was recognised by all clinicians. Menstrual irregularities are a fundamental health issue and when treating female athletes, it is critical that this is explored, as explained by PT4.

> *"Often disclosure happens with us or we are the first person to ask a young female athlete if they are menstruating. And it is, um, thank you Lydia Ko, It has to be a question. And um if the athletes under 16, you might ask a guardian or somebody to be with you there. But it is, it's an absolute. You can't have a tibial stress reaction on a young female athlete without asking that."*

In order to allow progression through the return to running process, eight clinicians recommended firstly ensuring athlete engagement in addressing RED-S. Two Sports Doctors discussed the use of the RED-S Risk Assessment Model which classifies athletes in low-, moderate- and high-risk categories depending on subjective and objective examination. Athletes classified as moderate or high risk should have a multi-disciplinary treatment plan, and be engaged in management, prior to progressing to running (26). The use of the RED-S Risk Assessment Model and utilising a management contract is demonstrated by SD4:

> *"So we use the RED-S contract...So it basically says if you haven't met these criteria, you know you shouldn't be going back to your running, but it isn't quite as isn't quite as straightforward as that. But it means you have all of those people working together to go now you're able to do this because you've met these criteria."*

The importance of an MDT approach to address the low energy availability underpinning RED-S, was recognised by all clinicians. PT2 highlighted the benefit of a MDT approach to address each athlete's individual needs:

> *"And so often with these ones, um it's probably about having a case management meeting, so having everyone around the table and working out more, what is it that we think these people need and that can be pretty bespoke because different people will have different needs."*

Half of the clinicians (n=5) identified the importance of screening for previous BSIs due to BSIs having one of the highest recurrence rates of all running-related injuries (13, 20, 23). The presence of prior BSI has been shown to increase the chance of recurrence by 5-6 times among female runners (18, 20, 23). Providing education on this association to ensure an athlete's understanding of the need to optimise their health to prevent further injury was identified by PT3:

> *"Then just really I guess the education to them around past history being their biggest risk factor for future injury. And um and just being really sure that they are in a good place and armed with as much info as they can be going forward to try and ensure that that type of injury doesn't occur again."*

Wider health screening, to detect nutritional issues, RED-S or previous BSI in the female athlete was deemed important by all clinicians as it will identify key components to address for successful management and to prevent injury recurrence.

3.4.1.3 Subtheme 3: Addressing Psychological Health:

Injury can have a large impact on an athlete's psychological health, and this was identified by the majority of clinicians (n=8). Being forced to take time off running can be difficult for some athletes, and strategies to manage this are important as identified by SD4:

> *"I would refer to sports psychology because of the time off. You know like it's a really big thing to then come and say to someone*

you need to take all this time off and then not have strategies of dealing with it."

All interviewed Physiotherapists, as well as one Sports Doctor, described screening for any psychosocial issues in the athlete's life, such as altered sleep or stress, that could impact on recovery or could have contributed to the initial injury:

"Psychosocial aspects, things like sleep, things like stress, you know those other, those other elements are really important." (SD4)

The final aspect of psychology identified by six clinicians was the need for referral to a Clinical Psychologist if any disordered eating or exercise addiction behaviours were identified.

"If you're concerned about disordered eating/ eating disorders you would be we would be looking to refer and include a psychologist and sometimes a psychiatrist." (SD3)

3.4.2 Theme 2: Bone Healing

The second theme 'Bone Healing' reflects the components clinicians work through to ensure and promote bone healing. Three subthemes were identified including using clinical signs of bone healing as opposed to radiological signs, the importance of symptom resolution, and load management to promote bone healing (Figure 6).

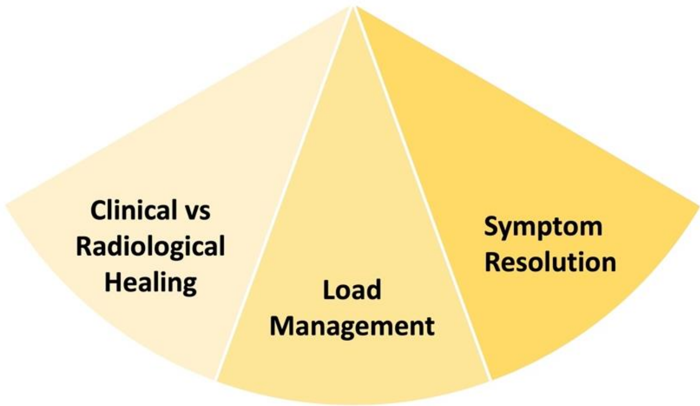

Figure 6: Bone Healing Theme

3.4.2.1 Subtheme 1: Clinical vs Radiological Bone Healing

Clinicians described using their own judgement, as opposed to radiological findings, to indicate bone healing and guide their decision of when to introduce running related loads. Nine of the clinicians highlighted that radiological evidence lags behind physiological healing and felt relying on imaging for low-risk BSIs could unnecessarily delay return to running.

> *" I don't use imaging in order to make that decision because I think typically kind of clinical union is earlier than radiological union. So I don't find that that's necessarily helpful. The bone oedema will remain for far longer than they need, and so if you use that you'll probably be a bit more delayed". (SD4)*

Four clinicians however highlighted that reimaging could be beneficial with elite athletes, high-risk fracture locations (e.g. anterior tibial BSIs), or in cases of delayed progress, as noted by SD4:

> *"If I was concerned that they weren't progressing or where someone who is not doing well as we reload them, then that might be when we'd reimage."*

3.4.2.2 Subtheme 2: Symptom Resolution

Clinicians identified the importance of symptom resolution when managing tibial BSIs. In contrast to soft tissue injuries, clinicians highlighted with bony injuries there should be minimal tolerance for pain:

> *"Pain is not our friend when it comes to bone pain." (SD5).*

The importance of being pain-free not only during, but also following activity was highlighted by all Physiotherapists and Sports Doctors. It was deemed by these clinicians that pain should have resolved before commencing running, as explained by PT3:

> *"Throughout the whole process I want to know pain during obviously. I certainly want to know pain afterwards. I want to know what happens to their generalised background level of pain, which clearly should be gone by the time we thinking about return to run."*

Palpation of the tibia is a key component of the objective assessment utilised by all the clinicians. Eight clinicians described the need for resolution of tibial bony tenderness prior to introducing running, as noted by SD3:

> *"Yeah, so I guess before we start that process, obviously they have to be pain-free. They have to be you know non tender to palpation and percussion. And so sort of clinically healed."*

However, two clinicians disagreed with the need for complete resolution of bony tenderness prior to resuming running due to the potential for lasting bony tenderness, as noted by SD5:

> *"I'm happy personally for them to start running while there's still bone pain. So if I stick my finger on the spot and there still pain there I'm that's not a, I'm not waiting for that to disappear before I say you can start running again because that'll be there, well can be there forever."*

The need for cessation of symptoms and monitoring these symptoms throughout the return to run process was evident across all the interviews. If the process is well managed, clinicians acknowledged there should be no return of any symptoms.

3.4.2.3 Subtheme 3: Load Management

The final subtheme reflects the need for load management to ensure and promote bone healing. An initial off-loaded period is important to allow healing, and was recommended by all clinicians. Often this is a medical decision as noted by PT2:

> *"I won't return to play until a doctor has sent me – "Yep I think that we've had sufficient time off feet or there has been sufficient time loading into running that I think that the bony health is ok for you to run again"."*

Although a period of off-loading from running is required, all clinicians described the importance of cross training to maintain muscle strength, build cardiovascular fitness, and for athlete's mental health. PH1 describes the importance for athlete's mental health and compliance:

> *"Taking exercise away from an athlete completely I think sometimes can be a little bit more detrimental to their mental health than actually just finding a way to keep them moving. Um so kind of finding that happy balance between, OK what's going to keep them happy, but also I guess compliant with what we're trying to achieve with them."*

Clinicians explained how a progressive increase in weight bearing can be achieved through cross-training, and is required to build the tibia's tolerance to load and promote healing (194). In order to progress from off-loaded to an athlete's normal load, clinicians described how cross-training can be used as noted by PT4:

> *"So in a good return to performance program after about four weeks, we've got them up to full load, but it's not running."*

Clinicians prescribing the return to running progressions described progressively substituting cross-training with running increments as healing progresses. They explained how running increments are initially for building bone tolerance as opposed to building fitness, as noted by SD5:

> *"So this is not your fitness training, this is your rehabilitation for this tibia."*

To build bone health clinicians involved in the return to running process and advanced stages of progression described the importance of including resistance training (n=7) and progressing load with plyometric strengthening (n=6) to provide bone stimulus and for injury prevention. PH5 highlighted the benefit of resistance training on bone health:

> *“I usually also try to prompt the physios on not only focusing on like the return to running plan, but also what are we doing either in the gym and strength wise. Again just purely because weight training and the stimulus from weight training, it's a perfect stimulus for bone growth and development. It is high load, high magnitude, short load and that is the perfect stimulus for bone turnover and bone health.”*

3.4.3 Theme 3: Functional Return to Running

The final theme describes the important steps clinicians work through and the progressive approach required to successfully return female athletes to running. Two subthemes were identified, firstly ‘Functional Tests’ reflects the tests clinicians use to ensure tissue capacity and movement competency as well as monitor progress through the return to running process. The second subtheme ‘Progressions’ describes the progressions of load clinicians work through from walking to returning female athletes to their usual running training regime (Figure 7).

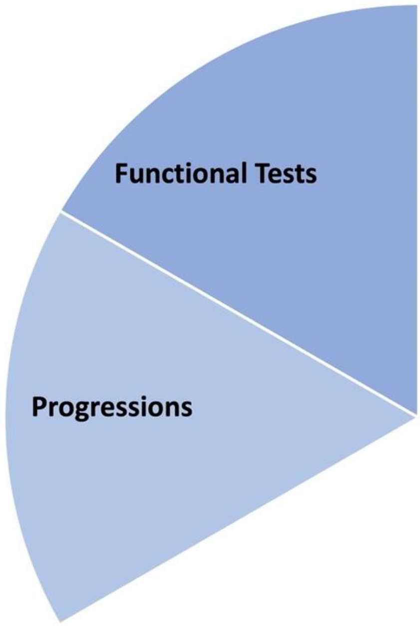

Figure 7: Functional Rehab Theme

3.4.3.1 Subtheme 1: Functional Tests:

To guide progression through the return to running process following a tibial BSI, clinicians described multiple functional tests along the way to ensure adequate tissue capacity and movement competency. Tissue capacity refers to the ability for an athlete to perform functional movements without exacerbating symptoms or causing tissue injury (195). As athletes are returning to running, they need to in parallel have good core and lower limb strength, as well as an adequate range of motion to accommodate the demands of running. Clinicians acknowledged strength and biomechanical deficits could be a precursor to why an athlete developed the tibial BSI, but all highlighted these factors will be individual to each athlete.

All the Physiotherapists described identifying key clinical tests to assess tissue capacity and movement competency, and then continuing to monitor these throughout the process to guide progression. PT2 explained how progression should be slowed if worsening of markers occurred and continued if there was no change:

> *"I think I am probably driven more by the clinical markers ... and so if I am finding that those clinical markers are like we're not*

getting any change- cool bump them. You know we can prove that. If we're finding that they are you know getting worse, then we've gone too far we need to, we need to back off... Or you're like, oh, actually we are ok because we know … we've got the tissue capacity and the movement competency. We know that with our key markers actually you're doing OK. So we can actually keep moving you up."

Clinicians acknowledged these clinical tests will be individual to the athlete, but there were some movement competency screening tests that the majority of clinicians assessed. The first being the single leg squat technique, where clinicians assessed for medial drift or pelvis dropping indicating poor gluteal control. However, several clinicians (n=3) acknowledged the challenges with assessing movement competency biomechanics due to individual variation and the potential for athletes to adapt to their biomechanics. PT4 explained how she assessed lower extremity alignment during a single knee bend, but she also recognised the athlete individuality:

"You'd obviously look at the kinetic chain so that their .. small knee bend looks good. That they haven't got a medial drift or a valgus moment. Having said that, some of the top athletes do. It's not an absolute but it has to be safe and controlled um with obviously posterior chain."

Another of the key movement competency tests identified by all Physiotherapists and Sport Doctors was assessing calf capacity. Clinicians described optimising calf strength and calf raise technique. Progressing on from this, the majority of clinicians (n=8) described assessing single-leg vertical hopping to measure an athlete's loading tolerance. SD4 describes this progression of assessing calf capacity as well as the tibia's tolerance to loading:

"Generally their calf has been affected… so you gotta get the bulk first, then the then the strength. And then the absorbing force. And then we would look at multiple hopping. And then we look at the biomechanical stuff, which is dynamic."

PT2, as well as several other Physiotherapists, emphasised the importance of assessing each of these functional tests consistently over time to ensure the athlete is truly able to tolerate the load and allow the effects following to be assessed:

"And so I kind of go the rule of threes, like you need to do it three times. I don't want to do it just once and that's a bit of you know magic. We need to actually try it a few times to be sure that that is actually where we're at."

When movement competency was optimised, and running-related loads were introduced, the majority of clinicians (n=9) described analysing an athlete's running gait and biomechanics. Clinicians acknowledged it may be necessary to address muscle imbalances and biomechanical issues if they are related to the onset of the tibial BSI, but once again recognised that athletes may have adapted to their biomechanics, which is further explained by PT4:

"They can still look really odd, but they have the tissue capacity to handle that load. And we've got Olympic athletes who've medalled that look pretty weird. You know asymmetrical, they wouldn't pass what you'd call a screen, but their own benchmarking they're very stable with and they're very strong within what they need to do."

As with other components of the return to running process, a MDT approach is important when addressing running biomechanics, in particular involving Podiatry and Physiotherapy where required as explained by SD1:

"So if there's a biomechanical problem, I often engage with the podiatrist who's a sports podiatrist to confirm what I see and discuss what we're doing about it, especially if they need supports or things like that. If I find in in my gait analysis that there is some significant muscle imbalance issues, then I engage one of the running physios and they might do a program which supports her rehabilitation."

3.4.3.2 Subtheme 2: Progressions:

When treating females with tibial BSIs, all clinicians described a progressive increase in load to return them successfully to running. Multiple progressions were discussed throughout the process in terms of building running distance, intensity, and frequency. These progressions were all guided by the athlete's end goal. Prior to introducing running-related loads, all clinicians described firstly building walking and daily activity tolerance. Although the majority of clinicians (n=7) suggested a certain walking tolerance (ranging from 20 minutes to 1 hour), the general consensus was using the period before running to build and assess tolerance to loading. Three of the Physiotherapists described progressing the walking to mixed terrains and ensuring the athlete can complete this multiple times prior to returning to running as explained by PT1:

> *"Are they able to walk one hour on different trains three-four times a week with no pain?"*

Initially when introducing running-related loads, a gradual progression of running increments using a walk-run programme, with alternate days of loading, was recommended by most clinicians. There was a clear consensus amongst clinicians that initial running increments needed to be small and progression gradual. Clinicians suggested running increments ranging from 20 seconds to 2 minutes, and progressing these by similar sized increments. However, they all acknowledged the importance of individualising the progressions to the athlete. SD4 describes how they begin a typical walk-run programme:

> *"I think the progressive loading is key to coming back. They're getting that building up as opposed to going I'm gonna run 20 minutes. It's all about we start really little. So it might be two lots of two minutes, that's it, then rest day. And we have alternate days of loading."*

A common recommendation among clinicians was to start athletes on flat, soft surfaces such as grass, treadmills, or soft paths. Clinicians (n=5) emphasised the importance of progressively adding in various terrains, especially those that the athlete normally trains or competes on as described by SD2:

> *"Those first couple of runs I would suggest a softer surface. Once that's going well then we'd start adding in what they normally run on."*

Whilst the 10% rule has been used extensively to guide running progression, clinicians all agreed that it is not generalisable, and athletes will tolerate different rates of progression. PT4 describes how the 10% rule has become embedded in clinical practice despite not being supported by any evidence, and she also highlights the challenges with actually using it clinically:

"I mean, my understanding is 10% it's actually quite a, when it sort of first came out, because I'm that old, it was quite convenient because people could understand it… There's absolutely no science behind it. But it's actually a very difficult thing to do if you just stick to it, because 10% of what? What are you talking about?"

The majority of clinicians (n=9) described progressing to steady state running and building running distance first, prior to increasing running intensity or frequency. Clinicians all acknowledged that the specifics of these progressions will be guided by the athlete's end goal. PT3 describes how she approaches this progression:

"I'd want their volume back at the normal volume of their long run or whatever else they're comfortable doing before worrying about bringing in tempo sessions. And again that depends a little bit on them and what their normal training week looks like and what their normal focuses are, because if any speed sessions are not part of their life, then I'm really not so worried about bringing in speed sessions."

Progressing from a controlled environment to allowing a bit more variability is important, not only to increase the bone's tolerance to loading, but also to keep the athlete engaged and motivated as explained by PT3:

"And so again it's a little bit about compliance, it's a little bit about helping them feel like they're making some progress at the same time as getting some stimulus."

Six clinicians explained the importance of the athlete's coach being involved if applicable, especially for the more individualised and sport-specific progressions as described by SD1:

"The key thing to is that after four weeks, if they have a coach, I usually pass them back to the coach with some feedback. I think what we don't do enough as sports doctors, is engage with the coaches. So the coaches are often left out of the rehabilitation time."

3.5 Discussion:

The aim of this study was to establish the process of how experienced sport medicine clinicians return female athletes to running following tibial BSIs, while determining critical components of management. For the purposes of creating a practically useful outcome, the themes and subthemes identified in the results have informed the development a framework of treatment, with components and subcomponents specifically for female athletes following a tibial BSI. There is clearly some information that is non-sex specific, and could relate to both males and females, however the focus in the interviews was on areas of particular relevance to females. Five components have been identified: optimising health and wellness, clinical measures to guide return to running, progression of load, running surface, and risk reduction. MDT management is important with all components. The different components of the framework will be a different weighting for everyone, but it is essential each component is checked off.

3.5.1 Component 1 – Optimising Health and Wellness

Addressing the original contributing factors of the tibial BSIs is a key consideration to ensure female athletes are 'well'. Clinicians identified the importance of addressing mechanical loading issues, and issues such as RED-S and psychological health, in order to optimise the athlete's health and set them up optimally to manage the process of returning to running. While these points have been previously acknowledged (7, 47, 48, 101), interviewed clinicians specifically emphasised the importance of ensuring the athlete and coach were actively engaged in the management of RED-S, and that the RED-S risk assessment model (26) was used to guide progression. Due to the increased risk of RED-S in female athletes (27) and the detrimental effect of RED-S and menstrual irregularities on bone health (22, 25, 26, 28, 29), this is a critical aspect when managing female athletes.

The psychosocial complexity related to injury and return to sport is a concept only recently gaining recognition (49, 103), and while psychological readiness to return to sport has been highlighted as a key consideration in the 2016 Return to Sport

Consensus Statement (42), this has not been recognised in most previous return to running guidelines related to BSI (7, 47, 101). Psychological issues, such as anxiety and depression, are particularly common in female athletes (196, 197), and single sport athletes such as long-distance runners are at an increased risk (198). The clinicians interviewed acknowledged the part that psychological health can play in BSI incidence, the potential psychological impact of sustaining a BSI, and therefore the importance of addressing psychological health, particularly in females during the return to running process.

3.5.2 Component 2- Clinical Measures to Guide Return to Running

Conflicting evidence exists in the current literature on the need for radiologic evidence of healing prior to introducing running-related loads (7, 47, 48, 71, 77, 103), with some suggesting imaging was not necessary, and others taking the opposite stance (78, 104, 110). The clinicians interviewed provided clarity that due to the limited sensitivity of radiographs (12, 121, 131), imaging is not required, except in the case of a high-risk BSI. There are similar disagreements when considering the need for the resolution of tibial bone tenderness prior to the introduction of running load, with some literature and clinicians recommending this (48, 98, 138), while others disagreed (7, 101).

The use of functional testing to assess tissue capacity and movement competency has been advocated in the existing lower extremity injury (49), general BSI (7), and tibial BSI (101) return to running guidelines. The single leg vertical hop test for pain has been cited as a highly sensitive test for predicting the return to unrestricted pain-free activity, and strongly correlated with functional progression (79). Clinicians also acknowledged the use of additional functional tests to guide the introduction of running loads, with calf raises, single leg vertical hopping and single leg squats specifically mentioned.

3.5.3 Component 3- Progression of Load

The 10% rule is widely cited in the literature as a method of progressing running distance as well as intensity when returning to running following lower extremity (61, 67, 69, 71) and tibial BSIs (47, 64, 101), however there is no empirical research providing validation. Buist et al. (155) found no difference in running injury prevalence in novice runners who followed a 10% average progression in weekly running distance, compared to those whose weekly progression was greater than 10%. Clinicians acknowledged the extensive literature citation of the '10% rule' to guide running progression, but did not support its use due to the lack of scientific evidence to support it.

Progressing distance prior to speed has been recommended in recent guidelines for competitive runners that states running distance should be built to 50% of pre-injury level, before interval speed sessions are introduced (49), as well as in return to running programmes following lower extremity BSIs (7). This is supported by mechanical fatigue tests that indicate that BSI risk increases more rapidly with progressions in running speed than running distance (47, 139, 140), and a recent paper that reported increased running speeds resulted in greater internal tibial loading (149). Clinicians all described first progressing distance to achieve continuous steady state running, ahead of introducing speed or frequency changes following a tibial BSI. However, with all progressions, clinicians emphasised the importance of individualisation and tailoring progressions based on pre-injury training status, severity of the injury, and goals of the athlete.

Previous guidelines following lower extremity BSIs have identified pain provocation during and following activity as the main factor to guide progression through the return to running process. (7, 47, 101). Return to competitive running guidelines not only recommend monitoring pain, but also form and control with functional movements such as single- and double-leg squat, step down, and single leg hop tests throughout the return to running process (49). The importance of monitoring functional tests was also highlighted in the 2016 Consensus Statement on Return to Sport (42). Similarly, clinicians identified using symptom provocation during and following activity, and also monitoring of functional tests and objective measures throughout the process, to guide progression of running load. The individuality of each athlete, and the need to tailor the process to each athlete, was reflected throughout all the interviews. Regular assessment of tissue capacity and movement competency throughout the process allows an individualised approach to management.

3.5.4 Component 4- Surface

Differing surface recommendations have been provided in previous guidelines on returning to running following lower extremity BSIs including starting on a treadmill (60, 61, 92, 94, 95, 111, 116) due to the more compliant surface, avoiding hard surfaces (7, 48, 77, 80, 89, 97, 98, 100, 103, 104, 106, 108, 109, 116), whilst other running programmes were prescribed on a running track (79, 90, 112). There is conflicting evidence in the literature regarding the influence of surface hardness on tibial acceleration. Harder running surfaces such as synthetic running track and concrete have been observed by some studies to result in lower vertical tibial accelerations in comparison to softer surfaces such as on woodchip trail (147) and a treadmill (123, 158). Contrasting these findings, running on grass on a level grade has been shown by Waite et al. (162) to result in higher tibial acceleration than concrete. Furthermore, two other studies found no difference in tibial acceleration between grass and sidewalk (158) or between dirt, gravel and paved surfaces (163). The relationship between surface hardness and injury risk is complex as some runners compensate for different running surfaces by altering leg stiffness depending on the surface compliance (164-166). Furthermore, those experiencing high tibial accelerations may not necessarily go on to develop a BSI (150). The majority of clinicians recommended introducing running on level surfaces such as grass, treadmills, or softer paths which provides some clarity regarding the initial running surface. However, the importance of introducing the athlete's normal training surface was emphasised. This individualisation is logical as it is likely athletes will be adapted to their usual training surface. Rice et al. (149) concluded that unfamiliarity of running conditions, such as running on an inclined surface compared to level running, may explain the increased internal tibial loading.

Applying similar reasoning, familiarity of training surface may assist in reducing tibial loading. Further research is needed in female athletes following a tibial BSI to make clear recommendations regarding optimal running surfaces.

3.5.5 Component 5: Risk Reduction

3.5.5.1 Gait retraining to alter bone loading:

With regard to running gait parameters, there is some evidence to suggest that greater peak hip adduction and rearfoot eversion angles (33, 34, 83), and increased vertical loading rates (32, 84, 170, 171) are associated with the development of tibial BSIs in female runners. A recent study has found that women with a history of BSIs experience greater increases in vertical average loading rate, vertical instantaneous loading rate, vertical stiffness, and tibial shock with exertion compared to women without a history of BSI (172). The authors recommend biomechanical interventions to reduce these variables with exertion to prevent injury recurrence(172). However Matijevich et al. (169) acknowledges that increases in ground reaction force metrics may not always be an indicator of tibial BSI. Increasing running cadence has also been shown to reduce the probability of a tibial BSI among cross-country runners, and among common measures of running mechanics cadence was determined to be the strongest biomechanics predictor of BSI (199). To prevent injury recurrence, assessing and addressing running gait biomechanics has been advocated in previous guidelines following tibial (47, 101) and lower-extremity BSI (7). All clinicians highlighted that as the athlete is returning to running, running gait should be assessed for biomechanical faults that might identify potential risk, and habits associated with inducing injury should be modified. The only specific gait re-training interventions identified by clinicians were correcting overstriding or increasing cadence, consistent with the recommendations of Kliethermes et al. (199). However clinicians acknowledged the challenges of assessment due to individual variation, and the potential for athletes to adapt to their biomechanics. This reflects return to competitive running guidelines that also recognised that running biomechanics are highly nuanced and difficult to define

(49). Future research assessing the influence of different biomechanical variables in an injured population would be beneficial.

3.5.5.2 Plyometrics and Resistance Training to Build Bone Health:

Running does not subject the body to high enough impacts to produce osteogenic effects (142). There is evidence suggesting the addition of resistance (173) and high-impact training (i.e. loads greater than four times body weight) (177), such as jumping or hopping can be highly osteogenic and energy efficient in females, and therefore likely to be beneficial for improving bone health (178, 180, 182, 200, 201). Clinicians recognised the importance of resistance and plyometric training to improve bone health. Whilst it was recommended that resistance training begins in the early stages, plyometric strengthening was recommended in the later stages, with the importance of modifying running loads accordingly acknowledged. However, further female tibial BSI specific controlled trials are needed to assess the influence of resistance training and plyometric loading following a tibial BSI in order to provide guidelines on its addition in the return to running process in this population.

3.5.6 Multi-disciplinary Team Management

Previous guidelines following BSIs have acknowledged the need for a MDT approach to management (7, 49). Similarly, a MDT approach to treatment was strongly advocated by all clinicians to address contributing factors and prevent recurrence, with the importance of scope of practice emphasised. It was highlighted that while all components are essential to check off, and it is critical that the questions are asked, the size and influence of those components will be different for every individual. Factors that clinicians identified as particularly important in females, and where a MDT team is vital, were the presence of RED-S, psychological factors and biomechanical factors. The members of the MDT team will be somewhat informed by where the individual sits in terms of the different components. For some women, certain components, and therefore certain disciplines, will be more important than others.

3.5.7 Strengths:

The inclusion of Sports Physicians, Physiotherapists and a Physiologist working in different areas of sports medicine provided a comprehensive overview of perspectives on returning females to running following a tibial BSI. All clinicians were had over 5 years of experience working with this population to ensure a high quality of clinical practice and provide high quality practice guidelines. The use of semi-structured interviews enabled flexible discussions to capture the thoughts and opinions of the clinicians regarding how they approached returning females to running following a tibial BSI and what they deemed as the important components in female athletes. Moreover, this study also provides valuable insights that may inform future intervention designs such as comparing different walk-run progressions, assessing the influence of biomechanical interventions, and investigating the influence of hormonal balance on BSI recurrence in female athletes following tibial BSIs.

3.5.8 Limitations:

Several limitations in this study are acknowledged. All participants were living and working in New Zealand, therefore specific cultures relevant to New Zealand may have played a role in the findings, and the transferability of the findings beyond the context of the New Zealand healthcare system may be limited. It is also worth noting that no Māori and Pasifika sports medicine clinicians took part in the study, who would likely have specific cultural knowledge, perceptions and practices, which this study would not have captured. There may also be an increased risk of bias as a purposive sampling approach was used to attain experienced clinicians. Eighty percent of the sports medicine clinicians were females which may influence their interview responses and provision of care. Gender differences in care provided by physicians and physiotherapists has been shown in the literature, such as increased empathic concerns in female clinicians (202, 203).

3.5.9 Future Research:

Further research is needed to investigate the beliefs and practices of experienced clinicians from countries other than New Zealand, different ethnic backgrounds, a more devise gender mix, and other sports medicine clinicians involved in the management of tibial BSIs to provide guidelines that can be transferred across a wider context. It would also be beneficial to interview female athletes regarding their experience with tibial BSIs, and what they deem as the important components of management. Furthermore an RCT to substantiate the common clinical practices and perceptions of experienced sports medicine clinicians would be valuable.

3.6 Conclusion:

When returning female athletes to running following a tibial BSI in a NZ context, their health should first be optimised, with nutritional status, and psychological and hormonal health particularly important in the female athlete. Progression of running load should be gradual and guided by pain and physical assessment findings. Experienced clinicians identified the need to veer away from a 'one size fits all approach' and individualise the return to running process. A notable thread that stretched across all three themes, was the importance of establishing a multi-disciplinary management approach, reflecting the many facets involved in tibial BSIs in female athletes. All components are essential to address, but the size and influence of those components will be different for every individual. Future research interviewing experienced clinicians worldwide as well as interviewing female athletes themselves is warranted to develop more transferable guidelines for the process of returning female athletes to running.

Chapter 4: Discussion and Conclusion

4.1 Summary and Main Findings

The overall aim of this thesis was to investigate criteria prior to introducing running and the process of returning female athletes to running following a tibial bone stress injury (BSI). To achieve this, two studies were conducted, firstly a scoping review which aimed to (1) outline the criteria used in clinical decision-making prior to resuming running for females following a tibial BSI and (2) establish evidence-based guidelines to support clinicians in the return to running process following a tibial BSI in females. Secondly, interviews with experienced sports medicine clinicians were conducted to establish how clinicians return female athletes to running following low-risk tibial BSIs, while determining critical components of management.

The findings from the literature and experienced clinician views are compared, and considerations for the return to running process proposed. To present this information in a manageable way it has been consolidated into two main sections, firstly the preparation for returning to running, and then the return to running process, acknowledging that there are areas of crossover between the phases. An infographic has been developed for this process (Figure 8). There is clearly some information that is non-sex specific, and could relate to both males and females, however this thesis has a focus on the areas of specific relevance to females.

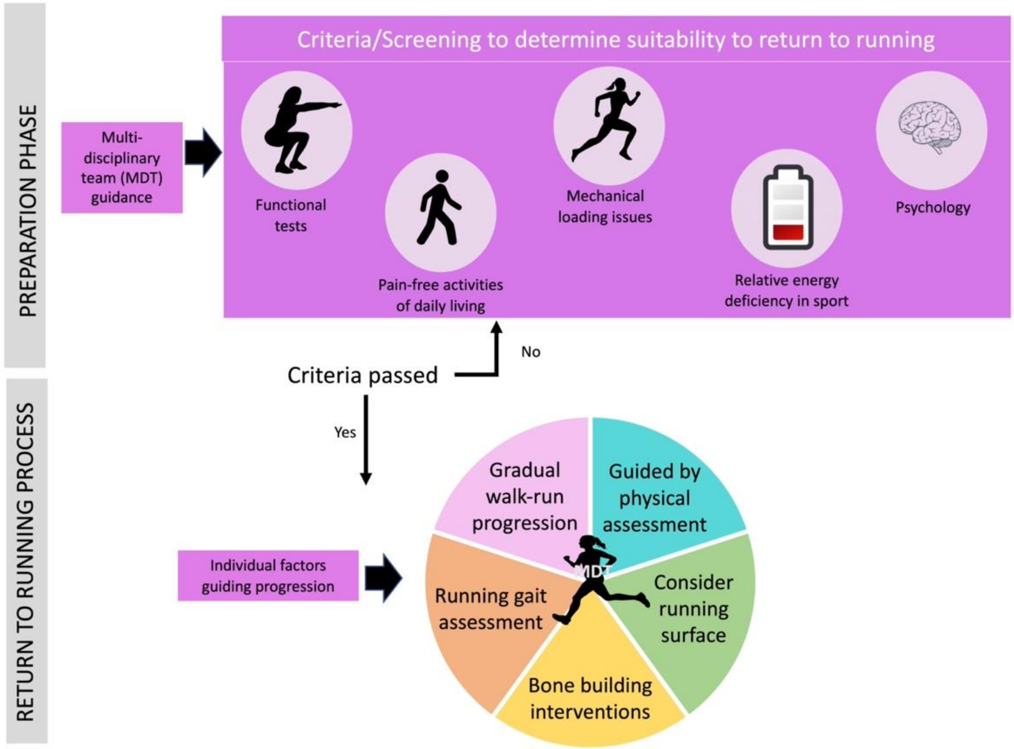

Figure 8: Preparation Phase and Return to Running Process

4.2 Preparation Stage:

4.2.1 Psychological Factors:

Recent return to competitive running guidelines following general lower extremity injury, but not specific to BSIs, have highlighted the importance of addressing and monitoring psychological health throughout the return to running process (49). This is not currently reflected in the BSI literature from the scoping review, with only 6% of studies discussing addressing psychological health (97, 103, 115). However, it was highlighted as an important component in the return to running process by all clinicians. The clinicians acknowledged the part that psychological health can play in BSI incidence, particularly the connection with Relative Energy Deficiency in Sport (RED-S), the psychological impact of sustaining a BSI, and the psychological support needed when returning to running.

The psychosocial complexity related to injury and return to sport is a concept only recently gaining recognition (49, 103), and psychological readiness to return to sport has been highlighted as a key consideration in the 2016 Return to Sport Consensus

Statement (42). It is a particularly important aspect of treatment in females, as an increased incidence of psychological issues such as anxiety and depression have been shown in females athletes (196, 197), and low energy availability which more commonly affects female athletes has known negative correlations with psychological health (25). A large proportion of the literature assessed within the scoping review was published before the importance of psychological health in the return to sport realm was recognised, explaining the limited acknowledgement of optimising psychological health in the BSI literature. Future research is needed to guide how it is implicated in a specific female way.

4.2.2 RED-S and Menstrual Health

RED-S is more common among female athletes (27), and it has a well-established effect on menstrual function and bone health in female athletes (25). The return to competitive running guidelines following general lower extremity injury did not acknowledge the importance of screening for RED-S or menstrual irregularities (49). The importance of assessing menstrual health and RED-S risk when treating a female athlete was reflected in the scoping review literature, with 70% of studies recognising the importance (7, 35, 40, 41, 47, 48, 60, 61, 64, 71, 74, 77, 78, 80, 89, 91-94, 96-98, 100-104, 106, 108, 110, 111, 116). Similarly, all clinicians emphasised the critical importance of screening for and addressing RED-S and menstrual irregularities when treating female athletes with tibial BSIs. The importance of sex-specific guidelines when dealing with injuries such as BSIs with sex-specific risk factors is critical. Where sex-specific guidelines are not presented, such as in the return to competitive running guidelines (49), areas such as RED-S risk, and menstrual health status, are often missed. As the return to competitive running guidelines are not specific to BSIs, the importance of screening for RED-S and menstrual health irregularities may not be deemed as important. Future return to running guidelines should be sex-specific to recognise sex-specific risk factors and important components of management.

4.2.3 Functional and Loading Tests Utilised Prior to Introduction of Running Loads

To determine readiness to return to running, the return to competitive running guidelines recommended performance of functional movements, such as double- and single-leg squat, and step-down and progressive variations of hop tests, pain-free and with good movement quality (49). The need to assess functional movements prior to returning athletes to running was identified in 33% of the scoping review studies (7, 35, 64, 77, 97, 98, 100, 101, 110, 111, 113). The only specific movements suggested to indicate preparedness for running were a single leg vertical hop test assessing for pain provocation (47, 48, 79, 90) and single leg squat movement assessing movement quality (7). In contrast, all clinicians involved in the return to running decision utilised key clinical tests to assess tissue capacity and movement competency and consequently indicate readiness to return to running. The movement competency screening tests that the majority of clinicians assessed included single-leg squat, heel raise and single-leg hopping, looking for pain or biomechanical faults associated with potential reinjury risk. The Physiotherapists highlighted the importance of testing these movements on multiple occasions during the rehabilitation process to monitor progress, and they also recommended continuing to address movement competency throughout the return to running process. The clinicians felt that optimising movement competency biomechanics was important to prevent injury recurrence. However, they acknowledged the challenges of assessment due to individual variation and the often unclear relationship between altered biomechanics and potential injury mechanisms.

Currently there is minimal research investigating the influence of functional movements, such as single leg hopping and single knee bend, with return to sport rates following tibial BSIs or BSI recurrence rates. Therefore, further female-specific research is required investigating the relationship between functional tests and BSI return to sport and recurrence rates to make specific recommendations.

4.3 Return to Running Process:

4.3.1 Progression Guided by Physical Assessment:

According to the return to competitive running guidelines, physical assessments should regularly be undertaken throughout the return to running process, with physical performance measures and pain guiding the process. These guidelines advised low levels of pain were acceptable, however these guidelines were not BSI specific (49). Similarly, the 2016 Return to Sport Consensus Statement identifies the importance of monitoring functional tests throughout the process to guide progression and at the time of clearance to return to sport (42). The use of functional tests to guide progression was not reflected in the literature from the scoping review, with pain the only metric identified. The experienced clinicians proposed guiding progression based on pain, as well as monitoring pain and performance with physical assessments to individualise the process. Pain is a complex phenomenon, it is not always closely linked to musculoskeletal damage and is mediated by numerous individual factors (151). Therefore, monitoring physical assessments is logical to allow more precision with monitoring patient response and to allow individualisation throughout the process. In contrast to soft tissue injuries, there should be minimal tolerance for pain when dealing with BSIs, as reflected by the literature in the scoping review and experienced clinicians. This was not acknowledged in the return to competitive running guidelines, highlighting the importance of BSI specific guidelines when returning to running.

Progressively increasing running distance by 10% per week, commonly referred to as 'the 10% rule' was widely cited as a method of returning to running following a lower extremity BSI among scoping review studies (47, 61, 64, 67, 69, 71, 80, 81, 101, 102, 105, 107, 110, 116). Clinicians acknowledged the extensive citation of the 10% rule, but all agreed that it is not generalisable, and athletes will tolerate different rates of progression.

There is increasing recognition that a one size fits all approach does not work when returning athletes to running or sport. This was reflected in the return to competitive running guidelines (49), 2016 Consensus Statement on Return to Sport

(42), and the experienced clinicians' opinions. Individualisation is important and this can be achieved through monitoring individual responses to training through provocation of pain and performance of physical assessments. Further research to better understand the individual rates of progression compared to the 10% rule for running progression following a tibial BSI would be beneficial.

4.3.2 Strengthening and Plyometrics:

Strength training has been acknowledged in return to competitive running guidelines as an important component of the process, with progression to plyometrics once the athlete has progressed through variations of hop tests (49). Although strengthening was regularly discussed, only 21% of scoping review studies described the inclusion of running drills and plyometric strengthening in the return to running process (47, 60, 67, 71, 89, 92, 94, 105, 109, 111), however this is likely related to the stages of treatment discussed in each study. In contrast, the clinicians who were involved in the return to running process acknowledged the inclusion of resistance training and plyometric strengthening to provide bone stimulus as well as improve running biomechanics. Whilst resistance training was recommended to begin in the early stages, plyometric strengthening was recommended in the later stages with the importance of modifying running loads accordingly acknowledged. Not all clinicians were routinely involved in the later stages of rehabilitation, therefore not all commented on the inclusion of plyometric strengthening.

Bilateral bone loss peaks around 12 weeks following a BSI (176), and running does not subject the body to high enough impacts to produce osteogenic effects (142). Evidence has shown that resistance training (173) and high-impact training such as plyometrics are osteogenic, and therefore beneficial for improving bone health in females (180, 200, 201); as such these are key components of the return to running process to prevent injury recurrence. As recognised in several of the scoping review studies (47, 109) and by experienced clinicians, athletes must have adequate strength and the increase in bone loading must be accounted for when introducing plyometric strengthening. However, future research is required to assess the effect and optimal timing of resistance training and plyometric strengthening in females following a tibial BSI.

4.3.3 Running Gait Assessment and Retraining

Optimisation of running biomechanics and gait retraining in the early stages of return to running is discussed in recent return to competitive running guidelines (49). However, the guidelines state running gait is highly nuanced and difficult to define, therefore the relative importance must be considered (49). Greater increases in impact biomechanics such as vertical average loading rate, vertical instantaneous loading rate, vertical stiffness, and tibial shock with exertion have been shown in women with a history of BSIs compared to women with no previous BSI, highlighting this could be an important consideration for gait re-training to prevent BSI recurrence (172). Only 29% of scoping review studies discussed different gait retraining interventions (7, 47, 48, 67, 69, 71, 89, 91, 98, 100, 101, 103, 105, 113). The main interventions acknowledged as showing potential value in female runners were increasing running cadence, as well as interventions aimed at reducing peak hip adduction and rearfoot eversion angles as these variables have shown an association with a history of tibial BSIs in females (7, 33, 34). All the clinicians discussed that as the athlete is returning to running, running gait should be assessed for biomechanical faults that might identify potential risk, and habits associated with inducing injury modified. The only specific gait retraining interventions identified by clinicians were correcting overstriding or increasing cadence, consistent with the recommendations of Kliethermes et al. (199) who determined running cadence to be the strongest biomechanical predictor of BSIs. The authors reported that increasing running cadence reduced the probability of a tibial BSI among cross-country runners (199). However clinicians highlighted that assessment of running biomechanics is complex because of individual variation and the potential for athletes to adapt to their running gait. The clinicians agreed with the return to competitive running guidelines, that clinical judgement must be used to determine the relationship between altered running biomechanics and potential injury mechanics. This individuality of running gait was also reflected in the scoping review literature, with multiple potential biomechanical interventions proposed, but with minimal strong evidence to support these. Barton et al. (204), in a mixed methods study on running gait retraining, concluded that tailoring of running retraining strategies to each injury and individual is required to optimise outcomes. Currently there is a dearth of current evidence for running gait retraining in an injured population (204). Further research is required specifically in female athletes following tibial BSIs to understand potential biomechanical considerations.

4.3.4 Running Surface:

Starting on a treadmill with gradual transition to overground running (e.g., track, road, trail) once the athlete is running more than 50% of their training volume has been proposed in return to competitive running guidelines (49). These guidelines acknowledged that musculoskeletal load can be influenced by utilising different inclines, overground running surfaces, and treadmill running surfaces (49). The scoping review identified there were differing recommendations among the literature regarding the optimal initial running surface. As with the return to competitive running guidelines, one quarter of scoping review studies recommended starting on a treadmill (60, 61, 92, 94, 95, 111, 116) due to the more compliant surface. Then multiple other reviewed studies recommended avoiding hard surfaces (98, 104, 108, 109, 116). In contrast, some reviewed studies provided examples of return to run programmes on a running track (79, 90, 112), which are harder surfaces. However, these studies were RCTs and a pilot study, so the recommendation of a running track may simply have been to control the surface, as opposed to a logical or even practical solution for running. In the initial stages post-injury, several reviewed studies recommended it may also be beneficial to avoid running on hills (7, 64, 69, 97).

There is conflicting evidence regarding the influence of running surfaces on tibial acceleration, plantar pressures and ground reaction forces which have all been used as surrogates of lower extremity loading in runners. Several studies have assessed changes in these variables on different surfaces and there is conflicting evidence regarding the influence of different surfaces on tibial BSI risk. Harder running surfaces such as synthetic running track and concrete have been shown by some studies to result in lower vertical tibial accelerations in comparison to softer surfaces such as on woodchip trail (147) and a treadmill (123, 158). Similarly, lower magnitudes of peak plantar pressures were produced when running on grass compared to running on concrete (160, 161). However conflictingly on level ground running on grass has been shown by Waite et al. (162) to result in higher tibial acceleration than concrete. Furthermore two other studies found no difference in tibial acceleration between grass and sidewalk (158) or between dirt, gravel and paved surfaces (163). There is also conflicting evidence in the literature regarding the influence of surface incline grade on internal tibial loading or tibial acceleration. When comparing running on level surfaces and uphill surfaces, Rice et al. (149) found that running uphill at 10% and 15% inclines resulted in greater internal tibial loading, however Waite et al. (162) reported no difference in peak tibial acceleration. In regards to running downhill, Rice et al. (149) found running on downhill surfaces to result in lower internal tibial loading in comparison to level or uphill running, whereas Waite et al. (162) found a significant increase in peak tibial acceleration on downhill surfaces compared to uphill surfaces. Clinicians provided some clarity regarding the initial running surface, initially introducing running on level surfaces such as grass, treadmills or softer paths. However, the individual nature of the process was again highlighted with several clinicians emphasising the importance of progressively adding in various terrains, especially those that the athlete normally trains or competes on. The clinicians highlighted that athletes may adapt to their usual training surface. Rice et al. (149) also concluded that unfamiliarity of running conditions such as running on an inclined surface compared to level running may explain the increased internal tibial loading. Applying similar reasoning, familiarity with the training surface may assist in reducing tibial loading.

So far, no research has investigated the influence of running surface in females returning to running following tibial BSIs, therefore research in an injured population is required to establish clear recommendations on the optimal running surface.

4.3.5 Multi-disciplinary Team Approach

A multi-disciplinary team approach to returning to running has been acknowledged in the return to competitive running guidelines, with the importance of setting goals and performing baseline testing as a rehabilitation team highlighted (49). The decision as to when an athlete is safe to return to repeated loading should be a shared decision between the rehabilitation team, coach, and athlete (49). A team approach has been further highlighted in the 2016 Return to Sport Consensus Statement for a successful return to sport, where the authors highlighted the importance of defining roles, establishing shared goals, regular communication between all members, and shared decision-making throughout the whole process (42).

The importance of identifying and addressing all contributing factors to the onset of the BSI was acknowledged by the majority of the scoping review studies, however the importance of shared decision-making, and a team approach was not frequently highlighted. The clinicians strongly advocated for a multi-disciplinary team approach to address contributing factors and prevent recurrence, with scope of practice highlighted.

An extremely important component of BSI management is addressing the many contributing factors to the initial injury and to do so, a multi-disciplinary team is vital. The members of this team will be somewhat informed by the components that are important in each individual female athlete. Further research could investigate the impact of shared decision-making on the return to running outcomes.

4.4 Strengths:

This thesis synthesises clinical reasoning with a comprehensive scoping review of the literature to provide a comprehensive overview of the process of returning female athletes to running following a tibial BSI. To the authors' knowledge, this is the first study to review how experienced sports medicine clinicians approach the process of returning female athletes to running process following a tibial BSI and no scoping review has been undertaken regarding the return to running process in female athletes following a tibial BSI. The findings from this thesis provide valuable insights that may inform future intervention designs such as comparing different walk-run progressions, assessing the influence of different running surfaces, assessing the influence of different biomechanical interventions, and investigating the influence of hormonal balance on BSI recurrence in female athletes.

The inclusion of interviews of Sports Physicians, Physiotherapists, and a Physiologist working in different areas of sports medicine provided a comprehensive overview of perspectives regarding the topic of returning females to running following a tibial BSI. The qualitative design, and use of semi-structured interviews, enabled flexible discussions to capture the thoughts and opinions of the participants regarding how they approached returning females to running following a tibial BSI and what they deemed as the important components in female athletes.

4.5 Limitations:

There are several limitations of this research that must be acknowledged. This thesis relies heavily on expert opinion with the scoping review containing a large number of clinical commentaries, and the recommendations for clinical management and guidelines in chapter 3 based on experienced clinicians opinion and practices. The current lack of evidence based literature in this area reflects the challenge completing large scale RCTs specifically in females with tibial BSIs.

In the scoping review a lack of evidence specific to female athletes was identified, therefore studies looking at BSIs in a non-specific location in the lower extremity as well as studies that did not specify gender were included. All included studies provided some guidance in terms of criteria prior to introducing running-related loads, or on the process of returning to running, following a tibial or lower extremity BSI, however no studies in this review specifically compared return to running approaches.

In the qualitative study all clinicians were living and working in New Zealand, therefore specific cultures relevant to New Zealand may have played a role in the findings, and the transferability of the findings beyond the context of the New Zealand healthcare system might be limited. Furthermore 80% of the clinicians were females which may influence their perspectives and practices regarding the important components of management. It is also worth noting that no Māori or Pasifika sports medicine clinicians took part in the study, who would likely have specific cultural knowledge, perceptions and practices, which this study would not have captured. There may also be an increased risk of bias as a purposive sampling approach was used to attain experienced clinicians.

4.6 Future Research:

The next stage of this research would be to research the implementation of the guidelines developed in this thesis to return females to running following a tibial BSI. Randomised controlled trials are needed to compare different walk-run progressions and different rates of progression when returning females to running following a tibial BSI. As the 10% rule does not have much value it would be valuable to assess an individualised approach to progression. Future trials investigating the influence of running surface and biomechanical interventions on female runners following a tibial BSI would also be beneficial. Further research investigating how much hormonal balance contributes to the recurrence of BSIs is also an important area in the female athlete.

Further research investigating specific tools that can help guide the return to running process may be valuable given pain is not always the best indicator and radiological evidence of healing has not been shown to be reliable. Competitive athletes in particular would benefit from improved indicators to guide this process. Randomised controlled trials could also consider investigating criteria prior to allowing running related loads following a tibial BSI, this may include evaluating objective measures such as resolution of bony tenderness and assessment of functional and loading tests to indicate readiness to begin the return to running process. Future research could investigate the impact of shared decision-making on the return to running outcomes. Further research is needed to investigate the beliefs and practices of experienced clinicians from countries other than New Zealand, different ethnic backgrounds and other sports medicine clinicians involved in the management of tibial BSIs, to provide guidelines that can be transferred across a wider context. It would also be beneficial to interview female athletes regarding their experience with tibial BSIs, and what they deem as the important components of management.

4.7 Conclusion:

This thesis has combined clinical reasoning with a comprehensive evidence synthesis to guide clinicians and researchers who seek to implement and evaluate return to running guidelines following a tibial BSI in female athletes. The reality is BSIs have a high rate of recurrence and unless contributing factors to the initial injury are addressed, there is a high likelihood the injury will recur.

In the preparation stage despite not being acknowledged in the BSI literature, experienced sports medicine clinicians and recent return to sport and running guidelines have highlighted the importance of identifying and addressing any psychological risk factors. There is consensus between the literature and experienced clinicians that screening and addressing RED-S and menstrual disturbances is critically important in the female athlete following a tibial BSI. Functional movement testing is frequently used by experienced clinicians in clinical practice to determine readiness to return to running in female athletes following a tibial BSI, however specific movements have not been tested or acknowledged in the literature.

During the process of returning to running, progression and components of this process should be individualised to the female athlete. Pain and monitoring of physical assessments can guide this process. Clinicians should move away from applying one rule to all athletes such as ‘the 10% rule’ to guide running progression. Running gait retraining and modification of running surface will be individual to the athlete but may include increasing running cadence and avoiding hard surfaces initially. In order to improve bone health, plyometric training may be a beneficial addition in the advanced stages of progression. A multi-disciplinary management approach should be utilised to address the many components involved in tibial BSIs in female athletes. All components are essential to investigate, but the size and influence of those components will be different for each individual.

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Appendix 1: AUTEC Ethics Approval

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

14 December 2021

Kelly Sheerin
Faculty of Health and Environmental Sciences

Dear Kelly

Re Ethics Application: **21/411 Guidelines for returning female athletes to running following a tibial bone stress injury**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 14 December 2024.

Non-Standard Conditions of Approval

Non-standard conditions must be completed before commencing your study. Non-standard conditions do not need to be submitted to or reviewed by AUTEC before commencing your study.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard and that all the dates on the documents are updated.
8. AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

Please quote the application number and title on all future correspondence related to this project.

For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: , estherrubygeorge@gmail.com; duncan.reid@aut.ac.nz

Appendix 2: Sports Medicine New Zealand Conference Abstract

GUIDELINES FOR RETURNING FEMALES TO RUNNING FOLLOWING A TIBIAL BONE STRESS INJURY

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Background: Tibial bone stress injuries (BSI) are common among distance runners and occur frequently in young female athletes (1-4). Additionally, BSIs have one of the highest recurrence rates of all running-related injuries (1-4). The causes and implications of BSIs can be multifactorial. The aims of this study were to establish a criteria to initiate a running related loads, and to establish clinical guidelines for the process of returning females to running following tibial BSI.
Methods: This scoping review followed the methodological framework proposed by Arksey and O'Malley (5). A systematic search was conducted using MEDLINE, CINAHL, SPORTDiscus, SCOPUS and AMED. Data regarding criteria prior to introducing females to running related loads and the process of returning females to running following a tibial BSI was extracted from all studies.
Results: 48 studies fulfilled the inclusion criteria. The key criteria identified prior to introducing running related loads following a tibial BSI were symptom resolution, walking 30-45mins pain-free, completion of single leg functional tests, and identification of contributing factors such as menstrual health, nutritional deficiencies, energy availability, biomechanical factors, training errors and footwear. The return to running process should involve a graduated return to running, consideration of running surface and addressing of biomechanical factors.
Discussion and Conclusion: Clinical signs of healing, rather than radiological findings, should be used to guide when it is appropriate to introduce running related loads. The tibia must have sufficient capacity first to cope with the demands of activities of daily living, and walking loads, before commencing higher level functional tasks such as running. Biomechanics, and other factors contributing to the BSI, should also be assessed to evaluate readiness to return to running and prevent risk of recurrence. These factors should continue to be addressed throughout the return to run process. A graduated return to running should commence using a walk-run progression individualised to the individual and their goals. Running volume and intensity should be considerably reduced from pre-injury levels, with progression of load based on symptom provocation. Although there is variation regarding the optimal surface to introduce running related loads on, it could be beneficial to initially limit hard surfaces and hills.
This scoping review highlights that returning a female athlete to running following a tibial BSI is a complex process and a multidisciplinary approach is important to reduce the risk of recurrence. Although there is a lack of consistency or strong evidence to guide the return to running process, this study highlights the fundamental principles and a potential approach to returning females to running following a tibial BSI. Further research, including insight from current practitioners, is required to develop robust guidelines for returning females to running following a tibial BSI.

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Appendix 3: The International Society of Biomechanics in Sport Conference Abstract

THE RETURN TO RUN PROCESS FOR FEMALES FOLLOWING A TIBIAL BONE STRESS INJURY: A SCOPING REVIEW.

Esther George[1], Kelly Sheerin[1] and Duncan Reid[1]

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Affiliation[2] will go here after blinded review

Tibial bone stress injuries (BSI) are common among female runners and have a high recurrence rate. Complete rehabilitation requires a successful return to running, but there is a lack of guidance for this. This review sought to establish the evidence supporting the return-to-running process following a tibial BSI in females. Sources were identified by searching databases using relevant terms. Study titles and abstracts were screened using inclusion criteria, and 48 articles were selected. An individualised graduated return-to-run programme should be instigated, beginning with walk-run intervals, and progressing running distance ahead of speed. The '10% rule' of graduated loading is not generalisable across all runners. Contributing factors to the initial injury should be addressed throughout the return-to-run process, including biomechanical factors and training errors.

KEYWORDS: running, stress fractures, recovery.

INTRODUCTION: Bone stress injuries (BSI) account for up to 20% of injuries seen in sports medicine clinics (Tenforde, Kraus, & Fredericson, 2016). Up to 95% of BSI occur in the lower extremities, with the tibia the most common location (Abbott et al., 2020). Lower extremity BSI are common among distance runners due to the repetitive loading of the sport, with more than one-third of long-distance runners experiencing lower extremity BSI, with females being particularly susceptible (Kelsey et al., 2007). Additionally, BSIs have one of the highest recurrence rates of all running-related injuries (Abbott et al., 2020). Following a tibial BSI, a critical component to complete rehabilitation is the successful return to running. While existing reviews have explored the general concepts of BSI management in females (Brukner & Bennell, 1997; Chen, Tenforde, & Fredericson, 2013), they have not been specific to running. There is a lack of information regarding when females should return to running, and a lack of guidance on how the process should take place. The aim of this review was to establish the research evidence to support the return-to-running process. This paper presents part of a larger study.

METHODS: The scoping review methodological framework proposed by Arksey and O'Malley (2005) and the JBI Evidence Synthesis (Peters et al., 2015) were followed for the design and reporting of this scoping review. Initial literature searches revealed no papers specific to tibial stress injuries in female runners, and as such the search scope was widened to include lower limb stress injuries, and any return to running-based activities. Combinations of the following keywords and constructs (i.e., Boolean phrases) were used: bon*, stress injur*/fracture*/reaction*, lower extremit*/limb*, leg*, tibia*, return* sport* play, training, activit*, run*. Studies were included if they outlined specific criteria prior to the introduction of running-related loads, or provided guidance on the process of returning to running-related activities, following a tibial or lower limb BSI. Studies that were specific to males, or detailed upper extremity, spinal or specific lower extremity BSI other than the tibia were excluded. An inductive thematic analysis was used to identify patterns, summarise consistent findings across studies, and generate common themes.

RESULTS AND DISCUSSION: The initial search identified 1040 studies, of which 48 studies met the inclusion criteria. Most articles (39) were reviews or clinical commentaries, three were retrospective cohort studies, two were randomised controlled trials, two were pilot studies, and one prospective observational study and case series. All studies provided guidance on the return-to-run process, and from this four key considerations were identified.

Consideration 1 - Walk-run progression: The introduction of running loads following a tibial BSI should be achieved progressively to promote tissue adaption, whilst preventing injury reoccurrence. Most frequently it is recommended that this is achieved via a 'walk-run' progression on alternate days, gradually substituting walking with increasing time increments of running (Warden, Davis, & Fredericson, 2014). The specific length of running increments varied considerably among reviewed studies, however starting with 30-60 second increments, and progressing by 1-2 minutes, or an equivalent distance was often suggested. While these recommendations appear to be based on expert opinion, there is scientific basis for them. As little as a few minutes of impact exercise will stimulate bone formation, however bone cells become desensitised to prolonged mechanical stimulation (Boudenot, Achiou, & Portier, 2015). Bone is a living tissue that can fatigue quickly so incorporating rest intervals to prevent bone fatigue is important (Edwards, 2018). These points support the inclusion of a walk-run progression consisting of short-duration running periods initially, with adequate recovery interspersed throughout.

Consideration 2 - Progression of load: It was consistently recommended that pain should guide running load progression, specifically detailing that there should be no pain during or following running. When pain is present, athletes should rest until symptom resolution, then resume at a lower intensity level (Warden et al., 2014). Despite this consistent recommendation, pain is a complex phenomenon, it is not always closely linked to musculoskeletal damage, and is mediated by numerous factors (Marchand, 2020), therefore close monitoring and documentation of pain levels are required. It is recommended that distance is progressed ahead of speed following a tibial BSI. This is in agreement with recent guidelines for competitive runners (Hegedus, Ickes, Jakobs, Ford, & Smoliga, 2021), and mechanical fatigue tests indicating that stress fracture risk increases more rapidly with progressions in running velocity than running distance (Edwards, 2018).

Progressively increasing running distance by 10% per week, commonly referred to as 'the 10% rule', is recommended to prevent injury during normal training, but is also widely cited as a method of returning to running following a lower limb stress injury (Warden, Edwards, & Willy, 2021). While the origins of this principle seem to be expert opinion, there is no empirical research providing validation. It appears to have originated as a progression of distance, but has been extrapolated across different variable domains, including time and intensity, still without evidence (Warden et al., 2014). As with many other injury- and training-related variables, runners are likely to tolerate the progression of distance, time and speed differently (Warden, Edwards, & Willy, 2021), and based on this and the evidence available, the rate of progression should be individualised, and should take into account the pre-injury training status and the severity of the injury.

Consideration 3 - Running surface: A quarter of studies recommended initiating running on a treadmill (Brukner, 2000) due to the more compliant surface. Similarly, several other studies recommended avoiding hard surfaces (Romani, Gieck, Perrin, Saliba, & Kahler, 2002). There is some supporting evidence for these recommendations, as hard surfaces are associated with increases in loading-related variables associated with tibial stress fractures (Wang, Hong, Li, & Zhou, 2012). Additionally, running on a treadmill has been shown to evoke 'moderate' decreases in tibial loading compared with running overground (Milner, Hawkins, & Aubol, 2020). Conflictingly, some studies provide example return to run programmes on a running track (Allen et al., 2004), which are generally a hard surface. With the experimental nature of these studies, it may be that the surface recommendation was to control this aspect of the study, as opposed to a logical or even practical solution for return-to-running post-BSI. A small number of studies also recommended that it may be beneficial to initially avoid hills, as running on hilly terrain has been found to be associated with a higher incidence of stress fractures and medial tibial stress syndrome. There is inconclusive supporting evidence regarding the effect of decline gradients, with some reporting that downhill surface gradients resulted in higher tibial acceleration (Chu & Caldwell, 2004), while others did not find such differences (Mizrahi, Verbitsky, & Isakov, 2000).

Consideration 4 - Biomechanical and strength factors: An essential component of return-to-running post-tibial BSI acknowledged by most studies was the need to address contributing biomechanical factors and muscle imbalances. There is evidence suggesting that greater peak hip adduction and rearfoot eversion angles (Milner, Hamill, & Davis, 2010), and tibial acceleration (Milner, Ferber, Pollard, Hamill, & Davis, 2006) are associated with the development of tibial BSI in female runners. As such running gait analysis, and potentially retraining, are appropriate steps for runners during the return-to-run process. Additionally, reduced lower limb muscle size and strength have been shown to be related to BSI risk in females (Beck, Rudolph, Matheson, Bergman, & Norling, 2015), specifically the calf muscles, as well as those supporting the hips and abdomen. To ensure muscles are prepared to provide active protection to the bone, resistance training, and ultimately plyometric strengthening, should be incorporated.

The majority of studies included in this scoping review were clinical commentaries or reviews containing considerable expert opinion, and will inherently have a high risk of bias. There were a lack of studies specifically detailing return-to-running post-tibial BSI, or those with female runners. While all reviewed provided some guidance on the process of returning to running following a tibial or lower limb BSI, no studies specifically compared approaches.

CONCLUSION: Although there is a lack of consistency across the evidence, this review highlights the fundamental principles of returning females to running following a tibial BSI. Four key areas of consideration have been identified. An individualised graduated programme should be instigated that begins with walk-run intervals, and progresses running distance, ahead of speed. Contributing factors to the initial injury should be addressed throughout the return-to-run process. In particular gait analysis to identify contributing biomechanical factors may be beneficial for the female runner. The addition of hip, abdominal and calf muscle strengthening are also important. Deciding when an athlete is ready to return to running is complex, and should be a shared decision between clinicians, coaches and athletes. Effective planning should involve addressing the athlete's risk profile and managing risk by balancing the athlete's interests and reinjury prevention.

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Appendix 4: New Zealand Manipulative Physiotherapists Association Conference Abstract

RETURNING FEMALES TO RUNNING FOLLOWING A TIBIAL BONE STRESS INJURY: EXPERT INTERVIEWS

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Introduction: Tibial bone stress injuries (BSI) are common among female runners and have one of the highest recurrence rates of all running-related injuries [1, 2]. Prior BSI has been shown to increase the recurrence rate 5-6 times among female runners [1, 3]. Following a tibial BSI, a critical component to complete rehabilitation is the successful return to running. While there is some evidence to guide clinicians in the return to running process [2, 4], there are still areas where evidence is lacking.

Aim: To establish the process of how expert sport medicine clinicians return female athletes to running following tibial BSIs, while determining critical components of management.

Methods: A qualitative study design was used to investigate the knowledge and perceptions of Sports Medicine Clinicians on the return to running process following a tibial BSI in females. Semi-structured interviews were completed with ten participants (four Physiotherapists, five Sports Doctors and one Physiologist), and a reflexive thematic analysis was used to establish key themes.

Results: Three themes were established, with the first theme 'Health and Wellness', clinicians emphasised the importance of addressing the underlying reasons for the tibial BSI occurring, such as training errors, RED-S and psychological health. In the second theme 'Bone Healing' clinicians described using clinical findings as opposed to radiological findings to guide the return to running process. The importance of symptom resolution and careful load management to build bone tolerance was emphasised when managing tibial BSIs. Finally, in the third theme, 'Functional Return', clinicians described using functional tests to ensure adequate tissue capacity and movement competency, and to guide progression through the return to running process. Regular functional testing allows an individualised approach to management. Multiple progressions were discussed throughout the process in terms of building running distance, intensity, and frequency. These progressions were all guided by the athlete's end goal. Clinicians acknowledged the extensive literature citation of the '10% rule', which refers to progressively increasing running distance by 10% per week, but did not support its use following a tibial BSI due to the lack of scientific evidence to support it and a

need for individuality. Introducing running on softer surfaces was recommended, whilst also including the athlete's normal training surfaces early in the process. The importance of addressing biomechanical factors was acknowledged, however clinicians advised careful modification as athletes may adapt to their individual biomechanics.

Conclusion: When returning female athletes to running following a tibial BSI their health should first be optimised. Progression should be gradual and guided by subjective and objective clinical findings. Expert clinicians identified the need to veer away from a 'one size fits all approach' and individualise the return to running process. A notable thread that stretched across all three themes, was the importance of establishing a multi-disciplinary management approach, reflecting the many facets involved in tibial BSI in female athletes.

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Appendix 5: Scoping Review Search Strategy

Searches completed July 2021

Database 1:
EBSCO Health (MEDLINE, SPORTDiscus, CINAHL)

"Bon* Stress Injur*" OR "Stress fracture*" OR "Stress reaction*"
AND
"lower extremit*" OR "lower limb*" OR leg* OR knee OR tibia*
AND
((return*) n3 (sport* OR play* OR training OR activit*)) OR run*

1074 results (CINAHL: 240, Medline 464, SPORTDiscus: 370)
767 results (after duplicates removed)

Database 2:
Scopus Search:
(TITLE-ABS-KEY ("Bon* Stress Injur*" OR "Stress fracture*" OR "Stress reaction*"))
AND
(TITLE-ABS-KEY ("lower extremit*" OR "lower limb*" OR leg* OR knee OR tibia*))
AND
((TITLE-ABS-KEY (return* W/3 (sport* OR play* OR training OR activit*)) OR TITLE-ABS-KEY (run*)))

657 results

Database 3:

AMED Search Strategy:

Search 1:

("Bon* Stress injur*" or "stress fracture*" or "stress reaction*").mp. [mp=abstract, heading words, title]
AND
("lower extremit*" or "lower limb*" or leg* or knee or tibia).mp. [mp=abstract, heading words, title]
AND
(return* adj3 (sport* or play or training or activit*)).mp. [mp=abstract, heading words, title]

12 articles

Search 2:

("Bon* Stress injur*" or "stress fracture*" or "stress reaction*").mp. [mp=abstract, heading words, title]
AND
("lower extremit*" or "lower limb*" or leg* or knee or tibia).mp. [mp=abstract, heading words, title]
AND

Run*
53 articles

63 (once the two searches were combined and duplicates removed)

Total record identified: 1794
All references: 1487 (when duplicates removed from EBSCO)
Duplicates: 824
Records after duplicates removed: 1040
Records excluded (n=931)
Records after titles and abstracts screened: 109 articles
Full text studies excluded (n=65)
No mention of return to running (n=51)
Focused specifically on males (n=5)
Not focused on BSI management (n=2)*

Total studies meeting eligibility criteria: 44 studies

Google Scholar forward citation tracking: 2 extra studies added
Hand searching reference lists: 2 extra studies added

Total studies: 48 studies.

Appendix 6: Question Guide for Interviews

Interview Topic Guide:

To start off with can you give a bit of a summary of:

- What setting you work in?
- What your background is/ training you have done?
- And also how often and the circumstances around how you would see or treat females with bony stress injuries?

So firstly when a female runner has sustained a tibial bone stress injury I want to discuss what **criteria you use to decide when they are ready to introduce running related loads**?

Possible prompts:

- Objective measures/signs and symptoms, Resolution of bony tenderness
- What load are you looking at them being able to tolerate before returning to running?
    - *What guidance, if any, do you provide on walking progression prior to introducing running loads*?
    - *Do you specify a certain walking distance to aim for prior to starting to introduce running related loads?*
- Radiological Healing:
    - *What role if any does imaging play in your decision to start the return to running process?*
- Physical Tests (hopping, strength)
    - *can you expand further on the certain tests you would perform and what you are looking for to decide when they are ready to introduce running related loads?*
- Biomechanics/ muscle strength assessments:
    - *What, if any, biomechanical / functional assessments/ muscle strength/endurance assessments do you deem as important to complete prior to or during the return to running process when treating females with tibial BSI? When in the process would you normally address this?*

- What other components/contributing factors do you deem as important to explore and address prior or during the return to running process when treating females with a tibial bony stress injury? *These could be something you specifically address or refer to another discipline.*
- Are there any other specific considerations or criteria that you use to decide when a female runner can begin to introduce running related loads following a tibial bony stress injury?
- What guidance do you provide in terms of cross training prior to starting the return to running process?

So now we will move onto the **return to running process** and discuss the different components of this and what guides your decision making:

- So once the return to running process starts what guides your decision on how much running to recommend the patient initially introduces? Like would you recommend a specific time or distance to begin with?
- What frequency do you suggest introducing running loads and what guides this decision?
  - *What indicates that you could progress the patient a little bit quicker?*
- Progression of distance
  - Are there specific things you are looking for before they can move onto the next stage (eg. Pain-free with X, Y and Z before moving on)
  - How would the level of the runner guide how you structure the return to running process?
- What do you use as indicators or markers to guide whether load or progression is manageable/ appropriate?
- What guidance if any do you provide in terms of terrain?
  - Do you provide any further guidance on this throughout the return to running process?
- The next area I want to talk about is speed/ intensity. What guidance if any do you provide on what speed/intensity to start with? What guides this decision?
- How would you progress speed side of things? Or do you let them do their own thing with maybe some broad guidelines? Or do you not talk about speed at all in this point in time?
  - Are there specific things you are looking for before they can move onto the next stage?
- What do you recommend in terms of cross training as they are building up their running mileage? How do you balance this?
- What other disciplines would you look at including in the management of tibial BSI? And what would prompt this referral?
- During the return to running process are there any other areas you deem as important to work on addressing? *Again these could be something you specifically address or refer to another discipline.*

  <u>Possible prompts:</u>
  - Biomechanics/strength, Nutrition, Menstrual Health
- Is there anything else you want to add in terms of important components in the process of returning female runners back to running following a tibial bone stress injury?
- How would the level of the runner guide how you structure the return to running process?

This interview will be transcribed following. Would you like a copy of the transcript to check accuracy? Also would you like a copy of the results?

Appendix 7: Sample of Thematic Analysis Coding

Participant	Extract	Coding
SD2	*We do tend to discuss the 10% rule because as you say, it's highly quoted everywhere. And look, it's just a nice basic guide to give someone who needs a number a number. Um in saying that there's some flexibility around that I guess as well. We know that the 10% rule is probably reasonably slow and safe um which is what we wanting in this sort of stress situation. Um so it's quite nice from that perspective. And again, it's probably gonna depend on the history of the athlete. Have they had, you know, is this the third stressie that we are rehabbing this year and there's all sorts of hormonal issues in the background? Or is this a person who has just had a very obvious increase in load prior to the onset of their symptoms and otherwise they are very well, haven't had any previous bone injuries and it's purely a training error, you know. And I think they're quite separate and um different situations where we would be a lot more conservative with the former um and probably be happier for the the one with the training errors to progress a little bit faster if they were going well.*	10% rule not generalisable (conservative)
PT1	*I know sometimes we talk about kind of a 10% rule about when you would kind of start to increase what they're doing, but I think there are so many variables in that.*	10% rule not generalisable.
SD3	*You know theoretically you talk we talk about sort of 10% per week increases in load. But I think in reality that's often a kind of a nice number but it's hard to measure.*	10% rule not generalisable
SD5	*The 10% rule you know that people talk about, it just doesn't work, right. I mean, you just can't do that because it just doesn't, it doesn't work that way.*	10% rule not recommended
P1	*And I don't think that 10% every week rule really works for everyone. It's like a cookie cutter program and it's like, Nah, like some people can't handle that and you just need to take time.*	10% rule not generalisable
PT2	*I find that 10% can take a really, really long time. And especially if, like we've got our like Ultra Marathon runners who sustain stress fractures and you know like you're like "oh you can do 10% more each day". They're not going to be back running for two years, you know? I have to be a little bit realistic that for them a short run is 15Km.*	10% rule not generalisable.

PT4	*I mean, my understanding is 10% it's actually quite a, when it sort of first came out, because I'm that old, it was quite convenient because people could understand it. And especially if you're talking about a 10 to 12 week program and you've got two weeks unloading, then you've got 10 weeks of 10% loading and you get to 100%. So it, you know, and that's why it was said. There's absolutely no science behind it. But it's actually a very difficult thing to do if you just stick to it, because 10% of what? What are you talking about?"*	10% rule not generalisable
PT3	*and the old 10% rule again, I mean it's sort of vaguely there, but the problem is when you start off at such a low load, you start off at 2 minutes, I mean 10% progression is pretty painful, right?*	10% rule not generalisable.
SD1	*I use the 10% rule a bit. But again, it's quite individual.*	Can use 10% rule but quite individual
SD4	*So depending on how they are responding. This depends on what distance they're trying to build up to running and what type of runner they are. It will be different for everyone.*	Individual progression (not 10% rule).
PT4	*And on the whole, for the first six weeks I probably, If you are keeping good load data, we probably don't increase people much more than 5 or 6%, but at the end when that really stable, they might be increasing by 15%.*	Difficult to put a number/ % on progression