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Severe lower extremity trauma in Ontario: A linked population-based analysis

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Abstract

Open tibia fractures (OTF) are a management challenge. Admission to a trauma center (TC) and a coordinated approach to bony fixation and soft-tissue reconstruction (STR) have been shown to improve outcomes. The objective of this study was to describe patients who had OTF in Ontario and analyze their outcomes. Linked population data pertaining to patients who had OTF between the years 2009-2020 were examined. Demographic information, admission location, and management course were collected. 4240 patients were found. The mean age was 47, and majority were males. Patients admitted to TC had greater proportion of having Injury Severity Score >15, and associated neurovascular injuries. Patients in TC were more likely to undergo limb amputation, but also more likely to get STR with an average delay of 20 days. These findings provide a comprehensive examination of the clinical course for patients experiencing OTF in Ontario. Further analyses can help identify factors that may improve outcomes.

Keywords

Open tibia fracture, extremity fracture, soft tissue reconstruction, plastic and reconstructive surgery

Summary for Lay Audience

Major extremity traumas, such as open tibia fractures, are devastating injuries that often require multiple surgical specialties to work together for bony fixation and soft tissue repair. Open tibia fractures are associated with numerous complications including inadequate bony union, hardware exposure, infections, and even amputations. Some of these complications can affect patients life-long, causing significant physical, emotional, and financial distress.

Previous research has demonstrated that early transfer to a tertiary trauma center that have trained specialists and resources available for expedited bony fixation and soft tissue reconstruction results in improved outcomes. At this time, there has not been a large population-based study examining these patients in Ontario. We do not have specific information on the characteristics of the people who get open tibia fracture, and their management and outcomes. The objective of this current work was to: (1) describe those who had open tibia fracture within an 11-year period using a linked population-based data, (2) explore what types of hospital they were admitted, and (3) examine their management and outcomes.

We saw that over 4000 Ontario individuals were affected by open tibia fracture in the described period. They were young individuals in their 40s, who were mostly male. More than 30% of the population experienced infections, and 4.5% underwent amputation of the affected limb within 1 year of their injuries. Those with more severe injuries were admitted to a trauma center, and more likely to be consulted by a plastic surgeon for a soft tissue reconstructive surgery. However, there was up to 20-day time period in these individuals in getting a soft tissue reconstruction since their injury.

This study demonstrates the current management patterns of open tibia fractures in Ontario and the patient outcomes. The results serve as a foundation for many other studies that can examine specific factors that may help improve the outcome of patients with severe lower extremity traumas.

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List of Abbreviations

ANOVA	Analysis of Variance
ATLS	Advanced Trauma Life Support
CCHI	Canadian Classification of Health Interventions
CCI	Charlson Comorbidity Index
CDC	Centers for Disease Control and Prevention
CIHI	Canadian Institute of Health Information
CA	Census Agglomeration
CI	Confidence Interval
CMA	Census Metropolitan Area
CTF	Closed Tibia Fracture
DAD	Discharge Abstract Database
ED	Emergency Department
EMS	Emergency Medical Services
I&D	Irrigation and Debridement
ICD	International Classification of Diseases
ISS	Injury Severity Score
LHIN	Local Health Integration Network
LSI	Limb Salvage Index
MESS	Mangled Extremity Severity Score

MMP	Metalloproteinase
MVC	Motor Vehicle Collisions
NACRS	National Ambulatory Care Reporting System
NTC	Non Trauma Center
NVI	Neurovascular Injury
OHIP	Ontario Health Insurance Plan
OR	Odds Ratio
OTF	Open Tibia Fracture
OTR	Ontario Trauma Registry
PMMA	Polymethylmethacrylate
PVD	Peripheral Vascular Disease
QOL	Quality of Life
RPDB	Registered Persons Data Base
SAIL	Secure Anonymized Information Linkage
SD	Standard Deviation
StDi	Standardized Differences
STR	Soft Tissue Reconstruction
TC	Trauma Center

Chapter 1

1 Introduction

This introductory chapter focuses on describing open tibia fracture. It iterates the definition of open tibia fracture, its relevant anatomy, and its epidemiology. Current standards of management of open tibia fractures, including the initial trauma response, approaches to bony fixation, and various options for soft tissue reconstruction (STR) are discussed. Common complications of open tibia fracture are also reviewed. The rationale of this thesis and its objectives are described in this chapter.

1.1 Epidemiology of Open Tibia Fracture

Open tibia fracture (OTF) refers to tibia fracture accompanied by a defect in soft tissue, such as the skin, musculature, nerves and vessels. OTF significantly differs from closed tibia fractures (CTF) in its complexity in management, often requiring surgeries for bony fixation as well as re-establishment of soft tissue coverage.

Open fractures are not un-common, occurring at a rate of 30.7 per 100,000 persons per year (1). Tibia and fibula fractures make up 11.2% of these injuries, which is the highest among long bones, as majority of reported open fractures are that of phalanges (1, 2). The mean age of patients who sustain OTF is 43 years, and occur more commonly in males (3).

The most common cause of OTF is motor vehicle collisions (MVC), causing greater than 50% of OTFs in the developed world (3–5). Other common causes include fall from height, industrial accidents, and in rare cases, ski and snowboarding injuries (2, 6–8). Due to the high-energy mechanism of the fractures, up to 25% of tibia fractures are open (2), and are associated with other injuries with high injury severity score (ISS) (3).

1.2 Anatomy of the Leg

The following section summarizes leg anatomy, based on descriptions of Moore's Clinically Oriented Anatomy to provide context for this project (9). *Figure 1* highlights the key anatomical landmarks of the tibia and major arteries of the leg and provides context to the classifications and management of open tibia injuries.

1.2.1 Bony and Ligamentous Anatomy

The proximal end of the tibia has an important role in forming the knee joint. The wide, medial and lateral condyles of the tibia articulate with condyles of the femur to form the knee joint. The relatively flat surface formed by the condyles is referred to as the tibial plateau. In addition to the condyles, the knee joint is stabilized by key ligaments including the anterior and posterior cruciate ligaments, medial and lateral meniscus, and the medial and lateral collateral ligaments. The meniscus and cruciate ligaments attach to a prominent region called intercondylar eminence between the condyles, whereas the collateral ligaments reside outside the joint.

The tibial tuberosity refers to the proximal anterior edge of the tibia that serves as an attachment site for the patellar ligament, further stabilizing the leg. Patellar ligament holds the patella to the tibia and is attached to the quadriceps tendon, ultimately aiding in extension of the leg at the knee joint.

The proximal tibiofibular joint refers to the articulation between the tibia and fibula by the knee. The joint is designed for gliding of the fibula, allowing movement. This joint is stabilized by a joint capsule, as well as anterior and posterior superior tibiofibular ligaments, and lateral collateral ligament that connects femur and fibula. The distal tibiofibular joint in contrast is a fibrous joint, and does not participate in movement. The tibia and fibula are conjoined tightly by the anterior and posterior inferior tibiofibular ligaments, and the interosseous membrane that runs along the entire length between the tibia and fibula.

The shaft of the tibia is a long, vertical structure that does majority of weight bearing of the leg (10), and is divided into the medial, lateral, and posterior surface. The medial surface is quite superficial and is easily palpable. The posterior surface contains the nutrient foramen, which allows passage of the tibia nutrient artery that perfuses the inner cortex and medulla (11). The lateral surface is the attachment site to the interosseous membrane that connects the tibia and fibula.

Distally, the end of the tibia articulates with the talus to form the tibiotalar joint. This is a hinge joint that allows dorsiflexion and plantarflexion of the foot. The medial aspect of the tibia protrudes to form the medial malleolus that is palpable under the skin. Likewise, the distal end of the fibula forms the lateral malleolus.

The overall ankle joint is stabilized by multiple ligaments. Medially, the tibia and the talus, extend into the tarsal bones. These are held together by the deltoid ligament which consists of the tibionavicular, tibiocalcaneal, and the anterior and posterior tibiotalar portions which connect the respective bones. Laterally, the tibia, fibula, talus, and calcaneus are held together by the anterior and posterior talofibular ligaments, and the calcaneofibular ligament.

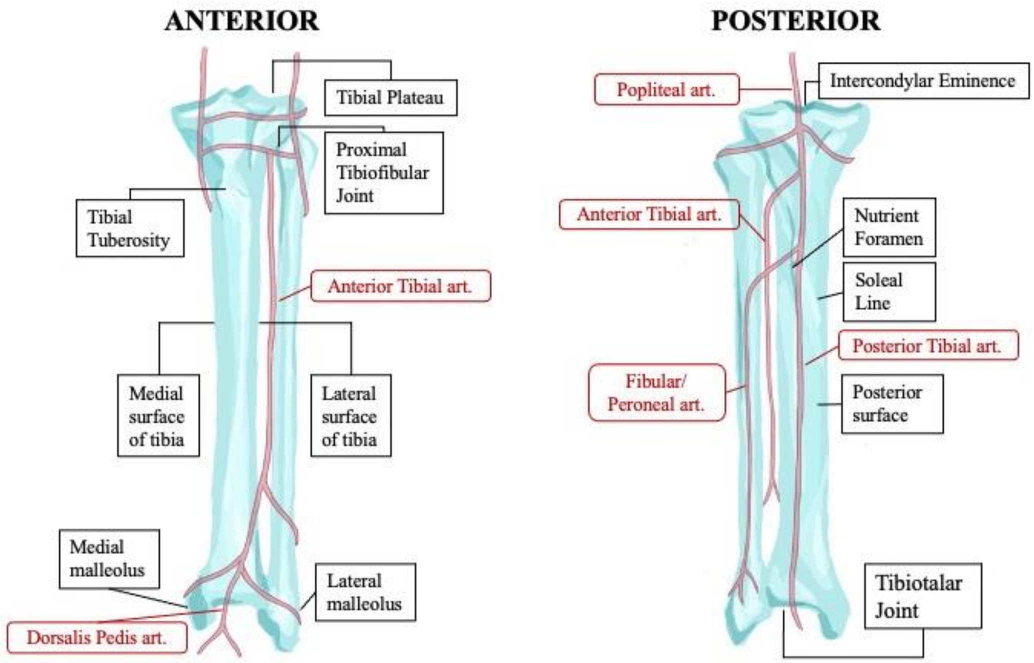

Figure 1. Simplified schematic of bones of the leg, tibia and fibula. Key anatomical landmarks and major arteries of the leg are depicted.

1.2.2 Anterior Compartment

The leg is divided into 3 compartments, separated by surfaces of tibia and fibula, interosseous membrane, and the anterior and posterior intermuscular septa. Each compartment has a distinct neurovascular supply and the muscles as a group have different function.

The anterior compartment is bordered by the interosseous membrane, the lateral surface of the tibia, and anterior intermuscular septum. It is innervated by the deep peroneal (fibular) nerve, a branch of the common peroneal nerve, and is vascularized by the anterior tibial artery and vein. Contrary to the motor nerve supply, the sensation of the overlying skin of the anterior leg and foot comes from the superficial peroneal nerve and the saphenous nerve. The tibialis anterior, extensor hallucis longus, extensor digitorum longus, fibularis tertius muscles reside in the anterior compartment and has role in dorsiflexion of the ankle, extension of the toes, and eversion and inversion of the foot.

1.2.3 Posterior Compartment

The posterior compartment is bordered by the interosseous membrane and the posterior intermuscular septum. The posterior compartment is further divided into deep and superficial layer, separated by the transverse intermuscular septum. The superficial layer houses the lateral and medial heads of the gastrocnemius muscle, which has important role in knee flexion and plantarflexion. The superficial layer also includes the soleus and plantaris, both aiding in plantarflexion. The gastrocnemius, soleus, and plantaris all insert as a conjoined tendon to the calcaneus, also known as the Achilles' tendon, the strongest tendon of the human body with crucial role in walking, running, and jumping (12).

The deep posterior compartment houses the tibialis posterior, flexor digitorum longus, flexor hallucis longus, and popliteus muscles, functioning in plantarflexion and flexion of the metatarsophalangeal joint and interphalangeal joints of the toes. The muscles of both compartments are innervated by the tibial nerve, and the main vascular supply comes from the posterior tibial artery. The skin is innervated by the medial sural cutaneous nerve and the saphenous nerve.

1.2.4 Lateral Compartment

The lateral compartment of the leg is bordered by the anterior and posterior intermuscular septum. It is innervated by the superficial peroneal nerve and vascularized by branches of the anterior tibial artery and fibular artery (13). Only 2 muscles make up this compartment, the fibularis longus and brevis, and aids in foot eversion. The sensation to this area is provided by the superficial peroneal nerve and the sural nerve.

1.3 Classification of Open Tibia Fractures

1.3.1 General Terminologies

Tibia fractures are broadly discussed according to the fracture's location along the tibia. For instance, proximal tibia fractures include tibia plateau fractures, which are intra-articular fractures commonly associated with ligamentous injuries. Due to involvement of the knee joint, open tibia plateau fractures require operative management for thorough irrigation, and restoration of the articular surface anatomy (14).

Tibia shaft fractures refer to fractures of the middle portion, or the diaphysis, of tibia. Depending on the amount and direction of the force applied to the bone, shaft fracture pattern varies widely from spiral to severely comminuted. The diaphysis of the tibia lacks sufficient soft tissue coverage on the anteromedial portion of the leg, resulting in many associated fractures to be open (15).

Distal tibia fractures generally refers to that of the diaphysis and the medial malleolus, but often the lateral malleolus as well (16). Fractures of these regions most commonly results from high-energy rotational force and/or axial loading. High-energy axial compression results in the tibia driven vertically into the talus, resulting in severely comminuted intra-articular injuries with significant soft tissue injury, a significant management challenge. These are referred to as plafond or pilon fractures, taking its name from the French word for "pestle" (16).

1.3.2 Gustilo-Anderson

Another common way to categorize tibia fractures is according to the associated soft tissue injury. One of the most used classification for OTF is the Gustilo-Anderson system, developed by Gustilo and Anderson in 1976. While this was a retrospective review of 673 open fractures, it also followed 350 open fractures prospectively. Their outcomes including infection rates were examined, categorized by the severity of soft tissue injury (17).

The classification overall aimed to give some prognostication to different degrees of acute traumas. It divides open fractures into 3 grades depending on the degree of soft tissue injury. Grade I refers to fractures with less than 1cm defect in the soft tissue. Grade II fractures have soft tissue defect of 1 to 10 cm in length, and Grade III fractures have greater than 10 cm of soft tissue defect. Grade III injuries are further divided into A, B, and C. IIIA fractures are injuries that have with >10cm soft tissue defect, but there's enough tissue locally for bony coverage. IIIB injuries involve periosteum and extensive soft tissue loss that likely necessitates a flap-based reconstruction, and IIIC involves vascular injury (18).

1.3.3 Assessment of Limb Salvage

Other classifications of OTF have been designed to assess the likelihood of whether the limb is salvageable or if amputation is indicated. The Mangled Extremity Severity Score (MESS) is a commonly used rating system based on the severity of injury, duration of limb ischemia, age, and presence of shock (19). Depending on the severity of the individual variables, numerical points are assigned and added, and a score greater than or equal to 7 has been associated with increased risk of amputation (19, 20). More recent literature however, suggest that the MESS system is less reliable in modern times, and has variable predictability of limb salvage (21). For instance, studies that looked at specific populations such as the pediatric population (22), and combat military population (23) showed inconsistent positive predictive value of MESS in limb survival. Overall, since the initial conception, the changes in management pattern and more advanced resources are thought to have made MESS a less effective tool in predicting limb survival versus need for amputation (24).

Limb Salvage Index (LSI) is another system developed to predict limb salvage versus amputation. Similar to MESS, LSI evaluates the degree of injury to the artery, vein, nerve, bone, skin, muscle, and ischemia time of the leg. Total score greater than 6 has been shown to be predictive of limb amputation (25). LSI has demonstrated good predictability in large cohorts of patients in multiple studies, with sensitivity and specificity of 82 to 83% (21, 26, 27).

1.3.4 Other Ways of Classifying Open Tibia Fractures

Other classification systems of OTF include those based on fracture patterns observed in radiographs, instead of soft tissue defect (28). The Muller AO system published in 1987 (1990 in English) categorized injuries based on the anatomical location and the fracture type (29). This was then later unified with the Orthopedic Trauma Association classification to give the AO/OTA system (30), and further updated in 2007 (31) and 2018 (32). The AO/OTA classification divides tibia fractures into those of proximal and distal. These proximal and distal fractures are then further classified into 9 different types based on the fracture pattern. The classification aimed to have standardized and reproducible clinical information for communication between providers, and also to follow patient outcome in each type of fracture (32).

The Schatzker classification system is another commonly used classification system for tibia fractures for assessing management and predicting outcome. It divides tibia plateau fractures into 6 different types based on location and fracture pattern. This system is however, limited to tibial plateau and does not take soft tissue injury into consideration (33).

1.4 Management of Open Tibia Fractures

1.4.1 Closed tibia fractures

Closed tibia fractures can be managed non-operatively or operatively depending on the severity of injury and stability of the injury. Nonoperative management, or cast immobilization, results in satisfactory outcomes with low-energy fractures with minimal rotation and shortening (34, 35). However, in general, operative management with intra-medullary nail has shown better outcomes such as increased union and improved daily function (36, 37).

1.4.2 Initial management of open tibia fractures

OTF are managed with similar principles, but often more complicated due to associated soft tissue injuries. It involves multiple surgeries by more than one surgical discipline in a coordinated manner for prompt fixation and reconstruction, and eventual rehabilitation involving allied professionals (38, 39).

The majority of patients with OTF have other injuries, due to high-energy mechanisms such as motor vehicle collision. Thus, the management of OTF follows Advanced Trauma Life Support (ATLS) principles, ensuring secure airway and general hemodynamic stability. It may also involve direct pressure over the open wound or tourniquet application to the leg, or even ligation of a bleeding vessel as needed for hemostasis (40).

Blood work, such as complete blood count and creatinine, group and screen should be completed for open wounds in preparation for transfusions, and activation of massive transfusion protocol may be necessary depending on the severity of the injury. After the initial stabilization of the patient, the rest of the extremity exam, such as viability of the limb is assessed (41). Concomitantly, presence of any increased compartment pressures should be ruled out at this time as OTF have high risk of compartment syndrome, potentially a limb threatening condition (42).

Patients require medications including analgesia, tetanus toxoid if not up to date, and prophylactic antibiotics. Antibiotic choice heavily depends on the mechanism and location of the injury. Broad spectrum antibiotics such as cefazolin or piperacillin-tazobactam is routinely administered for most open injuries (43). Local antibiotic therapy, such as antibiotic beads made of antibiotics and polymethylmethacrylate (PMMA) can additionally be placed in the wound to reduce the risk of infection from 12 to 3.7% in some extensive injuries (44).

1.4.3 Limb Salvage versus Amputation

Deciding limb amputation versus salvage for mangled extremity injury remains a challenging question for clinicians. This decision impacts the total number of surgeries required, the length of in-hospital treatment and ultimately patient’s day-to-day function, and return to society (45). The literature regarding the outcome of patients who undergo limb amputation or salvage is further discussed in later sections.

The current available guidelines for determining limb salvageability includes the classification systems mentioned in Chapter 1. 3. 3, such as the MESS and LSI. Although these had excellent predictability of limb survival at the time of publication, over the years with improved care and medical technology, they are now thought to be less accurate (21). The general predicters of non-salvageable limb remain unchanged however, such as concomitant vascular injury, segmental injury, and prolonged limb ischemia time greater than 6 hours (46). Another factor to consider in lower limb amputation for mangled lower extremity injury is transection of the posterior tibial nerve, as posterior tibial nerve provides sensation to the sole of the foot and plays role in plantarflexion, as lack of is associated with poor functional outcomes (46). However, recent studies have suggested that initial symptoms that may suggest nerve damage, such as numbness of sole, may not be the most reliable prognostic factor in determining amputation, as many patients’ function improve over time (47, 48).

Due to lack of definitive guidelines, limb salvageability is now decided at the providers' discretion considering patient's clinical status, such as comorbidities and other injuries. If applicable, the pros and cons of each option, and the prognosis should be explained in detail to the patient and their family, and a careful conjoined decision needs to be made (49, 50).

1.4.4 Stabilizing the Fracture

All OTF are taken to the operating room initially for irrigation and debridement (I&D) of the wound. This is a key step to reduce risk of infection, and entails debridement of any contaminants such as dirt, as well as non-viable tissue such as devitalized muscle and skin. I&D within 6 hours of injury was recommended back in 1898, timeframe thought to come from guinea-pig based studies where the animals had reduced infection rate when I&D was completed within 6 hours (51). Recent studies comparing the infection rates of patients have shown no significant differences whether the debridement is done in less than or after 6 hours of injury (52–55). Instead, the current recommendations for timing of I&D is within 24 hours of the injury (41).

Thorough I&D is followed by bony fixation. Often with heavy contamination and potential need for further debridement, temporary external fixation is considered until definitive internal fixation (41). In addition to its function as a temporary immobilization, external fixation is thought to provide advantages such as low risk of hardware-associated infection as the hardware is not placed within the wound (56), and reduced soft tissue injury since it avoids dissection around the bone compared to internal fixation techniques (57).

While external fixation has shown good outcome in patients with complex OTF, particularly for minimizing further soft tissue injury, its advantage over internal fixation is not consistent in the literature (57–59). In a meta-analysis comparing patient outcome between internal fixation and external fixation of OTF, external fixation was associated with increased incidence of malunion and superficial infection, but had decreased incidence of unplanned hardware removal, such as secondary to osteomyelitis (60). Another meta-analysis comparing external fixation to unreamed intramedullary nails showed increased rates of malunion in the external fixation group, with no differences in infection (61).

The most commonly used method of definitive fixation of OTF is intramedullary nailing (41). Reamed nails are thought to improve stabilization due to the increased diameter (62), but have disadvantages such as potential endosteal stripping and thinning cortical bone (61, 62). Multiple studies comparing patient outcome of reamed versus unreamed intramedullary nails on OTF have not shown significant differences in infection or need for revision surgeries (63–65). At this time, literature suggests case-by-case decision on which type of nail is to be used (41).

Plates and screws are not used as frequently in reducing OTF, as they have been thought to increase risk of complications due to the loss of periosteal blood supply in the context of soft tissue injury (66, 67). Recent studies have suggested however, that it can be a suitable option for many OTF with comparable rates of infection to intramedullary nailing (67, 68), especially when accompanied by early STR (38, 67), and minimally invasive plating techniques are used (69–71).

1.5 Soft Tissue Reconstruction

Soft tissue coverage over fractured site is essential. It restores vascularity, stability, provides coverage for vital structures such as nerves and vessels, and obliterates dead space. In this section, the general approach to lower limb STR in the perspective of plastic and reconstructive surgery is discussed. Different options for STR depending on anatomical site are also discussed, while minimizing donor site morbidity and providing reasonably aesthetic result (72–74).

1.5.1 The Reconstructive Elevator

Figure 2. Reconstructive elevator is used as guide for choosing different reconstructive options available for managing open tibia fracture

The STR of lower extremity injury follows the principles of any other open wound, the reconstructive ladder. It is referred to as the ladder, as with each higher level, it becomes more invasive and complex. The ladder is also referred to as the elevator, depicted in *Figure 2*, as surgeons often flexibly choose different options wherever on the level for desired outcome rather than taking stepwise approach. This section will explore the different levels of the elevator, including skin graft, local and regional flaps, and free flaps pertaining to lower limb trauma.

The bottom of the elevator is healing by secondary intention. While this is a commonly used for superficial wounds, it is not used in the setting of open extremity fractures due to the risk of infection and suboptimal coverage of exposed bone and hardware. Primary closure is completed for small injuries that have sufficient skin and soft tissue to cover bone. Locally based random pattern flaps, such as advancement or rotation can also be done, but may be limited in the setting of trauma where the general integrity of local soft tissue may be compromised.

The use of skin graft *only* in STR of open extremity injury is less frequent, and useful when there is ample amount of subcutaneous tissue remaining after debridement (75). Skin grafts require a bed of well-vascularized tissue such as fat or muscle, without exposed vessel and nerve. They cannot be placed on top of bone without periosteum, or tendon without peritenon, which are often removed during debridement, as well as internal fixation of fractures (76). These factors therefore limit the use of skin grafts over injured tibia, where there is not a lot of soft tissue over the bone. In recent literature, skin grafts have also been used along acellular dermal matrix substitutes to provide more reliable skin coverage in open leg wounds, but the results have been relatively poor in cases of exposed tendons and bones (77). More commonly, skin grafts are used in conjunction with muscle flaps for coverage in the setting of OTF (75, 78), or in post-fasciotomy wounds resulting from compartment syndrome (79).

Flaps, in general, refer to a portion of soft tissue containing skin, fat, or muscle that can be mobilized with its own blood supply to cover a defect. This is contrasting to grafts, which is vascularized by the recipient vascular bed until new blood vessels form. Flaps of different types are more commonly used to cover exposed vessels, nerves, and foreign bodies such as plates and screws, as they provide bulk and reliable coverage. Flaps can be classified into different types based on the pattern of the blood supply. Most basic type of flaps are random pattern flaps, which are based on local subdermal plexus. The size of such flaps are limited due to the constraints of blood supply and availability of surrounding tissue, thus they can only be used for small wounds (80).

For a more robust coverage of soft tissue injury in lower extremity trauma, muscle is used with or without skin, known as myocutaneous or muscle flaps. Muscle flaps have rich blood supply, allowing reliable soft tissue coverage of large areas, but also help suppress bacterial growth, and promote bony union (74). Regional flap utilizes tissue that is nearby, but not necessarily directly adjacent to the defect. Regional muscle and myocutaneous flaps, such as the medial and lateral gastrocnemius are considered workhorse flaps, and are relatively simple procedures that do not require specialized equipment or techniques. Free flaps in contrast, involve harvest of tissue from a distant part of the body and microsurgical revascularization with local artery and vein. Some of the examples of flaps that are commonly used in leg STR and their classification are summarized in **Table 1**.

Table 1. Common muscle flaps used in lower limb reconstruction.

Flap	**Dominant pedicle(s)**	**Type**	**Mathes and Nahai**	**Use**
Medial Gastrocnemius	Medial sural artery	Regional	Type 1	Proximal, middle, and distal thirds of tibia
Lateral Gastrocnemius	Lateral sural artery	Regional	Type I	Proximal and middle thirds of tibia
Soleus	Posterior tibial artery, Peroneal artery	Regional	Type II	Proximal, middle, distal thirds of tibia (reverse)
Gracilis	Descending branch of the medial femoral circumflex	Free	Type II	Any soft tissue defect (ex. Distal third)

Latissimus dorsi	Thoracodorsal artery, Posterior intercostal artery, Lumbar artery	Free	Type V	Any soft tissue defect (ex. Distal third)
Rectus abdominis	Superior epigastric artery, Inferior epigastric artery	Free	Type III	Any soft tissue defect (ex. Distal third)

More recently, flaps consisting of skin and subcutaneous tissue without muscle are popularly used for coverage of open extremity trauma. While these do not provide as much bulk as muscle-containing flaps, the surgery is thought to be simpler, result in less donor site morbidity, and the thinner tissue is more pliable for flexible wound coverage (74, 81).

These muscle-sparing flaps include fasciocutaneous flaps that consist of the skin, subcutaneous fat, and the underlying fascia. These flaps are supplied by multiple layers of vascular plexuses including the suprafascial, intrafascial, and subfascial plexuses (82). Perforator flaps in contrast, do not include the fascia, and is reliant on the subdermal and subcutaneous plexuses (83). These flaps are vascularized by vessels that perforate through underlying muscles (musculocutaneous), or travel between muscles (septocutaneous), or travel directly to the skin (direct cutaneous), and supply various vascular branches at different levels of tissue (83). Some of the frequently used perforator flaps for lower limb reconstruction, their location and use are summarized in **Table 2**.

Table 2. Frequently used perforator flaps in lower extremity reconstruction

Flap Pedicle	Branch of	Course to skin	Perforator Location	Use
Saphenous artery perforator	Descending genicular artery	Through or between the sartorius muscle and vastus medialis	Medial thigh ~12 cm knee (84)	Proximal leg
Sural artery perforator	Popliteal trunk	Through the medial gastrocnemius muscle	Medial leg ~8 cm from popliteal crease (85)	Proximal leg
Anterior tibial artery perforator	Anterior tibial artery	First: Travel either through tibialis anterior, or between tibialis anterior and extensor hallucis longus Second: through the anteromedial septum between peroneus tertius and brevis (80)	Mid anterior leg	Middle leg
Posterior tibial artery perforators	Posterior tibial artery	Travel between soleus and flexor digitorum longus	Mid posterior leg	Middle leg
Peroneal artery perforators	Peroneal artery	Through posterolateral septum between peroneus longus and soleus (80)	Lateral leg	Distal leg
Descending branch of the lateral circumflex	Profunda femoris	Between vastus lateralis and rectus femoris (86)	Lateral thigh (free flap)	Distal leg

1.5.2 Proximal Leg Defect

Along the length of the tibia, different local and free flap options are preferred for soft tissue coverage. For the proximal one third of the tibia, medial and lateral gastrocnemius pedicled muscle, or myocutaneous flaps are commonly utilized options due to the proximity and the bulk that they provide (87, 88). Some thigh based muscle flaps can also be used if the defect is close to the knee, such as the vastus lateralis, and the short head of biceps (89). For smaller defects, portion of the tibialis anterior can be used (90). If muscle sparing flaps are preferred, fasciocutaneous flap based on the perforators of the saphenous artery, or sural artery can be utilized for more superficial defects (85, 89, 91).

1.5.3 Middle Leg Defect

Similar to the proximal third of the leg, regional pedicled muscle flaps from gastrocnemius and soleus are workhorses for STR in the middle third of tibia (73). Soleus can be split into medial or lateral halves, which reduces donor site morbidity, and also makes the muscle more malleable to work with (92, 93). Other smaller muscle flaps that could be utilized in the middle third include flexor digitorum longus (94, 95), extensor digitorum brevis (96), and tibialis anterior muscle (90, 97). Because of the size of the muscles, these are ideal for supplementing larger flaps, or filling small defects. Fasciocutaneous and perforator flaps based of the regional vessels can again be used in ways such as V-Y advancement, and local transposition (72, 98, 99).

1.5.4 Distal Leg Defect

The distal third of the leg is particularly challenging as it does not contain adequate muscle bulk relative to the rest of the tibia, thus limited options exist for regional reconstruction (72). In some occasions, soleus muscle can reach to cover distal defects (100, 101). Use of distally based reverse soleus flap, supplied by the perforators of posterior tibial arteries, has also been previously described for distal third of leg (102–104). Defects at the lateral aspect can be covered with muscles of the lateral compartment, such as peroneus brevis (105, 106). Small, thin defects on the medial aspect can also be covered with reverse sural or reverse saphenous flap (107). In other occasions, skin flaps based on perforators of the posterior tibial and peroneal artery is rotated 180 degrees like a propeller, referred to as “propeller flap,” to reach distally located defects (72, 108).

Due to the limited local options, free flaps are often utilized for soft tissue coverage of the distal leg. These include muscle flaps from the thigh, such as the gracilis, and perforator flaps like the anterolateral thigh (72). Latissimus dorsi, rectus abdominus, and scapular flap are alternative options for reconstruction if thigh tissue cannot be used (109). These options provide reliable muscle bulk, but can have significant donor site morbidities. For instance, gracilis harvest leaves minimal morbidity, whereas rectus abdominis flap can leave a significant defect in 1 of the core muscles (110, 111). The different muscle and perforator flap options that could be used for the proximal, middle, and distal aspects of the leg is summarized in *Figure 3*.

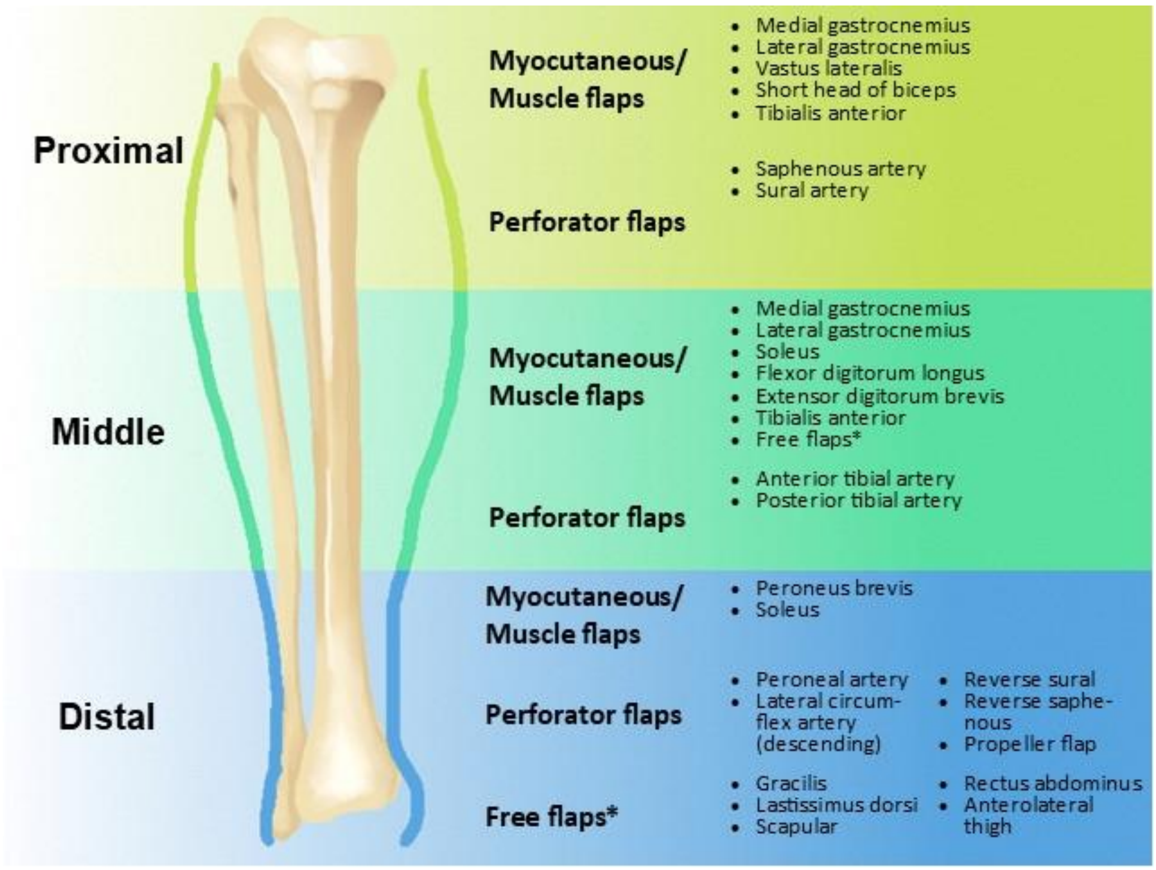

Figure 3. Schematic of the different reconstructive options of the lower limb.

1.5.5 Bone Defects

In occasions where there is a loss of bone segments, non-vascularized or vascularized bone graft is used to provide stability and preserve length. Smaller bone defects less than 5-6 cm can utilize non-vascularized bone grafts in presence of reliable vascularized soft tissue (112–114). Larger bone defects requires vascularized bone grafts, such as fibula, iliac crest, or scapula, some of which are done in conjunction with soft tissue transfer (114–117). Bone grafting can occur in two stages, known as the Masquelet technique, in which polymethylmethacrylate (PMMA) cement impregnated with antibiotics is used as a temporary spacer, followed by the autologous bone grafting in 4 to 6 week period (118).

In larger defects when bone grafts are insufficient to fill the gap, distraction osteogenesis, referred to as the Ilizarov technique, is used. The technique utilizes the ability of bone to form new bone when segmental traction is applied. Distraction osteogenesis for OTF generally result in greater than 90% union rate, but the time to osteogenesis and complications such as physical and psychological stress, and the risk of re-fracture are some of its disadvantages (119).

1.5.6 Negative Pressure Wound Therapy

Negative Pressure Wound Therapy (NPWT) became popular in the 1990s and has significantly changed the management of open traumatic wounds (120). NPWT works by sealing an open wound with polyurethane foam dressing and plastic film, and applying a consistent negative pressure over the wound. Different brands of NPWT have different combinations of sponge structure, suction catheter, and pressure settings, but they all work in similar mechanism (121). The NPWT is thought to be beneficial for open wounds for various mechanisms, such as by keeping the wound moist, reducing edema, and by removing wound exudate (121, 122). Wound exudate includes large amounts of immunoglobulins, electrolytes and proteins (123), which include metalloproteinases (MMP) (124). MMPs, while critical in tissue remodeling, can also be detrimental to wounds in high quantities as it can degrade the extracellular matrix (121).

NPWT is used for open fractures in different stages of surgical intervention, but most importantly as a bridge between debridement and soft tissue coverage. It functions to keep the wound covered, keeping it moist and clean to reduce the risk of infection, until definitive STR is completed (120, 125). NPWT is also thought to be useful to promote secondary wound healing by promoting cell division and angiogenesis (126), and minimize further soft tissue damage (120), and even decrease the likelihood of requiring STR, although this may be inconsistent (127–129) .

There is evidence that use of NPWT decreases the risk of infection in open fracture wounds. Park et al saw that patients with Gustilo-Anderson Grade III fractures who initially had I&D within 24 hours of injury and external fixation, followed by NPWT for up to 2 weeks until definitive intramedullary fixation and STR, had decreased incidence of infection, and the need for free flap surgeries due to smaller wound size over time (130). Study by Stannard et al also showed reduced risk of infection in NPWT group compared to those who had standard dressing (125). A systematic review by Liu et al further demonstrated the role of NPWT in reducing risk of infection in open fractures. With such advantages, NPWT overall is considered to have significantly changed the management of open fractures and the approach to STR in modern era (129).

1.6 Complications of Open Tibia Fracture

1.6.1 Infection

One of the key reasons why OTF is so difficult to manage for clinicians is the high rate of complications, especially infection. Gustilo and Anderson, in their original publication in 1976 describing open fractures of the long bone, described dramatically increased rate of infection with increasing complexity of the fracture. For instance, Grade II fractures had infection rate of 2.4%, whereas Grade III fractures had infection rate of 44% (17). Recent literature shows a wide range of infection rates for Grade III tibia fractures. For superficial infections such as skin and subcutaneous tissue, infection rate ranged from 6% to 9% and deep infection rate of 8.5% to 9% (38, 131). Other studies reported general infection rate that ranged from 11% to 34.3% (4, 7, 132, 133), but amputation as a result of serious infections is reported less than 10% in the literature (134, 135).

Many studies have aimed to look at factors that may affect infection rates of OTF. These include time of injury to I&D, and the type of internal fixation used (Section 1.4), usage of NPWT (Section 1.5), and the timing of soft tissue coverage (Chapter 2).

1.6.2 Bony Union

Tibia fractures can take up to 20 weeks to achieve bony union (136), but in OTF, nonunion and malunion tend to occur in high incidences (137, 138). It is thought that the high-energy mechanisms that result in the soft tissue injury further damages the regional smaller vessels, resulting in poor wound healing capacity (137).

Nonunion of bones occur when the fragments do not form a stable conjoined piece at 9 month mark (139). Malunion refers to when a bone goes through callus formation and mineralization, but do not join in the anatomical position for optimal function as a result of imperfect alignment at the time of reduction or post-operative change in position.

Finally, delayed union refers to when bones don’t join in the usual anticipated time frame (140).

Nonunion rates of OTF after salvage and STR has been reported as 15.5% in a systematic review by Saddawi-Konefka in 2008 that looked at 26 observational papers studying this population (49). This is high compared to the nonunion rates of 4.9 to 10% for fractures in general (141, 142). The study also reported delayed union of up to 10 months for patients who underwent limb salvage attempt. Newer studies have again demonstrated prolonged time to union, with average of 8.5 to 10 months (4, 7). In a retrospective study by Dickson et al, the nonunion and delayed union rates were as high as 46%, and tended to be associated with an arterial injury (137).

Malunion rates are also high in OTF, although this appears more prevalent in external fixation group. Giannoudis et al, in their literature review, reported malunion rates of 20% in fractures managed with external fixation only, 11% in those who later had internal fixation, and 4% in those who had early definitive fixation (61). More recent studies have shown similar malunion rates of 10.8% in only those whose fractures were internally fixated (143), and 13% in a systematic review by Bhandari et al that analyzed patients who had either external and internal fixation (64).

Issues with bony union results in need for a re-operation, which exposes individuals to many other risks associated with the surgical procedure and delays the healing process (144). Not only do these create a high burden of cost for the health care system, they also cause economic burden to the patients as well, due to prolonged hospital stay and delayed return to work (145, 146).

1.6.3 Compartment Syndrome

Tibia fractures, both open and closed, have high risk of compartment syndrome. The incidence of acute compartment syndrome in OTF is reported 8~9% in the literature (147, 148). Risk factors for compartment syndrome following include young age, diaphyseal fracture, and high-energy fractures (42, 148, 149). While prompt release of the compartment can result in good outcome for patients, delays can cause irreversible muscle and neurological damage, as well as delay in bony union (150, 151).

The treatment for compartment syndrome is fasciotomy, which comes with its own risks and morbidities. Fasciotomy, as the name suggests, entails making a longitudinal incision in the fascia to release the elevated pressures of the compartments. Typically, 2 incisions on either side of the leg are used to release all 4 compartments of the leg. The lateral incision, which is made 1 fingerbreadth anterior to the fibula, is used to release both the anterior and lateral compartments. The medial incision is made 1 fingerbreadth posterior to the palpable edge of the tibia, and is used to release both the deep and superficial posterior compartments (152).

While fasciotomy is completed to avoid permanent functional disabilities (149), fasciotomy itself is also accompanied by serious morbidity risks including injuries to the lesser saphenous vein, and peroneal nerves, and infections from the open wound (152). Due to the significant swelling and retraction of the skin edges, open fasciotomy wounds can be challenging to manage. Wounds can be left to heal secondarily, brought gradually together by shoelace technique or NPWT, or split thickness skin graft are used to close the wound (152–154).

1.7 Quality of Life of Patients with Open Tibia Fracture

In previous sections, the complexity of OTF management and the common medical complications were discussed. This long journey, even after discharge from the hospital, causes lifelong change in the quality of life (QOL) of the affected individuals. Some of the different aspects that patients with OTF have trouble with, regardless of whether they had amputation or not, include persistent pain, difficulties with day to day mobility, challenges at workplace, and the feeling of being disabled (155–157). Psychologically, many patients express anxiety and depression following their injury (155).

OTFs are further financially challenging for the affected individuals. In a study by Francel et al, less than half of the patients returned to their work after limb salvage, and this took greater than 1 year (157). In the author's subsequent study, they saw that in the context of an OTF, initial intervention of amputation or salvage did not significantly affect re-employment rate, and it was more dependent on the individual's pre-injury factors (158). Schade et al, in their recent comprehensive analysis of 34 studies including those by Francel, reported that only 60% of the individuals returned to work post-injury, with mean time of absence of 14 months (145).

Many studies have further investigated the difference in the QOL of patients who had limb amputation or salvage, consisting of bony fixation and STR. The most notable study is the Lower Extremity Assessment Project (LEAP), a multicenter study that investigated long-term outcome of patients in the United States who underwent limb salvage or amputation, for up to 7 years following injury. The study ultimately found that regardless of the initial intervention, the functional outcome of these patients was not significantly different on day-to-day basis. Many of them had long term disabilities both physically and psychosocially, and the study concluded the outcome were dependent more on socioeconomic factors than the type of intervention (159, 160).

Other studies including a meta-analysis by Busse et al in 2007, which analyzed 9 different observational studies on long term outcome of patients who underwent primary amputation and limb salvage, saw that there were no significant differences in the individuals' function up to 7 years post injury, and function was more influenced by personal psychosocial factors (161). In another meta-analysis by Akula et al in 2011, 11 studies were analyzed, and no significant differences in long-term physical morbidity were observed. However, the authors saw that those whose limbs were salvaged had better psychological outcomes (45). Not surprisingly, additional studies found that lower extremity amputees had significantly lower self-body image and QOL (162), and had higher prevalence of anxiety and depression (163).

As such, the impact of OTF on an individual beyond medical complication is immense. Regardless of the treatment they receive, patients continue to suffer from pain, difficulties in movement, and are burdened psychologically and financially. These findings suggest that there’s still room for improvement in how we manage OTF patients and enhance their long term QOL.

1.8 Thesis Rationale

The tibia has important functions in the human body, being the main weightbearing bone of the lower limb and forming the knee as well as the ankle joint that allow ambulation. The leg also houses key nerves and tendons that allow movement of the ankle and toes, which when lost, can impact a person's QOL.

Unfortunately, tibia fractures are common in the developed world. Due to the mechanism of injury which are usually high-energy forces like an MVC, a lot of injuries are associated with extensive soft tissue defect. This becomes a significant management challenge since not only do bones need to be appropriately fixated for weightbearing, the soft tissue also needs to be reconstructed to protect the bone and assist in restoring leg function.

In ideal circumstances, open injuries are managed with prompt irrigation and debridement, followed by external fixation and/or internal fixation of the fractured bones, and soft tissue reconstruction with local, regional, or free flap. There is currently a large pool of literature looking into what different management practices result in best patient outcome, such as timing of initial irrigation and debridement, how patients are admitted to a tertiary center, and when they get soft tissue coverage. Although some of these have become less relevant with improved antibiotics and negative pressure therapy over the past few decades, the importance of early management in a trauma center where relevant specialists like the orthopedics and plastic surgeons are available and can work together, persists.

Currently in Canada, there's no formalized protocol on how to triage and manage OTF from a peripheral site to a trauma center. Even upon arrival to a trauma center, patients are often seen separately by different surgical teams and there is no coordinated approach by the orthopedic and plastic surgeons for the bony and soft tissue management of these patients. This prompts the question what the management process of OTF in Ontario is, such as the location of admission. In addition, there is no granular data on how the differences in management affect patient outcome. The examination of the data will allow us to examine room for improvement of OTF patient care in Ontario.

1.9 Objectives and Hypothesis

The overall goal of this work is to find the characteristics of individuals with open tibia fractures in Ontario, analyzing their management patterns and room for improvement.

> Firstly, we aim to describe the characteristics of patients with open tibia fractures, including the demographic information, comorbidities, severity of injury, hospital admission and transfer, and interventions they had.
>
> Secondly, we aim to determine the proportion of patients who had a direct admission to a Level I or Level II trauma center, versus admission to a non- trauma center peripheral hospital, and investigate if there were differences in the cohorts and their outcome.
>
> Thirdly, we aim to identify the proportion of patients who had soft tissue coverage and how much delay they had to the reconstructive surgery.

We hypothesize that those who had direct admission to a trauma center would have early soft tissue reconstruction, and subsequently have reduced rates of amputation, infection, mal/nonunion, and revision surgery, compared to those admitted to a non-trauma center.

Chapter 2

2 Review of the Literature on Outcome of Lower Extremity Injuries

This chapter is dedicated to reviewing the current literature on the types of practices and management strategies that influence patient outcomes following a major lower extremity trauma. The discussed topics will include salvage versus amputation after complex limb injury, timing of soft tissue reconstruction, location of admission, and finally, the role of an orthoplastic team, and their effects on the rate of complication and general outcome.

2.1 Limb Salvage versus Amputation

As discussed in Section 1. 4. 3, the question of whether to salvage the limb or proceed with amputation for complex lower limb injury has been an interest to many clinicians for decades. Section 1.7 then discussed the QOL of those who had OTF, and briefly explored the difference in QOL between those who had limb amputation and salvage. Many other studies examined the medical outcome of patients who underwent primary limb amputation, and compared to those who had salvage consisting of bony reduction and STR.

Georgiadis et al published one of the earliest studies that compared the outcomes of the two groups, with their cohort consisting of 27 limb salvage and 18 primary amputations. They saw that those who had limb salvage had greater incidence of complications including infections, greater number of surgeries, and longer stay in the hospital (135). Similar findings were seen by Hertel et al, who in their group of 21 patients who had limb salvage and 18 who had amputations, observed that the salvage group had more procedures but longer rehabilitation period. In their analysis however, the long-term functional outcome was thought to be better in the salvage group (164).

Other studies found that the rate of infection was dependent on the nature of the injury rather than the intervention that was had, and otherwise there were no differences in self-reported satisfaction, mobility, and general physical function (165). A systematic review by Saddawi-Konefka in 2008 that compared 28 studies regarding limb salvage versus amputation, again did not demonstrate superiority of one management versus another, although the study was limited by significant heterogeneity and lack of data on those who had primary amputation (49).

Military personnel are at particularly high risk of open extremity injuries and several studies have examined their outcome after lower extremity fracture (166). In this study, complications following severe lower extremity injuries included infections, nonhealing wounds, and heterotrophic ossification. There were no significant differences between the amputation and limb salvage group, however those who had delayed amputation seemed to have poorer outcomes (166). The same group looked at outcomes at 4 years, and saw that the limb salvage group had lower rates of wound infections, and repeatedly saw that those who had later amputation after 90 days since injury had higher rates of complications in general (167). For other health related complications, they saw lowest rates of osteoarthritis in the early amputation group, but highest rates of osteoporosis, and all affected individuals had higher prevalence of psychological disorders.

Overall, these conflicting results demonstrate that there is no one particular management that results in improved physical outcome in patients with severe extremity trauma. Together with the lack of large difference seen in the QOL outcomes as described in Section 1.7, they suggest that the decision to salvage the limb or to amputate should be made in a case-by-case fashion. Multiple factors such as other injuries that need urgent attention, patient comorbidities, and preference need to be considered for this decision (49, 50).

2.2 Admission to a Trauma Center

In most developed nations, hospital systems are classified into categories by their differential capacity to admit and manage complex patients such as trauma and conditions that require intensive care and specialized surgeries. In Ontario, Canada, there are Level I and Level II trauma centers (TC) that are generally associated with universities, and have specialized services including the plastic and reconstructive surgery team, as well as advanced equipment such as operating microscopes and microvascular equipment.

Prompt transfer to a larger facility or TC for trauma is recognized as an important part of OTF management. A recent meta-analysis by Klifto et al analyzed 19 studies that looked at the outcomes of patients with lower extremity fractures that were treated at a tertiary center for definitive management (168). Upon comparison of patient morbidity of patients who were admitted directly to a tertiary center, versus those transferred after an admission to another non-tertiary hospital, there was overall better outcome in the direct admission group, with decreased risk of complications such as wound infection, osteomyelitis, and mortality. A retrospective review of 178 patients by the same research group in their tertiary center saw increased odds of osteomyelitis in the transferred group versus group that was directly admitted in a tertiary center (169).

Specifically, in a retrospective study by Crowe et al that looked at outcome of 34 patients that had transfer to their tertiary center versus direct admission, the direct admission group had quicker definitive management and less adverse complications (170). Another study by Page et al that looked at patient outcome using secure anonymized information linkage (SAIL) in the United Kingdom saw that patients with OTF that were directly admitted to tertiary centers that had a collaborative orthopedic and plastic surgery service had fewer surgeries, and fewer visits to their primary care physicians for one year following the injury (171). Other studies mentioned in the meta-analysis that looked at open ankle fractures showed that less surgeries were required in groups that were directly brought to TC (172, 173). Conversely, other studies that describe outcome of lower extremity trauma cases that were either directly admitted or transferred to a TC have only found trends, but no statistical differences in outcomes including infection rates (172, 174). The findings of key studies of this topic are summarized in **Table 3**.

Based on these studies, the United Kingdom currently recommends the following practices in their BOA and BAPRAS guidelines. In the most recent published "*Standards for the management of open fractures of the lower limb*" published in 2009, they recommend immediate transfer of complex open fracture patients to a specialist center for management including debridement, fixation, and soft tissue reconstruction (175). Analysis by Trickett et al showed the early positive effect of the published guideline in expediting transfer of patients to trauma centers (176).

In Canada however, the transfer pattern of patients with OTF is highly variable. There is no definite protocol in assessing patients with OTF and transferring them to a tertiary TC. Instead, the management can vary depending on the fracture appearance at initial presentation and other concurrent injuries. This becomes a concern if the injury that was thought minor and was admitted to a peripheral center later progresses, such as loss of soft tissue, and requires a transfer to a TC.

Table 3. Key studies comparing the effect of direct admission and transfer to a trauma center on patient outcomes

First Author, Year	Type of injury examined	Sample size	Comparison Groups	Outcome measure	Follow up time (Up to)	Result
Carragee, 1993	Severe ankle fracture	77	1: Direct admission to trauma center 2: Transfer to trauma center	Wound and reduction complications, Infections, hospital stay	Not specified	Transfer group had overall higher incidences of complications and longer hospital stay
Allison, 2005	Open tibia fracture	66	1: Direct admission to specialist center 2: Transfers to specialist center	Amputation, infection, bony union, flap failure	Not specified	No direct comparisons made
Naique, 2006	Open tibia fracture	73	1: Direct admission at specialist center	Enneking score, timing of soft tissue surgery, flap failure, infection	14 months (mean)	No statistical difference in the outcome of the two groups.

			2: Transfer after treatment from another center			
Stammers, 2013	Open tibia fracture	29	1: Directly admitted to institution 2: Transferred for specialist input from another hospital	Number of operations, length of stay	Not specified	Statistical difference seen for average number of operations being lower on direct admission group.
Page, 2015	Open lower limb trauma	100	1. Directly admitted to orthoplastic center 2: Transferred to orthoplastic center	Healthcare utilization, length of stay, outpatient health visits	1 year (12 months)	Direct admission group had fewer surgeries and post-discharge GP attendees
Chummun, 2015	Open ankle fracture	68	1. Seen and managed at tertiary center. 2: Initially stabilized at another center. 3: All managed at another and then transferred.	Enneking score, looking at overall limb function relative to unaffected limb, Number of total procedures	55 to 61 weeks (13 months)	Patients who were not directly seen at TC had a greater number of procedures, but similar functional outcome.
Crowe, 2017	Open tibia fracture	34	1: Transfers to tertiary center 2: Direct admission to tertiary center	Bony union, infection, length of stay, flap complications, amputation	2.5 years (mean)	Transfer group had more delay to definitive fixation, more osteomyelitis, and hardware removal
Boyd, 2018	Lower extremity fractures	669	1: Direct admission to author’s institution 2: Transferred to the institution	VTE incidence, time to surgery	Not specified	Transfer group had longer time to surgery, and incidence of VTE
Azoury, 2021	Lower extremity trauma	178	1: Transfers to TC 2: Direct admission to TC	Flap failure, osteomyelitis, amputation post salvage	941.5 days (31 months)	Transfer group had more delay to soft tissue coverage, and higher osteomyelitis

2.3 Time to Soft Tissue Reconstruction

The general importance of earlier than later STR following open fracture came to attention by Godina in 1986 (177). In his landmark paper, he examined a group of 532 patients who underwent limb salvage and reconstruction and saw that reconstruction using free flap within 72 hours was associated with improved outcomes, with reduced incidences of flap failure and infection, and total number of operations. This changed the overall paradigm of how we see the optimal timing of STR for best patient outcome (178).

Multiple studies have since examined the effect of timing of STR on the outcome of patients who had severe open extremity fracture. Hertel et al for instance, demonstrated decreased complications with immediate reconstruction utilizing internal and external fixation and local and free flaps, when compared to those who had delayed reconstruction for mean of 4.4 days (179). Gopal et al compared the 84 patients who had OTF with Gustilo IIIb/IIIc, and they again saw that early fixation, either intramedullary nailing or external fixation, with STR within 72 hours was associated with less infection and malunion (38). Tampe et al, in their nationwide study looking at those who had OTF in 15 year time, saw those who had STR within 72 hours were less likely to have secondary amputation (180). More recent study by Lee et al in 2019 revisited the effect of timing of STR in 358 patients, and again saw that best flap outcome was in the group who had early flap based reconstruction within 72 hours (178).

Other articles in literature showed importance of early STR, but not within the strict 72-hour period of time. In the abovementioned article by Lee et al for instance, they saw that the subgroup they had STR in less than 4-10 days had no significantly different flap outcome than those who had STR within 3 days (178). Mathews et al, in their group of 81 patients with Grade III OTF, saw no difference in adverse outcome such as infection when the STR was completed within 72 hours versus after. However, they did see a higher incidence of infections in the group that had delay in STR past 7 days, suggesting earlier STR may be beneficial (181). The improved outcome within 1 week period of time was again seen in a large multi-center cohort study by Pincus et al, as well as a single center studies by Alleyrand et al, Olesen et al, and Higgin et al (182–184). They saw fewer incidences of infections when STR occurred within 7 days of injury, and Pincus et al specifically saw fewer flap loss and amputation in those who had STR within 7 days (185). Soft tissue coverage within 1 to 2 weeks was associated with good outcome in another study by Fischer et al (186).

The findings supporting importance of early reconstruction within 3 to 7 days haven't been repeated in other studies in the literature. Hill et al for instance saw that flap failure, and need for re-operation was not different whether the free-flap based reconstruction was completed within 30 days or after (187). Comparison between the group who had STR within 15 days and after 15 days by Starnes-Roubaud et al did not demonstrate significant differences in flap failure and recovery (188). Other papers did not see significant adverse outcomes when STR was delayed after injury, up to 22 days (189, 190). Authors attributed these findings to NPWT and its role in reducing infection rates and promoting healing, as described in Section 1.5.6 (178, 187, 189).

From the authors' anecdotal experience in the local TC, OTF are seen initially by orthopedic surgery and taken to the operating room, and plastic surgery team may be consulted intraoperatively, or even few days after the surgery for concerns with soft tissue coverage. As a result, STR can also vary from immediate to delayed, up to weeks at times. This does not account for the patients who are transferred later, or those in other institutions. Currently in Ontario, and Canada at large, it is unknown when the patients receive STR following a complex OTF.

Table 4. Key studies comparing the effect of timing of soft tissue reconstruction on patient outcomes

First Author, Year	Type of injury examined	Sample size	Comparison Groups	Outcome measure	Follow up time (Up to)	Result
Byrd, 1985	Open tibia fracture	59	1: STR 1-6 days 2: 7 days to 6 weeks 3: >6 weeks	Osteomyelitis, nonunion, amputation	9 months (to union)	Lower complication rate in the group who had coverage within 6 days
Godina, 1986	Open extremity injury	532	1: STR <72 hours 2: 72 hours to 3 months 3: 3 months to 12.6 years	Flap failure, infection, bone union, length of hospital stay, number of anesthesia	29 months (to union)	Overall improved outcome in Group 1
Fischer, 1991	Open tibia shaft fracture	43	1: STR in 0-10 days 2: in 11 days to 6 weeks 3: >6 weeks	Infection, amputation, bone union	90 weeks (to union)	STR <10 days had shorter hospital stay, less infection
Francel, 1992	Open tibia fracture	72	1: STR < 15 days 2: > 15 days	Operation, length of stay, weight-bearing	42 months (average)	STR < 15 days had shorter stay in hospital and earlier weight-bearing
Kolker, 1997	Open lower extremity	416	1: STR < 21 days 2: 22 to 60 days 3: >60 days	Thrombosis, reoperation	Not specified	Timing of STR had no impact on outcome
Gopal, 1999	Open tibia fracture	84	1: STR <24 hours / single stage 2: <72 hours 3: up to 3 weeks	Infection, bone union, amputation	60 weeks (to union)	STR > 72 h associated with more complications
Hertel, 1999	Open lower leg injury	29	1: STR <24 hours 2: 2 to 9 days	Weightbearing, union, infection, length of stay	49 months (average)	Higher rates of infection, reoperation, and delay in union in Group 2
Karanas, 2008	Open lower extremity injury	14	No comparison groups. STR was completed in 22 days on average.	Graft loss, infection, length of stay	39 weeks (average)	No flap failure, low rates of complication
Choudry, 2008	Open tibia midshaft fracture	65	1: Flap coverage <7 days 2: >7 days	Flap failure, bony union	Not specified.	Subgroup (soleus flap) that had coverage in less than 7 days had less flap failure.

Hill, 2013	Open lower extremity injury	60	1: STR <30 days 2: 31 to 90 days 3: >90 days	Flap failure, re-operation, pedicle thrombosis, infection	Not specified.	No statistical differences
Raju, 2014	Open lower limb trauma	50	No comparison groups. STR was completed in 12 days on average.	Flap failure	Full text unavailable	Despite the delay of reconstruction of 12 days on average, fairly good post-operative outcome observed.
Alleyrand, 2014	Open tibia fracture	74	1: STR 1-7 days 2: STR >7 days	Infection, necrosis, thrombosis of flap or anastomosis	14 months (median)	Increased risk of infection if delayed past 7 days
Tampe, 2014	Open tibia fracture	342	1: STR < 72 hours 2. 4 to 90 days 3: STR> 90 days	Amputation after salvage	6 years (mean)	Reduced amputation rate in the early STR group
Starnes-Roubaud, 2015	Open lower extremity	51	1: STR < 15 days 2: STR >15 days	Flap failure, infection, bony union, ambulation	491 days (average)	No significant difference in the complication rates between two groups
Mathews, 2015	Open tibia fracture	74	1: Free flap < 72 hours 2: >72 hours	Deep infection	1 year (minimum)	No statistical differences
Olesen, 2015	Open tibia fracture	56	1: STR 1-7 days 2: STR >7 days	Infection	1 year (minimum)	Increased infection rate when STR was delayed past 7 days
Pincus, 2019	Open tibia and ankle fracture	672	1: STR < 7 days 2: >7 days	Infection, amputation	21 days (median stay in hospital)	Delayed coverage had greater complications
Lee, 2019	Below knee trauma	358	1: STR < 3 days 2: 4-90 days 3: >90 days	Flap failure, Reoperation	Not specified	Flap coverage within 10 days had improved outcomes compared to delayed
Higgin, 2021	Open tibia fracture	116	1: STR < 7 days 2: >7 days	Infection, bone union, amputation	46 months (average)	Early coverage group had lower superficial infection

2.4 Orthoplastic Approach

The term “orthoplastic,” first conjoined by L. Scott Levin in 1993, refers to the combined approach of the orthopedic surgery, and plastic and reconstructive surgery teams for complex musculoskeletal issues, such as open extremity trauma and oncologic processes. The two teams work together to provide bony fixation followed by soft tissue coverage utilizing regional or free-flap, instead of the teams separately assessing patients and providing care at separate time points (191, 192). The aim was to provide better patient outcome and reduce healthcare costs associated with complications and prolonged hospital stay (39).

Many trauma centers around the world have adopted the orthoplastic model in management of acute extremity traumas, and multiple studies have demonstrated good outcome with the orthoplastic approach in OTF. Fernandez et al for instance saw that the existence of an “orthoplastic” operating list, a dedicated time for the surgeons to work together for lower limb trauma, resulted in quicker bony fixation and soft tissue coverage (193). Other major centers of the UK also saw reduced time to surgery, overall number of surgeries, and infection rate in their lower limb trauma patients following implementation of an orthoplastic approach (181, 194, 195).

While a lot of these studies were completed in the UK, the model has begun to be adopted in other countries as well. In Italy for instance, Toia et al saw significant improvement in care delivery with implementation of orthoplastic approach. Patients had less surgeries, less infections, and had faster soft tissue healing and return to work (196). In Pakistan, orthoplastic practice has recently been adopted referencing the UK model. In a multi-center cohort study of 160 patients with OTF in Pakistan as well as other nations, Boriani et al saw significantly improved outcome in patients that were managed by orthoplastic team instead of the standard orthopedic surgery team, with faster soft tissue healing and bony union, and reduced rate of infection (39).

Although they are associated with good outcomes, commencement of such orthoplastic team is not without challenges. Thoroughly planned management protocol, availabilities of equipment such as C-arm and microscope, and personnel including surgeons, nursing staff, and emergency service is all required in the implementation of an orthoplastic team, which may be difficult to coordinate initially (196, 197).

In Canada, there is no formal orthoplastic team in TC to manage complex bony and soft tissue injuries. The two services may work together in pre-scheduled cases, such as in oncologic cases, where the teams would work together for ablation and reconstruction. In trauma settings however, we are not aware of any formal collaboration.

2.5 Conclusions

In this chapter, the current literature on management patterns of open extremity fractures was reviewed, and the types of practices that improve patient outcomes were examined. Specifically, those that reduce complications such as infection, malunion or nonunion, or secondary amputation, and shorten the length of stay in the hospital were examined. We saw that those who had limb amputation had comparable outcomes to those who had limb salvage. Among those who had limb salvage, we saw early involvement of orthopedic and plastic surgery specialists, preferably as a team in a tertiary trauma center, resulted in best patient outcomes. This pool of literature may be used as a guide for many institutions to re-evaluate their management practices and look at room for improvement.

Chapter 3

3 Open Tibia Fractures in Ontario and Patient Outcomes

This chapter will discuss the demographic information and baseline characteristics of patients who sustained OTF between the years 2009 and 2020 using linked population data held in the ICES, also known as “Institute of Clinical Evaluative Sciences.” This chapter will also describe how the patients were triaged and admitted to different hospitals in Ontario, and the differences in their outcome.

3.1 Introduction

As in most developed countries, acute traumas in Canada are managed following standardized protocols. The emergency medical services (EMS) are dispatched to the site, and the initial life-saving maneuvers, such as securing an airway, or application of pressure or tourniquet to open wounds are completed. Patients are then brought to the closest hospital for stabilization and initiation of different medications as needed, to maintain hemodynamic stability (40). The general principle of managing displaced long bone fractures in the emergency department (ED) at this stage is reducing the fracture under sedation and splinting in stable position. This is to minimize potential neurovascular compromise, pain, and the risk of compartment syndrome (40, 198).

Temporary bedside management is then followed by surgical intervention. At this point, the management pathways can diverge. If there were pressing concerns for the patient that required another specialist, or if the musculoskeletal injury was deemed overly complex for a community, or peripheral center, the patient is taken to a nearby Level I or Level II trauma center (TC) directly from the peripheral ED without being admitted to the local hospital.

In contrast, depending on the capacity of the peripheral hospital, patients may be admitted, and procedures such as I&D, and bony fixation consisting of external fixators and/or intramedullary nail may be completed locally. The open skin, or soft tissue injury may also be managed in the peripheral hospitals as well if it is not severe. However, the soft tissue injury that appeared initially small can evolve, lead to tissue necrosis and hardware extrusion, eventually necessitating an intervention by reconstructive specialist (199–201). In these circumstances, patients may be transferred to a TC.

There is a large pool of literature supporting that a direct admission to a TC, versus transfer after initial admission at another hospital, results in better patient outcome, such as less need for total number of surgeries, and reduced risk of infection (Section 2. 2). Thus, our objective was to investigate how lower limb traumas, especially OTF, were being managed in Ontario.

In this chapter, we aimed to take advantage of the available ICES data and answer the abovementioned objectives. This includes describing the baseline characteristics of patients who have OTF, and identifying the proportion of patients who were directly admitted to a Level I/II TC, versus admission to a peripheral, NTC. We then examined what types of management they had and their outcomes. We hypothesized that those who were admitted to TC, with more availability of plastic and reconstructive surgeons, would be more likely to have early STR.

3.2 Methods

In Ontario, different facilities including Ministry of Health stores administrative data to track the different diagnoses and interventions that has been taken for every individual with valid Ontario Health Insurance Plan (OHIP). Stored data includes International Classification of Diseases (ICD) codes representing the diagnoses of patient, and OHIP fee codes used by physicians to bill for the intervention that was completed for the patient. Other data includes information regarding admission, transfer, and discharge from all institutions in Ontario. All identifying information from these data is removed and then stored in the ICES database, allowing for large population-based studies with objective of improving delivery of health care in Ontario.

The current project is a population-based cohort study that utilizes ICES data for characterizing the management of patients who had OTF, particularly pertaining to their admission to an Ontario hospital. Details on the dataset that were utilized and the information they each contain is described in Appendix A.

3.2.1 Inclusion and Exclusion Criteria

Included patients of the project are those who sustained an OTF during the accrual period between April 1st of 2009 to March 31st of 2020. Exclusion criteria of the project included those whose data was incomplete, such as missing or invalid ICES number, missing age or sex, and death prior to index date. Non-Ontario residents were excluded. Those less than the age of 18 or greater than 105 were also excluded to limit the population to adults who were triaged based on adult protocols, and to exclude those that were likely added by error.

To ensure that the OTF we were capturing were truly significant fractures that would have eventually required inpatient management, and to exclude those whose diagnoses were potentially entered by error, we excluded those who did not have a record of visit to the Emergency Department (ED), or a record in the Ontario Trauma Registry within 3 days of the documented OTF. We also excluded those who did not have a record of admission to the hospital within 3 days of the documented OTF. Lastly, we excluded those who had previous record or evidence of a tibia fracture in the past 5 years, including malunion or nonunion, to ensure the outcome markers were not confounded by the previous injury.

3.2.2 Datasets

Multiple datasets within the ICES database were utilized to retrieve the critical information required for the objective. These included the Canadian Institute for Health Information (CIHI) Discharge Abstract Database (DAD), CIHI Same Day Surgery (SDS), National Ambulatory Care Reporting System (NACRS), Registered Persons Database (RPDB), ICES Physician's Database, Ontario Trauma Registry (OTR), Ontario Health Insurance Plan (OHIP) and the Facilities dataset. Smaller ICES derived cohort databases, including HYPER, ODD, CHF, and COPD was used, which contains information on patients with diagnosis of hypertension, diabetes, congestive heart failure, and chronic obstructive pulmonary disease, respectively.

3.2.3 Baseline Demographic Information

To better characterize the patients who underwent an OTF, basic demographic information, such as age, sex, and the general area of residence was collected. Pertinent past medical history including diabetes, hypertension, peripheral vascular disease (PVD), and chronic lung disease, and their overall Charlson Comorbidity Index (CCI) were examined. Lastly, factors to characterize the injury itself, such as mechanism of injury, associated vascular and nerve injury, and whether the ISS was greater than 15 at the initial assessment, were examined. ISS is calculated by adding the squares of the top three abbreviated injury score (AIS) for different body parts. The AIS ranges from 1-6, and the six different body parts that make up the scale are the head and neck, face, chest, abdomen, extremity, and external. Overall, ISS >15 is considered a "serious" trauma (202), and this was used to estimate the presence of other bodily injuries. Lastly, the patient's associated Local Health Integration Network (LHIN), and fiscal year of injury was examined.

3.2.4 Variable Definitions

The Level I and II TC were identified from provided list in Critical Care Services Ontario (203). The institution codes for all hospital facilities in Ontario were reviewed and the codes corresponding to the 9 adult trauma centers, namely the Winsor Regional Hospital, London Health Sciences Center, Hamilton Health Sciences, St. Michael's Hospital, Sunnybrook Health Sciences Center, Kingston General Hospital, The Ottawa Hospital, Health Sciences North, and Thunder Bay Regional Health Sciences Center, were selected to be included as the TC cohort.

3.2.5 Outcome Measures

Our primary outcome was whether there was a difference in the length of time to definitive STR surgery between the group that had admission to a TC, versus the group that was admitted to a NTC. This primary outcome was chosen to investigate whether the location of admission affected how quickly certain management was completed. STR was reported in binary status, but also when it was completed, and whether it was completed within 72 hours. In addition, secondary outcomes included incidence of early and late amputation, malunion or nonunion, need for further debridement for infection, compartment syndrome, external fixator placement, death, consultation to plastic surgery, and length of stay in the hospital.

Among the patients that were admitted to a NTC, the proportion that was later transferred to a TC was also identified. The detailed list of outcome measures and the codes that were utilized to identify them are summarized in Appendix A.

3.2.6 Statistical Analysis

Baseline variables were compared between the two groups using a combination of one-way analysis of variance (ANOVA) for means, Kruskal-Wallis for median, chi-square for categorical variables, and the Cochran-Armitage trend test for ordinal variables.

For outcomes, Mann-Whitney U analysis was completed for comparison of continuous variables with standard deviation (SD), and the Odds Ratio (OR) was calculated for the rest of the categorical variables. Confidence interval (CI) was also reported in applicable sections, and standardized differences (StDi) was also reported as a subtle measure of differences in the results when the sample size is large (204). Based on the Bonferroni correction with 10 variables, a p-value < 0.005 was considered statistically significant.

Regression models were used to analyze the outcome of the two groups. Covariates such as direct admission to a TC, patient age, patient sex, CCI, rurality, ISS > 15, neurovascular injury, and mechanism of injury was included. Then collinearity and correlation of chosen predictors, and the linearity of association between continuous variables and outcomes were assessed.

When presenting the results, any groups with data points ≤ 5, nor any data that would allow recalculation of the suppressed value, were removed as per privacy regulations.

3.3 Results

3.3.1 Cohort Build

A total of 5401 patients were found to have the record of OTF as seen in the DAD, SDS, and NACRS datasets between April 1st, 2009 and March 31st, 2020. 508 patients were excluded due to incomplete data, and age less than 18 or greater than 105. 180 patients were excluded due to lack of ER or OTR record, and 294 patients were excluded due to lack of hospital admission record. Lastly, 179 patients were excluded due to record of previous tibia fracture. The final cohort consisted of 4240 patients.

3.3.2 Baseline Characteristics

Among the 4240 patients who were admitted to a hospital, 1722 patients were admitted to what we defined as TC, and 2471 patients were admitted to a NTC. 47 patients were initially admitted to a NTC and later transferred to a TC.

The baseline characteristics of the total population and those admitted to either TC and NTC are shown in **Table 5**. Significant differences were seen between the TC and NTC groups in variables including patient age, sex, injury proportion of those with ISS >15, associated neurovascular injury, and the mechanism of injury. Those admitted to a TC had a lower mean age (45.63 versus 48.28, $p<0.001$), greater proportion of male population (72.4 versus 65.9%, $p<0.001$), and more likely to have been admitted from a MVC (62.6 versus 32.5%, $p<0.001$). They had greater rate of associated nerve and vascular injury (5.7 versus 1.3%, $p<0.001$).

For those who were later transferred to a TC, the mean number of days to transfer was 4.6 days.

Table 5. Baseline variables of the cohort population

Variable	**Value**	**NTC**	**TC**	**Transfer to TC**	**Overall**	**TC vs. NTC**	
		N= 2,471	**N= 1,722**	**N= 47**	**N= 4,240**	**StDi**	**p-value**
Patient Age	Mean (SD)	48.28 ± 18.87	45.63 ± 18.08	49.55 ± 18.03	47.22 ± 18.59	0.14	<.001
	Median (IQR)	48 (32-62)	45 (30-58)	47 (38-64)	47 (31-60)	0.14	<.001
Patient Sex	Female	842 (34.1%)	476 (27.6%)	21 (44.7%)	1,339 (31.6%)	0.14	<.001
	Male	1,629 (65.9%)	1,246 (72.4%)	26 (55.3%)	2,901 (68.4%)	0.14	
Rural resident	Yes	412 (16.7%)	309 (17.9%)	13 (27.7%)	734 (17.3%)	0.03	0.353
Income quintile	Missing	11 (0.4%)	12 (0.7%)	0 (0.0%)	23 (0.5%)	0.03	0.004
	Quintile 1	518 (21.0%)	441 (25.6%)	6 (12.8%)	965 (22.8%)	0.11	
	Quintile 2	503 (20.4%)	365 (21.2%)	8 (17.0%)	876 (20.7%)	0.02	
	Quintile 3	513 (20.8%)	317 (18.4%)	<=20	<=850	0.06	
	Quintile 4	500 (20.2%)	309 (17.9%)	<=5	<=820	0.06	
	Quintile 5	426 (17.2%)	278 (16.1%)	13 (27.7%)	717 (16.9%)	0.03	
Charlson Commor-bidity Index	Mean (SD)	0.17 ± 0.72	0.15 ± 0.70	0.09 ± 0.41	0.16 ± 0.71	0.02	0.563
	Median (IQR)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0.02	0.529
	0	2,288 (92.6%)	1,603 (93.1%)	<=5	<=3,940	0.02	0.657

	1	77 (3.1%)	56 (3.3%)	0 (0.0%)	133 (3.1%)	0.01	
	2	55 (2.2%)	29 (1.7%)	<=5	<=90	0.04	
	3+	51 (2.1%)	34 (2.0%)	0 (0.0%)	85 (2.0%)	0.01	
History of hypertension	Yes	693 (28.0%)	406 (23.6%)	9 (19.1%)	1,108 (26.1%)	0.1	0.001
History of diabetes	Yes	303 (12.3%)	192 (11.1%)	<=5	<=5	0.03	0.272
History of CHF	Yes	104 (4.2%)	63 (3.7%)	0 (0.0%)	167 (3.9%)	0.03	0.37
History of COPD	Yes	278 (11.3%)	168 (9.8%)	<=5	<=455	0.05	0.123
History of peripheral vascular disease	Yes	13 (0.5%)	13 (0.8%)	0 (0.0%)	26 (0.6%)	0.03	0.353
Injury Severity Score >15	Yes	365 (14.8%)	1,010 (58.7%)	9 (19.1%)	1,384 (32.6%)	1.02	<.001
Associated neurovascular injury	Yes	32 (1.3%)	98 (5.7%)	<=5	<=135	0.24	<.001
Nerve Injury	Yes	11 (0.4%)	18 (1.0%)	<=5	<=35	0.07	0.021
Vascular Injury	Yes	24 (1.0%)	89 (5.2%)	<=5	<=115	0.25	<.001
Mechanism of Injury	MVC	803 (32.5%)	1,078 (62.6%)	25 (53.2%)	1,906 (45.0%)	0.63	<.001
	Fall	1,106 (44.8%)	307 (17.8%)	16 (34.0%)	1,429 (33.7%)	0.61	
	Others	562 (22.7%)	337 (19.6%)	6 (12.8%)	905 (21.3%)	0.08	
Patient LHIN	LHIN 1	125 (5.1%)	62 (3.6%)	0 (0.0%)	187 (4.4%)	0.07	<.001
	LHIN 2	355 (14.4%)	18 (1.0%)	0 (0.0%)	373 (8.8%)	0.52	

	LHIN 3	196 (7.9%)	80 (4.6%)	<=5	<=280	0.14	
	LHIN 4	247 (10.0%)	300 (17.4%)	<=5	<=5	0.22	
	LHIN 5	187 (7.6%)	89 (5.2%)	<=5	<=285	0.1	
	LHIN 6	164 (6.6%)	74 (4.3%)	<=5	<=240	0.1	
	LHIN 7	167 (6.8%)	141 (8.2%)	0 (0.0%)	308 (7.3%)	0.05	
	LHIN 8	269 (10.9%)	168 (9.8%)	<=5	<=445	0.04	
	LHIN 9	311 (12.6%)	178 (10.3%)	6 (12.8%)	495 (11.7%)	0.07	
	LHIN 10	<=80	145 (8.4%)	<=5	<=225	0.24	
	LHIN 11	146 (5.9%)	189 (11.0%)	6 (12.8%)	341 (8.0%)	0.18	
	LHIN 12	127 (5.1%)	61 (3.5%)	<=5	<=195	0.08	
	LHIN 13	103 (4.2%)	117 (6.8%)	10 (21.3%)	230 (5.4%)	0.12	
	LHIN 14	<=5	100 (5.8%)	<=5	<=110	0.34	
Fiscal year	2009	232 (9.4%)	171 (9.9%)	8 (17.0%)	411 (9.7%)	0.02	0.033
	2010	219 (8.9%)	151 (8.8%)	6 (12.8%)	376 (8.9%)	0	
	2011	235 (9.5%)	141 (8.2%)	8 (17.0%)	384 (9.1%)	0.05	
	2012	214 (8.7%)	140 (8.1%)	<=5	<=360	0.02	
	2013	235 (9.5%)	131 (7.6%)	9 (19.1%)	375 (8.8%)	0.07	
	2014	213 (8.6%)	141 (8.2%)	<=5	<=360	0.02	
	2015	213 (8.6%)	170 (9.9%)	<=5	<=390	0.04	
	2016	202 (8.2%)	179 (10.4%)	<=5	<=385	0.08	
	2017	204 (8.3%)	173 (10.0%)	<=5	<=380	0.06	

	2018	266 (10.8%)	163 (9.5%)	0 (0.0%)	429 (10.1%)	0.04	
	2019	238 (9.6%)	162 (9.4%)	<=5	<=405	0.01	
Days to transfer to a trauma center	Mean (SD)			4.6 (3.5)			

3.3.3 Individual Variable Comparisons

Categorical variables were compared between those directly admitted to a TC or admitted to a NTC. The results, including the unadjusted OR are presented in **Table 6**. Out of the 1722 patients that were admitted to a TC, 277 (16.1%) had a STR in 90 days. On the contrary, 127 patients out of the 2471 that was admitted to a NTC (5.1%) had a STR in the same time frame (OR 3.54, p<0.0001). Those who were admitted to a TC were also more likely to have an early STR within 72 hours of the injury, although this was not significant based on the Bonferroni correction (OR 1.75, p=0.0066).

As mentioned in Chapter 1, patients with extreme lower extremity trauma can undergo limb salvage consisting of bony fixation and soft tissue reconstruction, whereas others may undergo amputation without a salvage attempt. In our analysis, we saw that 96 (5.6%) of those admitted in TC had amputation within 1 week since the injury, but 22 patients (0.9%) of those admitted in a NTC had amputation (OR 6.57 p<0.0001). When the group was followed for 1 year, we saw that a total of 138 patients (8.0%) among those admitted to TC had amputation, in contrast to only 54 patients (2.2%) who were admitted to a NTC (OR 3.90, p<0.0001).

On exam of management characteristics, we saw a large proportion had a consultation to plastic surgery service. Up to 552 patients (32.1%) among those admitted in TC had a plastic surgery consult, and 309 patients (12.5%) among those admitted in a NTC also had a plastic surgery consult (OR 3.30, p<0.0001). We also saw that a significant proportion of those who were transferred to a TC (40.4%) also had a plastic surgery consult.

We also saw a large proportion of the entire cohort (18.1%) had a history of external fixator placement within 30 days of the injury. The proportion was significantly higher among those admitted to a TC at 26.7%, versus 11.4% in a NTC (OR 2.84, p<0.0001)

Other outcome variables that were analyzed included wound infection and debridement, diagnosis of malunion and non-union, and compartment syndrome requiring fasciotomy. Infection and hardware removal were common complications, affecting one third (33.8%) of the total cohort. There were increased odds of infection and hardware removal in the TC group at 38.9%, compared to the NTC group at 29.9% (OR 1.49, p<0.0001). Based on the Bonferroni correction of the p-value, there were no significantly increased odds of malunion or nonunion, or compartment syndrome between the two groups, however the outcomes trended towards increased risk among patients admitted to a TC.

Mortality was examined within the first 30 days. There were significantly increased odds of death within 30 days when admitted to a TC versus NTC (OR 3.08, p<0.0001).

Continuous variables were examined by comparing the mean values and are demonstrated in **Table 7**. When time to STR was compared between the two groups, those who were admitted to a TC had a longer a period until STR, with mean of 20.6 days, and NTC had STR at mean of 17.4 days (p=0.0073). Those admitted to TC had significantly longer stay in the hospital with mean of 20.4 days, compared to those admitted to NTC with mean of 9.7 days (p<0.0001).

Table 6. Categorical outcomes of individuals with open tibia fractures, comparing those who were admitted to a trauma center to those admitted to a non-trauma center. Some exact numbers are not reported as per ICES policy to ensure confidentiality.

Outcome	Overall	NTC	TC	Transfer to a TC	TC to reference (NTC)	
					OR (95% CI)	p-value
Soft tissue reconstructive surgery	416 (9.8%)	127 (5.1%)	277 (16.1%)	12 (25.5%)	3.54 (2.84-4.41)	<0.0001
Soft tissue reconstructive surgery within 72 hours	97 (2.3%)	44 (1.8%)	53 (3.1%)	0	1.75 (1.17-2.63)	0.0066
Amputation within 7-days	118 (2.8%)	22 (0.9%)	96 (5.6%)	0	6.57 (4.12-10.45)	<0.0001
Amputation within 1-year	192 (4.5%)	54 (2.2%)	138 (8.0%)	0	3.90 (2.83-5.37)	<0.0001
Wound infection / debridement	1,433 (33.8%)	738 (29.9%)	669 (38.9%)	26 (55.3%)	1.49 (1.31-1.70)	<0.0001
Diagnosis of malunion or non-union	356 (8.4%)	190 (7.7%)	158 (9.2%)	8 (17.0%)	1.21 (0.97-1.51)	0.0865
Compartment syndrome	</=265	136 (5.5%)	122 (7.1%)	</=5	1.31 (1.02-1.69)	0.0365
External Fixator Placement	766 (18.1%)	282 (11.4%)	461 (26.8%)	23 (48.9%)	2.84 (2.41-3.34)	<0.0001
Death within 30-days	111 (2.6%)	36 (1.5%)	75 (4.4%)	0	3.08 (2.06-4.61)	<0.0001
Consultation to plastic surgery service	880 (20.8%)	309 (12.5%)	552 (32.1%)	19 (40.4%)	3.30 (2.82-3.86)	<0.0001

Table 7. Continuous Outcomes

Outcome	**Overall**	**NTC**	**TC**	**Transfer to a TC**	**P-value**
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	
Length of hospital stay	14.0 (20.7)	9.7 (13.5)	20.4 (27.0)	5.7 (3.5)	<0.0001
Time to STR (days)	19.5 (21.1)	17.4 (21.5)	20.6 (21.2)	17.4 (9.1)	0.0073

3.3.4 Regression Analysis

Regression analysis was completed with covariates including direct admission to TC, age, sex, rurality, ISS >15, CCI, NVI, and mechanism of injury, to reveal the adjusted ORs.

We previously saw the significantly increased odds of having a STR procedure (OR 3.54) if one was admitted to a TC based on the independent analysis in Section 3. 3. 3. When multiple other covariates were included in the regression analysis, shown in **Table 8**, we saw that the effect of admission location became smaller (OR 1.89, p<0.0001). Other covariates, including male sex, ISS>15, presence of a NVI and MVC as mechanism were other significant contributors to the odds of having a STR. When we examined early STR that was completed within 72 hours, we again saw ISS>15 (OR 2.31) and presence of NVI (OR 2.74) had a significant effect in having an earlier STR, but not the admission location.

Table 8. Regression analysis on soft tissue reconstruction and those within 72 hours

Covariate	Soft tissue reconstructive surgery				STR <72 hours			
	OR	**95 % CI**		**p-value**	**OR**	**95 % CI**		**p-value**
TC admission (Yes vs No)	1.89	1.47	2.42	<.0001	0.90	0.57	1.43	0.6556
Age	1.00	0.99	1.01	0.7499	1.00	0.99	1.01	0.9253
Sex (Male vs Female)	1.42	1.09	1.86	0.0091	1.45	0.87	2.41	0.1594
Rural residency (vs Urban)	1.08	0.82	1.42	0.588	1.06	0.63	1.79	0.8272
ISS > 15 (Yes vs No)	2.18	1.67	2.83	<.0001	2.31	1.39	3.86	0.0013
CCI	0.95	0.78	1.15	0.5935	0.78	0.46	1.34	0.3747
NVI (Yes vs No)	3.51	2.38	5.16	<.0001	2.74	1.42	5.30	0.0027
Mechanism of injury (Fall vs MVC)	0.37	0.25	0.54	<.0001	0.43	0.22	0.87	0.018
Mechanism of injury (Other vs MVC)	0.96	0.73	1.27	0.7966	0.86	0.50	1.47	0.5812

The odds of amputation within 7 days and 1 year with TC admission were adjusted with regression analysis. The unadjusted odds were as high as 6.57 for amputation within 7 days, and 3.90 for amputation within a year, when the TC group and NTC group were compared. In the regression analysis, these were adjusted to 2.32 and 1.79 respectively. Other covariates that were significant in the analysis included ISS>15, and presence of NVI. These are demonstrated in **Table 9**.

Table 9. Regression analysis on amputation as outcome

Covariate	Amputation within 7-days				Amputation within 1 year			
	OR	95 % CI		p-value	OR	95 % CI		p-value
TC admission (Yes vs No)	2.32	1.39	3.86	0.0013	1.79	1.23	2.59	0.0022
Age	1.01	1.00	1.02	0.2373	1.01	1.00	1.02	0.0039
Sex (Male vs Female)	1.03	0.66	1.61	0.8922	1.18	0.83	1.69	0.3613
Rural residency (vs Urban)	1.09	0.67	1.78	0.7306	1.26	0.86	1.85	0.2371
ISS > 15 (Yes vs No)	5.16	2.88	9.26	<.0001	3.60	2.37	5.46	<.0001
CCI	1.09	0.82	1.44	0.5693	1.33	1.15	1.54	0.0002
NVI (Yes vs No)	4.76	2.90	7.83	<.0001	7.61	4.96	11.68	<.0001
Mechanism of injury (Fall vs MVC)	0.26	0.10	0.69	0.0064	0.77	0.47	1.25	0.2898
Mechanism of injury (Other vs MVC)	1.14	0.70	1.88	0.5979	0.96	0.62	1.47	0.8395

In terms of infection and needing procedures such as debridement and hardware removal, similar factors such as ISS>15, NVI, and rural residency were significantly associated with increased risk, as demonstrated in **Table 10**. The admission location did not have a significant impact on the odds of wound infection and debridement.

Table 10. Regression analysis on wound infection and debridement

Covariate	Wound infection / debridement			
	OR	**95 % CI**		**p-value**
TC admission (Yes vs No)	1.02	0.88	1.19	0.7551
Age	1.00	0.99	1.00	0.2558
Sex (Male vs Female)	1.21	1.04	1.41	0.0129
Rural residency (vs Urban)	1.32	1.12	1.57	0.0012
ISS > 15 (Yes vs No)	1.84	1.56	2.18	<.0001
CCI	1.05	0.96	1.15	0.3
NVI (Yes vs No)	2.36	1.63	3.42	<.0001
Mechanism of injury (Fall vs MVC)	0.84	0.71	1.01	0.0566
Mechanism of injury (Other vs MVC)	0.88	0.74	1.06	0.186

As described in Chapter 1, external fixation is often used as a temporary measure for serious injuries that may require further procedures. On regression analysis, we saw that TC admission significantly increased odds of having external fixation (OR 1.72), as well as rural residency, ISS>15, and presence of NVI. This is demonstrated in **Table 11**.

Table 11. Regression analysis on external fixation

Covariate	External Fixation			
	OR	**95 % CI**		**p-value**
TC admission (Yes vs No)	1.72	1.42	2.08	<.0001
Age	1.00	1.00	1.01	0.1541
Sex (Male vs Female)	1.03	0.85	1.25	0.7461
Rural residency (vs Urban)	1.69	1.38	2.08	<.0001
ISS > 15 (Yes vs No)	3.15	2.55	3.88	<.0001
CCI	0.97	0.86	1.10	0.6392
NVI (Yes vs No)	2.14	1.47	3.12	<.0001
Mechanism of injury (Fall vs MVC)	1.15	0.91	1.45	0.2464
Mechanism of injury (Other vs MVC)	0.82	0.64	1.04	0.1056

Plastic surgery consultation record was also examined. Previously in direct comparison between the TC and NTC group, the TC group had 3.30 times the odds of having a consultation compared to the NTC. We saw that this was adjusted to 1.64 in the regression analysis. Other factors that significantly affected the odds of having a plastic surgery consultation included ISS>15, NVI, and having MVC as a mechanism of injury. The results are in detail in **Table 12**.

Table 12. Regression analysis on plastic surgery consultation

	Plastic Surgery Consultation			
Covariate	**OR**	**95 % CI**		**p-value**
TC admission (Yes vs No)	1.64	1.37	1.97	<.0001
Age	1.00	1.00	1.01	0.2981
Sex (Male vs Female)	1.29	1.07	1.56	0.0091
Rural residency (vs Urban)	0.95	0.77	1.18	0.6399
ISS > 15 (Yes vs No)	2.62	2.16	3.18	<.0001
CCI	0.96	0.84	1.09	0.5151
NVI (Yes vs No)	3.82	2.59	5.65	<.0001
Mechanism of injury (Fall vs MVC)	0.38	0.30	0.49	<.0001
Mechanism of injury (Other vs MVC)	0.64	0.51	0.80	<.0001

Compartment syndrome’s incidence was previously in unadjusted comparison was not significantly different between the TC and NTC groups (**Table 6**). In contrast, in regression analysis, we saw that TC admission was associated with decreased odds (0.55) of having compartment syndrome ($p<0.0001$). Other covariates that were significant in analysis included ISS>15, NVI, and MVC as mechanism of injury.

Table 13. Regression analysis on compartment syndrome

Covariate	Compartment syndrome			
	OR	**95 % CI**		**p-value**
TC admission (Yes vs No)	0.55	0.40	0.74	<.0001
Age	0.99	0.99	1.00	0.1142
Sex (Male vs Female)	1.68	1.19	2.37	0.003
Rural residency (vs Urban)	0.93	0.66	1.32	0.6813
ISS > 15 (Yes vs No)	3.07	2.21	4.27	<.0001
CCI	1.16	0.97	1.40	0.1107
NVI (Yes vs No)	6.04	4.00	9.11	<.0001
Mechanism of injury (Fall vs MVC)	0.45	0.29	0.70	0.0004
Mechanism of injury (Other vs MVC)	1.17	0.85	1.63	0.341

Malunion or nonunion incidence was not significantly different between the TC and NTC groups. Again, in the regression analysis, admission location did not significantly influence the malunion and nonunion. Other than male sex, rest of the covariates did not appear to affect the odds of malunion or nonunion, as shown in **Table 14**.

Table 14. Regression analysis on bony malunion or nonunion

Covariate	Diagnosis of malunion or non-union			
	OR	**95 % CI**		**p-value**
TC admission (Yes vs No)	1.04	0.81	1.34	0.7652
Age	1.00	0.99	1.00	0.1956
Sex (Male vs Female)	1.50	1.14	1.97	0.0035
Rural residency (vs Urban)	1.16	0.88	1.54	0.295
ISS > 15 (Yes vs No)	1.11	0.84	1.47	0.4691
CCI	0.90	0.74	1.11	0.3321
NVI (Yes vs No)	1.52	0.90	2.57	0.1207
Mechanism of injury (Fall vs MVC)	0.83	0.61	1.12	0.2195
Mechanism of injury (Other vs MVC)	0.88	0.66	1.19	0.4129

On the previous unadjusted analysis of the 30 day mortality, we previously saw significantly increased odds of death in the TC group, as high as 3.08 (**Table 6**). We saw that admission location was no longer significantly associated in the regression analysis. Instead, increasing age, ISS>15, and pre-existing comorbidities were significantly associated with 30 day mortality. The results are described in **Table 15**.

Table 15. Regression analysis on 30 day mortality

	Death within 30-days			
Covariate	**OR**	**95 % CI**		**p-value**
TC admission (Yes vs No)	1.58	0.97	2.55	0.0639
Age	1.04	1.03	1.05	<.0001
Sex (Male vs Female)	0.71	0.47	1.08	0.1137
Rural residency (vs Urban)	1.28	0.77	2.13	0.337
ISS > 15 (Yes vs No)	6.83	3.83	12.17	<.0001
CCI	1.42	1.23	1.64	<.0001
NVI (Yes vs No)	0.56	0.17	1.85	0.3448
Mechanism of injury (Fall vs MVC)	1.03	0.58	1.84	0.913
Mechanism of injury (Other vs MVC)	0.36	0.14	0.91	0.0317

Finally, length of stay (LOS) in the hospital was examined. Due to the significant overdispersion of the LOS, normality was violated in the analysis and a negative binomial model was used. All the included covariates were significantly associated with LOS, however in different ways. Factors associated with increased LOS were direct admission to TC, increased age, ISS>15, higher CCI, associated NVI (positive estimates). Rural residence, male sex, and non-MVC related injuries were associated with decreased LOS (negative estimates). The results are demonstrated in **Table 16**.

Table 16. Negative binomial model on length of stay

Covariate	Length of hospital stay	
	Estimate	**p-value**
TC admission (Yes vs No)	0.40	<.0001
Age	0.01	<.0001
Sex (Male vs Female)	- 0.10	0.0004
Rural residency (vs Urban)	- 0.16	<.0001
ISS > 15 (Yes vs No)	0.78	<.0001
CCI	0.13	<.0001
NVI (Yes vs No)	0.37	<.0001
Mechanism of injury (Fall vs MVC)	- 0.14	<.0001
Mechanism of injury (Other vs MVC)	- 0.22	<.0001

3.4 Discussion

Open extremity injuries are common, but devastating injuries that often require multiple surgeries and long period of rehabilitation until full return to one's normal daily activities. While previous literature has shown that these patients benefit from transfer to a specialized TC and early definitive management, the current management pattern of these injuries in Ontario is largely unknown.

In this study, we aimed to describe patients in Ontario who had an OTF between the April 2009 to March 2020. We gathered their basic demographic information, including age, sex, general area of residence, and details about their injury. We obtained information on the mechanism of injury, associated injuries, and few of the management patterns. We examined their outcomes and analyzed if they differed depending on what type of hospital they were admitted to, a TC or a NTC. In this section, the results of our analysis are discussed in depth, including the possible explanations of the results, its implications, and how they compare to the existing literature.

3.4.1 Discussion of Baseline Variables

Majority of the population was between the age of 30 to 60, with mean age of 47. Greater than two thirds of the patients (68.4%) were of male sex as described in RPDB. These results were similar to what was previously reported in the literature (205). Statistically, we found that the mean age of the TC group was younger, and the proportion of males was greater in the TC group. We also saw a large discrepancy in the mechanism of injury for the 2 groups, with MVC being the most common mechanism in the TC group (62.6%), compared to falls being the most common mechanism in the NTC group (44.8%).

Some of these differences could be explained that MVC is generally more common in males, and MVC in younger males is correlated with more severe and fatal injuries (206, 207), Younger males are also more likely to engage in higher risk behaviors, which could be contributing to their injuries (208, 209). These individuals with more complex injuries were likely brought to TC for multiple specialist involvement, contributing to the differences we saw.

We examined the general area of patient residence, whether they were in a rural area or urban area. The definition of rurality can vary, however for this study we described rurality as those living outside of urban centers such as the census metropolitan area (CMA) and census agglomeration (CA), which have population of 10,000 or more as per Statistics Canada (210). Those who lived in these non-CMA/CA regions accounted for only 17.3% of the entire study population. Based on the 2021 Canadian census, approximately 84% of the Canadian population (71.9% CMA, 12.0% CA) lived in urban regions (211), demonstrating that our population was fairly representative of the overall Canadian population. Despite TCs being located in larger cities, we saw no differences in the proportion of rural residents admitted to a TC versus NTC, demonstrating that residence location did not determine which hospital one was admitted to.

The income quintiles did not show significant differences among the groups and showed even distribution of approximately 17 to 20% per each income quintile. When we examined patient LHIN, we saw varied representation from all the different 14 LHINs, although certain LHINs such as LHIN 2, representing Southwest Ontario, seem to have greater proportion of people being admitted to NTC than TC.

Pertinent comorbidities were examined to identify any obvious risk factors for complications. Both the CCI and some of individual comorbidities were examined. We saw no significant difference in history of diabetes, congestive heart failure and chronic obstructive pulmonary disease between the TC and NTC group, but a statistically lower rate of hypertension diagnosis in the TC group. The lower rate of hypertension may have been due to a slightly younger group of patients in the TC, and its clinical impact is unclear. History of PVD was also examined, as PVD is thought to increase the risk of failure in STR, although recent studies showed acceptable success rates (212, 213). We saw only 26 patients (0.6%) had previous diagnosis from the entire cohort, which made this comparison difficult. The low numbers may be attributed to the younger population cohort, whereas the diagnosis of PVD and related procedures such as extremity arterial bypass is more prevalent in older patients (214).

CCI represents both the presence and severity of 17 patient factors, and was used as a composite measure of comorbidities in the current study (215). The majority of the population (>90%) scored 0 in the index, which was inconsistent with the history what we saw on examination of individual comorbidities such as diabetes, or hypertension, which was present in 11-26% of the population. Higher CCI was significantly associated with increased the odds of death within 30 days, amputation at 1 year, and longer hospital stay.

One of the most notable differences that was observed in the two groups was the proportion of those with ISS >15. As described previously, ISS accounts for injuries in multiple different body parts, and a higher total score is indicative of a more serious trauma. 14.8% of those admitted to a NTC had ISS >15, whereas 58.7% of those admitted a TC did. The results imply that majority of those admitted to TC had life-threatening extremity injury, or had other system injuries, bringing them a TC for specialist managements.

The last noteworthy portion of our baseline variable analysis was that only 47 patients (1.1%), out of 4240 total patients, were transferred to a TC after initial admission to a NTC. Many other studies that previously looked at the outcome of lower extremity trauma patients compared those admitted to a TC and later transferred to a TC (Section 2. 2). In contrast, we found that very small proportions of the patients were transferred, and instead the majority (58.2%) of the patients were managed in the primary NTC location. Interestingly, we saw a significant proportion of these transferred patients had an external fixator placed (48.9%) and had a plastic surgery consultation (40.4%), and none of them had amputation. While we were not able to describe all the details of this transferred population, we speculate that these were more severe injuries that required further specialist input and thus required transfer to TC.

3.4.2 Discussion of Management Patterns

In our analysis, we were able to gather information on the management patterns of the patient population. One of the primary outcomes of interest was the proportion of the patients that had STR and when they had the STR. We saw that close to 9.8% of the entire cohort with OTF had an STR. This value is similar to the nationwide register-based study in Sweden where approximately 9% of OTF had enough soft tissue damage to require STR (180). Other large scale studies that examined the distribution of OTF reported Gustilo-Anderson grade III injuries to make up 23 to 57% of all OTF (216, 217). Two thirds of these Grade III injuries were IIIb and IIIc, where flap-based STR are considered to be necessary (18, 41). There was a significant difference in the proportion of those who had STR surgery while admitted to a TC (16.1%) and NTC (5.1%). While this current work is limited by the fact that the different grades or severities of OTF were not identified, these differences were likely due to more severe injuries being brought to a TC, and further requiring a specialist involvement for flap-based reconstruction.

Despite 9.8% of the cohort having some form of STR, double the number of individuals (20.8%) had a consultation to plastic surgery. More patients in TC had a consultation (32.1%) compared to those in NTC (12.5%). This may be due to the plastic surgery service being more available in tertiary hospitals, or due to the severity of the injuries in TC that require the specialist input.

The discrepancy in the number of plastic surgery consultations versus the actual STR that were recorded in the Canadian Classification of Health Intervention (CCHI) could be explained by multiple factors. Firstly, the CCHI codes that we have identified for STR may not have fully captured the various procedures that plastic surgeons have done for reconstruction, as there are multiple ways to perform STR. While we included all the procedures that described local, regional, and free flaps, as well as skin grafts, some of the procedures that was completed may have been coded differently. It is an inherent limitation of an administrative database study where the documented codes are not necessarily representative of clinical scenarios (218). Another factor may be that many of the injuries that were initially thought to require some sort of plastic surgery input, and therefore had a consultation, did not ultimately require any STR. It could have also been consultation to other injuries, such as facial fractures, and not necessarily of the leg.

As previously discussed in Chapter 2, early STR in open extremity injuries have been shown to improve patient outcomes. We looked at how many patients would have a very early STR within 72 hours of their injury, and we saw that only a small number of patients (2.3%) had STR within this time frame. Contrary to our hypothesis, there was no statistical difference in the odds of one having STR within 72 hours between the TC and NTC group (p=0.0066).

Instead, we saw that the time to STR was generally long, with a mean of 19.5 days for the entire cohort, with standard deviation of 21.1. This was consistent with the recent literature that saw the time to STR can range from few days to 90 days (178, 181, 188). The TC group had a longer delay to STR at 20.6 days compared to 17.4 days in a NTC (p=0.0073), which was contrasting to some of the literature that saw specialist centers with both orthopedic and plastic surgeons contributed to earlier management (194, 195).

The delay in STR may be from multiple factors, including one’s other injuries requiring earlier attention, and the availability of NPWT, which has significantly off-loaded the need for early STR in recent times (129, 130). We also raise the question of resource availability. STR for an extremity trauma is a complex procedure that is highly resource-intensive (145). First, a trained microsurgeon needs to be available for the surgery and be granted an operating time from the hospital. In addition to the operating time, assistants, scrub nurses, and functioning tools including the microscope need to be available. Following the surgery, patients are closely monitored in the inpatient ward for multiple days which again can be resource-intensive. Limitations of human in addition to infrastructure resource availability may contribute to delays. We question if these factors had contributed to the significant delay we saw in our analysis, and believe it could be a topic of future research.

One of our key outcomes of interest was amputation. In the literature, the total amputation rate of OTF is reported to be between 3.6% to 8% (170, 219–221). This was comparable to our analysis where 2.8% of the cohort had early amputation within 1 week of injury, and 4.5% had amputation at some point within 1 year of injury. Amputation within 1 week represented primary amputation, amputation completed due to severe injuries, without attempt of limb salvage. This time frame reflects previous literature showing median time to amputation for non-salvaged limb was 4 days in a study by Jain et al (222), and also from Staruch et al who showed limb amputation in military and civilian personnel occurred within 5 to 8 days (223). We saw significantly increased odds of primary amputation in the TC group, which is likely related to the severity of their injuries as seen in the regression analysis.

For the remaining 1.7% of those who had amputation between 1 week to 1 year time. In this current analysis, it is unclear whether these were primary amputations that simply occurred after 1 week, or secondary amputation in those who initially had limb salvage. In the regression analysis, we saw that the degree of one's injuries, as seen in ISS score or associated NVI, were contributing significantly to the odds of amputation in this time frame in addition to initially being admitted to a TC.

While elevated age and CCI score were significant covariates that affected rates of amputation within 1 year time frame, they were not significant factors affecting amputation within 1 week time. Presence of comorbidities, such as diabetes has previously been shown be to a risk factor for complications after limb salvage following extremity trauma (224), whereas age was not (224, 225). Further analysis on the population who had STR may help delineate risk factors to complications after limb salvage.

External fixation was another management pattern we examined, and we saw significantly increased odds of external fixation among patients who were admitted to a TC. The effect persisted in regression analysis, while residency and the degree of their injuries as indicated by ISS and NVI also significantly influenced the odds. Many individuals may have required temporary fixation while other injuries were being managed, or temporary external fixation may have been necessary due to extensive contamination and comminution, with plans of return to the operating room in the future (41).

3.4.3 Discussion of Patient Outcomes

Wound infection is one of the most common complications of OTF, with the reported infection rates as high as 34.3% in the literature (4, 7, 132, 133). As per CDC criteria, wound infections can be described as superficial, or deep infections, as completed in previous literature. Bone infections, osteomyelitis, are also common, and can also be treated with intravenous antibiotics, but osteomyelitis in presence of foreign hardware such as plates and screws, require hardware removal and/or operative debridement (226, 227).

In our analysis, we looked at OHIP codes that describe incision and drainage, and debridement of the bone and/or soft tissue of the leg. We also included CCHI codes that describe hardware removal from the leg, given that many of these infections ultimately require hardware removal for source control. Using these specific codes allowed us to ensure that the infection cases we were extracting was that of the lower limb, instead of other body parts that may also have become infected in the setting of polytrauma.

The overall incidence of wound infection in our cohort was 33.8%, which is comparable to previous findings (4, 7, 132) We saw significantly greater incidence in the TC group versus the NTC group (OR 1.49), although this was no longer significant in regression analysis. Instead, factors that appeared to affect infection more was rural residency, ISS>15, and NVI. This methodology has few limitations. First, it overestimates the infection cases since not all hardware is removed due to infection, and sometimes due to pain or bony malunion (228, 229). However, it also underestimates, as many cases of milder soft tissue infections do not require a surgical debridement and are managed with antibiotics.

Similarly, malunion, and nonunion are common complications of OTF, each affecting 10% to 15.5% of the OTF. (49, 64, 143). The high rates are thought to occur due to the soft tissue injuries involving the vasculature that supply the bone (137, 138), hence the importance of early soft tissue coverage with well-vascularized flaps were emphasized (38, 179). Malunion or nonunion necessitates further surgeries for correction, such as hardware removal (229) and even amputation (230). In our analysis, the location of admission did not affect the diagnosis of malunion or non-union, and no other covariates were found to be significant in regression analysis.

Compartment syndrome is less common, but serious complication of tibia fractures (149). Compartment syndrome itself can result in numerous morbidities if not managed appropriately such as muscle necrosis (3, 151), and the management itself, fasciotomy, result in large soft tissue defects. Less than 6% of the cohort population had this complication which is consistent with what's reported in the literature (147, 148), and we did not see significant difference in incidence between the TC and NTC group. On regression analysis, we saw that those in TC were less likely to have compartment syndrome. The severity of injury, as indicated by NVI and ISS>15 significantly increased the odds.

In this work, we compiled the length of each hospital stay. In our analysis, we saw the mean length of stay (LOS) was 14 days for the entire cohort but varied significantly with standard deviation of 20.7. LOS was significantly longer in the TC group (20.4 days) compared to NTC group (9.7 days). Like other outcome measures, the LOS was significantly affected by multiple other factors, as seen on our regression analysis **Table 16**. Older age, ISS>15, increasing CCI, and presence of NVI increased the LOS, and male sex, rural residency, and non-MVC mechanisms decreased the LOS.

Work by Carragee et al and Page et al have previously shown that lower extremity trauma patients who were directly admitted to TC had shorter stay in hospital (171, 173). The discrepancy in our results versus theirs is likely because they compared to those who were transferred to a TC from a peripheral center, whereas we compared those admitted directly to a TC and those that was directly admitted in a NTC. Overall, the increased LOS in TC is likely due to more complex injury in general (216), requiring bigger surgeries such as a free-flap and prolonged monitoring (231). Complications and repeat operations may have also contributed to longer stay (171, 173, 232). Length of stay can also be confounded by patient factors, such as age and underlying comorbidities (233, 234). Additionally, in Ontario, physiotherapists and occupational therapists work in hospital settings and support trauma patients until they can mobilize safely. With more serious extremity traumas, this process could have contributed to their longer LOS.

Death from OTF alone is rare, and not well studied (221). The majority of the mortality likely resulted from confounding underlying disease, such as cardiovascular and respiratory illnesses, as well as complications from the initial injury (221). The mortality of patients who had OTF in the literature ranged from 2% to 11%, follow up period ranging from 3 months to 6 months (221, 235), but also as high as 33% in the elderly population at 120 days after injury (236). In our analysis, we saw very small percentage of the cohort (2.6%) died within 30 days, and there were significantly increased odds when they were admitted to TC. As seen in the literature, we saw that age, ISS>15, and CCI were significant contributors to the mortality in regression analysis, instead of the admission location alone.

Previous literature examining mortality after MVC-related polytrauma found patients who were directly admitted to a TC had 30% decreased mortality in the first 48 hours compared to those who were admitted to a NTC in Canada (237). Our study did not show similar findings in exam of 30-day mortality. Garwe et al saw that among major trauma patients who initially presented to a nontertiary center, those who were subsequently transferred to a Level I or II TC had improved 30 day mortality (238). In the current analysis, none of the transferred patients died within 30 days, however this could be a topic of further research in the future.

3.4.4 Strengths and Limitations

The current work has number of strengths and limitations. The main strength is that we were able to successfully capture a large cohort of population from the ICES database that had OTF in an 11-year period and describe these patients.

A strength, but also a limitation of this study is how the comparison groups were determined. In our initial study design, we aimed to compare the population that was directly admitted to a TC, and the population that were initially admitted to a NTC and later transferred to a TC. This comparison was previously discussed in Chapter 2, and we wanted to investigate if similar findings would be found in Ontario. However, we identified key limitations including small sample size, and the risk of immortal time bias for deaths and complications that could occur prior to transfer (239). Thus, we compared the groups based on admission location, and identified the small group of patients who were later transferred. While the current methodology makes it difficult to compare the results to some of the pre-existing literature, we were still able to describe the two patient populations and their outcomes.

A general limitation of the study, as mentioned in previous sections, is that we were not able to account for other bodily injuries. Serious injuries to the head injury or abdomen may have triggered automatic admission to a TC, given certain imaging modalities like computed tomography (CT), and specialized services such as neurosurgery is only available in larger tertiary centers. For example, according to the Critical Care Services Ontario, there are 11 designated adult neurosurgery centers in Ontario, many of which coincide with designated TCs, with the exception of Trillium Health Partners and Unity Health Ontario (240). Patients with head injuries who were brought to TC may have required imminent interventions before their OTF could be addressed. While the ISS>15 premium fee code was used to adjust for these associated injuries, more granular information would have given us better understanding to how patients were managed.

Similarly, we had to make assumptions to capture the index event and subsequent outcomes. For instance, when describing the time of the OTF, we made the assumption that it would be approximately same as the time of arrival to ED. EMS in Canada generally arrives quickly at the scene of incident, with 8 minutes as gold standard for life threatening events (241). In 2020 report of response times of EMS arriving to a patient in the Middlesex County, the times ranged from 6 minutes to 12 minutes (242). However, this methodology does not account for the transportation time to the admitting hospital, which may take hours. For instance, in London, trauma patients in Southwestern Ontario travel 1-3 hours from the periphery to Victoria Hospital, which does not consider the time to assess and stabilize the patient on the scene or at the local emergency room.

Other assumptions that were made in the study design is the use of administrative codes in identifying the baseline characteristics and outcomes. For example, for identifying those who had external fixation, one OHIP code (E555) in combination with other reduction codes were used to quality as a “fixation” event. However, the OHIP billing may vary depending on the surgeon and institution, which creates variability in what we were able to capture in our data extraction. To account for some of these limitations, we used CCHI codes for some of our variables, as CCHI codes list the anatomical location. However as discussed above, administrative codes are not always reliable, and discrepancies exist between what was completed in hospital and what was recorded (218). Future studies can address these limitations and improve methodology to investigate extremity traumas in Ontario and their outcomes.

3.5 Summary and Conclusions

The results of our study revealed that many young and healthy individuals of Ontario endure lower extremity traumas each year. These individuals came from diverse residential and economic backgrounds but were mostly male. Many patients had multisystem injuries, and one third of them were admitted to a trauma center. Complications of the injury included lower limb amputations and infections, and among those who had soft tissue reconstruction, it took an average of 3 weeks for them to have the surgery.

In Chapter 1, we hypothesized that the group that is directly admitted to a TC would have early STR, and subsequently have reduced rates of amputation, infection, mal/nonunion, and revision surgery. In our analysis, we saw that those who were admitted to TC did have more STR, but they were not necessarily earlier. Those admitted to TC had increased incidence of amputation within 1 week and 1 year, placement of external fixation, plastic surgery consultation, and have longer hospital stay. In contrast, there was reduced incidence of compartment syndrome in those admitted to a TC. There were no differences in the rate of wound infection, bone malunion or nonunion, or mortality within 30 days.

The above findings were after adjusting for multiple covariates found significant in our baseline analysis. The mixed findings of patient outcome in TC and NTC likely can be attributed to many other confounding factors that we were not necessarily able to adjust for.

Nevertheless, this descriptive study provides valuable information on how lower extremity traumas are managed in Ontario and what type of interventions could be implemented to improve outcomes.

Chapter 4

4 General Discussion and Conclusion

This chapter re-visits the objectives of previous chapters and summarizes the findings. It discusses the result in context of what's been previously described in the literature, and what other studies we can conduct in the future. Finally, it will discuss the significance of this work.

4.1 Summary of Chapters 1 and 2

The purpose of Chapter 1 was to help readers understand the complexity of lower limb traumas, and why collaborative effort between multiple specialties is required. It contained background information on leg anatomy, and trauma management in the context of OTF. Common complications of OTF and STR options for different areas of the tibia was discussed.

Chapter 2 aimed to review the literature on what type of management practices had been shown to improve outcome following an OTF. Several topics currently debated in the literature, such as the question of limb salvage versus amputation, direct transfer versus delayed transfer to a TC that has specialist service, and early versus delayed STR, were discussed. The notion of "orthoplastic" team was also reviewed in this chapter.

While the current literature is mixed, we found evidence of the following approaches to improve patient outcome after an OTF: direct admission to a TC, early STR, and early involvement of the orthoplastic team. In case of severe injuries with uncertain viability, limb salvage and primary amputation showed comparable long term functional outcome.

4.2 Summary of Chapter 3

Chapter 3 aimed to review the current trauma management protocol of OTF in Ontario, using linked-population data stored in the ICES, and see the differences in patient outcome.

Specifically,

1. To describe the characteristics of patients with OTF, including the demographic information, comorbidities, severity of injury, hospital admission and transfer, and interventions they had.
2. To determine the proportion of patients who get a direct admission to a Level I or Level II TC, versus an admission to a peripheral, NTC, and investigate differences in outcome.
3. To investigate whether admission location impacted how early they got a soft tissue reconstructive surgery.

We hypothesized that those who had direct admission to a TC would have early STR, and have reduced rates of complications such as amputation, infection, and mal/nonunion. However, in our population level analysis, we saw that those admitted to TC had higher rates of amputation, later STR, and more infections, and these results were confounded by the greater degree of associated injuries and accompanied neurovascular injuries in the TC population.

4.3 General Discussion and Future Directions

The question of amputation versus limb salvage has been an interest to trauma surgeons for decades, and a reason for many lower extremity studies that looked at their outcomes. Many studies have demonstrated that functional outcome in those who undergo either amputation or limb salvage are comparable (45, 158, 160, 161). And yet, an extremity amputation can be devastating to an individual. Amputees report significant dissatisfaction in their limb appearance and overall low self body-image, further affecting individual's participation in social situations and their overall psychological well-being (45, 162, 163). Secondary amputation may be a particularly devastating event, for those who thought they had a successful limb salvage, and this can occur many years following the limb salvage from various complications.

In our analysis, we saw 2.8% of the cohort population had primary amputation, one that was done without limb salvage attempt within 1 week time. We then another 1.7% had amputation between the 1 week to 1 year of follow up. The values were consistent with those reported in the past literature (182, 221, 243, 244). The numbers we found may have been underestimation however, as amputations following lower limb trauma can happen up to 2 years after injury (245, 246). Long-term follow-up up to 5 years, as well as functional outcomes, including time to ambulation, employment status, and general quality of life are topics that can be addressed in future studies.

Among those who did have limb salvage with STR in our cohort, we saw that the mean time to the surgery was 19.5 days following injury. Delay of STR for greater than 2 weeks have been previously reported in the literature, with large proportion of the patients having STR up to 3 months after their injuries (178, 180, 187–189) . Many of these studies however have also demonstrated that outcomes were better when STR was completed earlier, preferably in less than 10 days (178, 180, 185). Future studies can examine the current cohort population and compare their outcomes based on the timing of STR.

Another potential study is examination of the change of management practices over the years. With landmark analysis such as the LEAP study showing that overall functional outcome of patients who had amputation was comparable to those who had limb salvage (159, 160), we can investigate if overall amputation rates for lower limb traumas have changed over time. Other changes in practice that could be examined is reconstruction techniques, such as if the type of flaps surgeons utilize have changed over time.

A concept that was explored in Chapter 2, but not further addressed in this current work is the "orthoplastic" team. An orthoplastic team consists of orthopedic trauma surgeons and plastic/ reconstructive surgeons that work cooperatively to achieve definitive reduction and soft tissue coverage in complex trauma patients. Such teams currently exist in many parts of the world including the United Kingdom, but not in Canada. In contrast, Ontario has seen over 4200 patients with OTF in the span of 11 years, averaging to approximately 1 OTF a day. Such large number raises the question to whether implementation of an orthoplastic team would be reasonable to more effectively manage OTF, reducing the time of bony reduction and expediting STR. Future studies can interview clinicians across the province to survey whether they think orthoplastic team would be a reasonable implementation in the Canadian health care system.

Cost-utility analysis of the OTF management is another area that is not addressed in this current study, but can be studied in the future. The cost of OTF and the economic burden on the individual and the healthcare system has been addressed in multiple previous studies. In a systematic review by Schade et al, the initial hospitalization cost of OTF in the United States was estimated between £5705 to £126,479 in the author's own British pounds, equivalent to approximately $9600 to $210,000 Canadian dollars (CAD) (145). Among the analyzed was a Canadian study by Briel et al, who estimated the total cost of OTF to be between $10,000 and $13,000 CAD (247). This study did not include the cost of STR however, which can add a significant amount. While the average cost related to lower limb STR alone could not be found, literature on flap-based breast reconstruction may be used to estimate the costs. In a study by Tan et al, flap-based breast reconstruction with average 5 day hospital stay cost approximately $16000 CAD (248), and surgeon and anesthesiologist billings added additional thousands of dollars. Overall, it is undeniable that OTF and its management is significantly taxing to the current Ontario health care system. Past analysis has already shown that delays to surgical management in OTF had more associated costs (249). Questions such as whether early STR can reduce initial admission costs in Ontario and other future complications remain to be answered.

Many studies have also examined the cost of limb amputation versus salvage. Early amputation is thought to have lower initial costs due to the shorter hospital stay compared to those who undergo limb salvage (145). In terms of the lost economic potential, the rate of return to work was comparable between the 2 groups in the studies (21, 49, 250). 60% of the patients had returned to work, with a mean delay of 14 months (49). However, recent cost-utility analysis by Chung et al showed that the total life-time costs are higher in the amputation group, owing to the high costs of the prosthetics over the years. The lifetime medical cost of a patient in the United States with a salvaged limb was $133,704, versus that of a patient with amputation, which was $350,465 assuming 40 years of life was remaining (251). Similar studies can be conducted in the current Canadian population and see if the lifetime costs significantly differ among the two groups. The results may again, help make different policies and guidelines in the management of lower limb trauma in Ontario.

4.4 Significance

With OTF being a particularly challenging injury to manage with myriad of complications, a number of studies examined the topic in a population-based level using databases such as the American College of Surgeons National Surgical Quality Improvement Program (224), Nationwide Inpatient Sample (243), American College of Surgeons Trauma Quality Improvement Program (185). Many studies were also completed in Europe, where their own unique databases such as Secure Anonymized Information Linkage (SAIL) were utilized in the United Kingdom (171), but also in Sweden (180) and Germany (216) There has not yet been however, a study looking into the Canadian population.

Our work is the first in Canada that examined outcomes of open lower extremity injuries in a population-based level, gathering data from up to 155 hospitals in Ontario. Our study focused on the Ontario population with the available ICES data, which makes up 38.8% of the entire Canadian population (252). Previous literature reported variations in trauma systems across Canada, such as British Columbia having an "inclusive" trauma system model, distinct from the "exclusive" model in Ontario (253). Because of these differences, while some of our findings pertaining to TC admissions and interfacility transfer may not be generalizable to the entirety of Canada, the principles of efficient management of trauma are still important factors in improving patient outcome in nationwide level.

We were able to identify over 4000 individuals who had OTF over an 11-year period and identified their characteristics, and their management patterns including where they were admitted. We also identified their outcomes for up to 1 year period. These results provide high-quality evidence for initiating discussions on trauma triage and management in an institutional level, but also at provincial level to discuss new guidelines and policies for best outcomes. The results on outcome can also be used as a baseline for future studies, such as determining the cohort size for a clinical trial if a particular intervention was to be considered in this population. The presented results demonstrate there remains a lot of room for improvement in aspects such as reducing the vast number of OTF that occur each year by implementing public health campaigns, decreasing the infection rates among the OTF population, and facilitating earlier soft tissue reconstructive surgeries.

4.5 Conclusions

Open tibia fractures are common, but life-changing injuries that result in prolonged course of surgeries and rehabilitation. This work showed that these fractures affect significant number of individuals in Ontario and result in a myriad of complications, even amputations. More serious injuries were taken to a trauma center, and they were more likely to have such complications and have longer delay to a soft tissue reconstruction. Future studies can help delineate factors that could improve outcome on these patients.

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Appendices

Appendix A. Compiled list of codes used for analysis

Concept	Code Type	Code	Description
Open Tibia Fracture	DX10	S82101	Fracture of upper (proximal) end of tibia with or without fibula, open
		S82201	Fracture of shaft of tibia with or without fibula, open
		S82301	Fracture of lower (distal) end of tibia with or without fibula, open
Previous tibia injury	DX10	M8406	Malunion of fracture, lower leg
		M8416	Nonunion of fracture [pseudarthrosis], lower leg
		M8426	Delayed union of fracture, lower leg
		M8436	Stress fracture, not elsewhere classified, lower leg
		M8446	Pathological fracture, not elsewhere classified, lower leg
		S82100	Fracture of upper (proximal) end of tibia with or without fibula, closed
		S82101	Fracture of upper (proximal) end of tibia with or without fibula, open
		S82200	Fracture of shaft of tibia with or without fibula, closed
		S82201	Fracture of shaft of tibia with or without fibula, open
		S82300	Fracture of lower (distal) end of tibia with or without fibula, closed
		S82301	Fracture of lower (distal) end of tibia with or without fibula, open
	OHIP	F078	FRACT.TIBIA W/OUT FIBULA NO REDUC, RIGID IMMOBILIZATION
		F079	FRACT.TIBIA W/OUT FIBULA CL.REDUC.
		F080	FRACT.TIBIA W/OUT FIBULA OPEN REDUC SHAFT
		F081	FRACT.TIBIA W/OUT FIBULA MEDIAL/LATERAL TIBIA PLATEAU
		E041	Pseudoarthrosis intramedullary nail with distal and proximal locking screws tibia .

Nerve Injury	DX10	S8400	Laceration of (posterior) tibial nerve at lower leg level
		S8408	Other and unspecified injury of (posterior) tibial nerve at lower leg level
		S8410	Laceration of peroneal nerve at lower leg level
		S8418	Other and unspecified injury of peroneal nerve at lower leg level
		S8470	Laceration of multiple nerves at lower leg level
Vascular Injury	DX10	S850	Injury of popliteal artery
		S851	Injury of (anterior)(posterior) tibial artery
		S852	Injury of peroneal artery
		S857	Injury of multiple blood vessels at lower leg level
Mechanism of Injury	DX10	V0	MVA
		V1	
		V2	
		V3	
		V4	
		V5	
		V6	
		V7	
		W0	Falls
		W1	
Consultation to Plastic Surgery service	OHIP	A085	Consultation - general
		A086	Repeat consultation
		A083	Specific assessment
		A084	Partial assessment
		A935	Special surgical consultation
		C085	Consultation - inpatient
		C086	Repeat consultation
		C083	Specific assessment
		C084	Specific re-assessment

		C935	Special surgical consultation
Soft Tissue Reconstruction	CCHI	1VQ82LAXXF	Reattachment, tibia and fibula using free flap [e.g. myocutaneous or composite bone flap]
		1VQ58LAXXF	Procurement, tibia and fibula of free flap [e.g. fibular flap] using open approach
		1VQ87LAKDF	Excision partial, tibia and fibula with free flap [e.g fibular flap] using wire, mesh, staple
		1VQ87LAKDG	Excision partial, tibia and fibula with pedicled flap [e.g. myocutaneous flap] using wire, mesh, staple
		1VQ87LAKDQ	Excision partial, tibia and fibula with combined sources of tissue [e.g. graft, flap, bone cement] using wire, mesh, staple
		1VQ87LALQF	Excision partial, tibia and fibula with free flap [e.g fibular flap] using intramedullary nail
		1VQ87LALQG	Excision partial, tibia and fibula with pedicled flap [e.g. myocutaneous flap] using intramedullary nail
		1VQ87LALQQ	Excision partial, tibia and fibula with combined sources of tissue [e.g. graft, flap, bone cement] using intramedullary nail
		1VQ87LANVF	Excision partial, tibia and fibula with free flap [e.g fibular flap] using pin, nail
		1VQ87LANVG	Excision partial, tibia and fibula with pedicled flap [e.g. myocutaneous flap] using pin, nail
		1VQ87LANVQ	Excision partial, tibia and fibula with combined sources of tissue [e.g. graft, flap, bone cement] using pin, nail
		1VQ87LANWF	Excision partial, tibia and fibula with free flap [e.g fibular flap] using screw, plate and screw
		1VQ87LANWG	Excision partial, tibia and fibula with pedicled flap [e.g. myocutaneous flap] using screw, plate and screw
		1VQ87LANWQ	Excision partial, tibia and fibula with combined sources of tissue [e.g. graft, flap, bone cement] using screw, plate and screw

		1VQ87LAPMF	Excision partial, tibia and fibula with free flap [e.g fibular flap] using endoprosthesis [tibial head]
		1VQ87LAPMQ	Excision partial, tibia and fibula with combined sources of tissue [e.g. graft, flap, bone cement] using endoprosthesis [tibial head]
		1VQ87LAXXG	Excision partial, tibia and fibula with pedicled flap [e.g. myocutaneous flap], no device used
		1VR57LA	Extraction, muscles of lower leg [around knee] using open approach
		1VR58LAXXA	Procurement, muscles of lower leg [around knee] of muscle graft using open approach
		1VR58LAXXF	Procurement, muscles of lower leg [around knee] of free flap using open approach
		1VR80LAXXA	Repair, muscles of lower leg [around knee] using open approach and autograft [e.g. fascia]
		1VR80LAXXE	Repair, muscles of lower leg [around knee] using open approach and local transposition flap [e.g. realignment, advancement]
		1VR80LAXXF	Repair, muscles of lower leg [around knee] using open approach and free flap
		1VR80LAXXG	Repair, muscles of lower leg [around knee] using open approach and pedicled flap
		1VR80LAXXN	Repair, muscles of lower leg [around knee] using open approach and synthetic tissue [e.g. Goretex, mesh, Silastic sheath]
		1VR80LAXXQ	Repair, muscles of lower leg [around knee] using open approach and combined sources of tissue [e.g. graft/flap, mesh]
		1VR87LAXXA	Excision partial, muscles of lower leg [around knee] using autograft [e.g. fascia or skin] (for closure of surgical defect)
		1VR87LAXXE	Excision partial, muscles of lower leg [around knee] using local transposition flap [e.g. advancement muscle or Z-plasty skin flap] (for closure of defect)
		1VR87LAXXF	Excision partial, muscles of lower leg [around knee] using free flap [e.g.

			myocutaneous free flap] (for closure of defect)
		1VR87LAXX Q	Excision partial, muscles of lower leg [around knee] using combined sources of tissue [e.g. skin graft with flap] (for closure of defect)
		1VX87LAXX A	Excision partial, soft tissue of leg using autograft [e.g. fascia or skin] (for closure of surgical defect)
		1VX87LAXXE	Excision partial, soft tissue of leg using local transposition flap [e.g. advancement muscle or Z-plasty skin flap] (for closure of defect)
		1VX87LAXXF	Excision partial, soft tissue of leg using free flap [e.g. myocutaneous free flap] (for closure of defect)
		1VX87LAXX Q	Excision partial, soft tissue of leg using combined sources of tissue [e.g. skin graft with flap] (for closure of defect)
		1YV58LAXX A	Procurement, skin of leg of full thickness autograft using open approach
		1YV58LAXX B	Procurement, skin of leg of split thickness autograft using open approach
		1YV58LAXXF	Procurement, skin of leg of free flap using open approach
		1YV80LAXX A	Repair, skin of leg using full-thickness autograft
		1YV80LAXX B	Repair, skin of leg using split-thickness autograft
		1YV80LAXXE	Repair, skin of leg using local flap [e.g. rotation, advancement, transposition, Z-plasty]
		1YV80LAXXF	Repair, skin of leg using free flap [e.g. fasciocutaneous flap]
		1YV87LAAG A	Excision partial, skin of leg open [excisional] approach and laser using full thickness autograft
		1YV87LAAG B	Excision partial, skin of leg open [excisional] approach and laser using split thickness autograft
		1YV87LAAGE	Excision partial, skin of leg open [excisional] approach and laser using local flap [e.g. rotation, advancement, transposition, Z-plasty] for closure

		1YV87LAAGF	Excision partial, skin of leg open [excisional] approach and laser using free flap
		1YV87LAAYA	Excision partial, skin of leg open [excisional] approach and dermatome using full thickness autograft
		1YV87LAAYB	Excision partial, skin of leg open [excisional] approach and dermatome using split thickness autograft
		1YV87LAAYE	Excision partial, skin of leg open [excisional] approach and dermatome using local flap [e.g. rotation, advancement, transposition, Z-plasty] for closure
		1YV87LAAYF	Excision partial, skin of leg open [excisional] approach and dermatome using free flap
		1YV87LAXXA	Excision partial, skin of leg open [excisional] approach using full thickness autograft
		1YV87LAXXB	Excision partial, skin of leg open [excisional] approach using split thickness autograft
		1YV87LAXXE	Excision partial, skin of leg open [excisional] approach using local flap [e.g. rotation, advancement, transposition, Z-plasty] for closure
		1YV87LAXXF	Excision partial, skin of leg open [excisional] approach using free flap
		1YY84LA	Construction or reconstruction, skin of surgically constructed sites using open approach
		1YY87LA	Excision partial, skin of surgically constructed sites using open (excisional) approach
		1YY89LA	Excision total, skin of surgically constructed sites using open (excisional) approach
		1YY80LAXXA	Repair, skin of surgically constructed sites using open approach and full-thickness autograft
		1YY80LAXXB	Repair, skin of surgically constructed sites using open approach and split-thickness autograft
		1YY80LAXXE	Repair, skin of surgically constructed sites using open approach and local flap [e.g.

			rotation, advancement, transposition, Z-plasty]
		1YZ80LAXXA	Repair, skin NEC using full-thickness autograft
		1YZ80LAXXB	Repair, skin NEC using split-thickness autograft
		1YZ80LAXXE	Repair, skin NEC using local flap [e.g. rotation, advancement, transposition, Z-plasty]
		1YZ80LAXXF	Repair, skin NEC using open approach and free flap [e.g. microvascular free flap]
		1YZ87LAAGA	Excision partial, skin NEC open [excisional] approach and laser using full thickness autograft
		1YZ87LAAGB	Excision partial, skin NEC open [excisional] approach and laser using split thickness autograft
		1YZ87LAAGE	Excision partial, skin NEC open [excisional] approach and laser using local flap [e.g. rotation, advancement, transposition, Z-plasty] for closure
		1YZ87LAAGF	Excision partial, skin NEC open [excisional] approach and laser using free flap
		1YZ87LAAYA	Excision partial, skin NEC open [excisional] approach and dermatome using full thickness autograft
		1YZ87LAAYB	Excision partial, skin NEC open [excisional] approach and dermatome using split thickness autograft
		1YZ87LAAYE	Excision partial, skin NEC open [excisional] approach and dermatome using local flap [e.g. rotation, advancement, transposition, Z-plasty] for closure
		1YZ87LAAYF	Excision partial, skin NEC open [excisional] approach and dermatome using free flap
		1YZ87LAXXA	Excision partial, skin NEC open [excisional] approach using full thickness autograft
		1YZ87LAXXB	Excision partial, skin NEC open [excisional] approach using split thickness autograft
		1YZ87LAXXE	Excision partial, skin NEC open [excisional] approach using local flap [e.g.

			rotation, advancement, transposition, Z-plasty] for closure
		1YZ87LAXXF	Excision partial, skin NEC open [excisional] approach using free flap
Amputation	CCHI	1VC93LA	Amputation, femur using simple apposition technique [e.g. suturing] (for closure of stump)
		1VC93LARV	Amputation, femur using bone-anchored prosthetic bridge (or stem implant device)
		1VC93LAXXA	Amputation, femur using skin graft (for closure of stump)
		1VC93LAXXE	Amputation, femur using local flap [e.g. myoplasty, osteoperiosteal flap or myodesis] (for closure of stump)
		1VC93LAXXQ	Amputation, femur using combined sources of tissue [e.g. myoplasty or myodesis with free bone autograft] (to retain bony length and for closure of stump)
		1VG93LA	Amputation, knee joint using simple apposition technique [e.g. suturing] for closure of stump)
		1VG93LAXXA	Amputation, knee joint using skin graft (for closure of stump)
		1VG93LAXXE	Amputation, knee joint using local flap myoplasty or myodesis (for closure of stump)
		1VQ93LA	Amputation, tibia and fibula using simple apposition technique [e.g. suturing] (for closure of stump)
		1VQ93LARV	Amputation, tibia and fibula using bone-anchored prosthetic bridge or stem implant device
		1VQ93LAXXA	Amputation, tibia and fibula using skin graft (for closure of stump)
		1VQ93LAXXE	Amputation, tibia and fibula using local flap [e.g. myoplasty, osteoperiosteal flap or myodesis] (for closure of stump)
		1VQ93LAXXQ	Amputation, tibia and fibula using combined sources of tissue [e.g. myoplasty or myodesis with free bone autograft] (to retain bony length and for closure of stump)
	OHIP	R624	Extremities – Amputation through tibia & fibula

		R625	Extremities – Amputation at knee, gritti-strokes/callander
		R626	Extremities – Amputation through femur
External Fixation	CCHI	1VQ03HAKC	Immobilization, tibia and fibula with percutaneous traction[e.g. skeletal] using external fixator [percutaneous pin, wire]
		1VQ03HASR	Immobilization, tibia and fibula with percutaneous traction[e.g. skeletal] using splinting device
		1VQ03JZFQ	Immobilization, tibia and fibula with external traction[e.g. skin] using cast [e.g. support, weight bearing]
		1VQ03JZSR	Immobilization, tibia and fibula with external traction[e.g. skin] using splinting device
		1VQ03JZTA	Immobilization, tibia and fibula with external traction[e.g. skin] using traction alone
		1VQ74HAKD	Fixation, tibia and fibula percutaneous approach [e.g. with closed or no reduction] fixation device alone using wire
		1VQ74HALQ	Fixation, tibia and fibula percutaneous approach [e.g. with closed or no reduction] fixation device alone using intramedullary nail
		1VQ74HANV	Fixation, tibia and fibula percutaneous approach [e.g. with closed or no reduction] fixation device alone using pin, nail
		1VQ74HANW	Fixation, tibia and fibula percutaneous approach [e.g. with closed or no reduction] fixation device alone using plate,screw
	OHIP	E555	rigid external fixation (excluding casts) for closed reduction, to closed reduction fee
		F075	closed reduction ankle
		F076	closed reduction one malleolus
		F079	tibia with or without fibula - closed reduction
		F104	Ankle fracture with tibial Plafond burst closed reduction

Infection and Debridement	CCHI	1VQ55LAKD	Removal of device, tibia and fibula of wire/mesh/staple using open approach
		1VQ55LALQ	Removal of device, tibia and fibula of intramedullary nail using open approach
		1VQ55LANV	Removal of device, tibia and fibula of pin/nail using open approach
		1VQ55LANW	Removal of device, tibia and fibula of plate/screw using open approach
		1VQ55LAPM	Removal of device, tibia and fibula of endoprosthesis using open approach
	OHIP	R237	Incision and Drainage, tibia and fibula bone
		R238	Incision and Drainage, Saucerization and bone grafting tibia and fibula
		R239	Incision and Drainage, Sequestrectomy tibia and fibula
		R267	Removal of internal fixation device - general anesthetic
		Z226	Incision and Drainage, soft tissue tibia and fibula
		R220	Incision and Drainage, distal tibia and ankle bone
		R503	Incision and Drainage, foot and ankle joint
		Z228	Incision and Drainage, soft tissue open foot and ankle
		R201	Incision and Drainage, sequestrectomy foot and ankle
		R202	Incision and Drainage, Saucerization and bone grafting ankle
Compartment Syndrome	FEECODE	R495	Joint Fasciotomy – forearm/leg, decompression compartment syndrome
	INCODE	1VR72WK	Release, muscles of lower leg [around knee] using incisional technique [e.g. fasciotomy, myotomy]

Curriculum Vitae: Stephanie Mun Kim

EDUCATION

2021-	Master's of Science (MSc) in Surgery, Western University	
2020-	Residency, Plastic and Reconstructive Surgery, Western University	
2016-2020	Schulich School of Medicine & Dentistry, Western University	Doctor of Medicine
2012-2016	University of Toronto	Honours Bachelor of Science

HONORS AND AWARDS

2022 **Dr. Robert McFarlane Resident Research Award**
Awarded for the best overall research presentation in the annual Resident Research Day

2021 **Resident Research Grant, QI/ Patient Centered Research Category**
Research Grant of $4200 for study in assessing abdominal lymphedema with ultrasound

2021 **Canada Graduate Scholarships-Master's Award (CGSM)**
Scholarship of $17,500 to support the graduate student during their Master's studies.

2018 **Academic Enrichment Travel Fund, Western University**
Grant of $500 for medical students with outstanding research to allow travel to a research conference

2016 **Division of Teaching Labs Undergrad Research Award, Department of Physiology**
Research grant of $5000, based on academic performance and research experiences

2015 **Clara C. Benson Scholarship in Food Chemistry**
Awarded for excellence in Nutritional Sciences courses in UofT

2015 **Daniel Wilson Scholarship in Nutrition and Food Science**
Awarded for excellence in Nutritional Sciences courses in UofT, $100

2015 **Undergraduate Research Opportunity Program, Department of Physiology**
Research grant of $4800, based on academic performance and research experiences

2015 **Undergraduate Physiology Students' Association Community Involvement Award**
Awarded for excellence in Physiology courses and involvement in student community

2013-16 **University of Toronto Dean's List**
Awarded for excellence in academic performance with cumulative GPA>3.50

2012-15 **Bloor Lands Admission Scholarship**
Awarded for excellence in academic performance, total $18,000 over the course of 4 years

2013	**UofT Scholars Program In-Course Scholarship** Awarded for outstanding performance in first year of university, with value of $1500
2012	**UofT Scholars Program Admission Scholarship** Award of $5000 for first year students for excellence in their secondary education

RESEARCH, PUBLICATIONS & PRESENTATIONS

Peer-Reviewed Publications

Wu K, Kim S, Liu M, Sabino A, Minkhorst K, Yazdani A, Turley E. 2020. "Function-blocking RHAMM peptides attenuate fibrosis and promote anti-fibrotic adipokines in a bleomycin-induced murine model of systemic sclerosis" Journal of Investigative Dermatology.

Kim S, Truong J, Wu K, Gabril M, Grant A. 2019. "Malignant cylindroma of the scalp treated with staged perimeter excision: a case report and literature review" Journal of Plastic, Reconstructive & Aesthetic Surgery (JPRASO) 21:1-5.

Wu K, Kim S, Rajasingham S, Bruni I, Fung K, Roth K. 2019. "Simulation of urgent airway in a post-thyroidectomy hematoma". MedEd Portal. 15:10802

Kim S, Mcllwraith E, Chalmers J, Belsham D. 2018. "Palmitate induces an anti-inflammatory response in immortalized microglial BV-2 and IMG cell lines that decreases TNFa levels in mHypoE-46 hypothalamic neurons in co-culture" Neuroendocrinology 107(4):387-399.

Wu K, Kim S, Fung K, Roth K. 2018. "Assessing nontechnical skills in otolaryngology emergencies through simulation-based training" Laryngoscope 128(10): 2301-2306.

Tran DQ, Tse EK, Kim MH, Belsham DD. 2016. "Diet-induced cellular neuroinflammation in the hypothalamus: Mechanistic insights from investigation of neurons and microglia." Molecular and Cellular Endocrinology 438:18-26.
(Project published in former name: Mun Heui Kim)

Presentations

2022	Resident Research Day, Western University	Kim S, McClure A, Reid J, Simpson A. "Severe lower extremity trauma in Ontario: A linked population-based analysis	Oral
2021	Resident Research Day, Western University	Kim S, Garland K, Matic D. "Evaluation of unilateral primary cleft patients using the Nasolabial Aesthetics Scale"	Oral
2018	Canadian Society of Plastic Surgeons	Wu K, Kim S, Turley E, Yazdani A, DeLyzer T. "Effect of function-blocking RHAMM peptides on fibrosis in a bleomycin-induced scleroderma mouse model."	Oral
2018	Canadian Society of Otolaryngology – Head & Neck Surgery	Kim S, Wu K, Fung K, Roth K. "Teaching and Assessing Non-Technical Skills in Otolaryngology Emergencies through Simulation based training: a mixed methods study."	Oral

2018	Department of Surgery Research Day	Wu K, Kim S, Turley E, Yazdani A, DeLyzer T. "Characterizing primary fibroblasts in breast capsular contracture formation."	Poster

COMMUNITY INVOLVEMENT & CONTRIBUTIONS

2022 **Invited Speaker, Association of Women Surgeons Canada Regional Conference, Queens University**
Presented content on personal experience of being on different media platforms including TikTok, and encouraged medical students to make cautious decisions when posting on public platform

2017-18 **Emergencies in OTO-HNS Bootcamp**
Played the role of an ER nurse to assist in high-fidelity simulations designed for ENT and Emergency medicine residents at the C-STAR simulation-based training facility in London, ON

2017-18 **Senior & Junior Logistics Coordinator for "Hungry for Change" Gala**
Organized the logistics of the Gala, which raises funds for local charities and for summer elective students doing global health research abroad.

2017 **Invited Speaker at "Conversations in Health" by friends of MSF in Western**
Gave a talk about the pros and cons of medical voluntourism, and the ethical issues of non-medical professionals doing health-related work in foreign countries.

PROFESSIONAL DEVELOPMENT

2022 **Resident Teaching Committee.**
Represented the second year plastic surgery residents and participated in meetings with staff to create a more effective learning environment.

2015 **Host and Organizer of "HOPE was here, Documentary Screening and Panel Discussion"**
In collaboration with the 53rd week and Dalla Lana School of Public Health, organized a documentary screening event to educate the public about ethics of voluntourism, and invited experts in global health including the director of the documentary to facilitate discussion with the audience.

2015-16 **Co-President of Undergraduate Physiology Students' Association**
Organized many Academic and Social events for students in the Physiology program with the team. Ensured the logistics and finances of the events were well-managed.

2013-14 **Co-coordinator of High School Partnership Program of UofT International Health Program**
Organized the first "Take Action Conference" that included a speech competition of how students want to make a difference in global health. Now an annual event.