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Case Reports

Functional Rehabilitation of a Complex Pediatric Arm Trauma Following a Horse Bite

Mădălina-Elena Lupu[1], Cristina Brăileanu[2], Costel Bradea[3], Cătălin Ionițe[1,*], Bogdan Caba[1,2]

1 Faculty of Medical Bioengineering, Grigore T. Popa University of Medicine and Pharmacy Iasi, 700019 Iasi, Romania;
2 Saint Mary Emergency Hospital for Children;
3 "Sf. Spiridon" Emergency Clinical Hospital Iași

* Correspondence: catalin.ionite@yahoo.com

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Abstract: Horse bite injuries in children, although rare, are particularly severe due to the crushing mechanism involved, producing complex combined injuries: fractures, extensive muscle defects, nerve injuries, and soft tissue loss. The management of such cases requires a comprehensive multidisciplinary approach, ranging from surgical intervention (debridement, osteosynthesis, tissue reconstruction) to an extended functional rehabilitation program, in which kinesiotherapy plays the central role in restoring mobility, muscle strength, and functionality of the affected limb. We present the case of a 13-year-old boy with a complex bite wound on the left arm, associated with Gustilo-Anderson type IIIB open humeral fracture, injuries to the biceps, triceps, and brachialis muscles, radial nerve contusion, and an extensive soft tissue defect, surgical management included plate and screw osteosynthesis, muscle debridement, and skin grafting. The initial pain was rated as 10/10 on the Visual Analogue Scale (VAS) at hospital admission. The initial rehabilitation assessment, performed at 3 weeks postoperatively, revealed severe limitations in active mobility, predominant motor deficit in the radial nerve territory, "drop hand" attitude, and reduced grip strength. The rehabilitation program, conducted over 6 months with daily kinesiotherapy and physiotherapy sessions (10 consecutive days per month), was structured in progressive stages with therapeutical objectives adapted to the patient's evolving condition. At the final assessment, conducted at 6 months postoperatively, the results demonstrated considerable functional recovery: range of motion normalized almost completely at the shoulder and elbow, muscle strength reached MRC scores of 4/5–5/5, the „drop hand" attitude resolved entirely, and pain remained absent (VAS 0/10) throughout the rehabilitation period. This case study confirms that a well-structured and sustained kinesiotherapy program, combined with the exceptional healing potential of the child, can lead to near-complete functional restoration, avoiding secondary reconstructive surgical interventions and facilitating optimal socio-familial reintegration.

Keywords: horse bite, humeral fracture, radial nerve injury, pediatric rehabilitation, kinesiotherapy

1. Introduction

Animal bite injuries represent a frequently encountered pathology in children, who are particularly vulnerable due to their small stature and unpredictable behavior, with lesions predominantly located on the head, neck, and upper limbs [1,2]. Over 50% of victims are children aged between 5 and 14 years, with dogs responsible for 80-90% of cases and cats for a smaller percentage (5-15%) [1,3]. Although common, dog bites produce injuries through avulsion and crushing, while cat bites cause penetrating wounds, rarely resulting in fractures [4,5]. In contrast, horse bites, although statistically rare, are devastating due to their unique crushing mechanism: a jaw pressure exceeding 500 kg/cm², combined with tissue tearing, generates severe combined injuries – comminuted fractures, extensive muscle defects, neurovascular injuries, and major soft tissue loss, with an initially poor functional prognosis [6,7]. At the arm level, such a bite can severely compromise elbow flexion and extension, wrist and hand mobility, leading to profound functional disability, and recent reports emphasize the need for a multidisciplinary approach [8,9].

The management of these complex injuries invariably begins in the operating room and includes vital surgical techniques: aggressive debridement of devitalized tissues, abundant pressure lavage, thorough exploration of neurovascular elements, open reduction and stable internal fixation of fractures, nerve repair, and coverage of the skin defect through suturing, skin grafting, or flaps, with negative pressure therapy (VAC) playing an important role in preparing the wound bed for grafting [10,11]. In pediatric open fractures, recent guidelines emphasize that Gustilo's classification is recommended for its precision in describing severe grades, and that 24-hour prophylactic antibiotic therapy should be initiated as soon as possible, as in adults [12].

Nevertheless, long-term success depends on functional rehabilitation, which becomes the cornerstone of recovery once tissue healing has occurred. This complex and prolonged process synergistically integrates kinesiotherapy (passive, active-assisted, and active mobilizations, progressive muscle strengthening, re-education of functional gestures), physiotherapy (electrostimulation, laser, ultrasound), and occupational therapy (restoration of abilities for daily activities, from personal hygiene to writing and school tasks) – the only way to overcome profound deficits and achieve complete reintegration of the child [13,14].

2. Materials and Methods

2.1. Case Presentation

We present the case of patient A.R.M., a 13-year-old male, who was admitted as an emergency to the "St. Mary" Emergency Clinical Hospital for Children in Iași, in October 2025, following a horse bite injury. The clinical diagnosis at admission revealed multiple lesions on the anterolateral aspect of the left arm, forming a particularly severe traumatic picture: complex bite wound (horse) at the level of the left arm; open humeral fracture, type IIIB according to the Gustilo-Anderson classification; severe muscle mass injuries, involving the biceps brachii, triceps brachii, and brachialis muscles; radial nerve contusion, and extensive soft tissue defect.

Source: Personal archive

Figure 1. Complex bite wound (horse) at the level of the left arm

According to the operative protocol dated 14.10.2025, emergency surgical intervention was performed, consisting of: surgical debridement and abundant lavage, collection of secretions for bacteriological examination, thorough wound exploration, open reduction of the humeral fracture and internal fixation with a plate and 5 screws (Figure 1), debridement of devitalized soft tissues, including muscle tissue, exploration of the radial nerve (which proved to be in continuity but contused), hemostasis, placement of approximation sutures and sterile dressing, followed by the application of a negative pressure therapy system (VAC) at a pressure of 90 mmHg. The initial pain was rated by the patient as 10/10 on the Visual Analogue Scale (VAS).

Source: Personal archive

Figure 2. Radiograph of the humeral fracture upon admission to hospital

The patient remained hospitalized for a period of two weeks, during which complex local care was provided. According to the protocol dated 17.10.2025, VAC therapy was continued with periodic dressing changes. Subsequently, as documented in the protocol dated 22.10.2025, a new surgical intervention was required, during which wound debridement, hemostasis, suturing, and coverage of the skin defect with a split-thickness skin graft (STSG) harvested from the left thigh were performed, followed by reapplication of the VAC dressing. The effectiveness of NPWT in creating granulation tissue and preparing the wound bed for skin grafting in pediatric open fractures has been well documented, reducing the need for complex reconstructive methods [15]. In the last days of hospitalization, according to the protocol dated 27.10.2025, the VAC therapy was discontinued, with final local debridement using antiseptic solutions and application of a sterile dressing.

Considering the inherent immobilization period, required both for wound healing under the VAC dressing and for integration of the skin graft, the initial physiotherapeutic assessment was postponed until 3 weeks postoperatively. This waiting period was important to allow adequate soft tissue healing, to minimize the risk of wound dehiscence or graft loss, and to obtain correct and relevant functional measurements, uninfluenced by acute postoperative pain.

During the initial rehabilitation assessment (3 weeks postoperatively), inspection revealed that the skin graft on the left arm showed favorable integration, with a viable appearance, uniform pale pink coloration, and no local signs of infection or tissue suffering. The perilesional skin was warm, and the postoperative scar was in the healing process, presenting areas of superficial crusting. A visible deformity was observed at the level of the remaining muscle defect, associated with a characteristic "drop hand" (wrist drop) attitude, suggestive of radial nerve deficit. Split-thickness skin grafting is an essential technique in pediatric reconstructive surgery, with graft take depending on a clean, well-vascularized wound bed, as emphasized in recent surgical protocols [16].

Palpation and muscle assessment, the musculature of the left upper limb was hypotonic on palpation, with a global decrease in muscle strength.

Assessment of joint mobility (Goniometry), active joint mobility of the shoulder, elbow, forearm, wrist, and fingers was significantly limited, the patient performed all active movements with great difficulty and through evident compensatory mechanisms at the level of the shoulder girdle.

Assessment of muscle strength (MRC Scale): muscle strength, tested using the Medical Research Council (MRC) 0-5 scale, was globally diminished throughout the entire left upper limb. The motor deficit was particularly severe for the musculature dependent on the radial nerve: wrist extension, finger extension, and supination movements, grip was possible, but with reduced intensity.

Assessment of sensitivity, bilateral comparative testing of tactile and pain sensitivity, using tactile stimuli of different consistency, revealed the presence of perception for all stimuli, confirming the preservation of functional integrity of the sensory radial nerve, despite the contusion.

Functional neurological examination revealed a major motor deficit in the radial nerve territory, with the inability to fully perform active wrist and finger extension, with persistent "drop hand" attitude and severely limited thumb extension.

Assessment of grip, testing of different grip types demonstrated major difficulties. Both fine grips (thumb-index pinch) and power grips (cylindrical grip) were performed with great difficulty or were severely affected. Object retention was reduced, indicating a significant impairment of hand functionality.

Assessment of muscle trophicity, comparative measurements revealed installed muscle hypotrophy at the level of the left arm and forearm, secondary to immobilization and post-traumatic functional deficit.

2.2. Therapeutic management and rehabilitation program

The functional rehabilitation of the patient was carried out over a period of 6 months, through a structured program involving periodic day hospitalization. During each of the 6 months, the child attended the hospital daily from home for a 10-day intensive rehabilitation block, during which he benefited from daily sessions in the kinesiotherapy room. Each session consisted of approximately 60 minutes of active kinesiotherapy and 30 minutes of adjuvant physiotherapy. This model of episodic intensive day rehabilitation was chosen to allow close monitoring of the patient's progress by the therapist, immediate adjustment of the therapeutic plan based on clinical response, and concentrated delivery of therapy during each monthly block, while allowing the child to spend the remainder of each day at home, maintaining school attendance and family life.

For the home periods between these monthly day-hospitalization blocks, the family received training at the end of each 10-day cycle with a personalized maintenance exercise program, adapted to the patient's current stage of recovery [14,27]. Written and pictorial exercise sheets were provided to ensure correct execution. The home program was prescribed to be performed daily, in two short sessions (morning and evening) of 20-30 minutes each, to maintain joint mobility, prevent stiffness, and consolidate the gains achieved during the supervised sessions, without overloading the healing structures [13,14]. Specific home exercises were adapted monthly according to the recovery phase:

Month 1: passive self-mobilizations of the shoulder and elbow taught to the parent (5-8 repetitions, holding each position for 15-20 seconds at end range), active-assisted wrist and finger extension using the contralateral hand (10-12 repetitions), and sensory desensitization of the dorsal aspect of the hand and forearm using a soft brush (5 minutes, twice daily) [13,39].

Months 2-3: active wrist extension exercises and finger extension exercises (10-15 repetitions, 2 sets), elbow flexion and extension without weights (12-15 repetitions, 2 sets), forearm supination and pronation with a light stick (10 repetitions in each direction), and grip exercises squeezing a soft ball (15-20 repetitions, 2 sets) [14,27].

Months 4-5: strengthening with a yellow theraband for elbow flexors and extensors (12-15 repetitions, 2-3 sets), progressive weight lifting with small dumbbells (0.5 kg) for biceps and triceps curls (10-12 repetitions, 3 sets), and functional tasks such as opening jars, buttoning a shirt, and using utensils during meals [14,27].

Month 6: preferential use of the affected limb during all daily activities (eating, grooming, writing, carrying light objects), writing practice (10 minutes daily), and continuation of the strengthening exercises at the maximum level tolerated, with emphasis on endurance (increasing duration of activity rather than resistance) [13,27].

The family was instructed to record the completed exercises and any difficulties encountered in a simple logbook. A weekly telephone check-in with the therapist ensured remote supervision, allowed for minor adjustments to the home program, reinforced compliance, and addressed any concerns or questions from the patient or family [17].

The stages of the in-hospital rehabilitation program were the following:

Month 1 (Protection and Early Mobilization Phase)

Objectives. Maintaining trophicity and joint mobility, preventing stiffness and additional muscle atrophy, mild neuromuscular stimulation, passive integration of the limb into the body schema.

Exercises. Gentle, pain-free passive mobilizations of all upper limb joints (shoulder, elbow, wrist, fingers), with emphasis on wrist and finger extension; active-assisted exercises for the shoulder and elbow, within tolerance limits [13]. Sensory stimulation of the dorsal aspect of the hand and forearm through brushing, different textures, and mild thermal stimulation, to reactivate cortical connections [13]. Mild isometrics for the unaffected musculature of the shoulder girdle. Physiotherapy: drainage and toning massage, pulsed magnetic field for anti-inflammatory effect and stimulation of nerve regeneration [28].

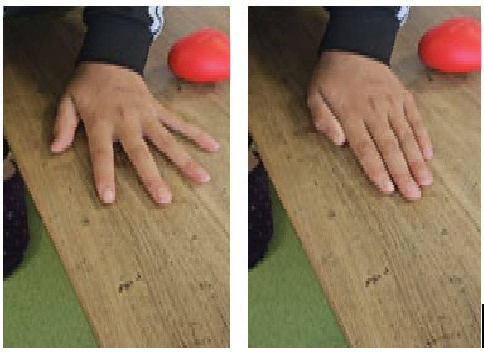
Months 2-3 (Active Mobility Recovery and Initiation of Strengthening Phase)

Objectives. Progressive increase in active range of motion, initiation of muscle strengthening for all groups, with emphasis on the extensor musculature.

Exercises. Free active mobilizations of all joints, progressing from facilitated gravitational planes to anti-gravity planes as strength increased, performing active-assisted exercises and active exercises with light manual resistance for wrist and finger extension [15]. Strengthening with theraband of minimal resistance (yellow) for elbow flexors and extensors, and shoulder abduction, performing functional exercises: rolling a physioball against the wall while maintaining pressure (isometrics for scapular and shoulder stabilizers), squeezing a spiky ball (for sensory stimulation and grip strengthening), finger abduction and adduction exercises (Figure 3A, 3B, 3C) [14, 27]. Physiotherapy procedures were also performed: electrostimulation (ES) of the wrist and finger extensor musculature with low-frequency currents [28].

Source: Personal archive

Figure 3A. Elbow flexion with the forearm in supination, using a stick



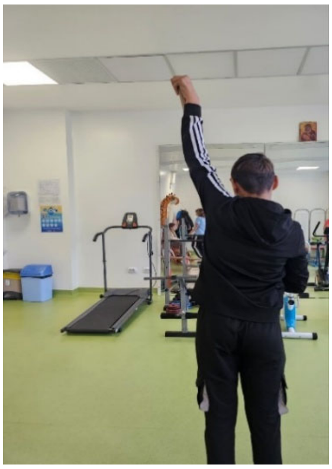
Source: Personal archive

Figure 3B. Finger abduction (spreading) and adduction (closing).

Months 4-5 (Muscle strengthening and functional integration phase)

Objectives. Increasing muscle strength and endurance, improving motor control and coordination, integrating the limb into bimanual activities.

Exercises. Progressive strengthening with small weights (0.5-1 kg dumbbells) and medium-resistance elastic bands (red/green): elbow flexion with supination, "rowing" (pulling toward the chest), elbow extension [14,27].



Source: Personal archive

Figure 3C. Shoulder lateral abduction using a stick.

The patient performed push-ups against the stall bars and squats with support on the stall bars, to engage the entire kinetic chain of the upper limb under stable conditions (Figure 3C), as well as bimanual coordination and fine grip exercises: screwing, picking up small objects [13], with a gradual increase in the number of repetitions (from 8-10 to 12-15) and sets (from 2 to 3), with 1-2 minute rest breaks between sets [14,27].

Month 6 (Functional optimization and reintegration phase)

Objectives: Maximizing strength and functional capacity, automating gestures, and achieving complete integration into daily and school activities.

Exercises: Continuation of the strengthening program at maximum tolerated intensity, with emphasis placed on complex functional exercises simulating ADLs (Activities of Daily Living): throwing and catching a ball, prolonged writing and drawing, controlled force activities [13,27]. The home program was also intensified, with emphasis on preferential use of the affected limb in daily tasks [14]. At this stage, the patient performed movements such as elbow flexion touching the shoulder, shoulder flexion to 160°, active forearm supination, and elbow extension with near-complete range of motion, proof of the considerable functional recovery (Figure 4, Figure 5).

Source: Personal archive

Figure 4. Scar after 6 months

Source: Personal archive

Figure 5. Forearm supination after 6 months

Throughout the program, careful monitoring of the response to effort dictated the progression. The increase in difficulty (resistance, repetitions, complexity) was done gradually, only after the patient demonstrated correct motor control and adequate cardiovascular adaptation, avoiding pain or excessive fatigue [13,14]. A fundamental principle was the individualization of the program, continuously adapted to the unique recovery potential of this child [13,27].

3. Results

The initial assessment, performed at 3 weeks postoperatively, revealed the clinical picture characteristic of a complex arm injury with radial nerve damage: severe motor deficit, significant limitations in joint mobility, and marked impairment of upper limb functionality. Following a structured rehabilitation program, carried out over a period of 6 months, the patient's condition improved significantly, with substantial progress in muscle strength, joint mobility, and overall function of the affected limb. The comparative results between the initial and final assessments are summarized in the tables below.

Table 1. Evolution of functional tests and pain status

Test / Scale	Initial Assessment	Final Assessment	Interpretation
Drop Hand Test	Present	Absent	Significant recovery. Elimination of the pathognomonic clinical sign for radial nerve injury, indicating restoration of neurological control over active wrist extension.
VAS Scale (Pain)	10/10	10/10	Total absence of pain throughout the entire therapeutic intervention, a major facilitating factor for active participation and progression of the rehabilitation program (3 weeks postoperatively and after 6 months of rehabilitation).
Cylindrical grip	Possible with difficulty	Fully achieved	Essential functional recovery, allowing the patient to handle and hold large volume objects (bottle, glass).
Fine grip **(thumb-index)**	Difficult to perform	Achieved with **minimal difficulty** minimal difficulty (thumb-index)	Significant improvement in fine dexterity, fundamental for school activities (writing, drawing) and daily tasks (buttoning).
Object retention	Reduced	Significantly improved	Increase in muscle strength and endurance, enabling prolonged functional use of the hand without fatigue.

Table 1 summarizes the main functional and pain outcomes, comparing the initial and final assessments. The data demonstrate a highly favorable recovery trajectory, correlated with the theoretical principles of peripheral nerve regeneration [18,19].

Drop Hand Test from present to absent. The complete resolution of this pathognomonic sign, present at the initial assessment, confirms the restoration of neurological control over the wrist extensor musculature. "Drop hand" is a definitive indicator of radial nerve injury, frequently associated with humeral fractures [20,21], and its elimination represents a primary clinical objective. This result aligns with the expected outcome following nerve regeneration and targeted rehabilitation [22]. The restoration of wrist extensor function is typically one of the first signs of motor recovery in radial nerve injuries, as these muscles are often reinnervated earlier than the distal finger extensors, a sequential pattern well documented in the literature on peripheral nerve regeneration [23,24]. The elimination of this sign confirms the reestablishment of sufficient neural pathways to command a fundamental anti-gravity movement.

VAS Scale (Pain) maintained at 0/10. The patient reported no pain (0/10) at any of the assessment points. The total absence of neuropathic pain represents an extremely favorable prognostic factor, as pain can significantly limit participation in therapy and overall recovery [25]. According to theories on neuropathic pain resolution, successful nerve regeneration can lead to the normalization of pain signals [26]. The fact that the patient remained pain-free throughout the entire rehabilitation program, including the advanced resistance strengthening phases, suggests the absence of significant nerve irritation or the development of a complex pain syndrome, creating an optimal framework for maximal effort and therapeutic engagement.

Grips and object retention. The transition from a cylindrical grip "possible with difficulty" to "fully achieved" and from a fine grip "difficult to perform" to "minimal difficulty" reflects not only the increase in muscle strength, but also the restoration of fine neuromotor control and coordination. This progression is the direct result of the functional exercises integrated into the intermediate and advanced phases of the rehabilitation program and confirms the importance of task-specific training in promoting cortical reorganization and sensorimotor integration [26,27].

Chart 1 Evolution of functional scores (percentage of normal function)

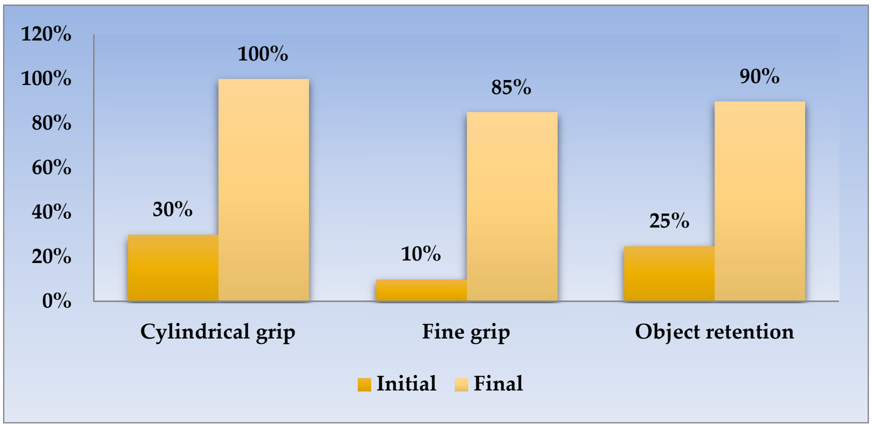


Chart 1 illustrates the progression of functional scores regarding the different types of grip and the ability to hold objects, expressed as a percentage of normal function. At the initial assessment, all parameters were below 30% of normal capacity, reflecting the severe functional impairment of the hand. At 6 months, cylindrical grip reached 100%, while fine grip and object retention recorded substantial increases to 85% and 90% respectively, demonstrating near-complete functional recovery.

Table 2. Evolution of muscle strength (MRC Scale)

Muscle Group	Initial Assessment	Final Assessment	Interpretation
Biceps brachii (elbow flexion)	3/5	5/5	Complete strength recovery, transition from contraction possible only against gravity to normal strength, essential for active elbow flexion.
Triceps brachii (elbow extension)	2/5	4/5	Significant improvement, from contraction possible only in a facilitated plane to movement against moderate resistance, with major impact on limb stability.
Brachialis (elbow flexion from pronation)	3/5	5/5	Complete recovery. Normalization of elbow flexor strength, fundamental for lifting and carrying activities.
Wrist extensors (hand extension	1/5	4/5	Considerable progress. From palpable contraction without movement to active extension against moderate resistance, enabling functional hand positioning.
Wrist flexors (hand flexion)	3/5	5/5	Complete recovery. Restoration of flexion strength, essential for grip and object retention.
Finger extensors (finger extension)	1/5	4/5	Significant improvement. From palpable contraction to active anti-gravity extension against moderate resistance, with marked reduction of the extensor lag.
Finger flexors (finger flexion)	3/5	5/5	Complete recovery. Normalization of finger flexion strength, fundamental for all types of grip.

Table 2 tracks the evolution of muscle strength in the key muscle groups involved in the injury, highlighting significant progress that aligns with established theories of nerve regeneration and demonstrates a classic pattern of functional recovery [21,22].

Wrist and finger extensors from 1/5 to 4/5. This represents the most significant functional improvement, the progression from a score of 1/5 (palpable muscle contraction, without joint movement) to 4/5 (anti-gravity movement against moderate resistance) reflects substantial reinnervation and hypertrophy of muscle fibers induced by progressive strengthening exercises. The finger extensors, being the most distally located, require the longest axonal regeneration pathway, which explains their slightly lower score compared to the wrist extensors, a proximal-to-distal recovery pattern well documented in the literature [23,24]. The marked reduction in the finger extension deficit (extensor lag) constitutes a direct clinical sign of improved neuromuscular control. This result is consistent with studies that emphasize the effectiveness of graded resistance training in the intermediate and advanced phases of nerve recovery [27,28].

Biceps and brachialis from 3/5 to 5/5. The complete recovery of elbow flexor strength demonstrates optimal muscle regeneration of the proximal muscle groups. These muscles, being more proximally located and partially independent of radial innervation, benefited from both partial immobilization and early strengthening, reaching a maximum functional score.

Triceps brachii from 2/5 to 4/5. Although it did not reach the maximum score, the improvement from contraction possible only in a facilitated plane (2/5) to movement against moderate resistance (4/5) represents a major functional gain, considering the direct injury to the triceps muscle mass. This recovery is crucial for elbow stability in extension, enabling activities such as pushing, leaning, and stabilizing objects.

The table clearly illustrates the proximal-to-distal gradient of recovery observed in peripheral nerve injuries: the proximal muscles (biceps, brachialis) achieved complete recovery (5/5), the triceps (intermediate) showed significant recovery (4/5), and the distal extensors (wrist, fingers) presented considerable but slightly incomplete improvement (4/5). This pattern is a direct reflection of the biological timeline of nerve regeneration and constitutes a fundamental pillar of the theoretical understanding of these injuries [23,24].

Chart 2 - Muscle Strength (MRC Scale)

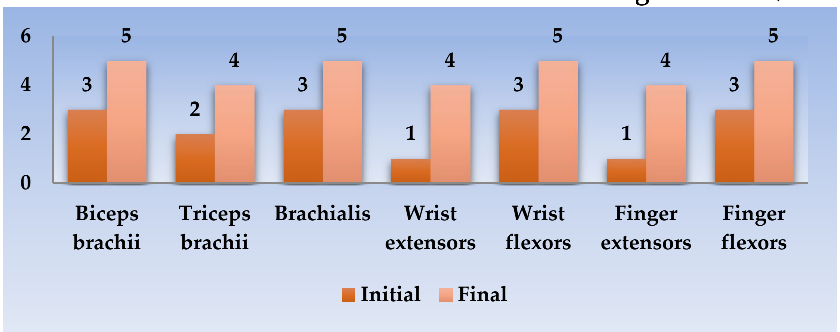


Chart 2 presents the comparative evolution of MRC scores for the main affected muscle groups, between the initial and final assessments, notable is the complete recovery (5/5) of the proximal muscles (biceps brachii, brachialis) and of the wrist and finger flexors, while the distal musculature dependent on the radial nerve (wrist and finger extensors) progressed from non-functional scores (1/5) to a significant functional level (4/5). This pattern reflects the proximal-to-distal gradient characteristic of peripheral nerve regeneration.

Table 3. Evolution of joint mobility (Goniometry – active movement)

Joint	Movement	Normal Value	Initial Value	Final Value	Interpretation
Shoulder	Flexion	165-170°	80°	160°	Near-complete recovery, allowing the arm to be raised above the head.
	Abduction	180°	70°	160°	Significant improvement, essential for dressing and hygiene activities.
	External rotation	80-90°	35°	60°	Good functional recovery, with impact on hand positioning in space.
Elbow	Flexion	140-150°	85°	140°	Near-complete recovery, enabling the hand to reach the mouth and face.
	Extension	0°	-10°	-5°	Significant reduction of the extension deficit, without major functional impact.
Forearm	Supination	70-80°	30°	70°	Complete recovery, essential for activities such as receiving coins or opening a tap.
	Pronation	70-80°	35°	65°	Substantial improvement, with major impact on writing and keyboard use.
Wrist	Flexion	90°	30°	60°	Significant functional recovery, essential for grip.
	Extension	60°	5°	40°	Considerable recovery, from near-absent extension to a functional range of motion, reflecting extensor reinnervation.

Fingers	Flexion	Complete	Incomplete	Nearly complete	Restoration of the ability to form a full fist.
	Extension	Complete	Severely limited	Slightly limited	Major improvement, enabling hand opening for prehension.

Table 3 documents the significant improvements in joint range of motion over the 6 months of recovery. These gains are not merely the result of joint stretching, but are directly linked to the recovery of muscle strength, the resolution of secondary complications from immobilization, and the restoration of functional movement patterns [30,31].

Wrist extension from 5° to 40°. The initial severe limitation of wrist extension (5°) is a classic consequence of radial nerve injury, having two main causes: weakness of the wrist extensors and the development of periarticular fibrosis (joint stiffness) after prolonged immobilization [31,32]. The recovery to 40°, although below the normal value of 60°, represents a substantial functional improvement, this is the direct consequence of the increase in extensor strength (from 1/5 to 4/5, according to Table 2), which became capable of actively mobilizing the joint against gravity and the resistance of fibrotic soft tissues. The restoration of active wrist extension is crucial for opening the hand in preparation for grip, an essential component of normal hand function [33].

Forearm pronation from 35° to 65°. Although pronation is primarily performed by muscles innervated by the median nerve, its limitation in this case represents an example of secondary complications from immobilization. Contracture of the interosseous membrane and stiffness of the superior and inferior radio-ulnar joints, consequences of prolonged immobilization, significantly limited this movement [32,34]. The substantial improvement to 65° demonstrates the effectiveness of the passive and active-assisted mobilizations applied in the early phases of recovery, specifically designed to prevent and reverse such contractures [26,31]. The functional impact is major, facilitating activities such as writing, using a computer mouse, or turning a key in a lock.

Wrist flexion from 30° to 60°, and finger extension from "severely limited" to "slightly limited". The initial limitation of wrist flexion, a muscle innervated by the median nerve, is almost exclusively a mechanical consequence of immobilization and muscle imbalance. As the wrist extensors regained their strength, the rehabilitation program balanced strengthening with flexor stretching, preventing adaptive shortening of the antagonists [31]. The restoration of finger extension close to normal also reflects the success of reinnervation and specific mobilization, enabling efficient hand opening.

The evolution presented in Table 3 convincingly illustrates that functional recovery is multidimensional. It is not enough for the nerve to regenerate and the muscles to become strong; the joints must also remain supple and mobile. The data confirm that the rehabilitation program successfully addressed both the neuromuscular deficits (through strengthening) and the musculoskeletal complications (through mobilization), leading to a comprehensive restoration of functional range of motion, an aspect supported by the literature on peripheral nerve injury recovery [26,27].

Chart 3 - Evolution of Joint Mobility (Degrees)

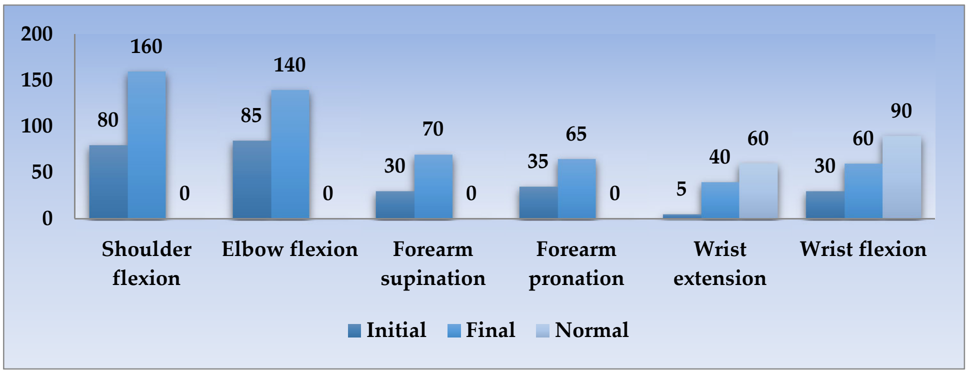


Chart 3 compares the active range of motion in the relevant joints, reporting them against normal values. At the initial assessment, all movements were severely limited, with values 2 to 8 times lower than normal. At 6 months, shoulder and elbow flexion, as well as forearm supination, reached near-normal values, and wrist extension recorded a spectacular improvement from 5° to 40°. Although minor differences from normal persist for some movements, functional recovery is considered excellent, allowing efficient use of the limb in daily activities.

Table 4. Evolution of Neurological and Trophic Parameters

Parameter	Initial Assessment	Final Assessment	Interpretation
Tactile and pain sensitivity	Preserved, slightly reduced on the dorsal aspect of the hand	Preserved, with no significant differences compared to the contralateral limb	Complete normalization of sensory function, confirming regeneration of the sensory fibers of the radial nerve.
Active wrist extension	Severely limited	Nearly fully possible	Major functional recovery, enabling hand positioning for prehension.
Active finger extension	Severely limited	Slightly limited	Significant improvement in distal motor control, with direct impact on dexterity.
"Drop Hand" attitude	Present	Absent	Elimination of the pathognomonic sign, marking the restoration of neurological control over the extensors.
Arm trophicity (circumference)	20 cm (affected) vs 22 cm (healthy)	21.8 cm (affected) vs 22 cm (healthy)	Near-complete trophicity recovery, with a residual difference of only 0.2 cm.
Forearm trophicity (circumference)	18 cm (affected) vs 20 cm (healthy)	19.7 cm (affected) vs 20 cm (healthy)	Significant recovery, with the difference reduced from 2 cm to 0.3 cm.

Table 4 completes the picture of recovery, demonstrating that the progress was not limited to strength and mobility, but encompassed all dimensions of the neurological and trophic impairment.

Normalization of sensitivity. The full recovery of tactile and pain sensitivity on the dorsal aspect of the hand confirms the complete regeneration of the sensory fibers of the radial nerve, a process favored by the initial neurapraxia and the superior neuronal plasticity of the pediatric patient [23].

Recovery of muscle trophicity. The muscle hypotrophy secondary to immobilization and functional denervation resolved almost completely. At the arm level, the circumference difference compared to the healthy limb decreased from 2 cm to 0.2 cm, and at the forearm from 2 cm to 0.3 cm. This considerable trophic recovery, objectified through comparative measurements, validates the effectiveness of the progressive strengthening and neuromuscular stimulation program, demonstrating muscle fiber hypertrophy in response to specific training.

The results obtained confirm a positive and comprehensive recovery process, with significant improvements in muscle strength, joint mobility, sensory function, and trophicity. This favorable evolution is consistent with data reported in other specialized studies on the recovery of complex upper limb injuries in children and emphasizes the importance of a structured, staged, and sustained rehabilitation program [27,32].

Source: Personal archive

Figure 6. Radiograph of the humeral fracture and internal fixation with plate and 5 screws

4. Discussion

This case study illustrates the recovery trajectory of a complex arm injury caused by a horse bite in a pediatric patient, highlighting the critical interplay between acute surgical management, the child's biological healing potential, and a meticulously structured rehabilitation program. Our case is particularly relevant given the rarity and severity of these injuries, which combine an open fracture with major soft tissue defects and peripheral nerve injury.

The particularity of combined injuries (bone, muscle, nerve) lies in the mutual potentiation of deficits, creating a cascade of complications. Furthermore, the fracture and muscle defect induce immobilization and hypotrophy, while radial nerve paralysis impairs movement initiation, rapidly favoring joint stiffness and abnormal postures. [21,22]. The specialized literature emphasizes the fact that radial nerve injuries associated with humeral fractures are frequently encountered; however, their evolution is generally favorable under conservative treatment, with spontaneous recovery rates of 70-90% [20,35]. However, in the context of an open wound with muscle crush, as in our case, the prognosis is considerably more reserved, and active intervention becomes important. Also, a recent STROBE-compliant investigation on radial nerve palsy in children following humeral shaft fractures recommends early surgical exploration of the nerves in high-energy trauma and open fractures, while expectant observation is considered reasonable only in closed fractures caused by low-energy trauma [21].

Traditionally, in cases of severe soft tissue and nerve injuries that do not show signs of recovery after 3–6 months, palliative reconstructive surgical techniques are used. Among these, for radial nerve deficit, classical tendon transfers include the transfer of the pronator teres muscle to the radial wrist extensors, the palmaris longus to the extensor pollicis longus, and the flexor carpi ulnaris to the finger extensors, with the aim of restoring active extension of the wrist and fingers [36,37], as well as other options including re-exploration of the radial nerve with nerve graft in cases of confirmed neurotmesis [38].

The results of this case suggest a substantial contribution of structured physiotherapy to functional recovery, and the considerable evolution, with almost complete recovery of active wrist and finger extension (MRC score 4/5) and complete abolition of the "dropped hand" posture at 6 months, ultimately obviated the need for these reconstructive procedures. According to the literature, complete or almost complete functional recovery (MRC score ≥ 4/5) after radial nerve neuropraxia or axonotmesis can take between 6 and 12 months [18,19]. Our case falls well within this range, confirming that a severe nerve contusion can evolve favorably when an optimal environment for regeneration is created by constant stimulation, prevention of joint fibrosis, and maintenance of muscle trophism [22].

The functional loss caused by damage to the biceps and triceps brachii muscles is devastating for an upper limb, the biceps is the main flexor and supinator of the forearm, while the triceps is the only extensor of the elbow; both are important for positioning the hand in space and for strength activities. Also, the recovery of strength to a functional level (5/5 for biceps, 4/5 for triceps) represented a milestone, allowing the patient to stabilize and use his upper limb in complex tasks, from lifting a backpack to providing support during school activities.

The literature on recovery rates for severe bite injuries in children is encouraging but emphasizes the need for prolonged recovery; a review of reported cases of horse bites indicates a "good" or "excellent" functional recovery rate in over 80% of cases, with a median recovery time of 5 to 8 months for complex injuries, although minor sequelae, such as mild mobility limitations or trophic differences, may persist [8,9]. The outcome observed in our patient, with almost complete recovery at 6 months, is at the favorable end of this statistic, reinforcing the concept that the child's superior neural plasticity, combined with adherence to an intensive rehabilitation program, can accelerate and optimize the healing process.

An important, often underestimated, component of the rehabilitation process was scar management. Following integration of the split-thickness skin graft, the patient presented with a visible scar on the anterolateral aspect of the left arm, which initially showed areas of hypertrophy and adhesion to the underlying muscle planes [39]. Starting from the second month of rehabilitation, a specific scar management protocol was introduced, including daily application of silicone gel sheets (worn for 8-12 hours, mainly overnight), gentle massage with emollient creams to improve flexibility and reduce adhesions, and progressive desensitization techniques using various textures (cotton, silk, rough material, soft brush) on the grafted and perigrafted areas [16,31], important to reduce tactile hypersensitivity, which can represent a significant barrier to functional use of the limb and wearing clothing [16]. Also, the cosmetic appearance improved considerably over the 6-month period, with the scar becoming flatter, paler, and more mobile, contributing positively to the patient's self-image and willingness to expose his arm during social and school activities [31].

Beyond the physical sequelae, a horse bite in a child has a profound psychological impact that must be recognized as part of a holistic rehabilitation approach, as the violent and unexpected nature of the attack can lead to symptoms of posttraumatic stress, specific phobia towards large animals, anxiety and social withdrawal [8]. In our patient's case, informal observations during therapy sessions revealed an initial reluctance to discuss the incident, mild anxiety about returning to rural environments where horses are present, and concerns about the appearance of his scar at school. The child occasionally expressed concerns that his arm would "never be the same again" and that other children would make fun of his scar [8]; these observations were addressed through supportive communication with the child and family, gradual exposure to images and videos of horses in the safe therapeutic environment, and active involvement in group therapy sessions with other pediatric patients recovering from traumatic injuries to normalize his experience and reduce feelings of isolation. The significant improvement in his limb function, coupled with the visible fading and flattening of the scar, played an important role in rebuilding his self-confidence and body image [13]. The therapist who worked with the patient maintained an encouraging and positive relationship, celebrating small functional victories to strengthen motivation. We believe that future similar cases would benefit from formal psychological assessment using validated pediatric instruments, such as the Revised Child Impact of Events Scale (CRIES-13), and structured counseling interventions integrated into the multidisciplinary team [8].

The only surgical intervention left to be planned is the removal of the osteosynthesis material, an elective procedure that will be decided based on radiological control and orthopedic consultation. The positive clinical evolution of our case, correlated with data from the specialized literature, reinforces the conclusion that a well-executed recovery strategy, combining surgical expertise, kinesitherapy and physiotherapy, can transform an initially poor prognosis into a functional favorable clinical outcome, avoiding major reconstructive interventions and facilitating the child's complete reintegration into the family and social environment.

5. Limitations of the study

This case study has several limitations that should be considered when interpreting the results. First and foremost, as a single-case report, the generalizability of the findings to all pediatric patients with horse-bite injuries is inherently limited [21]. The exceptional recovery trajectory observed may be influenced by individual factors specific to this patient - his age (13 years, an optimal period for neural plasticity), excellent pre-injury health, high level of intrinsic motivation, strong and consistent family support, and specialized multidisciplinary care received in a tertiary pediatric hospital - which may not be fully replicable in other settings or in patients with different personal and medical circumstances [13]. Second, the initial functional assessment was performed 3 weeks postoperatively, and not immediately after the injury, due to medical constraints related to wound healing and graft integration; thus, the true initial functional deficit in the acute post-traumatic period could not be measured, and some degree of early spontaneous recovery may have already occurred [18]. Third, the lack of a control group and the purely descriptive nature of the data limit our ability to draw firm causal inferences about the specific efficacy of individual therapeutic components (e.g., physiotherapy versus electrostimulation) compared with the natural history of peripheral nerve regeneration [27,14]. Fourth, validated patient-reported outcome measures (PROMs) specifically designed for the pediatric upper limb, such as the QuickDASH or ABILHAND-Kids questionnaire, were not systematically administered at baseline and follow-up; their inclusion would have strengthened the functional assessment with a patient-centered perspective [25]. Fifth, no formal psychological assessment was performed, which limited the objective measurement of psychological impact and recovery [8].

Despite these limitations, this case provides valuable and detailed clinical insights into the management and substantial recovery potential of this rare and severe injury in children and highlights the importance of a structured, intensive, and holistic rehabilitation approach [21,13].

6. Ethical consideration

This case study was conducted in accordance with the ethical principles of the Declaration of Helsinki. As this study represents a retrospective description of routine clinical care that does not involve experimental interventions, formal approval of the ethics committee was not required, according to the institutional policy of the "Sf. Maria" Children's Emergency Clinical Hospital in Iași.

Informed consent: Written informed consent for the publication of this case study and all clinical images used was obtained from both parents of the minor patient before the preparation of the article. The parents were provided with a detailed explanation of the purpose of the publication, the type of information and images that will be included, and the measures taken to protect the patient's identity.

Confidentiality: All identifying information has been removed from the manuscript and images to ensure complete anonymity of the patient. Furthermore, the patient is referred to only by initials (A.R.M.) and no demographic or clinical details that could lead to his/her identification have been disclosed.

7. Conclusions

This case study demonstrates the considerable functional recovery potential of a complex pediatric arm injury caused by a horse bite, achieved through a structured, sustained, and individualized kinesiotherapy program. The close multidisciplinary collaboration between the surgical team, the kinesiotherapist, and the family, together with the patient's excellent compliance, enabled significant improvement, leading to the near-complete restoration of joint mobility, muscle strength, and upper limb functionality.

The principal conclusion of this case report is that early rehabilitation intervention, progressively adapted and maintained over the long term, may optimize nerve and muscle regeneration, but also prevent the disabling complications of immobilization, thereby reducing or even completely eliminating the need for palliative reconstructive surgical interventions, apart from the routine removal of the osteosynthesis material. Furthermore, this case highlights the importance of integrating scar management and desensitization protocols into the rehabilitation program following skin grafting, as these directly influence functional outcomes and the patient's body image. Equally important is the acknowledgment and addressing of the psychological impact of the trauma, which, although not formally assessed in this case, represents a critical dimension of the holistic care of pediatric patients with disfiguring and functionally disabling injuries.

Although the generalizability of these findings is limited by the single-case nature of this report and by individual factors such as the patient's age, motivation, and family support, the detailed documentation of the rehabilitation process provides valuable clinical insights for practitioners managing similar complex pediatric traumas. This report emphasizes the fundamental role of kinesiotherapy as a central pillar in the management of complex upper limb injuries in children and advocates for the investment of resources and time in dedicated, multidisciplinary rehabilitation programs that address not only the physical, but also the psychological and aesthetic aspects of recovery, as decisive factors in ensuring an excellent long-term functional prognosis and a complete socio-familial reintegration of the child.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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