Isokinetic Strength Testing Following Intramedullary Nailing of Tibial Shaft Fractures Predicts Time to Recovery and Return of Muscle Strength in the Injured Extremity: A Prospective Case Series

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Received: 26 December 2017/Accepted: 2 March 2018/Published online: 27 April 2018
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Abstract *Background:* The speed and degree of functional recovery over time after surgery for tibial shaft fracture has been previously described using subjective methods. *Questions/Purpose:* This study aimed to quantitatively measure recovery of isokinetic strength in the injured leg after surgical repair of isolated closed tibial shaft fracture. *Methods:* In this prospective case series, patients were recruited after intramedullary nailing for isolated closed tibial shaft fracture at an academic medical center from January 2012 to December 2015. Recovery of isokinetic strength was quantified using an isokinetic dynamometer. Eight measures of isokinetic strength at 3, 6, and 12 months' follow-up were used to compare strength in the injured leg to the healthy leg. *Results:* In 36 patients recruited, there was a significant difference in strength between the healthy and injured legs at 3 months for seven of the eight metrics used, at 6 months for five of the eight metrics, and at 12 months for none of the eight metrics. Observing recovery of strength longitudinally, we saw significant improvement between 3 and 6 months for four of eight metrics and overall between 3

and 12 months for five of the eight metrics. All four metrics that showed a significant improvement between 3 and 6 months involved plantar flexion. No metrics showed significant improvement between 6 and 12 months. *Conclusions:* Patients exhibited equal strength between their healthy and injured legs at 12 months after surgery. Improvement in strength occurred to a greater extent between 3 and 6 months after surgery than between 6 and 12 months. Plantar flexion appeared to improve more rapidly than dorsal extension.

Keywords trauma · fracture · tibial shaft · isokinetic strength testing · torque · work · recovery · closed fracture

Introduction

The National Center for Health Statistics has reported an annual incidence of 492,000 fractures of the tibia and fibula in the USA, making tibial shaft fracture one of the most common long bone fractures [17]. These injuries are typically caused by road-traffic collisions or sports-related injuries [4]. Patients with tibial shaft fracture may be treated non-operatively or operatively, with intramedullary fixation being the preferred surgical method of treatment for both open and closed tibial shaft fractures [3, 6, 12].

The majority of studies that have evaluated functional recovery up to several years following tibial shaft fracture utilize subjective measures to draw their conclusions [2, 14]. With routine fracture healing, patients have reported varying degrees of functional recovery. There is also little longitudinal data on functional recovery, with most relevant studies reporting recovery at a single time point after intervention [2, 7, 11, 18]. Only one of these studies obtained objective

Level of Evidence: Level III, Prognostic Study (Prospective Case Series)

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s11420-018-9611-y>) contains supplementary material, which is available to authorized users.

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data using an isokinetic dynamometer [7]. Longitudinal, objective functional assessment of recovery following tibial shaft fracture has been completed once previously using the Hamlyn Mobility Score (HMS) [13].

The primary aim of this study was to use isokinetic strength to objectively compare injured and healthy leg function at 3, 6, and 12 months after surgical repair of an isolated closed tibial shaft fracture. The secondary aim was to quantify longitudinal recovery in the injured leg by comparing isokinetic strength scores between follow-up visits.

Methods

In this prospective case series all patients with isolated closed tibial shaft fractures at a single academic center from January 2012 to December 2015 were identified through hospital billing records and orthopedic trauma consults and recruited for study involvement post-operatively. The project was approved by the institutional review board, and informed consent was obtained from all human subjects. Inclusion criteria for the study were isolated closed tibial shaft fractures treated with an intramedullary nail in skeletally mature patients over 18 years of age. Patients with additional lower-extremity injuries and those with upper-extremity injuries that impacted their ability to bear weight were excluded. Patients with isolated tibia fractures who developed compartment syndrome necessitating fasciotomy were initially included; however, due to the small sample ($n = 5$) they were excluded from analysis. Retrospective chart review was performed to determine Orthopaedic Trauma Association (OTA) classification by the attending physician, surgical interventions, and demographic information for each participant. A Pearson's χ -square test was used to identify any variations in OTA classification by follow-up visit. Physical therapy began at the first post-operative visit, typically 2 weeks after surgery, and continued until the 3-month follow-up visit. Isokinetic strength evaluations of participants were performed at regularly scheduled 3-, 6-, and 12-month post-operative follow-up visits from April 2012 to July 2016.

The assessment of isokinetic muscle strength was performed bilaterally using an isokinetic dynamometer (System 3, Biodex Medical Systems, Shirley, NY, USA). The maximum isokinetic strength of the dorsal extensor and plantar flexor muscles of each leg was measured at two different angular velocities (60°/s and 120°/s), calculated as maximum torque per unit of body weight (Nm/kg) and total force per unit of body weight (N/kg) for each patient. The choice was made to use two angular velocities and two units of measurement to remain consistent with a previous analysis [7]. The validity of this tool has been proven in previous analyses [1, 5, 7, 9]. This yielded eight metrics of strength for the healthy and injured legs. Strength was assessed bilaterally at 3-, 6-, and 12-month follow-up times. Isokinetic dorsal extension strength was measured as Nm/kg at angular velocities of 60°/s (D60T) and 120°/s (D120T) and N/kg at angular velocities of 60°/s (D60W) and 120°/s (D120W). Isokinetic plantar flexion strength was measured as Nm/kg at angular velocities of 60°/s (P60T) and 120°/s (P120T) and N/kg at angular velocities of 60°/s (P60W) and 120°/s (P120W) (Table 1).

Table 1 Isokinetic strength metrics

Metric	Meaning
D60T	Dorsal extension at 60°/s, max torque/BW (Nm/kg)
D60W	Dorsal extension at 60°/s, force/BW (N/kg)
D120T	Dorsal extension at 120°/s, max torque/BW (Nm/kg)
D120W	Dorsal extension at 120°/s, force/BW (N/kg)
P60T	Plantar flexion at 60°/s, max torque/BW (Nm/kg)
P60W	Plantar flexion at 60°/s, force/BW (N/kg)
P120T	Plantar flexion at 120°/s, max torque/BW (Nm/kg)
P120W	Plantar flexion at 120°/s, force/BW (N/kg)

BW body weight, Nm newton meter, N newton, kg kilogram

Data were recorded and stored using REDCap electronic data capture tools hosted at the institution [8]. Isokinetic strength was recorded in each patient's injured and healthy leg by a trained physical therapy aide blinded to the patient's radiographic and medical progress since surgery. Testing was consistent for all patients and was completed per protocol according to the Biodex system. Patient warm-up consisted of 10 min on the bike followed by a three-repetition trial on the machine. Testing occurred supine with knees flexed to 20 to 30°. Range of motion was set by patient active range of motion. The uninvolved side was always tested first with one set (five repetitions) at 60°/s, followed by one set at 120°/s, with a 30-s rest between sets. The calculated average for the trials was used for analysis.

For each of the eight strength metrics that were analyzed bilaterally at the three follow-up interval times (3, 6, and 12 months), the data were visually screened and isokinetic strength scores yielding outliers were removed prior to plotting and analysis. Threshold for inclusion was defined by the conventional range ($Q1 - 1.5 \times IQR$, $Q3 + 1.5 \times IQR$), where $Q1$ is the lower quartile, IQR is the interquartile range, and $Q3$ is the upper quartile.

The data were compiled in a comma-separated values (.csv) file and imported to R for further analysis [16]. First, a paired t test was used to compare strength between the injured and healthy legs at each follow-up visit at 3, 6, and 12 months using the eight isokinetic strength metrics.

Second, a linear mixed-effects model [15] was used to assess strength of the injured leg modeled against follow-up time (fixed effect) and patient identification (random effect). Linear mixed-effects modeling was selected over a repeated measures analysis of variance (ANOVA) in order to preserve sample size and to allow for post hoc comparisons. This allowed for patients with missing data at a single follow-up time (i.e., those who did not attend all three follow-up appointments) to be incorporated in the longitudinal analysis. It also allowed for post hoc pairwise comparisons of strength at the three follow-up times in order to assess recovery rate [10]. Post hoc pairwise comparisons were done via the Tukey method, which corrects for family-wise error rate in multiple comparisons. Inter-patient variability was controlled by incorporating the patient identification random-effects term.

For all statistical tests, a p value of less than 0.05 was considered statistically significant.

Results

Of the 70 patients with closed tibial shaft fractures identified during the study as potentially eligible, 16 failed to return for post-op assessment, five declined enrollment, and three developed complications causing them to be excluded (two infections, one nonunion). Of the remaining 46 eligible patients who agreed to participate, five did not return for physical therapy follow-up appointments and could not be included, and five were excluded because they had undergone fasciotomies. A total of 36 patients with isolated closed tibial fracture were included in our final analysis.

Between April 2012 and July 2016, 72.2% of the intended observations (24 per patient) were collected, with loss to follow-up at 25% ($n = 27$), 16.7% ($n = 30$), and 41.7% ($n = 21$) at 3, 6, and 12 months, respectively (Table 2). Of the 36 included patients, 11 attended all three follow-up appointments. After removal of patients lost to follow-up, the patient demographics and OTA fracture classification distribution did not change at the later assessment periods (Table 3). There were no significant changes in mean strength in healthy legs throughout the study period.

The difference in mean isokinetic strength scores between the healthy and injured legs decreased with each subsequent follow-up visit of 3, 6, and 12 months (Table 4). At the 3-month assessment, injured legs demonstrated significantly lower isokinetic strength scores than healthy legs in seven of eight metrics: D60T ($p < 0.001$), D60W ($p < 0.001$), D120T ($p = 0.008$), P60T ($p < 0.001$), P60W ($p = 0.002$), P120T ($p < 0.001$), P120W ($p = 0.005$). At 6 months, there was still a significantly lower mean isokinetic strength score for injured legs in five of eight metrics: D60T ($p = 0.017$), D60W ($p = 0.024$), P60T ($p < 0.001$), P60W ($p = 0.002$), P120T ($p = 0.022$). At 12 months there were no metrics that showed a significant difference in mean isokinetic strength score between healthy and injured legs.

Mean isokinetic strength score in the injured legs improved significantly over time, with the majority of recovery occurring between 3 and 6 months (Table 5). A significant improvement in strength was observed in the injured leg between the 3- and 6-month assessments for four of the eight metrics: P60T ($p = 0.003$), P60W ($p < 0.001$), P120T ($p = 0.001$), and P120W ($p = 0.005$). No significant improvement in injured leg strength was found between 6 and 12 months for any of the eight metrics. One metric of strength improved significantly in addition to those that

improved between 3 and 6 months only when strength was compared throughout the study between the 3- and 12-month follow-up visits: D60W ($p = 0.006$).

Discussion

This study is the first to objectively characterize recovery of strength after surgical repair of isolated closed tibial shaft fractures over several follow-up visits using an isokinetic dynamometer. Recovery was assessed by comparing isokinetic strength metrics in the injured leg to the healthy leg at 3-, 6-, and 12-month follow-up visits. The difference in strength between the injured and healthy legs decreased over time, with comparable function between legs seen for the first time at the 12-month assessment. We also examined trajectory of recovery longitudinally by observing how strength changed in the injured leg between visits. The majority of improvement in isokinetic strength in the injured leg occurred between the 3- and 6-month assessments, with only measurements of plantar flexion showing a significant improvement. Only when isokinetic strength scores were compared between the 3- and 12-month assessments did one measurement of dorsal extension show a significant difference in isokinetic strength score.

The greatest weakness of this study is the limited sample size due to the loss to follow-up over the study period. One may surmise that patients would be more likely to return for follow-up visits if they had not experienced significant improvement in function, especially for the 6- and 12-month visits. This might explain why little improvement in dorsal extension or plantar flexion was observed between these visits. Furthermore, although a 9-month follow-up visit was not required for these patients, it would have been beneficial to know if strength was still significantly different between the healthy and injured leg at this time. Without an assessment of strength in the first few weeks after surgery it is also not possible to discern whether dorsal extension truly does not improve as fast as plantar flexion or if improvements in dorsal extension occur prior to the 3-month follow-up visit. It is possible that dorsal extension actually experiences a plateau in recovery before plantar flexion. Lastly, while return of strength is an important factor after surgery it is only one objective measure of function and may not provide a full picture of functional recovery. It is possible that pain would limit patient effort during testing, although we do not think that this accounts for the trajectory of our

Table 2 Demographic data presented as the mean of the population studied

	3 months (%)	6 months (%)	12 months (%)	Overall (%)	<i>p</i> value
Age	44 [18–76]	46 [18–76]	46.7 [19–76]	47.08 [18–76]	0.872
Gender* [male]	18 (67)	17 (56.7)	11 (52.4)	22 (61.1)	0.474
BMI	27.37 [18–35]	27.7 [18–36]	28 [18–36]	27.55 [18–36]	0.921
Length of stay [days]	5.26 [1–43]	5.17 [1–43]	6.43 [1–43]	4.92 [1–43]	0.844
Patients recorded*	27 (75.0)	30 (83.3)	21 (58.3)	36 (100.0)	
Missing data*	9 (25.0)	6 (16.7)	15 (41.7)	0	

Continuous variables are reported as a mean and range at each time point

*Categorical variables are reported as a count and percentage (%) of the total participants

Table 3 OTA classification of tibial fractures of the population indicated

OTA classification no.	3 months (n)	6 months (n)	12 months (n)	Overall (n)
42A: diaphyseal simple fracture	18	20	14	23
42B: diaphyseal wedge fracture	5	8	5	9
42C: diaphyseal complex fracture	4	2	2	4
Total	27	30	21	36

A Pearson's χ -square test indicated that the OTA fracture classification distribution did not vary with visitation time ($p = 0.853$)

OTA Orthopaedic Trauma Association

results or the differences in findings between plantar flexion and dorsal extension.

Other analyses have concluded that recovery to baseline function can take up to and over 12 months. One study found incomplete return to baseline functional status by 1 year following surgical fixation of the tibial shaft, using two health-related quality of life surveys (Short Form-36 [SF-36] and Short Musculoskeletal Function Assessment) [14]. Another study reported near-complete return to function (mean, 85 of 100 points) at follow-up times between 2 and 6.5 years for one of the same measures (SF-36) [2]. While important, these results are inherently limited by variability in psychological responses and cultural norms inherent to these subjective assessments. Our study corroborates the findings of these studies with objective data.

Isokinetic strength measurements have been performed previously to assess recovery objectively following tibial shaft fracture; however, these patients had undergone fasciotomies for impending compartment syndrome [7]. They found a significant difference in healthy and injured leg function for most of the isokinetic metrics at 2.4 years after admission (D60T, D60W, D120T, D120W, P60W). This is in contrast to our finding that none of the metrics showed a difference between healthy and injured legs at 1 year. It is unclear whether the impending compartment syndrome may have

Table 5 Improvement in isokinetic strength score in the injured leg between follow-up time points

Metric	3–6 months pairwise p value (n = 27, 30)	6–12 months pairwise p value (n = 30, 21)	3–12 months pairwise p value (n = 27, 21)
D60T	0.599	0.429	0.108
D60W	0.053	0.524	0.006
D120T	0.979	0.371	0.321
D120W	0.882	0.691	0.458
P60T	0.003	0.116	< 0.001*
P60W	< 0.001*	0.182	< 0.001*
P120T	0.001*	0.570	< 0.001*
P120W	0.005*	0.276	< 0.001*

An asterisk (*) next to an italicized term denotes statistical significance ($p < 0.05$)

D60T, D120T, P60T, P120T are reported as maximum torque/body weight (newton/meter/kilogram)

D60W, D120W, P60W, P120W are reported as force/body weight (newton/kilogram)

altered the biochemical environment for repair or if the fasciotomy procedure itself was the true causal agent of the lack of strength recovery. By contrast, our analysis eliminated patients with fasciotomy, thereby allowing us to draw conclusions about the recovery of strength that can be attributed to the fracture itself. The above analysis [7] also observed a greater deficit in dorsal extension than plantar flexion at 2.4 years after surgery. This is in contrast with our finding that strength is not significantly different between injured and healthy legs at 12 months for all measurements of dorsal extension and plantar flexion and may be attributed to which compartments in the fasciotomy were released.

A previous analysis used the HMS to assess recovery objectively over several visits for Gustilo-Anderson type II and III fractures [13]. The HMS provides an objective and subjective assessment of mobility through the combination of a sensor-based assessment of kinematic parameters of three activities of daily living with four questions. This analysis found improvements to be most significant between 3 and 6 months following surgery, similar to our study. While the HMS used in that study was found to be 50% more sensitive to changes in performance

Table 4 Mean isokinetic strength score in healthy and injured legs at 3, 6, and 12 months

Metric	Follow-up time								
	3 months (n = 27)			6 months (n = 30)			12 months (n = 21)		
	Healthy	Injured	p value	Healthy	Injured	p value	Healthy	Injured	p value
D60T	9.9 ± 3.1	7.5 ± 2.5	< 0.001*	9.6 ± 3.9	8.8 ± 3.3	0.017*	9.1 ± 3.1	9 ± 3.5	0.847
D60W	46.1 ± 22.4	29.9 ± 18.8	< 0.001*	48.4 ± 27.2	39.7 ± 24.9	0.024*	46.7 ± 23.7	45.8 ± 26	0.796
D120T	8.4 ± 2.4	6.9 ± 1.9	0.008*	7.7 ± 2.7	6.9 ± 2.2	0.090	7.4 ± 2.2	7.6 ± 2.2	0.726
D120W	96.5 ± 49.1	82.8 ± 47.2	0.092	103.6 ± 68.5	86.9 ± 55.1	0.050	93.3 ± 40.8	95.6 ± 47.2	0.762
P60T	16 ± 8.5	8.7 ± 6.7	< 0.001*	20.8 ± 12.8	13.3 ± 8.5	< 0.001*	19 ± 10.3	16.2 ± 9.7	0.102
P60W	50 ± 47.4	15.5 ± 17.9	0.002*	73.8 ± 56.8	47 ± 44.4	0.002*	73.8 ± 58	61 ± 54.5	0.096
P120T	13.7 ± 7	6.5 ± 4.4	< 0.001*	13.1 ± 7.5	10.8 ± 6.3	0.022*	13.3 ± 6.8	11.6 ± 6.8	0.107
P120W	100.5 ± 109	30.9 ± 41.7	0.005*	121.3 ± 112	91.2 ± 91.3	0.056	125.5 ± 118.7	115.7 ± 119.9	0.489

An asterisk (*) next to an italicized term denotes statistical significance ($p < 0.05$)

D60T, D120T, P60T, P120T are reported as maximum torque/body weight (newton/meter/kilogram)

D60W, D120W, P60W, P120W are reported as force/body weight (newton/kilogram)

than questionnaires about quality of life, we believe isokinetic strength testing to be a superior method to estimate functional recovery. Strength testing with an isokinetic dynamometer does not require walking on a treadmill, which can be painful to patients, and is not subject to potential inconsistencies that may result from the use of mobility aids. The isokinetic dynamometer also tests strength in individual muscle groups, allowing for the isolation of specific functional deficits.

In conclusion, strength in the injured leg after surgical repair of isolated closed tibial shaft fracture is not significantly different from the uninjured leg for the first time at the 12-month follow-up visit. Patients should therefore be advised that recovery may not be complete until 12 months after surgery and their ability to return to work may be affected up to this time. Improvement in strength occurs most rapidly between 3 and 6 months after surgery, especially for plantar flexion, with little continued improvement between 6 and 12 months. As significant recovery occurs up to at least 6 months post-surgery, patients should consider ongoing physical therapy up to 6 months. Our observation has been that patients often complete physical therapy by 3 months. Isokinetic strength testing can be used to objectively measure recovery of strength in order to describe functional outcomes following tibial shaft fracture repair.

Compliance with Ethical Standards

Conflict of Interest: Alexandra I. Goodwin, BA, Brittany E. Haws, BS, Ziyad O. Knio, BS, Per Kristian Moerk, DPT, PT, and Anna N. Miller, MD, FACS, declare that they have no conflicts of interest.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2013.

Informed Consent: Informed consent was obtained from all patients included in this study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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