



Transverse Process Fractures: A Clinical Series and Coronal Injury of the Spine

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■ **BACKGROUND:** Transverse process fractures in trauma patients frequently are diagnosed using computed tomography and result in severe pain and limitation of motion. However, there is no accepted standard of care. Thus, these fractures can be treated with excessive measures or inadequately treated. In this study, diagnosis and treatment of transverse process fractures are examined.

■ **METHODS:** The mechanisms of trauma, findings, and associated organ injuries of 50 patients with transverse process fractures and no other spinal injuries treated between 2013 and 2015 were recorded. The same treatment protocol was applied to each patient. The results of the treatments were examined retrospectively and recorded.

■ **RESULTS:** Deformation and edema of the fascia and muscles around the transverse process fractures were detected by computed tomography and magnetic resonance imaging. The average pain intensity of the patients before treatment was 8.8 of 10 on a visual analog scale and 5.2 of 10 after treatment with nonsteroidal anti-inflammatory drugs, muscle relaxants, flexible support corsets, and mobilization. Patients hospitalized for additional pathologies were primarily treated in thoracic surgery wards (11 of 15 patients). Transverse process fractures were caused by backward falls or blows to the back in 49 patients.

■ **CONCLUSIONS:** Transverse process fractures can be treated quickly and effectively with the recommended

protocol after excluding any accompanying organ injuries or other spinal injuries. Transverse process fractures most often occur during backward falls or blows to the back, commonly low-energy injuries. This trauma mechanism can be described as a “coronal injury of the spine.”

INTRODUCTION

Transverse processes (TPs) are bone extensions on both lateral sides of the lumbar, thoracic, and cervical vertebrae (Figure 1).^{1,2} In the lumbar vertebrae, the middle layer of the thoracolumbar fascia (MLF) attaches to the TP tips (Figure 2A).³ On the other side of the MLF, it fuses with the transversus abdominis (TrA) muscle. The TrA reaches the anterior abdominal wall, where it surrounds the waist like a corset.^{1,2} The quadratus lumborum (QL) muscle attaches to the superolateral and inferolateral sides of the TP tips, reaching the pelvis and thorax (Figure 2B).⁴ On the anterior aspect, the psoas major muscle attaches to the anteromedial borders of the TPs. On the posterior aspect, deep lamina of the posterior layer of thoracolumbar fascia, known as the paraspinous retinacular sheath and the longissimus muscle, attach to the lumbar TPs, and the TP is covered with deep and superficial back muscles (Figure 1).^{1,3,4}

TPs are important anatomic landmarks for spinal surgeons, but the fracture of one is insignificant surgically due to the stable nature of this spine injury. In the thoracolumbar injury classification, Denis⁵ considered transverse process fractures (TPFs) to be

Key words

- Coronal injury of the spine
- MLF
- Myofascial injury
- Psoas
- Quadratus lumborum
- Thoracolumbar fascia
- Transverse process fracture

Abbreviations and Acronyms

- CT:** Computed tomography
- HEI:** High-energy injury
- LEI:** Low-energy injury
- MLF:** Middle layer of the thoracolumbar fascia
- MRI:** Magnetic resonance imaging
- MVA:** Motor vehicle accident
- NSAID:** Non-steroidal anti-inflammatory drug
- QL:** Quadratus lumborum
- RICE:** Rest, ice, compression, elevation
- TLSO:** Thoracic lumbar sacral orthosis

TP: Transverse process

TPF: Transverse process fracture

TrA: Transversus abdominis

VAS: Visual analog scale

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minor injuries. However, studies conducted at trauma centers found that TPFs were more serious than other spinal injuries and it was demonstrated that the Injury Severity Score was greater for TPFs than other spinal injuries.^{6,7} Miller et al.⁷ found that the abdominal injury rate associated with TPF was 48%, whereas it was only 6% in non-TPF spinal injuries. Lombardo et al.⁶ reported that TPF usually is accompanied by pelvic and rib fractures, as well as splenic, liver, and kidney injuries, and 94.4% of TPFs were associated with systemic injuries.

Sports medicine publications have reported TPFs not accompanied by organ injuries and published diagnostic and treatment examples in professional football players,⁸⁻¹¹ cricket players,¹² skiers and snowboarders.^{13,14} Spinal surgery studies report that TPF is a stable injury of the spine and can be treated conservatively without spine consultation.¹⁵⁻¹⁸ Conservative treatment studies proposed bedside pain control^{19,20} and physiotherapy.²⁰ Nevertheless, there are a wide spectrum of TPF therapies in practice. At one end of the spectrum, patients are discharged with a paracetamol prescription and suffer pain and movement limitation for a long time. On the other end of the spectrum, treatments have included intubation and immobilization for 4 days for further examinations.²⁰

In this study, the importance of TPs for spine and torso and treatment of TPFs were discussed in light of experimental and clinical studies in anatomy,^{1-4,21} biomechanics,^{3,22} sports medicine,^{8-14,23,24} emergency medicine,^{6,7,25-27} spinal surgery,^{15-18,28-30} radiology,^{7,31} pathology,²³ and our clinical series.

MATERIALS AND METHODS

Fifty patients with fractures of isolated transverse process (i.e., TPF) who were examined in consultation by the same neurosurgical specialist during a 350-day period at Düzce Atatürk State Hospital Emergency Department between October 2013 and October 2015 were included in this study. Patients with TPF with additional spinal injuries were excluded from the study.

In patients with TPF, trauma history, mechanism of injury, localization and severity of pain, examination and imaging findings, accompanying injuries, and treatment outcomes were recorded. To assess pain severity, patients were asked to choose a score from 1 to 10 that represented the pain they felt on the visual analog scale (VAS). Medical treatment and corsets were applied in the bed as an extremity bandage then patients were mobilized or sitting. Application of the corset and patient mobilization by the nursing staff is demonstrated in **Video 1**. VAS was first assessed at the patient's arrival, with a second assessment after treatment. Short- and long-term outcomes of treatment and VAS were evaluated after 1 week, 6 weeks, and 18–36 months. All results were analyzed retrospectively. Research data were analyzed using the Statistical Package for the Social Sciences (SPSS Statistics for Windows, version 13.0; SPSS Inc., Chicago, Illinois, USA). Descriptive statistics and the χ^2 test were used, and the significance level was set at $P < 0.05$.

RESULTS

Included in the study were 36 male patients (72%) and 14 female patients (28%) between the ages of 18 and 81 years with a mean

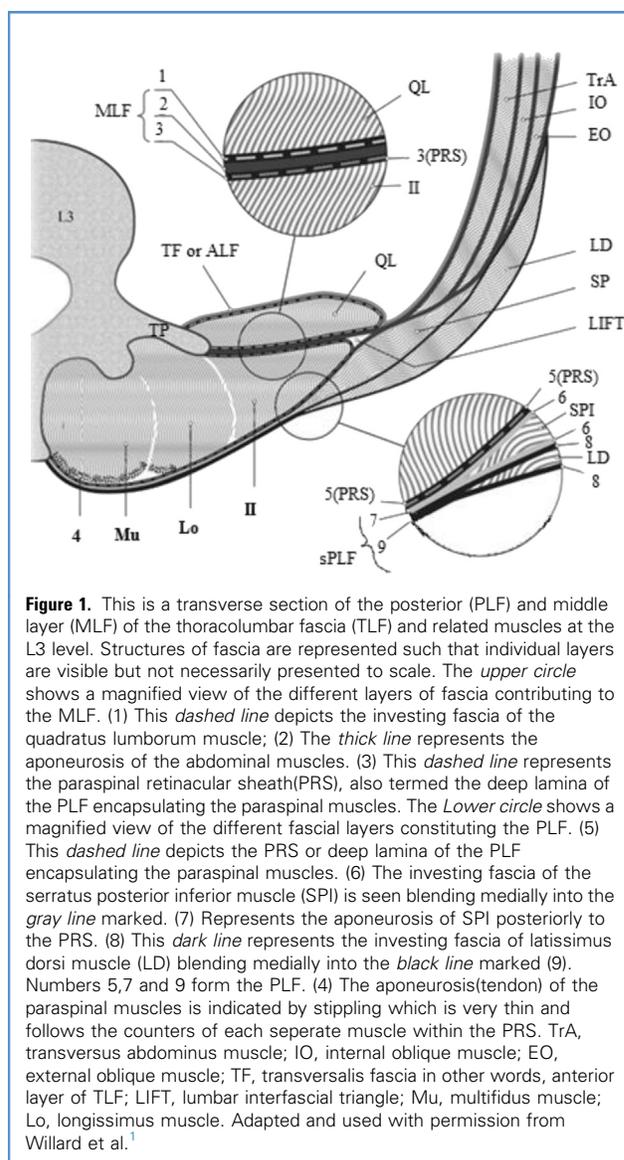
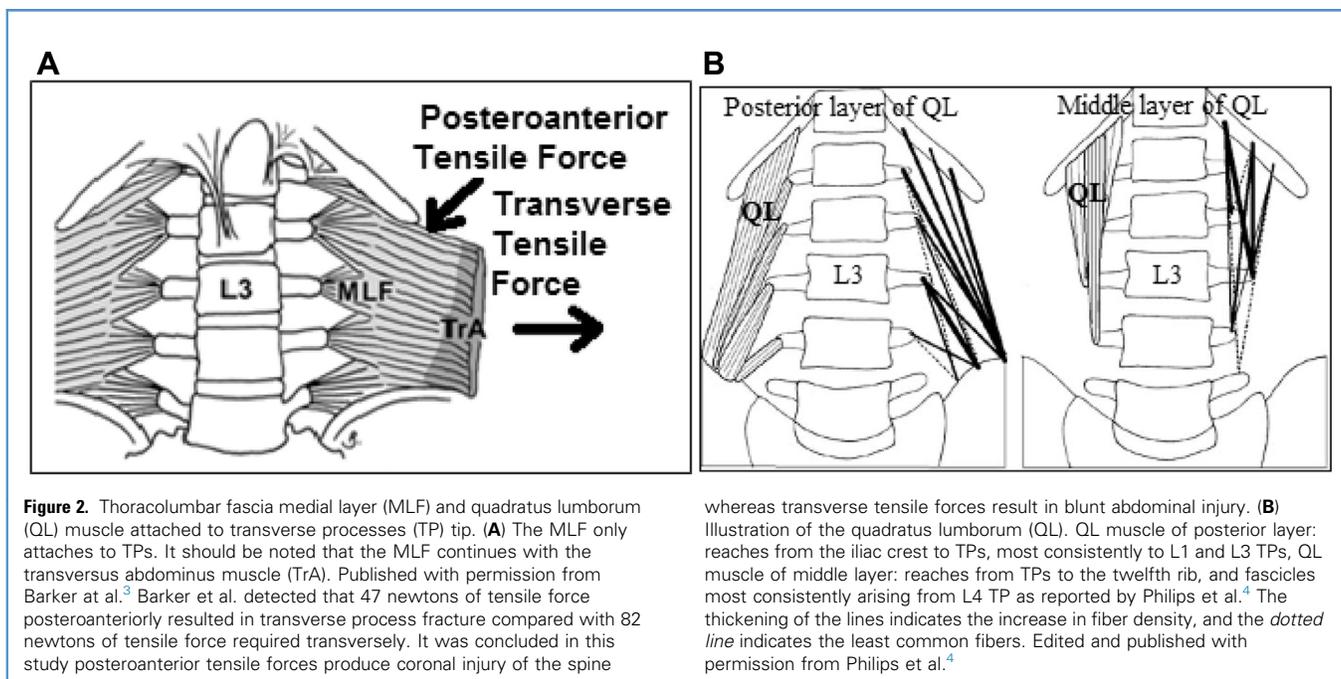


Figure 1. This is a transverse section of the posterior (PLF) and middle layer (MLF) of the thoracolumbar fascia (TLF) and related muscles at the L3 level. Structures of fascia are represented such that individual layers are visible but not necessarily presented to scale. The upper circle shows a magnified view of the different layers of fascia contributing to the MLF. (1) This dashed line depicts the investing fascia of the quadratus lumborum muscle; (2) The thick line represents the aponeurosis of the abdominal muscles. (3) This dashed line represents the paraspinal retinacular sheath (PRS), also termed the deep lamina of the PLF encapsulating the paraspinal muscles. The lower circle shows a magnified view of the different fascial layers constituting the PLF. (5) This dashed line depicts the PRS or deep lamina of the PLF encapsulating the paraspinal muscles. (6) The investing fascia of the serratus posterior inferior muscle (SPI) is seen blending medially into the gray line marked. (7) Represents the aponeurosis (tendon) of the PRS. (8) This dark line represents the investing fascia of latissimus dorsi muscle (LD) blending medially into the black line marked. (9). Numbers 5, 7 and 9 form the PLF. (4) The aponeurosis (tendon) of the paraspinal muscles is indicated by stippling which is very thin and follows the contours of each separate muscle within the PRS. TrA, transversus abdominis muscle; IO, internal oblique muscle; EO, external oblique muscle; TF, transversalis fascia in other words, anterior layer of TLF; LIFT, lumbar interfascial triangle; Mu, multifidus muscle; Lo, longissimus muscle. Adapted and used with permission from Willard et al.¹

age of 40.18 years. In these 50 patients, 132 TPFs were detected, with patients having between 1 and 10 fractures. This resulted in an average of 2.6 fractures per patient. Thirty-four patients (68%) had 2 or more fractures. There was also a correlation between the number of fractures and vertebral levels (**Table 1**). TPFs were found in the lumbar vertebrae for 47 patients (94%), in the thoracolumbar junction (T11, T12, L1, L2) for 2 patients (4%), and in the thoracic vertebrae for 2 patients (4%). One patient had both thoracic and thoracolumbar junction TPF. The most frequently affected vertebra was L2 (38 patients), followed by L3 (34 patients). Unilateral TPF were detected in 48 patients (96%), and bilateral TPFs were detected in 2 patients (4%). TPFs were equally distributed on the left and right sides.



Video available at
www.sciencedirect.com



Clinical Findings

Forty-nine patients (98%) were conscious; 1 patient was unconscious, intubated, and had multiple systemic injuries. Severe back pain in the right or left paraspinal area, restricted movement, and superficial respiration were present in 49 patients. The mean VAS was 8.8 of 10. No motor or sensory deficit was detected in any patients. Additional pathology was found in 46% of patients with TPF.

Radiology

TPF was diagnosed using thoracic and abdominal computed tomography (CT; 1-mm cross sections) taken at the time emergency services were administered. CT axial sections showed the QL muscle and the MLF on the fracture side were thickened and lost their tension and that the psoas muscle was deformed

(Figures 3A–B and 4A–B). T2-hyperintense images of the muscles around the TPFs taken with lumbar magnetic resonance imaging (MRI) also were assessed as edema (Figures 3C and 5). X-ray films were also taken in 10 of the 50 patients. When examined retrospectively, TPF could be identified in 1 of 10 x-ray films.

Treatment and Follow-Up Results

All of the patients with TPFs were administered nonsteroidal anti-inflammatory drugs (NSAIDs; intramuscular diclofenac sodium 75 mg or intravenous tenoxicam 20 mg), muscle relaxants (intramuscular thiocolchicoside 2 mg), and a mucosal protective agent (intramuscular ranitidine 50 mg) at emergency services if there was no contraindication. Then, flexible support corsets with steel stays were applied to the patients while they were in the bed, like

Table 1. Number of TPFs, Localizations, and Frequencies

TPF Number	Frequency (Patient)	The Most Commonly Affected Vertebrae	Discharged—Hospitalized	Hospitalization Rate	Results
1	16 cases (32%)	50% L1	13—3	18.7%	Multiple TPFs (2–10) were found in 68% of the patients. Hospitalization rate is greater with 4 or more TPFs.
2	12 cases (24%)	53% L2, L3	10—2	16.2%	
3	9 cases (18%)	55% L2, L3, L4	8—1	12.5%	
4	7 cases (14%)	71% L1, L2, L3, L4	3—4	57%	
5	4 cases (8%)	60% L1, L2, L3, L4, L5	1—3	75%	
6	1 case (2%)	T11, T12, L1, L2, L3, L4	1—0	0%	
10	1 case (2%)	Bilateral L1, L2, L3, L4, L5	0—1	100%	

TPF, transverse process fracture.

an extremity bandage and, immediately afterward, the patients were mobilized (Video 1 shows how to use the corset). A lumbosacral corset was used for L2, L3, L4, and L5 TPFs, and a thoracolumbar corset was used for L1 and thoracic TPFs.

After corset application, severe pain and movement limitation decreased, breathing improved, and patients relaxed. After treatment and mobilization, the mean VAS was 5.2 of 10. Of the 50 patients, 35 (70%) without other systemic pathology were discharged with prescribed oral diclofenac 50 mg, thiocolchicoside 4 mg and lansoprazol 30 mg. Patients with 1–6 TPFs were included in this group (Table 2).

Fifteen of the 50 patients (30%) were hospitalized due to additional pathologies by emergency medicine and related specialists. Of these 15 patients, 11 (73%) were treated by the thoracic surgery service. Most of the additional pathologies were detected in this patient group (Table 2). L1 and L2 TPFs were detected in 10 of the 11 patients (91%) hospitalized on the thoracic surgery service, and significant correlation was detected between those who had L1 and L2 TPFs along with thoracic injury ($P = 0.00$). One patient with TPF with displaced pelvic fractures and bladder rupture underwent surgery by urology and died in the intensive care unit. A patient with TPF with a complicated intramuscular hematoma was hospitalized on the neurosurgical service for follow-up; CT, MRIs, and photograph of the lumbar area are presented in Figure 3A–C. Patients with between 1 and 10 TPFs were included in the hospitalized group. After urgent treatment of visceral injuries, hospitalized patients with TPF were administered NSAIDs, muscle relaxants, a mucosal protective agent, were applied flexible support corset with steel stays and were mobilized or sit if there was no contraindication. Patients with 4 or more TPFs detected and additional systemic injuries had a significantly greater hospitalization rate, whereas those with 1, 2, or 3 TPFs had a very low hospitalization rate, and a significant correlation was detected ($P = 0.02$) (Table 3).

After 1 week, 42 of the 50 patients were examined for control. Pain and movement limitation were largely healed with medical treatment and flexible support corset, and the mean VAS was 1.6 of 10 (Table 2). Hospitalized patients were discharged over 10 days by related specialists. Flexible support corsets were recommended for 2 weeks in 1 or 2 TPFs and or 3–6 weeks in 3–6 TPFs. Muscle immobilizations and usage was decreased gradually. NSAIDs, muscle relaxants, and the mucosal protective agent were terminated, and symptomatic analgesic was recommended. Sick notes were given for 2 weeks in 1–2 TPFs and for 3–6 weeks in 3–6 TPFs.

After 6 weeks, when all of the patients had stopped using the corset, 36 of the 50 patients were examined for control. All patients had recovered completely and returned to work and daily routines, with a mean VAS of 0.09 of 10. At 18–36 months after the trauma, 22 of the 50 patients were examined, and they had no complaints and VAS was 0. Treatment and follow-up results for TPF patients are summarized in Table 2.

Trauma Mechanism

It was detected that TPFs were caused by a fall in 28 of the 50 patients, motor vehicle accidents (MVAs) in 20 patients, and a heavy object falling on the person's back in 2 patients. The case cohort was categorized as high-energy injury (HEI) and

low-energy injury (LEI) based on the triage classification of emergency medicine.* Thirty-nine of the patients were exposed to a LEI, whereas 11 were exposed to an HEI. However, a different classification was used in this study. Therefore, it was discovered that TPFs were caused by backward falls (maximum height 2.5 meters) such as on stairs, slippery floors, in showers, from open vehicles, or fall from trees or walls in 39 patients, whereas TPFs were caused by a blow to the back, such as in a car collision with a rear impact or a heavy object falling on the back, in 10 patients (Table 4). Thus, a total of 49 of the 50 patients (98%) were found to have a coronal plane impact/load on the spine, which occurred with an LEI in 39 patients (80%) and with HEI in 10 patients (20%). This trauma mechanism was identified as coronal injury of the spine.

In the coronal injury group of hospitalized patients, thorax injury was the most commonly diagnosed additional injury (11 of the 14 patients) (Table 5), and there was a significant correlation between TPFs caused by coronal injury of spine and thorax injury ($P = 0.044$) (Table 5). In 49 patients with coronal injury, 122 TPFs were detected; of these, 120 TPFs were unilateral and 2 were bilateral. Thus, it was found that 99.2% of the unilateral TPFs were found in the coronal injury cohort (Table 6). A significant correlation was found between TPFs and coronal injury of the spine ($P = 0.00$) (Table 4). It was concluded that while backward fall or blow to the back may contact fracture side firstly and receive the main blow and result unilateral TPFx.

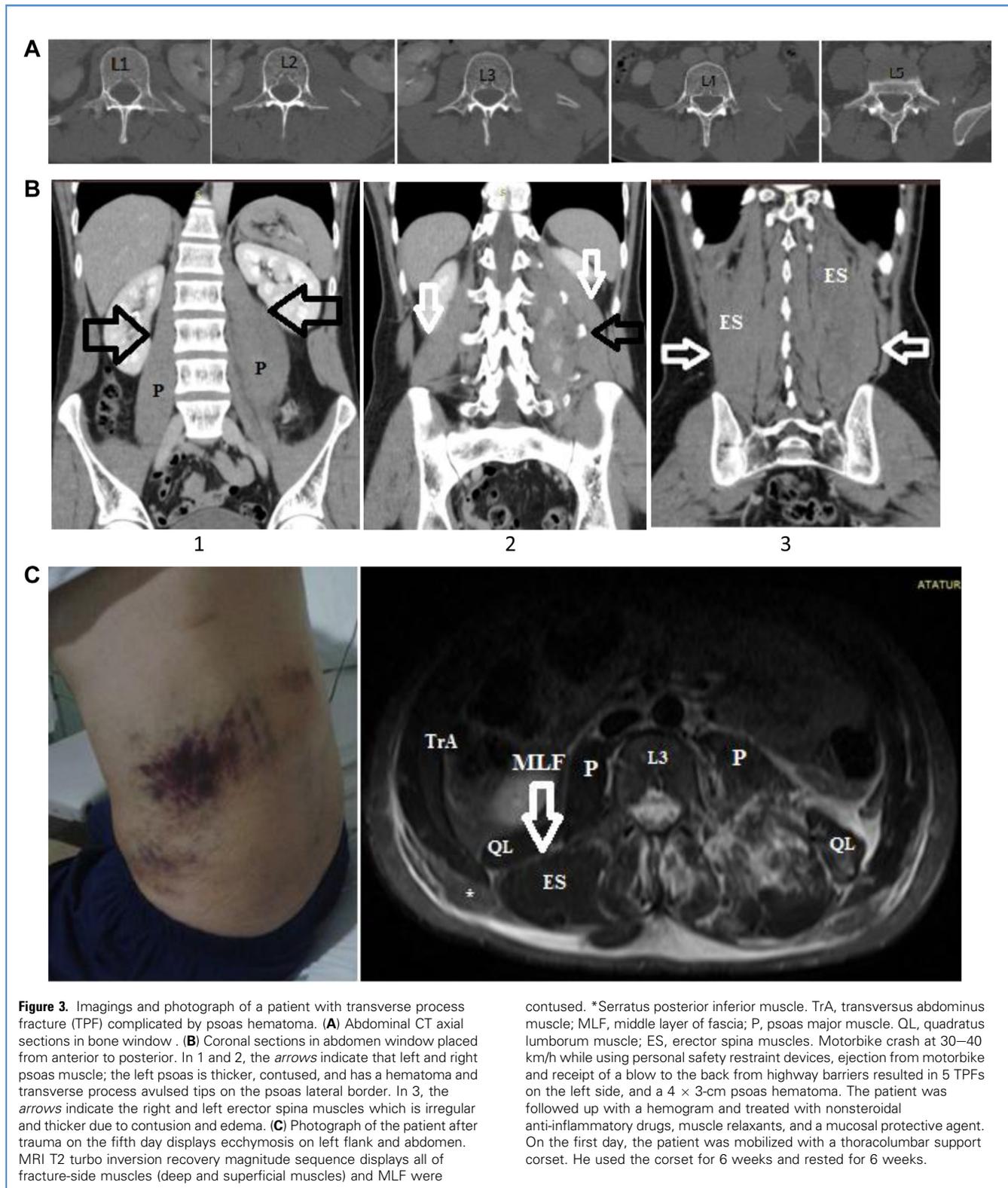
TPF caused by blunt abdominal trauma was detected in only 1 patient (2%) in this study, due to a HEI with displaced pelvic fractures, bladder rupture, and bilateral L1, L2, L3, L4, and L5 TPFs. This patient's CT imaging result is presented in Figure 6.

DISCUSSION

When TPFs were being diagnosed with plain radiography, articles reported only skipped and chronic TPFs.^{3,33,34} After routine use of CT in trauma patients began, TPFs were detected very often and were reported as the most common spinal pathology in a comprehensive trauma center study.²⁵ Thus, it can be concluded that TPF is only a recently discussed injury.

Biomechanics and anatomic studies of the area around the TPs have recently been performed with the assistance of electrophysiology and microscopy. Willard et al.¹ studied the muscular ligamentous and neural structures of the lumbosacral region and its relationships to low back pain (Figure 1). Barker et al.^{2,3} studied TPs, as well as muscle and fascia attachments, and performed experimental cadaveric biomechanics studies to examine TPFs and role of MLF in segmental control (Figure 2A). Phillips

*High-energy injury (HEI): 1) Ejection of the patient from an enclosed vehicle. 2) Auto/pedestrian or auto/bike or motorcycle crash with significant impact (>20 mph/32 km/h) with the patient thrown or run over by a vehicle. 3) Falls greater than 20 feet (6 meters) for adults or greater than 10 feet (3 meters) for pediatric patients or a distance 2–3 times the height of the patient. 4) Significant assault or altercation. 5) High-risk auto crash 6) Motor vehicle crashes when the patient has not used personal safety restraint devices. 7) Death in the same passenger compartment. 8) Rollover. 9) High-speed auto crash. 10) Compartment intrusion of auto greater than 12 inches (30 cm) at occupant site or greater than 18 inches (50 cm) at any site (https://www.ok.gov/health2/documents/TRAU_T3Algorithms04202009.pdf). In this study, heavy objects falling on the back were added to the HEI list, feet/m, mph/km/h, and inches/cm equivalences were added approximately.



et al.⁴ studied the fascicular anatomy of the QL muscle, which is composed of 3 layers, and its importance in stability (Figure 2B).

In this study, 50 patients with TPF were seen in consultation and treated by the same neurosurgeon, and results were analyzed. Compatible with previous studies, TPFs were most commonly detected in lumbar vertebrae (47), unilaterally (48), and in men (36). Fifteen patients (30%) were hospitalized with additional systemic pathologies. In previous studies, additional pathologies associated with TPFs were found to be quite high, between 80% and 95%.^{6,15,16,19,20} In this study, additional pathologies were detected in 46% of the patients. This difference was due to the fact that previous studies were done at level 1 trauma centers, whereas this study was performed at a level 3 first-referral hospital. Thus, rates of additional systemic pathology and hospitalization are lower than in previous studies. In this study, the most common additional pathology (11 patients) was thoracic injury, such as pulmonary contusion and hemothorax with or without rib fractures (Table 2). This result is compatible with previous studies.^{6,16,19,20}

Number of TPFs, Additional Pathology, and Hospitalization

In this study, a high rate of hospitalization and additional system pathology were detected in patients with 4 or more TPFs. The hospitalization rate was 61.2% in patients with 4 or more TPFs. Nineteen percent of patients had 1, 2, or 3 TPFs. There was a significant correlation between the need for hospitalization and the number of TPFs ($P = 0.02$) (Tables 1 and 3). Tewes et al.¹⁰ reported a study in which professional athletes suffered TPFs through LEI, and they observed a maximum of 3 TPFs with no additional pathology. Other studies differed from our result. Xia et al.²⁶ detected no relationship between TPF number and additional pathology and Boulter et al.¹⁶ reported a greater additional pathology rate in patients with 2 or more TPFs.

Clinical Findings and Treatment of TPFs

Spinal surgery publications have suggested that TPFs are stable injuries that do not cause neurologic deficits, and conservative treatment has been proposed.¹⁵⁻¹⁸ Bradley et al.¹⁵ also reported that conservative treatment of TPF could be managed without spinal surgery consultation. Boulter et al.¹⁶ reported that, in their study, no patients with TPF were hospitalized on the spinal surgery service, and no corsets or surgeries were required. This study is the first clinical study in the field of neurosurgery for TPFs diagnosis and treatment management.

It is believed that TPF pain is not acknowledged, and any pain the patient experiences is caused by other systemic injuries.¹⁶⁻¹⁸ Treatment for TPF is recommended when pain is symptomatic and analgesics are recommended.^{15,17,20} Unlike in previous studies, TPF was measured for the first time using a standardized method, which demonstrated that it is one of the most severe pains experienced by patients (mean VAS = 8.8/10). Severe back pain in the right or left paraspinal region, movement limitation, and superficial respiration were detected. Sports medicine publications support these results.^{8-11,31} Gray et al.⁹ reported that paracetamol, ibuprofen, and codeine were given to a professional-league football player with 2 TPFs. Severe spasms developed in the low back muscles after 2 days, and diazepam was prescribed and back massages applied. In this study, QL and MLF

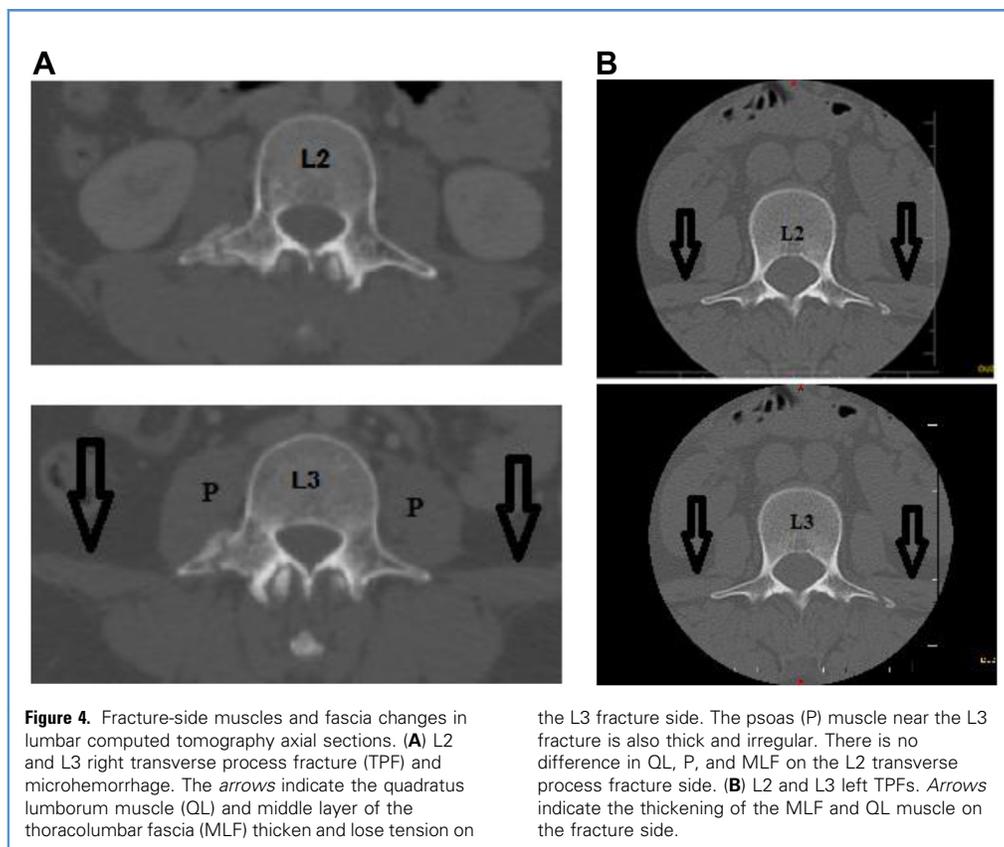
thickening, loss of tension, and psoas deformation were detected on CT (Figure 4A–B) and edema in the muscles and fascia around the TPs were detected on MRI (Figures 3C and 5).

Barker et al.² demonstrated tearing of the MLF in TPFs in a cadaver trial. Armstrong³⁵ reported that TPF is important because of extensive rupture of the psoas and related muscle damage. These muscles and fascia extend from the TPs to the anterior abdominal wall, thorax, and pelvis and support the lumbar vertebrae (Figures 1 and 2A–B).¹⁻⁴ It was concluded that dysfunction of these muscles, due to contusion or micro-hemorrhage, causes severe pain over a large area, movement limitation, and superficial breathing. Thus, instead of considering TPF only a fracture of a small bony prominence, it should be identified and treated as a more extensive muscle and fascia injury.

Muscle injuries are widely treated in the emergency department with the RICE approach of rest, ice, compression, and elevation. Järvinen et al.²³ demonstrated histologically that this treatment prevents intramuscular bleeding, re-tearing of muscle fibrils, and the formation of excessive connective tissue.²³ They also showed that treatment with short-term NSAIDs for muscle injuries prevented excessive inflammation and connective tissue formation and did not cause side effects.²³ In this study, patients were treated with NSAIDs, muscle relaxants, and a mucosal protective agent was routinely used for 1 week, and our results were consistent with Jarvinen et al. All patients also had lumbosacral or thoracolumbar flexible support corsets with steel stays applied, and the patients were immediately mobilized by nursing in the emergency department if there was no contraindication. It was observed that pain was well-controlled when the muscle and fascia inflammation was inhibited with NSAIDs, and muscle spasm was inhibited with muscle relaxants.

Boulter et al.¹⁶ emphasized the importance of NSAIDs and muscle relaxants in patients with TPF with soft-tissue inflammation and axial back pain. The function of the flexible support corset in TPF was identified as immobilization and movement support of the muscles and fascia and prevention of their contraction and resultant tissue compression. Patient mobilization or sitting from the supine position means elevation of the back muscles. Thus, it was concluded that patient mobilization with a flexible support corset corresponds with the rest/compression/elevation principles of the RICE approach, and ice also may be recommended. In previous studies, the corset was assessed as nonfunctional and only recommended for comfort¹⁵⁻¹⁸; however, in this study, the flexible corset was used for treatment of myofascial injury. Boulter et al.¹⁶ reported 15% of patients with TPF were prescribed a brace. Akinpelu et al.¹⁹ prescribed 8.5% of patients a thoracic lumbar sacral orthosis (TLSO). Homnick et al.²⁰ reported 23% of patients wore a corset and 3.5% wore a TLSO after spinal consultation. It was concluded that using orthoses (Jewett TLSO) is unnecessary because TPFs are stable injuries. Tewes et al.¹⁰ reported that, even if football players were not given corsets, they were wearing lead training pads or elastic bandage pads around their bodies. In the current study, 49 of the 50 patients (98%) had a lumbosacral or thoracolumbar flexible support corset with steel stays applied.

Järvinen et al.²³ reported that muscle immobilization for 3–5 days prevents re-ruptures and bleeding, but it could be done



simply with a firm adhesive tape, and the best results were achieved with gradual muscle exercises, as allowed by pain. Consistent with these results, the use of the flexible support corset was reduced gradually in this study over a 6-week period. It was concluded that flexible support corsets with steel stays are suitable for immobilization of back muscles. After treatment with NSAIDs, muscle relaxants, flexible support corset, and patient mobilization, it was observed that movement limitation and superficial respiration resolved, and pain control was rapid. The mean post-treatment VAS was 5.2 of 10. All 35 patients (100%) without additional systemic injury, even those with 6 TPFs, were discharged, and it was concluded that hospitalization was unnecessary.

It was observed that, in studies without corset treatment, hospitalization continued for significant time periods.^{16,19,20} Muscle immobilization with corset was associated with more rapid healing. Without corset application, there will be severe pain, movement limitation, and longer hospitalization for injectable treatments. An MRI was not ordered for any patient in emergency service. Homnick et al.²⁰ reported prolonged hospitalizations and use of log-roll precautions for further examinations. Boulter et al.¹⁶ reported that according to the hospital registry, the ratio of discharge from emergency service is 71.2%, which is compatible with this study. In the 1-week control, any of patients experienced pain, movement limitation, or respiratory distress while using a corset and had a mean VAS of 1.6. In the 6-week control,

after patients had stopped wearing the corset, all patients had recovered completely with no detected pain and a VAS of 0.09.

Rest is an important component of the RICE approach.²³ In this study, excuse notes were given after discharge for at least 2 weeks for patients with 1 or 2 TPFs and for 3–6 weeks for patients with

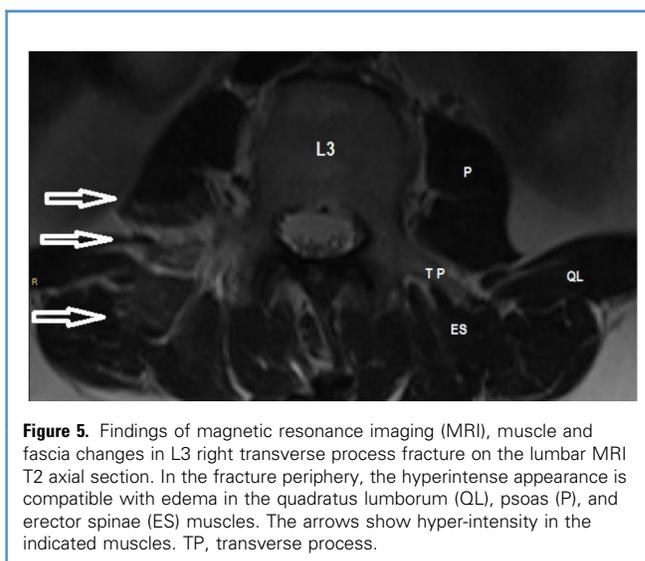


Table 2. Clinical Findings, Treatment, and Follow-Up Results of Patients with TPFs

Distribution of Patients with TPFs	Additional Pathologies	Emergency Treatment	Results After Emergency Treatment	Control at Week 1	Control at Week 6	Control at months 18–36
VAS: 8.8			VAS: 5.2	VAS: 1.6	VAS: 0.09	VAS: 0
In 35/50 (70%) of the cases, there is no additional systemic pathology.	Spinous process fracture in 2 patients, stable pelvic fracture in 1 patient, pars interarticularis fracture in 1 patient, cephalic hematoma in 1 patient.	70% of patients were treated with injectable NSAIDs, muscle relaxant and mucosal protective agent, flexible support corsets were applied in the bed then patient was mobilized if there was no contraindication.	70% of the patients with TPFs were discharged from the emergency service. NSAIDs, muscle relaxants, and mucosal protective agent were prescribed.	42/50 (84%) of the patients were examined. Pain and movement limitation were recovered. Patients used corset when lying down or sleeping on television seat.	36/50 (76%) of the patients were examined. Patients were found to reduce corset use after 2 weeks. Pain not detected in any patient after discontinuing corset use.	22/50 (44%) of the patients were examined. No persistent back pain or any other finding was detected in long-term follow-ups.
Additional systemic pathologies were present in 15/50 (30%) of TPF cases.	11/50 (22%) of patients had thoracic pathology (pulmonary contusion, hemo/pneumo-thorax or rib fracture), 1 patient had a temporal contusion, 1 patient had sacral and scapular fractures, 2 patients had pars interarticularis fractures, and 1 had a zygomatic fracture.	22% of the patients were hospitalized and treated in thoracic surgery service. Patients were treated with injectable NSAIDs and a mucosal protective agent, they were supplied with a flexible support corset that permitted lung expansion, then it was recommended they sit down or stand up if there was no contraindication.	30% of the patients with TPF were admitted and treated at the relevant clinic's service.	NSAIDs, muscle relaxants, and a mucosal protective agent were terminated, and symptomatic analgesic was recommended. Patients were advised to reduce the use of corset gradually in accordance with the level of pain and stop using it at the sixth week. Patients with 1–2 TPFs were given 2 weeks of sick notes, and those with 3–6 TPFs were given notes for 3–6 weeks.	No complications from the flexible support corset or medications were detected.	
	2/50 (4%) with neuro-surgical pathology (occipital fracture and hematoma in 1 case, and psoas hematoma and spinous process fracture in 1 case).	4% of the patients were hospitalized and treated at neurosurgery clinic service. Patients were treated with injectable NSAIDs, muscle relaxants, and a mucosal protective agent, were supplied with a flexible support corset in bed, then assisted for sitting or mobilization if there was no contraindication.				
	1/50 (2%) of patients had a fragmented tibia fracture.	2% of the patients were admitted and treated at the orthopedics clinic service. Patients were treated with injectable NSAIDs, muscle relaxants, and a mucosal protective agent, were supplied flexible support corsets in the bed, then assisted for sitting in the bed.				
	1/50 (2%) of the patients had 10 TPFs, displaced pelvic fracture and bladder rupture.	2% of the patients operated on by urology for bladder rupture died in the ICU due to hypovolemic shock.				

TPF, transverse process fracture; VAS, visual analog scale; NSAID, nonsteroidal anti-inflammatory drug; ICU, intensive care unit.

Table 3. Correlation of TPF Number and Hospitalization

TPF Number	Number of Patient s	Hospitalized	Discharged	Hospitalization Rate	Result
1 TPF	16	3	13	3/16; 18%	<i>P</i> 0.02 4 or more TPFs have more risk for additional pathology and hospitalization
2–3 TPFs	21	4	17	4/21; 19%	
4 or more TPFs	13	8	5	8/13; 61.5%	
Total	50	15	35	15/50; 30%	

TPF, transverse process fracture.

3–6 TPFs. Tewes et al.¹⁰ reported football players returned to play at 16 days after 1 TPF, 19 days after 2 TPFs, and 36 days after 3 TPFs. It has been observed that required resting time is 2–3 times greater in patients without corset treatment.^{9,12,16}

In previous conservative treatment studies for TPF, Akinpelu et al.¹⁹ and Homnick et al.²⁰ suggested bedside pain control with analgesics and narcotics. Homnick et al.²⁰ additionally applied routine physiotherapy for early mobilization. Because these treatments did not prevent inflammation or provide muscle immobilization, it was concluded that pain control was difficult in the acute phase, long hospitalization was required, and that re-rupture with muscle use could not be prevented. Järvinen et al.²³ reported that physiotherapy is widely used as pain reliever despite showing no histologically proven contribution to muscle recovery in the long term. In other treatment options for TPFs, it was reported that anesthesia and steroid application with CT guidance as an in situ block around the TPFs allowed for rapid recovery and return to work in a short time.³⁶ It was concluded that an in situ block could provide more rapid pain control, but long-term outcomes were unknown, therefore we recommend a flexible support corset and rest after an in situ block.

In conclusion, the routine use of NSAIDs, muscle relaxants, flexible support corsets, and rest provided successful pain control, prevented muscle spasm and chronic pain, and allowed a rapid return to activities of daily living. Furthermore, hospitalization and physiotherapy were not necessary with this treatment approach, which was less expensive, less painful, and easier for the patient than other approaches. For these reasons, this approach is proposed as a treatment protocol for TPF.

Chronic Pattern in TPFs

The long-term treatment results in the study by Boulter et al.¹⁶ study revealed that 23.7% of patients with isolated TPF experienced back pain for up to 6 months. It also was observed that skipped and untreated TPFs were responsible for persistent severe back pain.^{12,31–33} Armstrong³⁵ reported that, because of associated muscle damage, symptoms tended to be persistent, and persistent pain was described as being in the flank. Also, it has been reported that, when the RICE approach and immobilization are not applied for a sufficient period of time, edema and hematoma in the muscles and soft tissues, myositis ossification with intramuscular calcification, and persistent pain can result.^{33,34} Billet et al.³² reported in their large radiologic series that, in chronic cases of TPF, bony bridges form between TPs in all cases after myositis ossificans and result in persistent back pain.

In this study, we prevented transformation to chronic pain with NSAIDs, muscle relaxants, a sufficient period of flexible support corset wear, early patient mobilization, and sick notes. In some studies, recurrent compulsive movements were thought to be responsible for chronic back pain in athletes with TPFs.^{12,31} This would mean that fatigue-type stress fractures were responsible for TPFs. In previous studies, no stress fractures were detected at TPs.³⁷ L3 TP syndrome can be caused by overuse and injury of soft tissues adhering to the TP of L3, resulting in aseptic inflammation.³⁸ TPF in L3 TP syndrome were not reported. In this study, it was concluded that chronic athletic TPFs are more likely to be formed by trauma and skipped diagnosis when the RICE approach, NSAIDs, and adequate corset treatment and rest are not applied, as this results in chronic back pain due to excessive connective tissue formation, atrophy and ectopic calcifications in the muscles. Nevertheless, if stress fractures are suspected, bone scintigraphy is recommended.³⁷ It was concluded that chronic TPFs manifest with persistent flank pain, and lumbar MRI reports should contain evaluation of the TP and surrounding muscles and fascia for diagnosis of chronic and acute TPF. Nonetheless, in a radiology study, Wang et al.³⁹ reported that TPF is in the most skipped 5 diagnosis in MRI reports.

TPF Pseudoarthrosis

It should be noted that in situations in which TPF is not painful, it may be caused by a previous TPF nonunion. Leidholt²⁸ suggested that TPFs frequently exhibit fibrous healing. Tewes et al.¹⁰ detected nonunion in 1 of 29 patients in their study. During this study, lumbar TPFs were commonly observed incidentally in other CT imaging. Because of the adherent muscles and fascia on the TP end, TPs were influenced by superolateral, lateral, and inferolateral tensile forces (Figure 2A–B). Therefore, it was concluded that fusion of the fracture is difficult in TPF. Acute TPF and nonunion TPF (pseudoarthrosis) may be distinguished on CT image with thickening or deformation in fracture-side muscles and fascia in acute TPF.

How Can Patients with TPF Manage?

Based on our results, instead of asking for neurosurgical consultation in the emergency department for all 50 patients in this study, patients could have been treated with this treatment protocol and discharged. The patients with additional systemic injury could have been referred for consultation to the appropriate clinics. With this approach, the rate of neurosurgical consultation in TPF could have been reduced to just 4% (Table 2).

Table 4. Trauma Mechanisms in TPFs: Coronal Injury of the Spine and Blunt Abdominal Injury

Backward fall (Maximum 2.5 m) 38/50 (74%)	From stairs, on a slippery floor 	Fall 12 patients (24%) (12 discharged)	<i>(P</i> = 0.00) 49/50 (98%) patients TPFs were caused by either backward falls or receiving a blow on the back, and this trauma mechanism was identified as coronal injury of the spine. Coronal injury of spine occurred in 39/49 (80%) with low-energy injury. 10/49 (20%) were HEIs
In the shower		Fall 4 patients (8%) (1 chest surgery ward, 3 discharged)	
Fall from open vehicle (tractor, motorbike)		MVA 10 patients (20%) (3 chest surgery, 1 orthopedics, 1 neurosurgery wards, 6 discharged) 4 HEIs	
From a tree or wall (maximum 2.5 m)		Fall 11 patients (22%) (2 chest surgery, 1 neurosurgery ward, 8 discharged)	
At the soccer game		Fall 1 patient (2%) (1 discharged)	
Receiving a blow from the back 11/50 (24%)	Auto collision with rear impact 	MVA 9 patients (16%) (3 chest surgery ward, 6 discharged) 3 HEI	
	Heavy object falling on the back (box, etc.) 	Other 2 patients (4%) (2 chest surgery ward) 2 HEI	
Blunt abdominal trauma 1/50 (2%)	Pedestrian injuries by heavy vehicles	MVA 1 patient (2%) 1 urology, intensive care unit 1 HEI	1 (2%) patient TPF caused by blunt abdominal trauma 1/1 HEI

TPF, transverse process fracture; MVA, motor vehicle accident; HEI, high-energy injury.

Bui et al.¹⁸ reported that, according to the hospital registry, the spine (neurosurgery or orthopedics) consultation rate was 72.9% in TPF. Akinpelu et al.¹⁹ consulted a spine service for only 11% of patients with TPF, but aggressive pain management was applied, and the reported mean hospitalization time was 4.2 ± 4.8 days in pediatric patients aged 12–18 years. Homnick et al.²⁰ reported a 100% spine consultation rate, but they were managed with conservative therapy with a mean hospitalization time of 14 ± 20 days. It should be considered that there were greater additional pathology rates in these studies. Boulter et al.¹⁶ reported that reflex consultation in TPF remains common.

It was determined as a new concept in this study that TPFs can be treated as myofascial injuries instead of spine injuries, and they can be treated with NSAIDs, muscle relaxants, a mucosal protective agent, flexible support corset, and early mobilization. At the same time, TPF is an important marker for abdominal, pelvic, or thoracic organ injury because TPs are junction points for respiratory, gastrointestinal, and genitourinary systems via adherent muscles and fascia.^{1,3,4} Thus, we concluded that Denis,⁵ Lombardo et al.,⁶ and Miller et al.⁷ were correct in their results. Denis⁵ looked at TPFs from a spinal perspective, and Lombardo et al.⁶ and Miller et al.⁷ looked at them from the perspective of the torso.

Mechanism of Trauma

In previous studies, TPF trauma was considered to be the result of HEIs, such as MVAs and falls from heights.^{6,8,13,17,20,40} The question of why and how TPFs in HEIs occur without ligament injuries and corpus, lamina, and joint fractures has always been considered. In this study, 28 of the 50 patients suffered a fall, and 20 patients were involved in an MVA. These results are consistent with previous studies, but examining the trauma mechanisms more closely revealed that the injuries classified as falls was either backward falls from the height of the human body or a height not exceeding 2.5 meters. The injuries described as a result of MVA appeared to be backward falls from an open vehicle (tractor, motorbike), or they occurred during rear-impact traffic accidents at relatively low speeds. In accordance with these results, Akinpelu et al.¹⁹ noted that TPF often is associated with soft-tissue and skeletal injuries, although HEIs can also be responsible. Based on these observations, TPF trauma mechanism was redefined.

Coronal Injury of the Spine and TPF

The results show that TPF injuries in this study were caused by a backward fall or as a result of receiving a blow to the back in 98%

of cases (Table 4). Low-energy trauma was responsible for 80% of cases, and the remaining 20% of cases were the result of HEI. This trauma mechanism, backward fall or with a blow to the back was described as coronal injury of the spine. Publications in the field of sports medicine have provided support for this result. During a football game, one player collided with another and fell onto his back. L2 and L3 TPFs were detected in the football player, and snapshot photos of the fall were in the paper.⁹ During a soccer match, one player received a severe blow to the back, and L2 and L3 TPFs were detected.⁸ A cricket player slipped in the mud and fell onto his back, and he was diagnosed with L1, L2, L3, L4, and L5 TPFs.¹²

Classifications of spinal injuries are based on the mechanism of axial injury, attempts to determine the presence of instability and the need for surgical stabilization.^{41,42} It was concluded that TPF could not be included in these classifications, and it was suggested that coronal injury of the spine should be classified as a separate title. TPFs, spinous process fractures and other stable spinal injuries may also be included in this class. Thus, a new trauma mechanism and a new classification were defined and recommended for spinal injuries.

It was concluded that this trauma mechanism from backward fall or a blow to the back, usually with low energy, would be identified as coronal injury of the spine and would guide TPF treatment. In this type of injury, spine stability is protected, but it causes spinal and paraspinal region muscles and fascia contusion, edema and micro- or macro-hemorrhage, which may result in myofascial injury (Figures 3–5). It was concluded that, while axial injuries of the spine are stabilized with surgery or orthoses, coronal injuries of the spine should be treated as injuries of significant muscle groups and fascia of the torso. A backward fall or a blow to the back that commonly occurs with low energy results in coronal injuries of the spine; whereas, when these injuries occur with high energy, they will transform to axial injuries of the spine due to destruction of spine stability via ligament tearing or corpus, lamina, or joint fractures. Coronal injury of the spine requires additional review and research.

Blunt Abdominal (Upper, Lower) Trauma, and TPF

We attempted to determine the difference between TPF in high-energy blunt abdominal trauma associated with frequent abdominal or pelvic organ injuries and TPF in commonly LEIs from sports and other activities of daily life. In their biomechanical cadaveric study, Barker et al.² applied tensile force to TrA muscle

Table 5. Correlation of Trauma Mechanism, Hospitalization and Clinic

Trauma Mechanism	Discharged	Hospitalized				Total P = 0.00	Result
		Thoracic surgery	Neuro-surgery	Orthopedics	Urology		
Coronal injury of spine	35	11	2	1	0	49	P 0.044 98% coronal injury of spine 79% most commonly hospitalized in thoracic surgery clinic service 70% discharged
Blunt abdominal trauma	—	—	—	—	1	1	

Table 6. Coronal Injury of the Spine and Unilateral TPF Correlation

TPF Mechanism	Patient Number	Unilateral TPF Number	Bilateral TPF Number	Total TPF	
Coronal injury of spine	49	120	2	122	$(P = 0.00)$ In TPF with coronal injury of spine were very high rate unilateral TPF 99.2%
Blunt abdominal injury	1	0	10	10	
Total	50	120	12	132	

TPF, transverse process fracture.

aponeuroses via the MLF in transverse and posteroanterior directions. On average, 47 newtons of force applied to the posteroanterior plane and 82 newtons applied to the transverse plane resulted in TPF (Figure 2A). In light of this result, TPFs form in the posteroanterior plane at about half the force required in the transverse plane. Thus, posteroanterior tensile forces explain low-energy TPFs formed by backward falls and blows to the back. Transverse tensile forces explain TPF after high-energy blunt abdominal trauma and avulsion of the TPs by traction of the TrA muscle and MLF.³ It was concluded in this study posteroanterior tensile forces produce coronal injury of the spine whereas transverse tensile forces result in blunt abdominal injury.

In their previous work, Barker et al. showed that tensile forces, with traction on the TrA and MLF, were transmitted to the lumbar vertebrae, causing TPFs from L1 to L4.^{2,43} The study by Barker et al. showed that TPF occurred when the MLF was forced.^{2,3} Marshall⁴⁴ clinically supported these views and reported that transverse tensile and raised intra-abdominal pressure play a role in the formation of TPF during blunt abdominal trauma. An example of TPF formation as a result of force to the transverse plane also was found in sports medicine publications: The football player in the example above jumped to head off the ball, and his abdomen collided with the goalkeeper's knees, which resulted in a transverse colon rupture and an L1 TPF.²⁴

TPFs frequently are encountered along with blunt abdominal trauma in level 1 trauma centers.^{6,7,26,29} Dağlar et al.²⁹ detected that 58.5% of patients who had undergone laparotomy also had TPFs.²⁹ Barker et al. reported that MLF attachment was strongest at the L2 and L4 TPs, whereas the TPs varied in size and diameter. The thinnest TP is L4.² Xia et al.²⁶ found a significant association between the L4 TP and abdominal injury and suggested that as a marker. One of the strongest MLF attachments is to the thinnest TP the L4. As a result of transverse tensile on the MLF, the L4 is often broken first, and for this reason it is the most commonly detected result of blunt abdominal trauma.

It was concluded that TPFs occur by transverse tensile pressure on the MLF in high-energy blunt abdominal traumas. In other words, TPs are pulled by the MLF and TrA muscles and avulsed. Thus, it became clear that visceral organ injury in TPF is more frequent than other spinal injuries. It is understandable that Lombardo et al. and Miller et al. concluded that TPF is more serious than other spinal injuries. Blunt upper abdominal trauma was not detected in the current study.

The L5 TP is not attached to the MLF but, instead, to the ilio-lumbar ligament, which extends to the iliac crest.²¹ It has been reported that L5 TPFs occurs when this ligament is pulled due

to a displaced pelvic fracture.²⁷ Trauma center studies also have found a significant correlation between displaced pelvic fractures and L5 TPF and suggested that as a marker.^{6,27,30,45} In the current study, high-energy blunt abdominal trauma, L5 TPF, displaced pelvic fractures and bladder rupture were detected in only 1 patient (Table 2 and Figure 6). It was concluded in that case, spinal surgery consultation was unnecessary, although it was a difficult case for emergency medicine. The emergency department should define the system pathology and rapidly start treatment together with related clinics such as vascular and endovascular surgery, orthopedics, urology, general surgery, and anesthesia. After emergency treatment of systemic injuries, TPFs can be treated as a serious myofascial injury with NSAIDs, muscle relaxants, a mucosal protective agent, flexible support corset, and early mobilization if there is no contraindication.

In conclusion, 2 different types of TPF trauma mechanisms have been identified in this study: coronal injury of the spine caused by commonly low-energy trauma and blunt abdominal trauma caused by high-energy trauma commonly accompanied by additional organ injury. It was concluded that TPF treatment should be managed as a serious myofascial injury regardless of trauma mechanism.

Classification of coronal injury of the spine contributes to distinguishing stabilized spinal injuries from suspected unstable injuries resulting from axial injuries of the spine. This classification

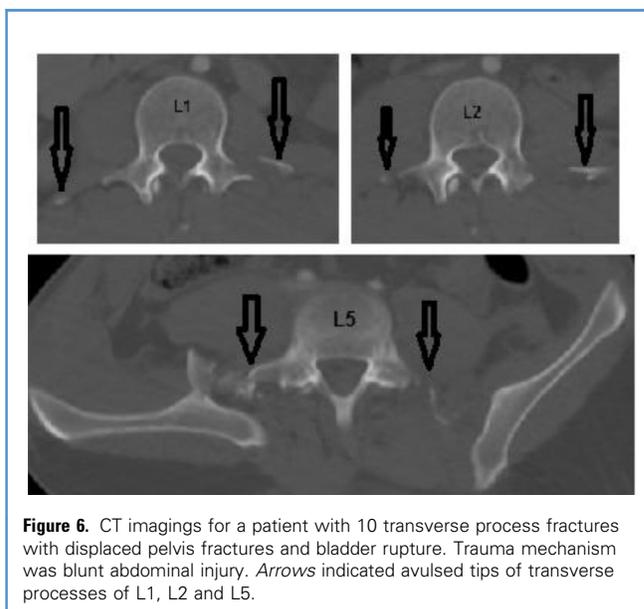


Figure 6. CT imagings for a patient with 10 transverse process fractures with displaced pelvis fractures and bladder rupture. Trauma mechanism was blunt abdominal injury. Arrows indicated avulsed tips of transverse processes of L1, L2 and L5.

can provide a common language between neurosurgery and emergency medicine as well as general surgery, thoracic surgery, urology and anesthesia. Further investigation of TPF and coronal injury of the spine is needed.

Correlation of Coronal Injury of the Spine and Thoracic Injury

There was a significant correlation in the current study between those patients with coronal injury of the spine and hospitalized patients on the thoracic surgery service (11 of 49 patient 22%) ($P = 0.044$) (Table 5). We concluded that this result should be examined as part of a broader study.

Correlation of TPF Level and Additional Injuries

TPF has been reported to occur with avulsion or direct trauma.³ Previous studies have shown that avulsion-type TPF is caused by traction of the TrA via MLE,^{2,3} traction of the QL muscle,^{2,46} resulting traction of TPs by psoas muscle contraction^{22,35,40} and traction of the L5 TPs by the iliolumbar ligament.²⁷ Along with coronal injury of the spine or blunt abdominal injury, all of these mechanisms could be effective and, in the current study, a new relationship was proposed. L1 and L2 TPFs were detected in 10 of the 11 patients (91%) who were hospitalized for thoracic injuries. The lumbocostal ligament connects to the 12th rib and the L1 and L2 TPs.²¹ At the time of thoracic trauma, the volume of the thorax shrinks, and the elevation

of the 12th rib and retraction of the lumbocostal ligament may cause an L1 and L2 avulsion-type TPF in patients with thoracic injury. This correlation requires further investigations with a broader study.

CONCLUSIONS

When TPF is detected by the emergency medical team without any other spinal injury in a trauma patient, abdominal, urogenital, and thoracic organ injury examinations should be carried out, especially in cases of 4 or more TPFs. Because TPs are junction points, these systems are connected via muscles and fascia. In cases in which TPFs are detected on CT imaging without another spinal injury, MRI is unnecessary. TPFs occur after coronal injury of the spine, commonly in LEIs or during blunt abdominal trauma in HEIs. Both mechanisms cause fascia and muscle injury around the TP and result in inflammation, edema, and hemorrhage. These injuries can be treated effectively with NSAIDs, muscle relaxants, and a mucosal protective agent for 1 week; flexible support corset with steel stays for 2–6 weeks; early patient mobilization; and sick notes for 2–6 weeks to promote rest. The flexible support corset is used for muscle immobilization. The case should be treated as a stabilized spinal injury, and its management should be the same as a myofascial injury rather than a spinal injury.

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