Title: Returning females to running following a tibial bone stress injury: The practices of experienced sports medicine clinicians in New Zealand.

Running Title: Return to running following a tibial BSI.

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Abstract:

Aim: This study aimed to explore different perspectives and practices of experienced sports medicine clinicians in New Zealand regarding how to return female athletes to running following low-risk tibial BSIs, as well as what they considered critical components of management.

Study design: Qualitative, semi-structured interviews.

Setting: New Zealand

Participants: Ten experienced sports medicine clinicians,

Interventions: Semi-structured interviews were completed with ten experienced sports medicine clinicians virtually via Microsoft Teams.

Outcome Measures: The development of a framework of treatment for female athletes following a tibial BSI via semi-structured interviews with experienced clinicians. The

perspectives and practices of experienced sports medicine clinicians were established using reflective thematic analysis.

Results: Three key themes were revealed. 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. A notable thread highlighted throughout was the importance of establishing a multi-disciplinary management approach, reflecting the many multifaceted nature of BSIs in female athletes.

Conclusion: This study highlights the need to move away from a 'one size fits all approach' and individualise the return to running process in female athletes following a tibial BSI.

Keywords: stress fracture, injury management, return to sport, bone healing, running injuries.

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 (1). There is a growing consensus BSIs occur due to an accumulation of load-induced microdamage that exceeds bone remodelling (2). BSI is a holistic term that encompasses low-grade stress reactions through to fractures of the bone (3).

Tibial bone stress injuries (BSIs) are common among female runners and have one of the highest recurrence rates of all running-related injuries (4, 5). Prior BSI has been shown to increase the recurrence rate by 5-6 times among female runners (4, 6). Relative energy deficiency in sport (REDs) results from a mismatch between energy intake and expenditure during exercise (7), and is more common among female athletes (8). REDs has a negative effect on menstrual function, bone health, and consequently BSI risk in female athletes (7, 9).

Following a tibial BSI, a critical component of complete rehabilitation is the successful return to running. Whilst a number of publications present generalised elements of return to running programmes (10-14), there is minimal evidence documenting the clinical reasoning and management from the perspective of experienced medical practitioners. Warden and

colleagues (2, 15) present a management protocol for non-specific BSIs, and a loading protocol specific to tibial and metatarsal BSIs. The authors propose a graduated walk-run progression, and highlight the importance of addressing contributing risk factors, including running biomechanics, muscle strength and endurance, training structure, running surface and footwear (2, 15). While not specific to BSIs, Hegedus et al. (16) propose a six-phase progression to guide the successful return to competitive distance running following lower extremity injury, progressively replacing cross-training with running increments. The importance of individualising the process, and monitoring physical and psychosocial measures were highlighted, however no sex-specific guidelines were provided. While collectively these publications provide a degree of clinical guidance, it is unknown whether clinicians are using these types of guidance.

It is possible that how experienced clinicians manage tibial BSIs differs from what is documented in empirical evidence. Additionally, it has been highlighted that in general there is a dearth of sports science research focused on females (17). 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.

The practice of evidence-based medicine means integrating individual clinical expertise with the best available external clinical evidence from systematic research (18). 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 sports medicine clinicians return female athletes to running following tibial BSIs, while determining critical components of management.

METHODS

This study followed a qualitative methodology thematically analysing semi-structured interviews with expert sports medicine clinicians. The three researchers involved in the analysis process are Physiotherapists, and the primary researcher is a female runner. While due care was taken at all stages to reduce bias, this will inevitability have influenced the creation of questions, interview interpretation and the analysis. This study was approved by the Auckland University of Technology Ethics Committee (#21/411).

Participants

Sports medicine clinicians (Physiotherapists, Sports Physicians, Physiologists) with at least five years' experience working with female runners with tibial BSIs in New Zealand 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 (19). Potential participants were identified through the authors' professional networks. Fourteen potential participants were approached between March and October 2022, and recruitment ceased when the target of 10 participants consented (20, 21). The research team regularly discussed the number of participants included in the study. When the 10 participants included in the manuscript had been interviewed, it was concluded that data saturation had been achieved as adequate data had been collected to draw conclusions.

Data collection

Semi-structured interviews of 45 to 65 minutes in duration were conducted by the primary researcher (EG). The interviews were completed virtually 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 adapted after piloting with an experienced Physiotherapist (Supplementary File A).

Interviews were transcribed by EG, and participants were offered the opportunity to check transcripts for accuracy.

Data analysis

A six-phase framework for reflexive thematic analysis was used for the data analysis (22) (Figure 1). An inductive, semantic and critical realist approach was used, focused on identifying and discussing the salient themes repeated across, and within, transcripts (22, 23). 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?

Relevant codes were developed, and the data were coded into broad themes by EG, in consultation with KS and DR, and in reference to the original transcripts. Themes and subthemes were then reviewed and refined by all authors. 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 that didn't align with their expertise.

(Insert Figure 1 here)

RESULTS

The ten participants included were clinicians working across a range of community and high-performance environments (Table 1).

(Insert Table 1 here)

Thematic analysis, using verbatim transcripts of the semi-structured interviews resulted in three key themes, and two or three sub-themes within each theme (Figure 2). Within the first theme 'Health and Wellness' clinicians emphasised the importance of addressing the 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 themes, and it was presented as an overarching message to emphasise the many facets raised that needed to be addressed as part of the comprehensive management of returning to running.

(Insert Figure 2 here)

Theme 1: Health and Wellness

Addressing factors contributing to the initial occurrence of the tibial BSI was a key consideration in successful management according to clinicians. Three subthemes were identified including assessing and addressing mechanical loading errors (sometimes referred to as training errors) and psychological health, as well as screening for issues potentially impacting bone healing (Figure 3).

(Insert Figure 3 here)

Subtheme 1: Assessing and addressing mechanical loading issues

As acknowledged by all clinicians, mechanical loading issues are often associated with BSI occurrence. A thorough review of an athlete's training history to identify any recent changes to running frequency, intensity, or distance was recognised as essential by all the Sports Doctors and three Physiotherapists. Three clinicians also identified the importance of reviewing the athlete's footwear. The importance of load management and adequate recovery between sessions were highlighted by PT4:

"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…" (PT4)

Potential mechanical loading issues should be highlighted, and education provided to prevent further injury when athletes are returned to their usual running training. Clinicians also

highlighted the importance of involving the athlete's coach, if applicable, to ensure lasting changes in training are achieved.

"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 whether there were and where there might have been any training errors, and how we could again try and prevent this from happening again." (SD2)

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 re-injury. Screening for factors potentially negatively influencing their health in the period prior to resuming running. Three Sports Doctors and one Physiotherapist also highlighted the importance of identifying vitamin D and calcium deficiencies due to the importance for overall bone health. A particular emphasis was placed on nutrition, especially where low energy availability is suspected. All clinicians emphasised the relationship between low energy availability and impaired bone health particularly in female athletes, and highlighted the critical importance of screening for REDs.

"All of the REDs 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." (PH1)

The relationship between REDs and menstrual disturbances, and consequently the importance of screening menstrual health to identify current or historical irregularities, was widely recognised.

"Often disclosure happens with us or we are the first person to ask a young female athlete if they are menstruating… 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… You can't have a tibial stress reaction on a young female athlete without asking that." (PT4)

To allow progression through the return to running process, eight clinicians recommended firstly ensuring athlete engagement in addressing REDs. Two Sports Doctors discussed the use of the REDs 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. The importance of an MDT approach to address the low energy availability underpinning REDs, was recognised by all clinicians.

"So we use the REDs contract... So it basically says if you haven't met these criteria, you know you shouldn't be going back to your running… it means you have all of those people working together." (SD4)

"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." (PT2)

Half of the clinicians (n=5) identified the importance of screening for previous BSIs due to the high recurrence rate and providing education to ensure the athlete's understanding of the need to optimise their health to prevent ongoing injuries.

"I guess the education to them around past history being their biggest risk factor for future injury, 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." (PT3)

Subtheme 3: Addressing psychological health

Being forced to take time off running due to injury can be difficult for some athletes, which can impact their psychological health, a point identified by most clinicians (n=8). 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 recovery or could have contributed to the initial injury. Finally, as noted by six clinicians, there was a need for referral to a

Clinical Psychologist if disordered eating or exercise addiction behaviours were identified.

"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." (SD4)

"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)

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 4).

(Insert Figure 4 here)

Subtheme 1: Clinical vs Radiological Bone Healing

Based on radiological evidence lagging behind physiological healing, nine clinicians indicated they relied on their judgement to guide their return to running decisions. They suggested that relying on imaging for low-risk BSIs could unnecessarily delay a return to running. However, four clinicians 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 were someone who is not doing well as we reload them, then that might be when we'd reimage."

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. 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.

"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 think about return to run." (PT3)

Palpation of the tibia is a key component of the objective assessment utilised by all clinicians, however there were conflicting opinions regarding the need for complete resolution of pain before the introduction of running loads, eight clinicians suggested the need for no bony tenderness, while two

suggested that bony tenderness can remain despite clinical healing, 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 not waiting for that to disappear before I say you can start running again because that'll be there, well can be there forever."

Subtheme 3: Load management

The final subtheme reflects the need for load management to ensure and promote bone healing. An initial off-loaded period of no additional loading above activities of daily living is important to allow healing and was recommended by most clinicians. The length of this period was rarely specified by clinicians, rather tailored to the individual and their injury.

"Criteria based return to sport is certainly number one but I think there's a time where we have to be aware that time based return is also important. That's not giving an overall time and saying in six weeks you're going back to sport, but that might be giving them an initial period of offloading whether they've got pain or no pain you know like no matter what they tell me." (PT3)

Whilst a period of no running is required, all clinicians described the importance of cross-training to maintain muscle strength, cardiovascular fitness, and positive mental health. PH1 highlights the importance of 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."

Cross-training can also be a method of progressively increasing the weight-bearing load through the tibia, ultimately promoting healing through bony regeneration.

"So in a good return to performance programme after about four weeks, we've got them up to full load, but it's not running." (PT4)

Clinicians prescribing the return to running progressions described progressively substituting cross-training with running increments as healing progresses. They highlighted that the purpose of the initial running increments is to build bone tolerance rather than fitness. Seven clinicians described the importance of including resistance training and progressing load with plyometric strengthening (n=6) to provide bone healing stimulus, and to prevent injury recurrence.

"I certainly would want some plyometrics in prior to their return to run… And then I would move from that to basic plyometrics to two leg or stride stance split lunges or something like that. Not your high-level tuck jumps and you know any of that sort of stuff, but

some of the other basic plyometrics absolutely I would want that in and I would look at that from a competency perspective as well as utilising that from a bone healing perspective. With a stress injury, I would tend to do that as a separate session. So I tend to do one in the morning and one in the evening for example. So they've got that split period of time in the day from a bony healing perspective." (PT3)

Theme 3: Functional rehabilitation

The final theme describes the important steps clinicians work through, and the progressive approach required to successfully return female athletes to running. The two sub-themes outline the tests clinicians use to ensure tissue capacity and movement competency and describe how clinicians provide guidance to progress female athletes from walking to their typical running training regime (Figure 5).

(Insert Figure 5 here)

Subtheme 1: Functional tests

As athletes return to running, they need to ensure they have good core and lower limb strength, as well as an adequate range of motion to accommodate the increased demands. 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. Clinicians acknowledged strength and biomechanical deficits could be a precursor to an athlete

developing the tibial BSI, but all highlighted 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 outlined some potential key tests to monitor for pain throughout the process:

"With your key tests, which are maybe like 10 hops, jumping on 2 feet for a minute, jump and land, are you getting any pain with those?" (PT2)

"So pain clearly as my number one and there may be other aspects that I'd consider like dorsiflexion range of motion for example… I'd want that as a sort of self-measure each day just to double check after they've done their running sessions they had no loss of dorsiflexion and no remaining loss the following day." (PT3)

While some clinicians (n=3) acknowledged that individual variation and the potential for athletes to adapt to their biomechanics, make it challenging to assess movement competency, there were screening tests that the majority of clinicians used. The single-leg squat was often referred to, where medial knee drift or pelvic drop could indicate poor gluteal control.

"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, so it's not an absolute..." (PT4)

All Physiotherapists and Sports Doctors highlighted the need to assess calf capacity, to ensure calf strength was optimised. This would begin with the calf raise technique, and the majority of clinicians (n=8) described progressing to single-leg hopping to assess advanced load tolerance, as described by SD4:

"Generally, their calf has been affected… so you gotta get the bulk first, 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."

When movement competency was optimised, and running-related loads were introduced, most clinicians (n=9) described analysing an athlete's running gait and biomechanics. Clinicians acknowledged it may be necessary to address muscle imbalances, biomechanical issues, and footwear issues if they are related to the onset of the tibial BSI, recognising the value of the MDT approach, involving Podiatry and Physiotherapy where required, as explained by SD1:

"So if there's a biomechanical problem, I often engage with the 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 my gait analysis that there are some significant muscle

imbalance issues, then I engage one of the running physios and they might do a programme which supports her rehabilitation."

Subtheme 2: Progressions

When treating females with tibial BSIs, all clinicians described a progressive increase in load to ensure a successful return to running. Multiple progressions were discussed, including running distance, intensity, and frequency, with progression rates guided by the athlete's end goal. Prior to introducing running-related loads, all clinicians described firstly building walking and daily activity tolerance. Although most clinicians (n=7) suggested different time-specific walking tolerances (ranging from 20 minutes to 1 hour), the consensus was that the period before running should be used to build load tolerance, which could also include walking on mixed terrains.

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 for each athlete.

A common recommendation among clinicians was to start athletes on flat, soft surfaces such as grass, treadmills, or soft paths. Five clinicians 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 described how the 10% rule has become embedded in clinical practice despite not being supported by any evidence, and she also highlighted the challenges with using it clinically:

"…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?"

Most 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 details 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…, because if any speed sessions are not part of their life, then I'm really not so worried about bringing in speed sessions." (PT3)

DISCUSSION

The aim of this study was to establish the process of how experienced sports medicine clinicians return female athletes to running following tibial BSIs, while determining critical components of management. 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. For the purposes of creating a practically useful outcome, the themes and subthemes identified have informed the development of 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. Management utilising a multi-disciplinary team is important with all components. The different components of the framework will have a different weighting for each individual, but it is essential each component is addressed.

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 REDs and psychological health, 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 (2, 11, 13, 15), interviewed clinicians specifically emphasised the importance of ensuring the athlete and coach were actively engaged in the management of REDs, and that the REDs risk assessment model (24) was used to guide progression. Due to the increased risk of REDs in female athletes (8), and the detrimental effect of REDs and menstrual irregularities on bone health (7, 9), this is a critical aspect when managing female athletes.

The psychosocial complexity related to injury and return to sport has gained increased recognition in recent times (16), and

while psychological readiness to return to sport has been highlighted as a key consideration in the return to sport consensus statement (25), this was not recognised in previous BSI return to running guidelines (2, 13, 15). Psychological issues, such as anxiety and depression, are particularly common in female athletes (26), and single sport athletes such as long-distance runners are at an increased risk (27). The clinicians interviewed further emphasised 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.

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, with some suggesting imaging was not necessary (11, 14, 28), and others taking the opposite stance (29-31). The clinicians interviewed provided clarity that, due to the limited sensitivity of radiographs (32), imaging was of limited clinical value, except in the case of high-risk BSIs. There were 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 (11, 12, 33), while others disagreed (2, 13). Previous guidelines

following lower extremity BSIs have identified the absence of pain both during, and following, activity as a primary indicator to guide progression through the return to running process (2, 13, 15). Similarly, all clinicians identified using symptom provocation during and following activity.

The use of functional testing to assess tissue capacity and movement competency has been advocated in the existing lower extremity injury (16), general BSI (2), and tibial BSI (13) 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 (34). 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.

Component 3 - Progression of load

The '10% rule' is widely cited as a method of progressing running distance and intensity following tibial BSIs (13, 15), however there is no empirical research validating this approach. The interviewed clinicians acknowledged the 10% rule, but all suggested that they adopted more individualised approaches to progression.

Progressing distance prior to speed has been recommended in recent guidelines for competitive runners (16), as well as in return to running programmes following lower extremity BSIs (2), with a specific direction that distance should be built to 50% of pre-injury levels, before interval speed sessions are introduced (16). While this guidance is not specific to tibial BSIs, it is supported by evidence from mechanical fatigue tests indicating that BSI risk increases more rapidly with progressions in speed than distance (35), as well as increased running speeds resulting in greater internal tibial loading (36). In this case, the approach of clinicians was consistent with the evidence, but once again they emphasised the importance of individualisation and tailoring progressions based on pre-injury training status, severity of the injury, and goals of the athlete. Return to competitive running guidelines have recommended monitoring 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 to guide progression (16). The importance of monitoring functional tests was also highlighted in the 2016 Consensus Statement on Return to Sport (25). Despite this, monitoring of functional tests has not been identified in previous guidelines following lower extremity BSIs (2, 13, 15). The Physiotherapists identified the importance of monitoring functional tests and objective measures throughout the process, to guide the

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.

Component 4 – Running surface

Differing surface recommendations have been provided in previous guidelines on returning to running following lower extremity BSIs, including beginning on a treadmill due to the more compliant surface (10, 37), and avoiding hard surfaces (2, 11, 12, 28), whilst other running programmes were prescribed on a running track (34, 38, 39). 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.

There is conflicting evidence in the literature regarding the influence of surface hardness on lower limb load (as measured by tibial acceleration). Running on harder running such as synthetic tracks and concrete has been shown in some studies to result in lower vertical tibial accelerations in comparison to softer surfaces such as on a woodchip trail (40) or a treadmill (41, 42). Contrasting these findings, running on grass on a level grade has been shown to result in higher tibial acceleration than

concrete (43). The importance of introducing the athlete's normal training surface was emphasized by the clinicians interviewed. This individualisation is logical as it is likely athletes will be adapted to their typical training surface. Rice et al. (2023) concluded that unfamiliarity with running conditions, such as running on an inclined surface compared to level running, may explain the increased tibial loading. Applying similar reasoning, familiarity with the 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.

Component 5: Risk reduction

With regard to running gait biomechanics, looking at control of the hip and the foot may be important to reduce stress on the tibia (44-46). Increasing running cadence has been shown to reduce the probability of a tibial BSI among cross-country runners, and among common measures of running mechanics, reduced cadence was determined to be the strongest biomechanics predictor of BSI (47). To prevent injury recurrence, assessing and addressing running gait biomechanics has been advocated in previous guidelines following tibial (13, 15) and lower-extremity BSIs (2). All clinicians highlighted that as the athlete is returning to running, running gait should be assessed for biomechanical faults that might identify

potential risks, and habits associated with inducing injury should be modified.

Despite the inconclusive evidence regarding the effects of hip strengthening on gait biomechanics (48, 49), clinicians also emphasised the importance of including pelvic, knee and ankle strengthening to address muscle imbalances and improve single-leg alignment. Several clinicians also identified the need to review footwear and consider orthotics. The only specific gait re-training interventions identified by clinicians were correcting overstriding or increasing cadence, consistent with the recommendations of Kliethermes et al. (2021). However, experienced clinicians acknowledged the challenges of assessment due to individual variation, and the potential for athletes to adapt to their biomechanics. This reflects the return to competitive running guidelines that also recognised that running biomechanics are highly nuanced and difficult to define (16). Future research assessing the influence of different biomechanical variables in an injured population would be beneficial.

Running produces relatively small impact loads and although the first few minutes of impact exercise stimulate bone formation, bone fatigues quickly (50). Therefore, the addition of resistance (51) and high-impact training (i.e. loads greater

than four times body weight) (52), such as jumping or hopping can be highly osteogenic and energy efficient in females, and therefore likely to be beneficial for improving bone health (53-57). 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 acknowledged accordingly. 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.

Multi-disciplinary team management

Previous guidelines following BSIs have acknowledged the need for an MDT approach to management (2, 16), a point that was strongly advocated for by all clinicians to address contributing factors and prevent injury recurrence. Potential members to be involved in the MDT included Physiotherapist, Podiatrist, Sports Physician, General Practitioner, Dietician, Psychologist, and Coach. The clinicians also recognised the importance of being aware of scope of practice. It was highlighted that while all components are essential to check off, and it is critical that the questions are asked, the influence and

importance of each component will be different for every individual. Factors that clinicians identified as particularly important in females, and where an MDT team is vital, were the presence of REDs, psychological and/or biomechanical factors. The members of the MDT team will be informed by where the individual sits in terms of the different components. For some females, certain components, and therefore certain disciplines, will be more important than others.

Clinical implications:

Based on the perspectives and practices of experienced sports medicine practitioners an infographic has been developed to outline the process of returning females to running following a tibial BSI (Figure 6). Relevant information has been consolidated into two main sections, firstly the preparation steps, followed by an outline of the process, for returning to running, acknowledging that there are areas of crossover between the phases.

(Insert figure 6 here)

Strengths and limitations:

This study provides valuable insights that inform future intervention design aimed at assessing return to running approaches in female athletes following a tibial BSI and challenges the current low evidence base. The inclusion of information directly from sports medicine clinicians from a

range of backgrounds provides a range of perspectives on managing the return to running, specific to female athletes, and the challenges of the current low evidence base. Despite this, several limitations are acknowledged. Bias may have been introduced because of the purposive sampling that was used to attain experienced clinicians. All participants were living and working in New Zealand, therefore elements specific to working in this environment may have played a role in the findings. As such, further research is needed to investigate the practices of experienced clinicians from other countries, and different ethnic backgrounds, involved in the management of tibial BSIs to provide guidelines that can be transferred across a wider context. 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 have been shown in the literature, such as increased empathic concerns in female clinicians (58, 59). Additionally, it would also be beneficial to interview female athletes regarding their experience with tibial BSIs, and what they deem important components of management.

CONCLUSION

When returning female athletes to running following a tibial BSI, their health should first be optimised, with nutritional

status, and psychological and hormonal health particularly important. The 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 that is often presented in the literature, and instead 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 including experienced clinicians worldwide, as well as the perspectives of female athletes themselves, is warranted to develop more transferable guidelines for the process of returning female athletes to running.

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Table 1: Participant demographics and experience

Identifier	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	10 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	8 years

FIGURES:

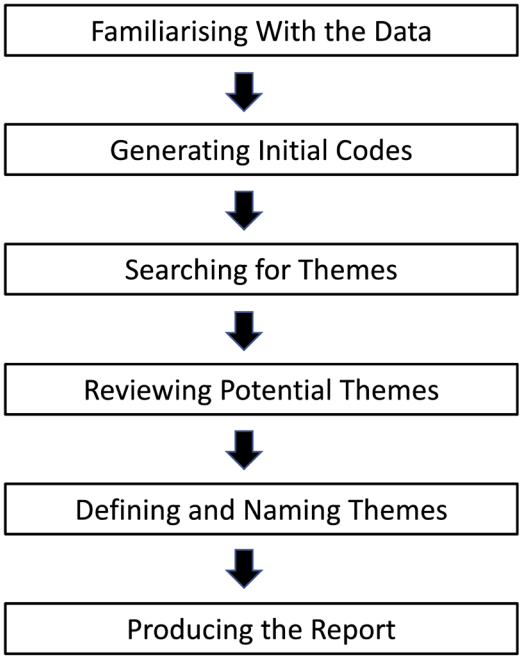

Figure 1: Thematic analysis six-phase framework

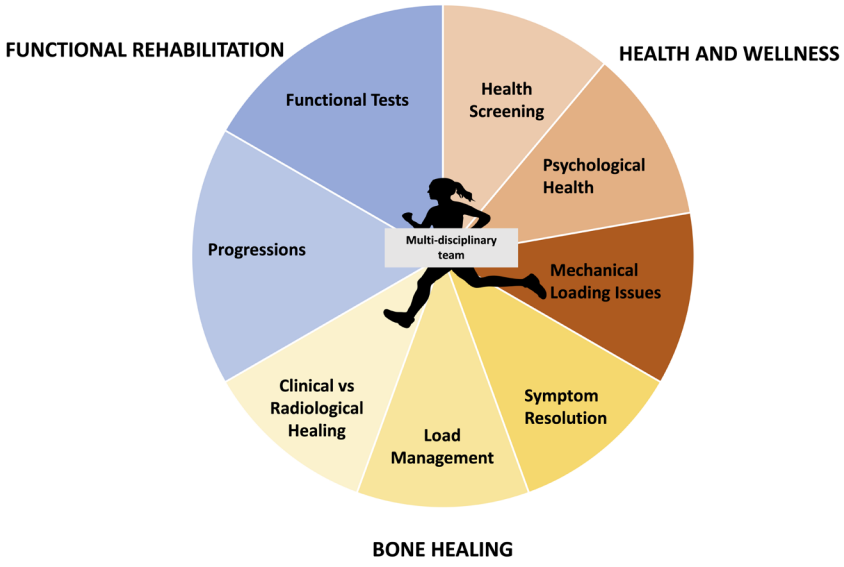

Figure 2: Themes and Subthemes

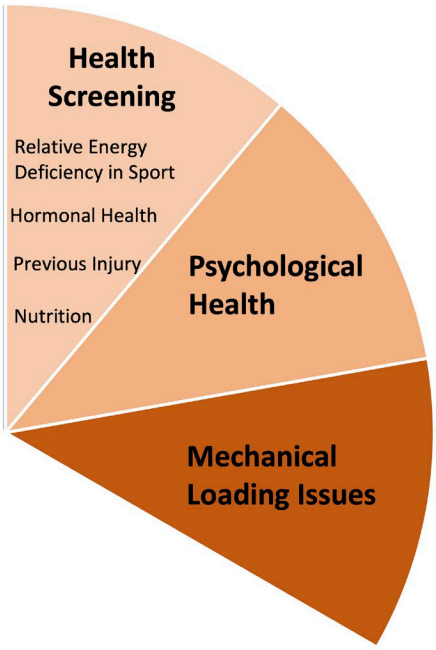

Figure 3: Health and Wellness Theme

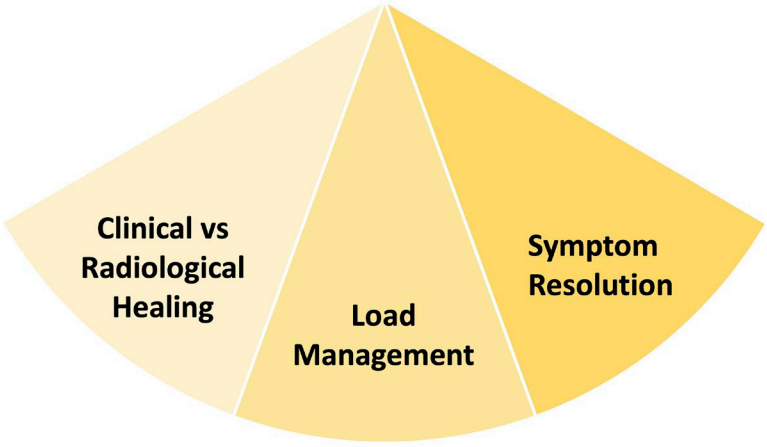

Figure 4: Bone healing theme

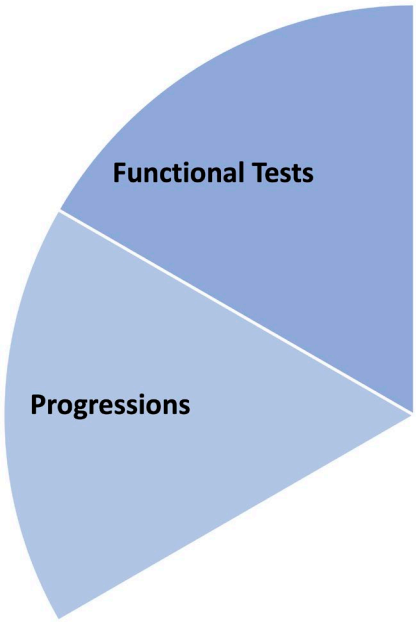

Figure 5: Functional rehabilitation theme

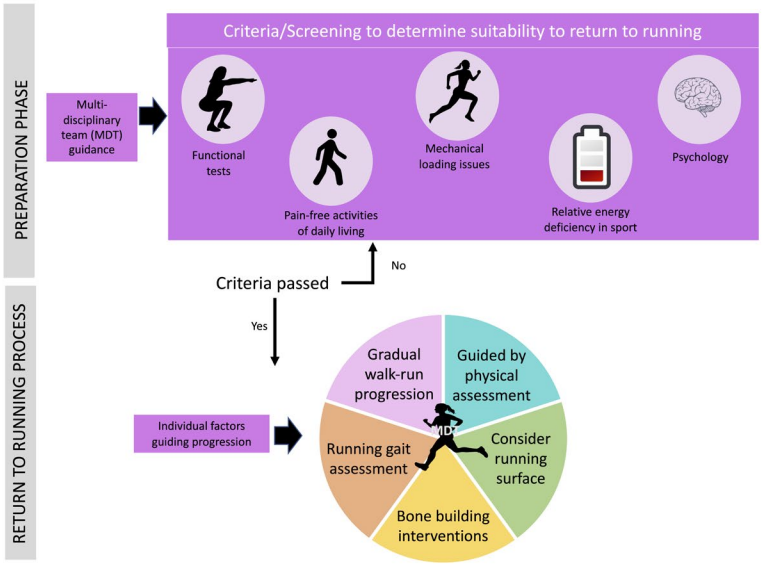

Figure 6: Preparation Phase and Return to Running Process

Supplementary File A: 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?