

Systematic review regarding treatment of tibial tuberosity avulsion fractures in young dogs

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Received 31.03.2023

Accepted 17.05.2023

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Summary

Tibial tuberosity avulsion fractures represent a small proportion of proximal tibial fractures in dogs. We distinguish between different types of this trauma. This disease is commonly encountered in young and skeletally immature animals. In the past, dogs with tibial tuberosity avulsion fractures were not treated, which resulted in chronic lameness. At present, various therapeutic methods are available for managing this disease. The aim of this article was to present the therapeutic protocols for managing tibial tuberosity avulsion fractures in dogs. The present article reviews the data regarding the treatment of tibial tuberosity avulsion fractures in dogs. Many veterinarians are reluctant to use conservative methods in the treatment of tibial tuberosity avulsion fractures due to the uncertain outcome and possible fracture progression. There are many surgical treatment options, but Kirschner wires with a tension band are the surgical method of choice for managing the problem. This article also contains a detailed description of the surgical procedure with the recommended method. The manuscript additionally touches on rehabilitation and conservative treatment of tibial tuberosity avulsion fractures.

Keywords: tibial tuberosity avulsion fracture, Kirschner wires, tension band, dog

Fractures of the proximal tibial shaft account for 7% of all tibial fractures in skeletally immature dogs (81). Tibial tuberosity avulsion fractures (TTAF), previously known as Osgood-Schlatter disease, represent a small proportion of proximal tibial fractures in dogs (39, 61). The incidence of TTAF is very low, and fractures of the proximal tibial epiphysis (Salter-Harris type II fractures) are even more sporadic (74, 76). Most of the injured dogs are three to eight months of age, and the tibial tuberosity at this point is in the apophyseal stage of development (62).

The following classification of TTAF has been proposed:

1. Isolated TTAF without damage to the growth plate or the proximal tibial epiphysis;
2. TTAF with damage to the growth plate and separation of the proximal tibial epiphysis from the tibial metaphysis;
3. TTAF with a fracture through the growth plate and the tibial metaphysis – Salter-Harris type II fracture (27).

Minimally displaced TTAF (MDTTAF) constitute a separate category of injuries that are classified as follows:

- type I – fracture without displacement or with minimal displacement (less than 2 mm) of the tibial tuberosity;
- type II – fracture with displacement (greater than 2 mm) of the tibial tuberosity (62).

Tibial tuberosity avulsion fractures are commonly encountered in young and skeletally immature animals. According to some researchers, this injury is most widespread in dogs aged 3-10 months with an average body weight of 11.2 kg, whereas in other studies, TTAF was most frequently reported in dogs aged 8-12 months with a median body weight of 26.1 kg (27, 62). In general, TTAF is most often noted in animals aged 4-8 months, regardless of body weight (60). These injuries are particularly common in highly active male dogs (27, 62). Predisposition to TTAF differs across breeds, yet terriers, hounds and poodles are at the greatest risk of TTAF (16, 34, 74, 76). Staffordshire

Bull Terriers, West Highland Terriers and Jack Russell Terriers are also predisposed to TTAF. These breeds are characterized by high levels of physical activity which can play a role in the pathogenesis of TTAF (27). Tibial tuberosity avulsion fractures are most frequently encountered in skeletally immature dogs, but older animals are also at risk. These injuries were reported in 21- and 22-month-old hounds with completely hardened growth plates (26). In adult dogs, TTAF can occur as a complication associated with surgical procedures such as tibial tuberosity advancement (TTA) and tibial plateau leveling osteotomy (TPLO) (8, 14).

The etiology of TTAF has not been fully elucidated. The growth plate of the tibial tuberosity is the weakest element in the system of anatomical structures responsible for stifle joint extension in young dogs. The growth plate comprises a separate proximal tibial epiphyseal ossification center (26, 64). Tibial tuberosity avulsion fractures are probably caused by excessive loading of the patellar tendon. The pathological mechanism of TTAF involves a forceful contraction of the quadriceps femoris muscle with a small flexion of the stifle joint and the foot firmly planted on the ground (26, 64). In most cases, TTAF is caused by acute injury, sudden movement or an uncontrolled jump. Other causes include chronic irritation and loading of the tibial tuberosity, but these factors play a less important role in the etiology of TTAF. When growth plate fractures (cracks, breaks, microtraumas) take place, the avulsed bone fragment from the tibial tuberosity is proximally displaced, resulting in the avulsion of the patellar tendon (18, 26, 27, 61, 67, 84).

It has been suggested that TTAF can be caused by internal factors, such as the weakening of the growth plate due to osteochondrosis (OCD). Genetic, dietary and hormonal factors can also play a significant role in TTAF (27). However, the results of a histopathological analysis did not confirm the above hypothesis. Histological images of ongoing repair processes revealed prolonged tissue trauma, which confirms the chronic character of pathological changes (62).

Tibial tuberosity avulsion fractures can be unilateral or bilateral (26). Lameness can occur suddenly in acute injuries or it can be chronic. The following grading scale has been proposed for evaluating the severity of pelvic limb lameness associated with TTAF (Tab. 1) (62).

Tab. 1. Grading scale of pelvic limb lameness in dogs with TTAF

Grade 1	normal limb loading at rest, but abnormal limb loading during gait
Grade 2	changes in weight bearing distribution (maximal pressure exerted on the tips of digital pads) at rest and during gait
Grade 3	changes in weight bearing distribution at rest, but the affected limb is not loaded during gait
Grade 4	the affected pelvic limb is not loaded at rest or during gait

The degree of lameness varies depending on the time elapsed since injury. Immediately after injury, the animal visibly unloads the affected limb. Limb loading increases on successive days, but normal weight distribution is never restored without medical intervention (26, 27, 67).

Tibial tuberosity avulsion fracture leads to swelling above the site of injury which is extremely tender on palpation. The tibial tuberosity can be proximally displaced in some patients. Flexion and extension of the stifle joint in the injured limb leads to discomfort which is manifested by most animals. Patients with bilateral injuries adopt an abnormal crouching posture and appear to be dragging their limbs when walking (36, 39, 67).

Tibial tuberosity avulsion fractures are diagnosed in an orthopedic examination and an X-ray examination in the mediolateral view. The following characteristic features of TTAF can be identified in radiographic images: proximal displacement of the tibial tuberosity; high lucency of an enlarged fracture gap between the tibial tuberosity and the metaphysis; patellar displacement and impaction into the femoral trochlea; periosteal reaction in the proximal tibia; absence of distinct epiphyseal and metaphyseal edges (26, 61, 64). Fractures without displacement (Salter-Harris type 5) or with minimal displacement of the tibial tuberosity may be very difficult to diagnose. Radiographic images of both the affected and the unaffected limb should be compared (Fig. 1). A lateral radiograph with hyperflexion of the stifle joint could be useful because a stretched patellar tendon pulls the avulsed tibial tu-

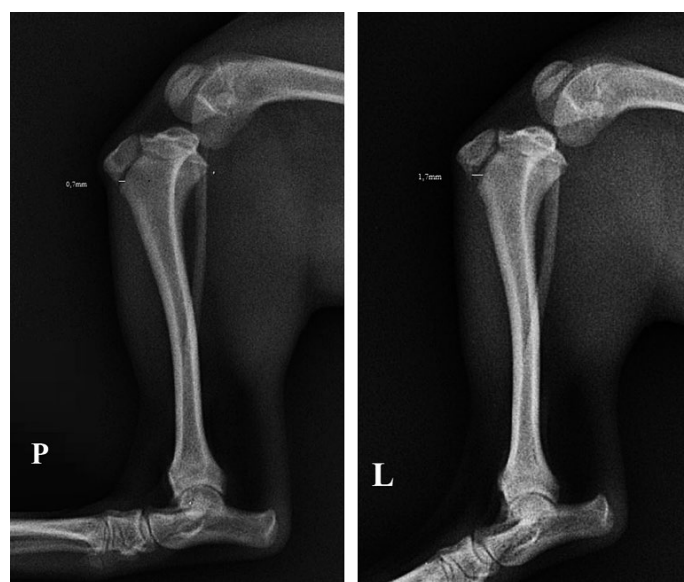


Fig. 1. X-ray pictures of two limbs of one patient (seven-month-old Yorkshire Terrier). In the left knee joint, we can see: proximal displacement of the tibial tuberosity and high lucency of an enlarged fracture gap between the tibial tuberosity and the metaphysis in the distal part of the tibial tuberosity. An X-ray of the right knee was taken for comparison purposes. This is an example of type I MDTTAF. The patient was treated conservatively.

berosity, which increases the lucency of the fracture gap between the bone fragment and the metaphysis. This approach enables the physician to detect subtle changes and diagnose subclinical cases of TTAF (21, 22, 26, 61, 62, 64). A less experienced radiologist could overlook the fine differences between radiographs of the affected and the healthy limb, which is why a critical evaluation is very important when diagnosing type I MDTTAF (62).

In the past, dogs with TTAF were not treated, which resulted in chronic lameness (73). At present, various therapeutic methods are available for managing TTAF. Both conservative and invasive methods have been proposed for treating this injury. The optimal therapeutic protocol should be selected based on the degree of tibial tuberosity displacement relative to the proximal tibia, the animal's weight, severity of clinical symptoms, and the remaining growth potential (39). The aim of this article is to present the therapeutic protocols for managing TTAF in dogs.

Conservative treatment

Conservative treatment options include cold compression and the administration of non-steroidal anti-inflammatory drugs, analgesics and sedative drugs to reduce the patient's movement and prevent further damage to the injured site (62). Conservative treatment can be considered in the following cases: tibial tuberosity displacement is less than 2 mm (in particular in type I MDTTAF), small dog breeds, the owner does not consent to surgical treatment (62, 84).

Non-invasive treatment is less effective in large and active dogs (62, 65, 84).

Following orthopaedic surgery, a rehabilitation program's objectives include pain management, oedema and swelling reduction, better mobility and range of motion, and controlled limb use (56). Modalities must be introduced carefully during the early stages of healing (often the first 72 hours) to prevent oedema from worsening or soft tissue contusions that can impede healing (47). Reducing swelling and pain, keeping joint nutrition and range of motion, promoting vascularization and healing of the shattered bone and injured joint should be the key goals of further recovery (4).

The patient's movement and activity should be restricted for 2 to 3 weeks. In some cases, movement should be completely restricted by placing the animal in a cage, whereas in other cases, short walks on a leash are allowed. Movement is difficult to restrict in hyperactive and temperamental dogs. Sedatives can be administered to relax the patient, temporarily tame the animal, and maximize the success of conservative treatment (62, 64). There are many medyanets with a sedative effect that can be used in conservative treatment, e.g. acepromazine, dexmedetomidine, clonidine, imipramine and trazodone (29, 36, 48, 58). Nowadays, trazodone is gaining popularity (29, 87).

The injured limb can also be immobilized in an orthopedic cast or a splint for 2 to 3 weeks to stabilize the fracture (34). The success of this treatment is debatable because effective immobilization of the stifle joint is difficult, if not impossible, in hyperactive patients and/or in dogs with short legs (64, 65). In these animals, a cast or a splint can compromise fracture healing and stifle joint biomechanics. A cast or a brace increases the relative weight of the pelvic limb without preventing the patient from extending the knee, which can further traumatize injured tissues (65). A period of rest combined with the application of Robert-Jones bandage can be an alternative approach in this group of patients (26).

Regardless of the therapeutic method selected by the physician, conservative treatment lasts 2 to 8 weeks in dogs, and in most cases, lameness is abolished after 28 days on average (26, 27, 67).

Surgical treatment

Surgical treatment is necessary when tibial tuberosity displacement is greater than 2 mm or if clinical symptoms do not subside after conservative treatment (62, 84). Various surgical techniques for repositioning TTAF have been described, including methods that involve Kirschner wires with or without a tension band, intramedullary nails (in particular in Salter-Harris type II fractures) and lag screws (65).

Regardless of the selected surgical technique, the patient is placed in a supine position with the hip joint flexed and the stifle joint extended. An incision is made in the laterocranial direction, directly under the patella, to a depth equivalent to two-thirds of the length of the tibial crest (80). If a tension band is used, the cranial tibial muscle is separated on the side of the tibia to expose the site where a transverse tunnel will be drilled (39, 65, 80). The clot in the original tibial tuberosity site may have to be removed, especially if it prevents anatomical reduction (65). It should be noted, however, that clotting is required for proper osteosynthesis. Research has demonstrated that clot removal slows down regenerative processes (31). The dislocated tibial tuberosity is moved to its original location with the use of reduction forceps; special care should be taken, particularly in small dog breeds, to prevent secondary fragmentation of the bone (39, 65). The tibial tuberosity is then anchored in place with the use of the selected method.

Kirschner wires, when used as a sole surgical technique, should be directed caudally and proximally to counteract the pull of the quadriceps femoris muscle. This method is recommended only for very young and small dogs with lesser tibial tuberosity avulsion. Special care must be taken when inserting Kirschner wires to prevent damage to the joint cavity (39, 65). In small breeds, two wires may be impossible to insert, and a single central wire is introduced in such cases.

It should be noted that the application of Kirschner wires alone does not counteract the rotational forces acting on bony elements (84).

The preferred surgical technique involves the use of Kirschner wires with a tension band. The tension band can be applied in both small and large breeds (39, 65). This method differs from the approach involving Kirschner wires only in that it increases bone resistance to shear and dissipative forces as well as rotational forces (69, 80). The traditional tension band comprises stainless steel wire with a diameter of 0.5 mm to even 1.6 mm, depending on the size of the manipulated bony elements. Wires with a diameter of 1 mm are most widely used (26). A tension band may be difficult to apply in small breeds due to the small amount of bony tissue and its fragility. Locking sutures offer a viable alternative. The tension wire may be replaced by a figure 8 suture made of absorbable material with a long half-life, which is passed through the patellar tendon and the tibial tunnel (39, 80).

The surgical procedure involves one or two Kirschner wires. Wires with a diameter of 1.6 mm (in larger dog breeds) and 1.1 mm (in smaller patients) are most widely used (26). The Kirschner wire is placed centrally in the site where the patellar tendon attaches to the tibial tuberosity (39). The wire can damage the tendon when positioned proximally, and it can contribute to further bone fragmentation when positioned distally. The end of the wire is bent to prevent the wire from migrating and irritating the surrounding tissues (65). The tension band is introduced to achieve inter-

fragmentary compression, and it is suspended on nails along the patellar tendon (Fig. 2). In smaller patients, the wire can be positioned more proximally to make use of bone material (80).

In surgical treatment of fractures, compression between bony elements is generally desirable, in particular in adult patients. However, in immature dogs, the tension band can lead to premature closure of the growth plate. Therefore, the fixation device should be removed as soon as possible after surgery, especially in very young animals where the growth plate is still open (62, 65). In small breeds, a locking suture is the preferred material for achieving interfragmentary compression. Unlike stainless steel elements, an absorbable material with a long half-life suture provides optimal compression and minimizes the risk of premature closure of the growth plate of the tibial tuberosity and the proximal tibial epiphysis. However, locking sutures can only be applied in small animals with a body weight of up to 2.5 kg (39, 80).

A similar technique is applied in the surgical treatment of Salter-Harris type II TTAF, but Kirschner wires are crossed to prevent the displacement of the epiphysis relative to the metaphysis (67).

Possible complications associated with the use of Kirschner wires and a tension band include cracking of the fixation device, seroma, secondary fragmentation of the tibial tuberosity, incorrect positioning of the Kirschner wire through the proximal growth plate, deformation of the tibial plateau angle, bending of the fixation device and secondary irritation of the surrounding tissues, flattening and distal translocation of the tibial tuberosity, and in extreme cases, patellar subluxation (18, 26, 39, 65, 84). Post-operative complications are relatively rare. Flattening and distal translocation of the tibial tuberosity are most frequently reported, but in most cases these complications do not compromise stifle joint function (18, 26, 84).

In 2001, an attempt was made to assess the quality of reduction of the avulsion fracture of tibial tuberosity and possible deformation of the tibial plateau angle. Lateral radiographs were obtained before and after surgery. Two lines were drawn (one along the long axis and the second parallel to the tibial plateau angle), and the angle between these lines was measured. The same method was used to measure the tibial plateau angle in the healthy limb for comparative purposes. In most cases, the tibial plateau angle was identical or somewhat greater. The greatest difference relative to the healthy limb was 5 degrees. In one case, the tibial plateau angle was 2 degrees smaller relative to the healthy limb, but it was greater than before surgery (64).

Tibial tuberosity avulsion fractures can be also surgically managed with the use of lag screws or intramedullary nails. However, these devices exert greater static compressive force on the ossification centers of the



Fig. 2. A. X-ray before the procedure, showing proximal displacement of the tibial tuberosity, high lucency of an enlarged fracture gap between the tibial tuberosity and the metaphysis and patellar displacement and impaction into the femoral trochlea. 2B and 3B. X-ray image after the surgery showing the correctness of the performed procedure.



Fig. 3. A. X-ray image taken 6 weeks after surgery showing bone tissue fusion (only Kirschner wires have been used). 3B. X-ray image after removing Kirschner wires.

tibial tuberosity and the proximal tibial epiphysis than Kirschner wires with a tension bend, thus increasing the risk of post-operative complications (65, 69, 80). Lag screws are not recommended for young patients because their bone tissues are still soft. Despite the above, this technique is a viable alternative for adult patients and dogs approaching skeletal maturity (80).

After surgery, the patient's movement should be restricted for up to 2 weeks, and the dog should be walked on a leash for up to 6 weeks after treatment (39). The Robinson sling is recommended for temperamental patients that are not easily controlled (65). A follow-up clinical and radiographic examination should be performed 6 weeks after surgery. Surgical treatment is successful if bony bridges are formed between the tibial tuberosity and the metaphysis, and the growth plate is partly closed (Fig. 3) (26).

In animals with a high growth potential (small breed dogs younger than 4 months and large and medium-sized breed dogs younger than 6 months), the fixation device should be removed as soon as possible to prevent premature closure of the growth plate and/or distal translocation of the tibial tuberosity (39). The fixation device does not have to be removed in patients approaching skeletal maturity (between 8 and 10 months of age) (39, 65, 80).

Discussion and conclusions

Many veterinarians are reluctant to use conservative methods in the treatment of TTAF due to uncertain outcome and possible fracture progression (34, 64, 65). However, according to some doctors, TTAF with minimal or no displacement can be effectively man-

aged in small breed and inactive dogs with the use of non-invasive methods (62, 64, 65, 84).

Use of sedation and movement limitation are both components of conservative therapy. Historically, the phenothiazine tranquilizer acepromazine has been used to facilitate confinement (29). However, this agent may cause excessive sedation, and this increases the risk of falling and damaging the operated limb (25, 29, 30, 87). Except that, to obtain a sedative effect, the following can be used: dexmedetomidine, clonidine or imipramine (29, 36, 48, 58), but they aren't first-line drugs (29, 87).

Trazodone has been used in dogs to reduce anxiety, facilitate veterinary procedures and postoperative confinement (25, 29, 30). It is commonly used to reduce stress and anxiety during hospitalization of veterinary patients (87). This drug is classified as a serotonin antagonist and reuptake inhibitor, which may account for its moderate hypnotic effects, and additionally is well tolerated in dogs. Trazodone is also successful used no matter what kind of the type of surgery is performed (29, 37). Additionally, this drug does not cause much sedation in dogs, therefore administration of trazodone does not improve or inhibit trained responses (29). Clinicians often prescribe trazodone for a treatment duration of weeks to months for surgical patients, because it is a safe drug for long-term use (37), as evidenced by the results of blood parameters (29).

The disadvantage of using trazodone is the need to constantly adjust its dose. It should be started with the lowest possible dose (3.5 mg/kg PO, q 12 h) with the necessity of observation to evaluate the behavior of the animal. If the sedative effect is too small, it should be increased (from 7 to 10 mg/kg PO, q 12h) (29). It is also possible to increase the frequency of trazodone administration (every 8 hours) (29, 36). Moreover, care must be taken when using painkillers in combination with trazodone, e.g. the concomitant use of trazodone with tramadol. Tramadol's action in combination with trazodone may inhibit the reuptake of serotonin, causing a toxic concentration of serotonin in the central nervous system (a condition called serotonin syndrome) (29, 58). The symptoms of such an action are: disorientation or confusion, hyperreflexia, motor restlessness, tremor, seizures, gastrointestinal tract signs including vomiting and diarrhea, and signs of physiologic decompensation, such as hyperthermia (58, 68). Therefore, it is important to choose the right analgesia. The use of NSAIDs can be tolerated well (29). Despite the risk of complications, the use of trazodone does not rule out the use of opioids in the treatment of postoperative pain. In a study conducted in 2014, both substances were combined, but while receiving tramadol, the minimum dose of trazodone was halved. None of the animals developed complications that posed a direct threat to life (29). In addition to the serotonin syndrome, the

authors of the publications mention the following side effects of this sedative drug: somnolence, drowsiness, gastrointestinal complaints, anorexia, weight loss, hyponatraemia (25, 29, 30, 37, 87). According to the authors of the 2014 study, the most common adverse effect in dogs that received trazodone was a transient state of somnolence, but no owners reported ataxia, disorientation, or stumbling (29). Side effects occur in a small percentage of patients, because trazodone has minimal effects on muscarinic cholinergic receptors and so has few anticholinergic adverse effects and the drug-enhanced behavioral calmness and reduced anxiety improve patient welfare with few adverse effects (29). Trazodone use in conservative treatment in dogs would be safe, enable confinement, and result in behavioral tranquillity, according to owners' assessments of their pets' behavior. Trazodone can also be used during post-operative treatment in unruly, mobile dogs.

Most writers differentiate a restriction of movement, such as with a kennel cage, among the conservative TTAF therapy approaches, and especially in the treatment of MDTTAF (34, 62, 64, 65). However, prolonged immobilization can have negative effects on the muscles (2, 4, 12, 59, 82).

In the first 3-10 days following injury, different modalities can be employed in addition to cryotherapy and exercises used during the acute inflammatory period (4). These include neuromuscular electrical stimulation, therapeutic ultrasound and photobiomodulation (laser therapy) (4, 50, 51, 56). However, these procedures must not be done directly over metallic implants, like bone plates, because they will become too hot and risk thermally destroying the tissues (4).

In the conservative treatment or early postoperative period, it has been demonstrated that cryotherapy – the administration of external agents to lower tissue temperature – reduces edema in the stifle joint (4). When compared to dogs who underwent comparable surgery without cryotherapy, this method lowered nerve conduction and pain perception in addition to reducing blood flow, swelling and the creation of tumour necrosis factor alpha and thus reduced inflammation (4, 35, 53, 70). These outcomes help the animal recover more quickly and tolerate other forms of rehabilitation better (4). The majority of medical professionals employ a treatment plan that includes various combinations of bandaging, cold packing, and/or application of cold compresses (70). For deeper tissue penetration (to a depth of 1.5 cm in dogs) and longer-lasting effects, ice pack administration should last 10 to 20 minutes per session (1). It has been advised to employ cryotherapy treatments for the first three days following the injury, which are applied once daily or every 4-6 hours. At the same time, the greater frequency brought the greater relief (4). A compression system that pumps ice water in a bladder around the limb while mechanically massaging it and lowering tissue temperature is

another way to administer cryotherapy (45). In comparison to dogs not receiving the therapy, this system increased weight-bearing when used every 4-6 hours in the first 24-72 hours after injury. It also improved range of motion, decreased pain scores, and decreased lameness for up to 42 days after the incidence (23). However, this method has not been studied in dogs with TTAF. Simple cold compresses with an ice pack or compresses without massage might be a preferable option. Cryotherapy is a quick and efficient way to recover from orthopedic surgery or as a conservative treatment. It is helpful for the first 48 to 72 hours after surgery, starting right away after an injury, although it may be continued for longer if swelling and oedema continue after the first 72 hours (55).

Neuromuscular electrical stimulation (NMES) therapy has been used frequently to reduce post-injury edema, maintain muscle mass and strength through protracted periods of immobility, and strengthen muscles (2, 3, 13, 49, 77, 86). In humans electrical stimulation has been recommended to restore the quadriceps muscles' arthrogenic muscular inhibition after anterior cruciate ligament surgery (71, 78). This technique was applied to dogs to help them recover from extracapsular CCL rupture surgery (9, 38), chronic spinal cord injury patients (10), and to increase bone turnover in cast-immobilized animals (86). The healing effect of NMES is based on regular muscle contraction of unused limbs (11) and increases blood flow in the muscle tissue (blood flow has a close relationship to the fracture healing) (17, 54, 75, 79). In 2012, Berte et al. found that after electrostimulation, the muscle mass in dogs with cranial cruciate ligament injuries increased in comparison to the control group which did not get this form of rehabilitation. In this study, for the neuromuscular electrical stimulation (NMES), the dog had to undergo trichotomy. A 2-mm layer of conducting gel was then applied to the four electrodes, two of which were fixed to the motor points of muscles nearest the injury, and the others as far away from those points as possible, closing the quadripolar current. The rehabilitation lasted 5 weeks, and the current that was released was a 2500 Hz sine wave with an average frequency that was homogeneously alternating at 50 Hz (9). Likewise, dogs treated with transcutaneous nerve stimulation in Johnson's research had better weight-bearing, greater thigh circumference, and decreased radiographic bone indications of osteoarthritis when compared to controls (38).

Due to the requirement for everyday use, transcutaneous electrical nerve stimulation is an underused method in veterinary medicine (4). In spite of this, NMES has the advantage of using less expensive equipment and can be used at the owner's home (4, 15, 56). Additionally, to choose the right intensity level of therapy for the dog, the owner and rehabilitation therapist must consult one another (4, 50).

The health properties of laser therapy include the activation of cytochrome C oxidase, oxygen production, the creation of proton gradients across mitochondrial and cell membranes, the production of adenosine triphosphate, deoxyribonucleic acid, cell proliferation and reduced cyclooxygenase and prostaglandin E2 (5, 28, 40-43, 56, 60). Through these actions, laser therapy promotes tissue restoration and an earlier return to functioning after injury (5, 19, 24). Despite the advantages already mentioned, findings from research on dogs have been ambiguous. Some authors fail to mention how effective laser therapy is (7, 44). However, most authors agree that photobiomodulation is more or less effective (19, 24, 72). In a 2020 study, the most common medical condition treated with laser therapy was osteoarthritis. In a study conducted in 2020, osteoarthritis was the most frequent medical ailment effectively managed using laser therapy. The average duration of the laser treatment was 4 weeks, and the average beam force was 2-3 J/cm² of the cutaneous (5). This is important knowledge because TTAF can lead to osteoarthritis if left untreated (26, 27, 64). Despite this, electrostimulation could be employed with greater therapeutic efficacy in the conservative treatment of TTAF because it increases blood and lymph flow in the deeper layers of tissues in comparison to photostimulation (2, 4). Nevertheless, laser therapy can be applied as a postoperative treatment to improve the fascia's mobility over the operated tissue (5).

Extracorporeal shock wave as a conservative therapy option for TTAF may be an intriguing alternative. This rehabilitation technique might promote bone and tendon repair (4). According to several studies, using shock wave caused the internal fixation of induced tibial fractures to result in larger calluses and more cortical bone as well as quicker bone density development after tibial tuberosity advancement or TPLO surgery (4, 6, 46). However, as shock wave therapy may produce discomfort, edema, or erythema after administration, sedation is frequently necessary (20). Additionally, it is a technique that is primarily focused on tendon and ligament injuries and the reduction of inflammation (52).

If a conservative treatment protocol is selected, several methods should be combined for best results, such as restriction of movement, immobilization of the affected limb, and administration of analgesic and anti-inflammatory drugs (65). Nevertheless, the use of only immobilization is long-lasting and does not bring the expected therapeutic effects.

In addition, long-term inflammation may cause a defensive reaction of the body and the formation of scar tissue, which in the subsequent surgical procedure makes the procedure more complicated, and tissue traumatization is greater (34, 62, 64). Therefore, in order to obtain complete therapeutic effectiveness, it is crucial to combine the aforementioned physical therapy techniques with passive and active exercises (4). The table

below lists various therapy approaches based on the injury's stage (Tab. 2). The following protocol can be used both in conservative treatment and in rehabilitation after surgery (4).

Various reasons of tibial tuberosity avulsion fractures have been discussed. The most probable cause is excessive tensile stress on the attachment of the patellar straight ligament at the tibial tuberosity (27, 61, 62, 67). Poodles, Terrier breeds, and Greyhounds are reportedly predisposed to tibial tuberosity avulsion fractures with displacement, with males being overrepresented (16, 27, 77). Twenty-nine from 50 dogs (58%) in one study were recorded to have fallen or jumped and become acutely lame with non-weight-bearing

Tab. 2. Protocol for dog rehabilitation based on the phase of the injury (39)

Injury phase	Objectives	Methods
Acute phase	minimize pain and swelling	– cryotherapy
	promote healing	– passive range of motion exercises (proximal joints to the support) – manual physiotherapy (limb and spine) – therapeutic ultrasound/laser therapy/shock wave/electrical stimulation*
	greater range of motion and mobility	– exercises like partial weight bearing to stimulate bone organization
Subacute phase	mobilize muscle activation	– heat therapy – stretching of muscles – therapeutic ultrasound/laser therapy/shock wave/electrical stimulation*
	regain proprioception and weight bearing	– carefully exercises: two- and three-legged stand, active toe pull (flexor reflex), sit to stand
	normal patterns of movement	– very short walking on a short leash
Chronic phase	increase flexibility, range of motion and muscle strength	– passive range of motion exercises – limited to full range with heat therapy – mobility therapeutic exercises – stretching – therapeutic ultrasound/laser therapy/shock wave/electrical stimulation*
	normal neuromuscular patterning	– longer walks on a leash – aquatic therapy
	reverse compensatory patterns in other limbs	– plyometric exercises – mobility therapeutic exercises

Explanation: * – only when conservative treatment (or no metal elements in the electrically conductive tissues)

of the limb immediately after injury (27). One of the major differences in signalment that have been noted with minimally displaced tibial tuberosity avulsion fractures in comparison to the displaced (Type 3) TTAF was age of the dogs at the time of injury. Type 3 displaced TTAF was diagnosed in dogs that are approximately 5-months-old, whereas minimally displaced tibial tuberosity avulsion fractures was diagnosed in older patients at the age between 9 to 14 months of age (27).

According to the literature, surgical reduction of TTAF and fixation of avulsed tibial tuberosity rapidly restore the patient to pre-injury levels of physical activity (27, 39, 65, 67, 84). Kirschner wires with a tension band are the surgical method of choice for managing TTAF (39, 65). In the group of the described techniques, this is the only approach that protects bones against all types of forces (39, 69, 80). In addition, the tension band fixes fracture fragments in the axial direction and converts dissipative forces to compression forces at the fracture site, which promotes healing (61, 67, 76). In most cases tension bands were stainless steel wire, but there are reports of the use of polydioxanone suture material as tension bands (PDS II, Ethicon) (27, 61, 62). Single Kirschner pins with a tension band or double Kirschner's with tension band are reported to stabilize the detachment of the tuberosity. In thirty-six stifles that were stabilized using one Kirschner wire and tension band and twenty-four using two Kirschner's and a tension band, 24 owners' reported that their dogs had no stiffness or lameness, 4 owners' reported some stiffness and 3 reported some lameness 14 month postoperatively (27). The size of Kirschner pins ranges between 1.1-1.6 mm (27).

Complications associated with surgical reduction of TTAF are rare (26). The most frequently reported complications include tibial tuberosity deformation and premature closure of the growth plate (26, 84). In dogs, deformation (flattening) of the tibial tuberosity does not affect stifle joint functioning, but when accompanied by premature closure of the growth plate, it can cause a caudal tilt of the tibial plateau angle and increase the risk of cranial cruciate ligament rupture (26, 31). It should be noted that a decrease in the tibial plateau angle is very rarely reported, and a correct surgical procedure involving the use of Kirschner wires and a tension band increases the tibial plateau angle and improves stifle joint function (31). The risk of post-operative complications can never be fully eliminated, but the prognosis for patients who undergo this surgical procedure is very good or even excellent (26, 39, 65, 84).

In human medicine, open reduction approach with internal fixation is recommended for all but minimally displaced TTAF (33). Tibial tuberosity avulsion fracture repair in humans is associated with a good prognosis and low incidence of complications (57).

Percutaneous tibial tuberosity avulsion fracture repair was described in 14 dogs and 3 cats (63). One or two negatively threaded pins of the selected size were used to reattach the tuberosity under fluoroscopic or digital radiography control. In some cases, a hypodermic needle was inserted through the skin to help assess the angle and orientation of insertion. Generally, Kirschner wires were cut without bending whereas small diameters pins were bent slightly prior to being cut. No intra-operative complications were reported with successful fracture reduction for all cases. Minor complications included seroma formation from Kirschner pins left intentionally long at the surgery and mean patient return to function was 1.9 weeks (63).

Other methods of internal reduction and fixation of TTAF have also been described in the literature (18, 67). However, due to a high complication rate, negative implications for the patient's growth potential and the risk of failure, these approaches are presently regarded as outdated (26, 39, 65, 84). Surgical treatment of TTAF with Kirschner wires and a tension band is considered to be the most effective approach because it is simple, leads to full recovery of limb function and does not compromise the growth of immature dogs (26, 27, 62, 84).

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