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Isolated Transverse Process Spinal Fractures Increase the Likelihood of Incurring Visceral and Pelvic Injuries: A Retrospective Review at a Level-1 Trauma Center

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Abstract

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By Lucas R. Philipp

Background: Although isolated transverse process fractures (ITPF) do not confer any inherent risk of compromised spinal stability, there is growing interest in their overall prognostic significance. As a proxy for localized or directional forces in high energy traumatic mechanisms, ITPF may serve as an indicator for the presence of other coexisting traumatic injuries. Specific injuries may be predicted by the presence of ITPF at specific spinal levels, but few studies have examined this in depth and may not account for confounding variables.

Methods: We retrospectively analyzed data from 306 patients presenting with acute traumatic ITPF. ITPF number and location by spinal segment were determined from initial CT. Mechanism of trauma, Injury Severity Score (ISS), and extent of non-spinal-associated injuries (NSAIs) were recorded. Correlation analysis compared ITPF location to injury severity, NSAI location, type, and patterns. Significant injury associations were further explored with logistic regression analysis controlling for age, mechanism of injury, and ISS.

Results: The adjusted odds of pulmonary visceral injury was 4.69 (95% CI: 2.33 , 9.44) times higher among patients with thoracic level ITPF compared to other ITPF levels. Lumbar ITPFs had increased odds of abdominal visceral injury (OR = 4.85, p=0.0002), pelvic fractures (OR = 4.2, p<0.0001). The "number needed to scan" to observe a pelvic injury among patients with lumbar ITPF was 3 patients. Other significant associations were also observed.

Conclusion: Spinal level of ITPF is associated with increased likelihood of specific patterns of injury, and additional investigation is warranted.

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Chapter I:

Background & Review of Literature

The advent of newer, more robust technologies has afforded clinicians increasing access to high-quality scans. The incorporation of this technology into routine practice in trauma management has led to an increased detection of more subtle traumatic spinal pathologies including isolated fracture of the vertebral transverse process (1-6). In a large retrospective study of the National Hospital Ambulatory Medical Care Survey, spanning 12 years and including data from 368,680 patients, Kocher et al reported a 330% increase in the use of computed tomography (CT) scans in the emergency department (ED) (4). The sensitivity of multi-detector row CT for the detection of unstable vertebral fractures can exceed 97.2%, compared with 33.3% for conventional radiography (6). The efficacy of helical CT in this and other applications in urgent/emergent settings is the basis for which it has largely supplanted traditional anteroposterior and lateral X-ray films (1, 7).

One prospective, cross-sectional study of 2,404 blunt trauma patients presenting to a level 1 trauma center between 1997-1998 found a prevalence of thoracolumbar spine injury equal to 6.3% (2). The most common of these injuries (48%) was transverse process fracture, however these estimates were produced on the basis of traditional radiographic imaging techniques (3). With more than half of all transverse and spinous process fractures missed on traditional radiographs, 6.3% is a clear underestimate of the true prevalence of these lesions. Homnick et al, reported a prevalence of 10% for isolated transverse process fractures (ITPFs) in blunt trauma patients (8). Lombardo et al, in a series of 10,186 trauma patients undergoing diagnostic MDCT imaging, reported TP fractures in 8.6%—24% of which were ITPF (9). Patten et al found somewhat lower estimates. Among 536 prospectively evaluated patients with an emergent history of blunt abdominal trauma, helical abdominal CT found ITPF in only 7.3% of patients (10). While prospective in design, this study was conducted at a single center and the sample size was considerably smaller than the studies previously described. Additionally, this sample was restricted to patients with abdominal trauma, and did not include several mechanisms of injury on this basis. Similarly, in an analogous study of 865 consecutive patients, 2.4% of those presenting after high-energy blunt trauma were found to have cervical level ITPF (11).

The majority of the literature reporting on these injuries consists of retrospective single-center cohorts, and the true epidemiology of these fractures has not been clearly elucidated. It appears that ITPFs occur more often in men, however it has been suggested that this is merely a reflection of increased likelihood of occupational risk factors in men (12). Schotanus found that cervical ITPFs most often affected a single level (11). Thoracolumbar ITPF has been consistently reported as more likely to affect multiple vertebral levels (8, 10, 13), a finding corroborated in the meta-analysis by Nagasawa et al (12).

Though much more commonly observed today, the clinical significance and implications of isolated transverse process fractures remain in question (12). The role of transverse processes in maintaining the overall structural integrity of the spinal column is seemingly insignificant, and in isolation, these fractures do not confer any inherent risk of compromised mechanical stability of the spine (11, 14).

Schotanus et al prospectively identified 21 patients with cervical ITPF after high-energy blunt trauma (11). No patient was treated for their ITPF, and follow-up demonstrated stable, intact subaxial c-spine performance measures and radiographs, with a mean patient satisfaction of 9.3 out of 10 (sd 1.48). No compromise of structural integrity was apparent in cervical ITPFs (11). With consideration of all spinal levels, Bradley et al reported on 84 patients with TPF, all of whom were found to be neurologically intact (14).

None of the 47 ITPF patients required spinal support/bracing or surgical intervention for spinal stability. In a recent meta-analysis including 398 patients with 819 ITPFs, no evidence of spinal instability or deformity on the basis of radiographic studies was found for any case (12).

There is also evidence in the literature that in the absence of other associated spinal fractures, ITPFs can be effectively managed through conservative measures, and may not even require a spine surgery consult (14). Citing their evidence that ITPF patients benefit most from early mobilization, and the considerable resources consumed in delaying care, Homnick et al concluded that these patients require no neurosurgical or orthopedic expertise (8). Additionally, activating spine precautions may delay routine diagnostic workup including the secondary survey and log roll, thereby prolonging the diagnosis of more serious injuries. No risk of long-term sequelae has been found—Boulter et al reported 100% of ITPF patients as neurologically intact without need for bracing, and at 6 months follow-up all patients were fully ambulatory (15).

Although benign themselves, the detection of these lesions may warrant additional radiological and general diagnostic workup. Some studies have suggested that the presence of ITPF may serve as an indicator for the presence of other coexisting traumatic injuries, or for the severity of injury in general (9, 16). The mechanism by which these fractures occur has been described as requiring high-energy trauma. Data collected during military conflicts in Iraq and Afghanistan found a number of spinal injuries in association with improvised explosive device (IED) detonation (17). NSAI correlation with TP fracture level was dependent upon whether injured personnel were on foot (unmounted) or in a vehicle (mounted) at the time of detonation, and Newell et al propose multiple specific high-force mechanisms by which each TP fracture is likely to occur. Lumbar TP fractures in mounted individuals were associated with pelvic injury, hemorrhage of the torso, and death; thoracic TP fractures in unmounted individuals were associated with head and chest wall injuries primarily (17). These findings illustrate the importance of mechanism in ITPF-NSAI patterns of injury.

Specific patterns of ITPF at specific spinal levels may be associated with specific patterns of injury. For example, L5 level fractures have been positively correlated with pelvic fractures and solid organ injury (9, 16, 18). Similarly, T1-T4 level ITPF has been associated with an increased prevalence of rib fractures (9). An association between cervical level TP fractures and NSAI was reported as early as 1975 by Arndt et al (19). These fractures and related injuries are proposed to occur as a result of oblique hyperflexion and/or hyperextension, such as are seen in rapid deceleration injuries, whiplash, or in direct head trauma wherein the force is transmitted to the neck (19, 20). Though describing only a series of 4 patients, the proposed association of cervical TP fractures with brachial plexopathy and vertebral artery injury has been validated on multiple occasions in more recent studies (19).

In a retrospective study of 216 patients, including 52 patients with cervical TPFs, Woodring et al found that cervical radiculopathy and brachial plexus palsy were present in 10% of those with cervical TPF (21). Bonney et al reported that the incidence of cervical vertebral artery injury was higher in patients with multi-level ITPF, compared to single ITPF patients (22). However, in this small series examining a relatively rare event, only 4 patients with cervical TPF, and 1 patient without cervical TPF had vertebral artery injuries, which failed to reach statistical significance ($p=0.35$).

NSAIs have been most often studied and reported in association with lumbar level ITPF, most commonly as solid organ injury or pelvic fractures. Miller et al analyzed 91 patients with assorted lumbar spine fractures, with 42 TPFs (13). Patients with TPF were more likely to have had abdominal organ injuries (48%) than patients with non TP fractures (6%), $p<0.05$. Lombardo et al found a univariate association between L5 level ITPF and both solid organ injury and pelvic fractures (9). However, after adjusting for injury severity score (ISS) in multivariate analysis, only pelvic fractures remained significantly associated (OR=6.81 [95% CI: 3.14-14.78]). Starks et al reviewed hospital records to identify 80 patients with pelvic fractures between 2006-2010 (23). An associated L5 ITPF was present in 17 patients, and the odds ratio for an unstable fracture of the pelvis was 9.3 (23). This analysis was strictly univariate without statistical adjustment for confounding variables. The biological plausibility for this injury association has been postulated by Reis et al, in their description of the mechanism by which L5 TP fractures may occur (24). Briefly stated, in the setting of hemipelvic dislocation, traction through the iliolumbar ligament places direct stress on the L5 TP, specifically through vertical shearing forces of Malgaigne's fracture-dislocation, or a lateral crush fracture-dislocation. Coordinately, L5 ITPFs may often signify posterior instability of the ipsilateral pelvis (24).

A more rigorous statistical analysis was employed by Xia et al in their analysis of 375 ITPF patients selected from a larger series of 1,181 patients with vertebral fractures (16). This study was principally concerned with the potential for specific vertebral segments, the number of ITPFs present, and concomitant presentation with other vertebral fractures to confound the correlation between NSAIs and ITPF. Adjusting for these factors, their study corroborated findings of L5 ITPF in association with pelvis injury (RR = 11.875 [95% CI, 2.966 - 47.546]). Additionally, L5 ITPF had an increased risk of head injury, limb fracture, and NSAIs in general. Isolated L4 TP fractures were associated with abdominal injury in this study as well (RR = 2.27 [95% CI, 1.23-4.20]) (16). Although this study was characterized by a large sample population, and the analysis considered the role of multi-level and level-specific pathology in predicting patterns of NSAI through multivariate methods, additional variables remain unaddressed. The study was restricted to lumbar level fractures, and did not control for confounding factors such as age, ISS, or mechanism of injury.

Chapter II:

Manuscript

Isolated Transverse Process Spinal Fractures Increase the Likelihood of Incurring Visceral and Pelvic Injuries: A Retrospective Review at a Level-1 Trauma Center

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Short Title: ITPF Associated Injury

Abbreviations: AUC = area under the curve, CI = confidence interval, ED = Emergency Department, GSW = gun shot wound, IQ range = interquartile range, ISS = injury severity score, ISS15 = binary ISS at threshold of 15 points, ISS24 = binary ISS at threshold of 24 points, ITPF = isolated transverse process fracture, MVC = motor vehicle collision, NNS = number needed to scan, NSAI = non-spinal associated injury, OR = odds ratio, ROC = receiver operating curve, SD = standard deviation

Abstract

Background: Although isolated transverse process fractures (ITPF) do not confer any inherent risk of compromised spinal stability, there is growing interest in their overall prognostic significance. As a proxy for localized or directional forces in high energy traumatic mechanisms, ITPF may serve as an indicator for the presence of other coexisting traumatic injuries. Specific injuries may be predicted by the presence of ITPF at specific spinal levels, but few studies have examined this in depth and may not account for confounding variables.

Methods: We retrospectively analyzed data from 306 patients presenting with acute traumatic ITPF. ITPF number and location by spinal segment were determined from initial CT. Mechanism of trauma, Injury Severity Score (ISS), and extent of non-spinal-associated injuries (NSAIs) were recorded. Correlation analysis compared ITPF location to injury severity, NSAI location, type, and patterns. Significant injury associations were further explored with logistic regression analysis controlling for age, mechanism of injury, and ISS.

Results: The adjusted odds of pulmonary visceral injury was 4.69 (95% CI: 2.33 , 9.44) times higher among patients with thoracic level ITPF compared to other ITPF levels. Lumbar ITPFs had increased odds of abdominal visceral injury (OR = 4.85, $p=0.0002$), pelvic fractures (OR = 4.2, $p<0.0001$). The "number needed to scan" to observe a pelvic injury among patients with lumbar ITPF was 3 patients. Other significant associations were also observed.

Conclusion: Spinal level of ITPF is associated with increased likelihood of specific patterns of injury, and additional investigation is warranted.

Introduction

The body of literature regarding possible associations between spinal level of ITPF and various patterns of injury is sparse, and previous studies have restricted their investigations to specific spinal levels/groups, and reported only positively correlated, broadly classified injury types. It is also possible that these ITPF level/injury pattern associations may be the product of one or more confounding variables, including mechanism of injury, age, and general injury severity, which no single study has comprehensively evaluated or considered in statistical analysis. To that end, ITPF number, level, and/or pattern may serve as a predictor of injury severity itself. The purpose of this study is to conduct a rigorous examination of the relationship between the presence of ITPF and specific patterns of injury controlling for other associated factors.

Material & Methods

After institutional review board approval, we reviewed an existing single-center cohort of 306 consecutive patients who presented to the ED of our level-I trauma center between October 2012 and February 2015 with acute traumatic ITPF. Patients who presented with additional spinal fractures—acute, chronic, or healed—were excluded from this study. Patient records were reviewed for sociodemographic factors and clinical histories. Radiological and ED reports were compared against registry data regarding mechanism of trauma, location, number, type, and extent of non-spinal-associated injuries (NSAIs), including the Injury Severity Score (ISS) for each patient. The location and number of ITPFs were determined from the first computed tomography images obtained on admission. The presence or absence, and number of ITPFs were recorded for each patient according to three classification scales. First, as cervical, thoracic, or lumbar, then as subgroupings of each spinal section, and finally as individual vertebrae. NSAIs were grouped according to anatomic location and by involvement of orthopedic or visceral organs.

Outcome Classification

The primary outcomes of interest were the overall injury severity, and the presence of specific injuries as described previously. Injury severity was defined according to each patients' ISS on admission. There is debate regarding the appropriate handling of ISS data in statistical analyses (25, 26). Most often, ISS is treated as a continuous variable, however it has been suggested that treating ISS as a categorical/ordinal or binary variable would be more suitable. In the latter case, there is also disagreement regarding the specific threshold score which defines "severe trauma" (25). For this study, when considered as the dependent variable, analyses were conducted using each definition: as a continuous variable, as a binary variable with a "severe" threshold of 15, and as a binary variable with a threshold score of 24. When treated as a continuous dependent variable in our analyses, ISS was transformed as $\sqrt{ISS}$ to satisfy assumptions of normality.

Statistical Analysis

All statistical analysis for this paper was conducted using SAS/STAT® software, Version 9.4 for Windows (Copyright © 2013 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA). Crude correlation analysis was conducted comparing ITPF location to injury severity. Analyses considered ITPF level as continuous (number of fractures at each level/group) and as binary (presence or absence of ITPF at each level/group). Chi square tests of independence, and Fisher-exact tests were performed where appropriate to determine the presence of any association, with significance defined at alpha=0.10. Pearson correlation coefficients were determined for each comparison, or reported as point-biserial correlation coefficients, or phi as appropriate. Correlation coefficients were compared as trends according to ordinal groupings of ITPF spinal level using Fisher z transformations.

Crude measures were similarly determined for associations between ITPF level/group and specific injury patterns at a significance level of alpha=0.05. Significant injury associations were further explored with logistic regression analysis. Models were produced to predict each specific injury or pattern of injury. Automated variable selection methods were used to generate the most optimal prediction models from higher-order models, initially controlling for age, sex, mechanism of injury, and any anti-correlated ITPF level groups. Final models predicting specific injuries included age, mechanism of injury, and ISS as important confounders.

Results

General characteristics of the study population are shown in Table 1. Of the 306 total patients, two-thirds were male, with a mean age of 42 ± 15.51 years. The most common mechanism of injury was motor vehicle collision (MVC), accounting for 46.41% of all traumas. The median ISS was 17, with scores of 12 and 24 at the 25^{th} and 75^{th} percentiles respectively. There were 633 ITPFs in total. Approximately half of all patients presented with a single ITPF, and 18.63% had 3 or more ITPFs. Most ITPFs were located in the lumbar vertebrae (73.78%), and cervical ITPFs were least common (9.79%).

Crude correlation analysis found several potential associations between spinal level of ITPF and ISS at the 90% significance level (**See Appendix, Table A.1**). Considered as a binary variable describing the presence of 'severe injuries' above a threshold ISS of 15, severe injury was positively correlated with the presence of cervical ITPF ($\chi^2 = 2.77$, $\phi = 0.10$, p =0.0961). Low cervical level ITPF accounted for the majority of the variability in ISS15 among all cervical ITPF patients ($\chi^2 = 4.10$, $\phi = 0.12$, p =0.0430). At a severity threshold of 24, ISS was positively correlated with low lumbar ITPF ($\chi^2 = 4.37$, $\phi = -0.11$, p =0.0365). An inverse correlation was demonstrated by high lumbar ITPF ($\chi^2 = 2.96$, $\phi = -0.11$, p =0.0851). This trend was mirrored by the results of point-biserial correlation. A trend between spinal section fracture and strength of correlation with ISS was noted (**Figure 1**), Fisher z transformation determined a p for trend of 0.046 for ISS15.

Crude analysis also determined numerous correlations between spinal level of ITPF and the frequency of various specific injuries (**See Appendix, Tables A.2a & A.2b**). Lumbar level ITPFs in general shared a moderate strength, positive association with splenic injury ($\chi^2 = 5.04$, $\phi = 0.13$, p = 0.0248), hepatic injury ($\chi^2 = 3.86$, $\phi = 0.11$, p = 0.0495), and other abdominal visceral injury ($\chi^2 = 10.59$, $\phi = 0.19$, p = 0.0011). Low level lumbar ITPFs (L4-L5) were more strongly associated than upper lumbar ITPFs, and were most strongly correlated with Other Abdominal Injury ($\chi^2 = 20.00$, $\phi = 0.26$, $p < 0.0001$). An inverse correlation of moderate strength was seen between lumbar ITPF and pulmonary visceral injury ($\chi^2 = 12.18$, $\phi = -0.20$, p = 0.0248). Pulmonary injuries were positively correlated with thoracic level ITPF ($\chi^2 = 29.38$, $\phi = 0.31$, $p<0.0001$), and most strongly associated with upper level thoracic (T1-T4) fractures ($\chi^2 = 20.09$, $\phi = 0.26$, $p <0.0001$). Cervical level ITPFs were negatively correlated with the frequency of abdominal visceral injuries and hepatic injuries.

Similar trends were observed in crude associations between ITPF level and orthopedic injuries. Pelvic fractures were inversely correlated with cervical and thoracic ITPFs (ϕ = -0.17 and -0.21, p = 0.0032 and 0.0002, respectively). Low lumbar level ITPFs were strongly, positively correlated with pelvic fractures (χ^2 = 40.77, ϕ = 0.37, p < 0.0001). Upper extremity fractures and rib fractures shared a significant positive association with Thoracic level ITPFs, and craniofacial fractures were positively correlated with cervical ITPF.

Logistic Regression analysis adjusting for age and mechanism of injury supported these associations, as demonstrated by the adjusted odds ratios for each injury shown in **Table 2a**. Sex was not a significant predictor of any injury and its inclusion did not confound the estimates presented for any model, and was therefore dropped from all final models. The odds of pulmonary visceral injury was 4.69 (95% CI: 2.33 , 9.44) times higher among patients with thoracic level ITPF. Lumbar ITPF, though associated with pulmonary injury in crude analysis, was not a significant or meaningful confounder and was dropped from the final model. The presence of low lumbar ITPF was associated with an odds of splenic injury (OR=3.14; 95% CI: 1.10 , 8.96) and hepatic injury (OR=2.59; 95%CI: 1.02 , 6.54), adjusting for ISS, age, and mechanism of injury. Anti-correlated ITPF levels were not significant confounders and dropped from these models.

Orthopedic injuries were similarly predicted by ITPF presence at certain spinal levels (**Table 2b**). The adjusted odds ratio of pelvic fracture among patients with L4-L5 ITPF was 4.20 (95% CI: 2.37 , 7.43) compared to those without low lumbar ITPF. Patients with thoracic level ITPFs had an odds of rib fracture 18.49 (95% CI: 4.14 , 82.49) times higher than those without thoracic level ITPF at a given ISS. There was a meaningful interaction between ISS and thoracic ITPF with respect to prediction of rib fracture, which was included in this model. Number of thoracic ITPF was an independent predictor of rib fracture, and total number of rib fractures (**See Appendix, Table A.3**). Cervical ITPF was independently associated with craniofacial fractures ($p = 0.0075$) controlling for age, ISS, and mechanism of injury. Of all models generated, the model predicting craniofacial fractures was most optimal (Area under ROC curve = 0.94). Respective AUC for each model is shown in **Figure 2**. Mid-level thoracic ITPF appears to be associated with increased odds of upper extremity fractures, however upper extremity fractures were not significantly predicted when controlling for other factors.

Discussion

In this study, we sought to validate existing hypotheses and to conduct a more comprehensive analysis, with regard to the association between ITPF and various specific patterns of injury. Previously, our institution reported that ITPFs could be treated conservatively without concern for long-term sequelae—a conclusion which has been supported throughout the literature (8, 14, 15, 27, 28). Though these fractures appear benign in true isolation with respect to the spine, they have been noted to frequently occur in conjunction with additional injuries, and there has been a growing interest in their overall prognostic significance. In a previous study at our institution, we determined that there was no relationship between the number of ITPFs and the number of NSAIs in this cohort, but proposed that ITPF may serve as a marker of injury severity (15). This is the largest single-institution series on this subject, incorporating data from 306 patients. Previous studies have been smaller, with the exception of one meta-analysis including data from 819 patients across 4 studies (12), but no study to date has thoroughly investigated the role of confounding or intervening covariates.

In the present study, this hypothesis was supported by several significant associations between ITPF level and ISS. However, while ITPFs do appear to be correlated with greater injury severity, the specific relationship between them is dependent upon how injury severity is mathematically defined. When defined as a binary variable, 'severe' injuries are those characterized by scores greater than a predetermined threshold. With a lower 'severity' threshold [15], higher spinal level ITPFs were more often implicated as markers of injury severity in our population. With a higher threshold [24], lumbar ITPF were more often implicated. This may indicate that upper level ITPFs are associated with mid-range ISS [15-24], while lumbar ITPFs are associated with generally higher injury severity. Although the relationship between injury severity and ITPF remains unclear, they do appear to be associated (**Figure 1**). ISS may also be used to define the presence of specific injuries. Therefore, we determined that it is appropriate to include ISS in subsequent analyses as an important confounding variable.

In our population, we found multiple significant associations between ITPF level and specific injuries. Adjusting for mechanism of injury, age, and ISS, thoracic level ITPF was independently associated with the occurrence of pulmonary visceral injuries. Compared to patients with ITPF at other spinal levels, the adjusted odds of pulmonary injury were 4.69 (95% CI: 2.33 , 9.44) times greater among those with thoracic level fractures. Considering all thoracic level ITPFs as a single exposure group produced a better predictive model than considering spinal levels alone, grouped, or in combinations of groups. Additionally, although negatively correlated in crude analysis, lumbar ITPF was not a significant confounder of the association between thoracic level ITPF and pulmonary injury.

Similarly, a number of injuries were associated with lumbar level ITPF, including splenic injury, hepatic injury, and other injuries to the abdominal viscera and soft tissues. In each case, low lumbar (L4-L5) ITPF was most predictive, collectively representing a 3-fold increased odds of these abdominal injuries, independent of age, mechanism of injury, and ISS. More significantly, low lumbar ITPF was found to share a strong correlation with the occurrence of pelvic fractures. Adjusting for other confounding variables, patients with L4-L5 lumbar ITPF had a 4.20 (95% CI: 2.37 , 7.43) times greater odds of pelvic fracture compared to ITPF patients without low lumbar ITPF.

Intuitively, cervical level ITPF was anticorrelated with injuries to the pelvis, however these fractures were not a significant independent predictor for pelvic fracture, nor were they a significant confounder of the effect of low-lumbar ITPF. This result is most likely due to the rarity with which low-lumbar and cervical ITPF occurred in conjunction, and therefore sparse data by which to draw conclusions. Additionally, while craniofacial fractures were demonstrated to be independently predicted by cervical ITPF, there is marked variability in estimated odds. This low precision is likely due to the relative scarcity of cervical ITPF and craniofacial fractures in this series. On the basis of the present study's data alone, the use of cervical ITPF as an indicator in guiding further diagnostic workup would not be advisable, but warrants further investigation.

Previous studies have reported a possible association between upper thoracic level ITPFs and the concomitant occurrence of rib fractures (9). This association was supported by our study as well, with significant crude correlations of ITPF in any thoracic spinal level group with both the frequency of rib fracture, and the number of rib fractures. Adjusting for mechanism of injury, age, and ISS, upper and mid-level thoracic ITPF were independently associated with increased odds of rib fracture. Taken together, a patient with a thoracic level ITPF would have an odds of rib fracture 18.49 (95% CI: 4.14 , 82.49) times higher than a patient of the same age, presenting with the same mechanism of injury and ISS without thoracic level ITPF. The lack of precision in this estimate is believed to be due to the inclusion of mechanism of injury into the final model, and on behalf of the significant effect modification produced by injury severity. Interpreted simply, this can be understood to mean that among patients with thoracic ITPF, there is a baseline increased risk of rib fracture of at least 4 times that of patients with ITPF of other spinal levels, and the risk of rib fracture appears to increase as ISS increases.

Applied clinically, these results might be used to determine pretest probabilities of the various injuries discussed. The presence of ITPF at certain spinal levels may therefore be used to guide clinical decision making and diagnostic workup, however additional investigation is required in this regard. One potential application is the refinement of imaging protocols targeted towards a suspected injury on the basis of ITPF on initial CT scans. For example, in a patient presenting with a low lumbar ITPF, concurrent pelvic pathology may be suspected, given the 4.20 times greater adjusted odds of pelvic fracture we report. The corresponding 'number needed to scan' (NNS) for patients presenting with low lumbar ITPF to detect 1 associated pelvic injury is 3 (2.2 – 4.1) patients (**Table 3**). Additionally, injuries to the pelvic vasculature might be suspected in these cases. Sub-analysis of our population did, in fact, demonstrate such a trend, with a NNS of 4 patients (2.3-4.9) with low lumbar ITPF to detect 1 associated injury to the pelvic vasculature.

Strengths & Limitations

This study has some limitations. This is a retrospective chart review, and statistical associations do not necessarily mean causality. Another limitation of this study is the lack of a non-ITPF trauma patient comparator group. Without such, the associations and conclusions reported herein are generalizable only to patients presenting with ITPF. In spite of this weakness, the present investigation still has value in that it controls for confounding variables among ITPF patients and suggests relative measures of association dependent upon spinal level of ITPF. As a preliminary investigation, the results presented in this study offer a valuable framework upon which future studies may build. Additionally, these results support the standing hypotheses regarding the pathophysiology and clinical significance of ITPF.

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Tables & Figures

Table 1. Patient Characteristics

Characteristic	All Patients (n=306) n	%
Sex		
Male	202	66.01
Female	104	33.99
Age (years), Mean ± SD	42	± 16.51
ISS, Median (IQ Range)	17	(12 - 24)
Mechanism of Trauma		
MVC	142	46.41
Pedestrian vs. Vehicle	53	17.32
Fall from Height	46	15.03
Motorcycle collision	21	6.86
GSW	19	6.21
Assault Victim	9	2.94
Ground-level Fall	5	1.63
Bicycle Accident	5	1.63
Other	6	1.96
Number of ITPFs per patient	(n=633)	
1	157	51.31
2	63	20.59
3	29	9.48
4	26	8.50
5	15	4.90
6+	16	5.23
Fracture Location		
Cervical	62	9.79
Thoracic	134	21.17
Lumbar	467	73.78

Abbreviations: SD = standard deviation, ISS = Injury Severity Score, IQ range = interquartile range, MVC = motor vehicle collision, GSW = gunshot wound, ITPF = isolated transverse process fractures

Table 2a: Adjusted Odds Ratios of ITPF-Associated Visceral Injuries Estimated by Logistic Regression Analysis

	Wald χ^2	P	OR	95% Wald CI
Pulmonary Visceral Injury				
Age	7.28	0.0070	0.97	0.96 , 0.99
ISS	34.65	<0.0001	1.11	1.07 , 1.15
Thoracic ITPF Present	18.67	<0.0001	4.69	2.33 , 9.44
Mechanism of Injury	3.96	0.8605		
Abdominal Visceral Injury				
Age	0.00	0.9710	1.00	0.98 , 1.02
ISS	8.88	0.0029	1.05	1.02 , 1.09
T9-T12 ITPF Present	8.03	0.0046	6.01	1.74 , 20.79
L4-L5 ITPF Present	14.26	0.0002	4.85	2.14 , 11.00
Mechanism of Injury	0.82	0.9992		
Splenic Injury				
Age	0.06	0.8114	1.00	0.97 , 1.03
ISS	13.84	0.0002	1.08	1.04 , 1.13
L4-L5 ITPF Present	4.55	0.0329	3.14	1.10 , 8.96
Mechanism of Injury	2.78	0.9472		
Hepatic Injury				
Age	0.00	0.9515	1.00	0.97 , 1.03
ISS	8.93	0.0028	1.06	1.02 , 1.10
L4-L5 ITPF Present	4.04	0.0444	2.59	1.02 , 6.54
Mechanism of Injury	4.55	0.8047		

Abbreviations: ITPF = isolated transverse process fractures, CI = confidence interval, T9/T12/L4… = spinal segment, ISS = injury severity score, OR = adjusted odds ratio. Significant Associations defined at alpha=0.05. Non-significant covariates included in model as meaningful confounders. Other Abdominal Injury includes hemoperitoneum, pneumoperitoneum, shock bowel, bowel injury, perinephric hematoma, retroperitoneal hematoma, abdominal wall hematoma, other abdominal soft tissue injury, excluding non-bowel organ injury.

Table 2b: Adjusted Odds Ratios of ITPF-Associated Orthopedic Injuries Estimated by Logistic Regression Analysis

	Wald χ^2	P	OR	95% Wald CI
Rib Fracture				
Age	8.92	0.0028	1.03	1.01 , 1.05
ISS	28.73	<0.0001	*1.04	0.98 , 1.10
Thoracic ITPF Present	14.62	0.0001	†18.49	4.14 , 82.49
ISS*Thoracic ITPF	3.70	0.0543	4.85	2.14 , 11.00
Mechanism of Injury	13.41	0.0985		
Pelvic Fracture				
Age	0.04	0.8322	1.00	0.98 , 1.02
ISS	2.79	0.0950	1.02	1.00 , 1.05
L4-L5 ITPF Present	24.23	<0.0001	4.20	2.37 , 7.43
Mechanism of Injury	9.89	0.2728		
Upper Extremity Fracture				
Age	3.14	0.0764	0.98	0.96 , 1.00
ISS	13.55	0.0002	1.06	1.03 , 1.09
T1-T4 ITPF Present	1.44	0.2298	1.65	0.73 , 3.72
T5-T8 ITPF Present	3.46	0.0630	3.20	0.94 , 10.90
Mechanism of Injury	2.81	0.9458		
Craniofacial Fracture				
Age	0.17	0.6810	1.01	0.96 , 1.07
ISS	4.44	0.0351	1.10	1.01 , 1.21
Cervical ITPF Present	7.16	0.0075	13.47	2.00 , 90.57
Mechanism of Injury	13.97	0.0825		

*=Thoracic=1; †ISS=constant. Abbreviations: ITPF = isolated transverse process fractures, CI = confidence interval, T9/T12/L4… = spinal segment, ISS = injury severity score, OR = adjusted odds ratio. Significant Associations defined at alpha=0.05. Non-significant covariates included in model as meaningful confounders.

Table 3: Number Needed to Scan to Detect ITPF-Associated Injuries

Number of patients presenting with ______ level ITPF…	…To detect 1 associated ______	=	Adjusted NNS	Crude NNS (95% CI)
Thoracic	Pulmonary Visceral Injury		3	3 (2 – 4)
	Rib Fracture		2	3 (2 – 4)
L4-L5	Abdominal Visceral Injury	=	6	6 (4 – 10)
	Splenic Injury		15	10 (6 – 25)
	Hepatic Injury		16	11 (6 – 37)
	Pelvic Fracture		3	3 (2 – 4)
	Pelvic Vascular Injury		4	4 (2 – 5)

Abbreviations: NNS = number needed to scan to detect 1 associated injury. Adjusted NNS calculated from multivariate logistic regression OR and the unexposed event rate.

Figure 1: Relationship of Phi Correlation Coefficient for Binary Injury Severity Score with ITPF Spinal Level

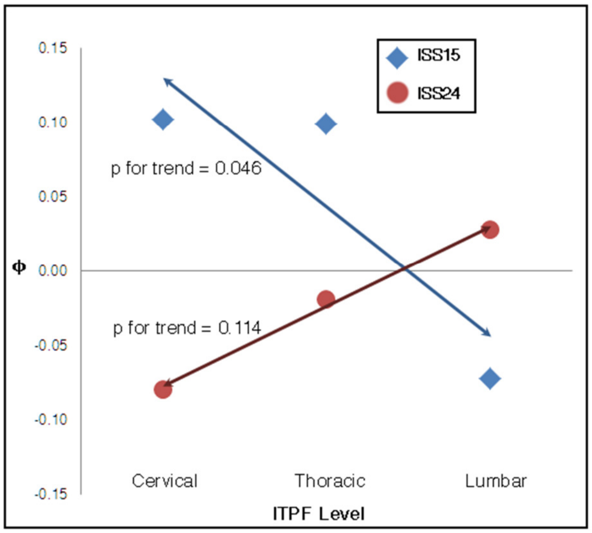

Figure 1: Relationship of Phi Correlation Coefficient for Binary Injury Severity Score with ITPF Spinal Level. Phi correlation coefficients describing the relationship between injury severity (ISS) and each spinal level group were plotted in anatomical order. Injury severity scores defined 'severe' injury at a threshold of 15 (ISS15) or 24 (ISS24). Correlation coefficients were compared as trends according to ordinal groupings of ITPF spinal level using Fisher z transformations. With a lower 'severity' threshold (15), higher spinal level ITPFs were more often implicated as markers of injury severity in our population. With a higher threshold (24), lumbar ITPF were more often implicated.

Figure 2: Receiver Operating Curves for Corresponding Models Predicting Injury Types

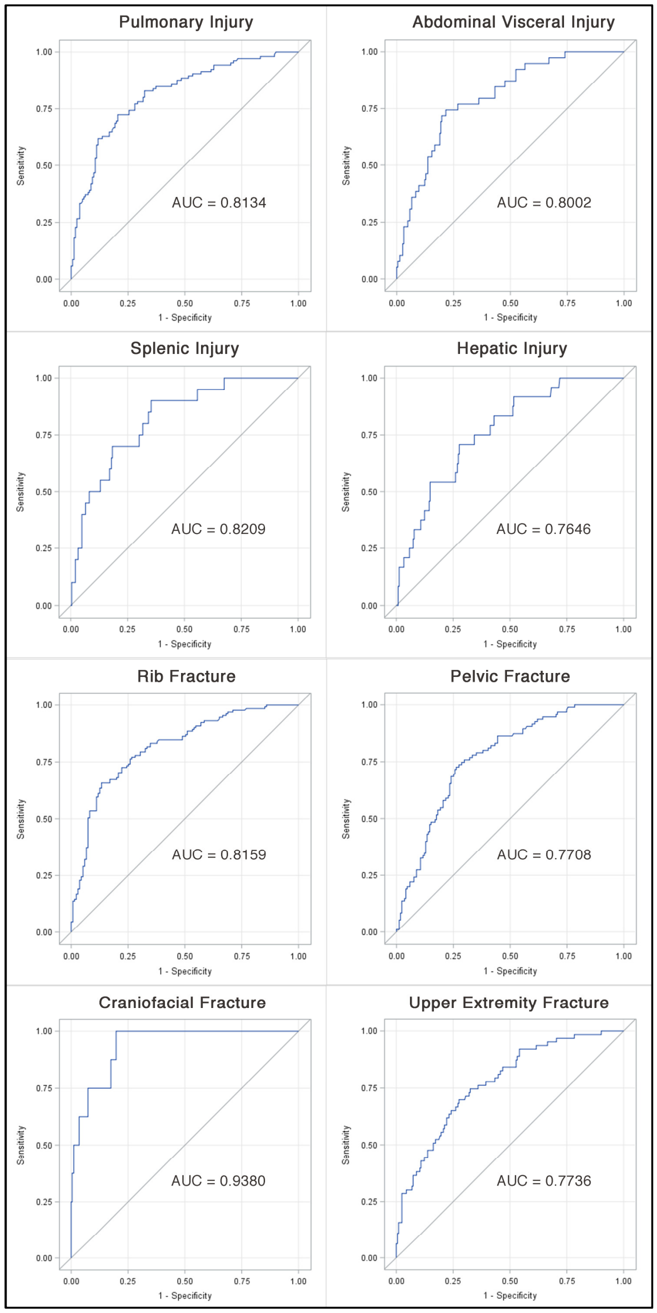

Figure 2: Receiver Operating Curves for Corresponding Models Predicting Injury Types. Logistic regression models predicting NSAIs from ITPF spinal level and covariates described in Table 2 demonstrated moderate to high predictive value. Area under the curve (AUC) ranged from 0.76 to 0.93.

Chapter III:

Summary, Implications & Future Directions

The anatomical correlation of specific traumatic injuries with spinal level of ITPFs is readily demonstrated by this investigation. This supports the hypothesis that these fractures are generated from localized or directional forces in high energy mechanisms. In conclusion, it appears that spinal level of ITPF is associated with specific patterns of injury, and additional investigation is warranted. Thoracic ITPFs significantly increase the odds of having a pulmonary contusion, Lumbar ITPFs increase the odds of finding abdominal visceral injury and lower lumbar ITPFs greatly increase the odds of having a pelvic fracture. While ITPFs by themselves are benign injuries and don't need surgery, they are associated with an increased likelihood of finding other associated injuries in a trauma patient.

Applied clinically, these results might be used to determine pretest probabilities of the various injuries discussed. The presence of ITPF at certain spinal levels may therefore be used to guide clinical decision making and diagnostic workup, however additional investigation is required in this regard. One potential application is the refinement of imaging protocols targeted towards a suspected injury on the basis of ITPF on initial CT scans.

The lack of a non-ITPF trauma patient comparator group is a major limitation of this study. Without such, the associations and conclusions reported herein are generalizable only to patients presenting with ITPF. In spite of this weakness, the present investigation still has value in that it controls for confounding variables among ITPF patients and suggests relative measures of association dependent upon spinal level of ITPF. As a preliminary investigation, the results presented in this study offer a valuable framework upon which future studies may build.

Appendices:

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Table A.3: Prediction of Rib Fracture and Number of Rib Fractures from Regression Models

Table A.1: Crude Correlation Between Spinal Level and ISS

	ISS as Binary Outcome						Point-Biserial Correlation*	
	ISS15			ISS24				
	χ^2	ϕ	p	χ^2	ϕ	p	r	p
Cervical	2.77	0.10	**0.0961**	1.67	-0.08	0.1957	-0.01	0.8963
C3-C5	0.14	-0.02	0.7063	0.14	-0.02	0.7119	0.01	0.9238
C6-C7	4.10	0.12	**0.0430**	0.81	-0.06	0.3669	0.01	0.8223
Thoracic	2.63	0.10	0.1052	0.09	-0.02	0.7585	0.08	0.2178
T1-T4	2.71	0.10	**0.0995**	0.02	0.01	0.8828	0.08	0.1901
T5-T8	0.38	0.04	0.5355	1.57	0.08	0.2102	0.13	**0.0340**
T9-T12	0.39	-0.04	0.5303	1.05	-0.06	0.3059	-0.06	0.3669
Lumbar	1.38	-0.07	0.2393	0.21	0.03	0.6446	-0.02	0.6999
L1-L3	1.85	-0.08	0.1739	2.96	-0.11	**0.0851**	-0.12	**0.0599**
L4-L5	0.00	0.00	0.9992	4.37	0.13	**0.0365**	0.10	**0.0931**

*ISS treated as a continuous variable, and transformed (sqrt[ISS]) to satisfy assumption of normality; Abbreviations: ISS = Injury Severity Score, ISS15 = severe injury threshold of ISS of 15, ISS24 = severe injury threshold of ISS of 24, r = point biserial correlation coefficient, C3 through L5 = vertebral levels

Table A.2a: Crude Correlation Between Spinal Level and ITPF-Associated Visceral Injuries

	Other Abdominal Injury			Splenic Injury			Hepatic Injury			Pulmonary Injury		
	χ^2	ϕ	p	χ^2	ϕ	p	χ^2	ϕ	p	χ^2	ϕ	p
Cervical	***3.87***	***-0.11***	***0.0491***	1.64	-0.07	0.2001	***6.23***	***-0.14***	***0.0126***	0.69	0.05	0.4067
C3-C5	0.97	-0.06	0.3238	0.52	-0.04	0.4705	0.57	-0.04	0.4509	1.08	-0.06	0.2990
C6-C7	3.01	-0.10	0.0826	1.22	-0.06	0.2691	***5.55***	***-0.13***	***0.0185***	2.11	0.08	0.1462
Thoracic	0.54	-0.04	0.4610	0.03	0.01	0.8596	0.18	0.02	0.6698	***29.38***	***0.31***	***<0.0001***
T1-T4	***4.21***	***-0.12***	***0.0403***	0.16	-0.02	0.6857	1.28	-0.06	0.2570	***20.09***	***0.26***	***<0.0001***
T5-T8	1.23	-0.06	0.2684	0.20	0.03	0.6533	1.39	0.07	0.2391	***15.36***	***0.22***	***<0.0001***
T9-T12	***7.07***	***0.15***	***0.0078***	0.38	0.04	0.5360	1.94	0.08	0.1638	3.71	0.11	0.0543
Lumbar	***10.59***	***0.19***	***0.0011***	***5.04***	***0.13***	***0.0248***	***3.86***	***0.11***	***0.0495***	***12.18***	***-0.20***	***0.0005***
L1-L3	1.89	0.08	0.1692	0.21	0.03	0.6465	0.14	-0.02	0.7075	***6.95***	***-0.15***	***0.0084***
L4-L5	***20.00***	***0.26***	***<0.0001***	***11.52***	***0.19***	***0.0007***	***8.54***	***0.17***	***0.0035***	1.24	-0.06	0.2660

Abbreviations: ϕ = phi correlation coefficient, ITPF = isolated transverse process fracture. Significant Associations defined at alpha=0.05, shown in bold italics. Other Abdominal Injury includes hemoperitoneum, pneumoperitoneum, shock bowel, bowel injury, perinephric hematoma, retroperitoneal hematoma, abdominal wall hematoma, other abdominal soft tissue injury, excluding non-bowel organ injury.

Table A.2b: Crude Correlation Between Spinal Level and ITPF-Associated Orthopedic Injuries

	Pelvic Fracture			Upper Extremity Fracture			Rib Fracture			Craniofacial Fracture		
	χ^2	ϕ	p	χ^2	ϕ	p	χ^2	ϕ	p	χ^2	ϕ	p
Cervical	***8.69***	***-0.17***	***0.0032***	0.14	0.02	0.7102	1.51	0.07	0.2194	***7.19***	***0.15***	***0.0073***
C3-C5	3.06	-0.10	0.0802	0.16	-0.02	0.6890	2.27	-0.09	0.1320	3.48	0.11	0.0623
C6-C7	6.32	-0.14	0.0119	0.20	0.03	0.6525	2.87	0.10	0.0901	***4.23***	***0.12***	***0.0396***
Thoracic	***13.81***	***-0.21***	***0.0002***	***14.68***	***0.22***	***0.0001***	***35.66***	***0.34***	***<0.0001***	0.07	-0.02	0.7891
T1-T4	***6.65***	***-0.15***	***0.0099***	***8.81***	***0.17***	***0.0030***	***22.35***	***0.27***	***<0.0001***	0.17	0.02	0.6790
T5-T8	2.81	-0.10	0.0939	***13.30***	***0.21***	***0.0003***	***8.27***	***0.16***	***0.0040***	0.26	0.03	0.6135
T9-T12	3.77	-0.11	0.0522	0.00	0.00	1.0000	***6.25***	***0.14***	***0.0124***	0.61	-0.04	0.4355
Lumbar	***25.36***	***0.29***	***<0.0001***	***12.44***	***-0.20***	***0.0004***	***15.66***	***-0.23***	***<0.0001***	2.45	-0.09	0.1173
L1-L3	0.42	-0.04	0.5178	***6.93***	***-0.15***	***0.0085***	1.08	-0.06	0.2995	0.39	-0.04	0.5339
L4-L5	***40.77***	***0.37***	***<0.0001***	0.41	-0.04	0.5208	***6.17***	***-0.14***	***0.0130***	0.26	0.03	0.6096

Abbreviations: ϕ = phi correlation coefficient, ITPF = isolated transverse process fracture. Significant Associations defined at alpha=0.05, shown in bold italics.

Table A.3: Prediction of Rib Fracture and Number of Rib Fractures from Regression Models

Logistic Regression Predicting Any Rib Fracture		
	OR	**P**
Age	1.03	0.0039
ISS	1.09	<0.0001
Number of Thoracic ITPF	1.44	0.0188

Linear Regression Predicting Number of Rib Fractures		
	β	**P**
Intercept	-2.60	<0.0001
Age	0.06	<0.0001
ISS	0.11	<0.0001
Number of Thoracic ITPF	0.37	0.0134

Abbreviations: ITPF = isolated transverse process fractures, ISS = injury severity score (continuous variable), OR = adjusted odds ratio. Significant Associations defined at alpha=0.05. Logistic regression model predicts binary incidence (yes/no) of rib fracture. Linear regression model predicts total number of rib fractures in a single patient.