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# Assessment of the Forearm Tendon Transfer with Irreparable Radial Nerve Injuries Caused by War Projectiles

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## ABSTRACT

**Introduction:** Injuries to the radial nerve can occur at any point along its anatomical route, and the etiology quite varies. A particular entity are war injuries of the extremities, which have high morbidity but low mortality. After irreparable radial nerve injury, the only treatment is tendon transfer (if we neglect arthrodesis) with over then 40 methods. Four tendon transfers are considered as better than the other and two of them are the subject of our article flexor carpi radialis (FCR) and flexor carpi ulnaris (FCU). **Aim:** To evaluate the ultimate functional results of forearm tendon transfers for irreparable radial nerve damage caused by war injuries and indicate the better operative treatment choice in accordance with the evaluation schemes. **Methods:** This retrospective research included 40 patients with isolated irreparable radial nerve damage. Patients were operated from 1993 to 1996. The follow-up period is from 3.5 to 11.5 years (until 2007). Twenty patients were operated using FCR tendon transfer method and twenty patients were operated using FCU tendon transfer method. The surgery was performed at the Clinic for Reconstructive and Plastic Surgery, Clinical Center University of Sarajevo. Three score evaluation schemes were used: Zachary, Neumann Pertecke and Tajima scheme, along with subjective evaluation of treatment. **Results:** Measured by the Zachary Evaluation Scheme, the overall score in patients undergoing FCR tendon transfer is 92.25%. In patients undergoing FCU tendon transfer, the total score was 82.20%. The total result of all 40 operated patients was 87.25%. The Zachary evaluation scheme showed a significant difference between FCR and FCU results by tendon transfer ( $p < 0.05$ ) in favor of the FCR tendon transfer. Tajima scheme proved a statistically significant difference between the two tendon transfers ( $p = 0.024$ ), also in favor of FCR tendon transfers. **Conclusion:** Forearm tendon transfer is a relevant method to compensate for the loss of function of the wrist, fingers and thumb extensions as a result of irreparable damage to the radial nerve. FCR tendon transfer provides better functional results than FCU tendon transfer in irreparable radial nerve damage. The time elapsed from the injury to the performed surgery of the tendon transfer has no effect on the final functional result. There is no surgical tendon transfer procedure that can be recommended as a standard for any patient. Practically, the surgeon must tailor the surgery to the patient's needs. It is necessary to develop a unique and generally accepted evaluation scheme for the results of tendon transfers that will enable comparisons of results achieved. Both methods can be used for irreparable damage of radial nerve due to any etiology.

**Keywords:** tendon transfer, radial nerve palsy, trauma, war injury.

## 1. INTRODUCTION

Radial nerve (RN) is the nerve that innervates the muscles of the posterior and outer lodges of the forearm, that is, the extensors of the forearm, hands and fingers, as well as the supinators, and participates in the movements of the elbow extension, the supination of the forearm, the extension of the hand and fingers. The radial nerve divides into the terminal branches: posterior interosseous nerve (motor branch) and ramus superficialis radial nerve (sensory branch). Also, triceps brachii (TB) muscle can be afunctional in a high lesion of RN. Usually a high lesion

occurs below the nerve for TB, and such complete paralysis results in the afunctionality of the extensors of the wrist, fingers (II-IV) and thumb. In this case we are talking about a typical image, which in clinical practice is referred to as a wrist drop. There are three basic functional deficits that need to be restored: wrist extension; finger extension; extension (and abduction) of the thumb. (1, 2, 3). Moving a functional muscle and tendon from its normal position to a new location to replace a muscle that is paralyzed or severely damaged seems logical. Therefore, it seems surprising that tendon transfers were

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not practiced for the treatment of paralysis or loss (damage) of muscle-tendon units until the end of 19th century (2). There are over 40 tendon transfers for the restoration of RN paralysis (2). After irreparable radial nerve injury, the only treatment is (if we neglect arthrodesis) tendon transfer with over then 40 methods. This article presents two methods—flexor carpi radialis (FCR) tendon transfer and Flexor carpi ulnaris (FCU) tendon transfer (Table 1 and 2) (4-8).

Donor tendon	Recipient tendon
Pronator teres (PT)	Extensor carpi radialis longus (ECRL), and the extensor carpi radialis brevis (ECRB).
Flexor carpi radialis (FCR)	Extensor digitorum communis (EDC)
Palmaris longus (PL) or Flexor digitorum superficialis (FDS) III or IV	Extensor pollicis longus (EPL)

**Table 1. Flexor carpi radialis (FCR) tendon transfer**

Donor tendon	Recipient tendon
Pronator teres (PT)	Extensor carpi radialis longus (ECRL), and the extensor carpi radialis brevis (ECRB).
Flexor carpi ulnaris (FCU)	Extensor digitorum communis (EDC)
Palmaris longus (PL) or Flexor Digitorum superficialis (FDS) III or IV	Extensor pollicis longus (EPL)

**Table 2. Flexor carpi ulnaris (FCU) tendon transfer**

Forearm tendon transfer began with Murphy in 1914, who introduced the FCR muscle for finger extension and Henry in 1916 who used FCR for wrist extension. Latissimus dorsi muscle is used for restoration of TB function or elbow extension. In high RN lesions, “full” tendon transfer for restoration of function is indicated (2, 3) According to the name of the transferred tendon performing finger extension (II-IV), the tendon transfers are named FCR or FCU and are considered an optimal treatment option (2, 3, 5, 6). Radial nerve palsy (RNP) is a severe injury which mostly occurs due to fractures of the humerus and/or iatrogenic lesions caused by surgical procedures (8, 9).

Injuries to the radial nerve can occur at any point along its anatomical route, and the etiology quite varies (9, 10).

A particular entity are war injuries of the extremities, which have high morbidity but low mortality (1, 2).

The treatment of war injuries of the extremities are characterized by two stages. The initial phase involves primary surgical care, the primary goal of which is to prevent early complications such as bleeding, shock, infection and limb ischemia. This phase is short and lasts about seven to ten days. It should be emphasized that the further course of treatment depends entirely on the primal surgical treatment. In the second or so-called “repair phase,” complications such as bone infections, pseudoarthrosis, poorly healed fractures, shortening of the extremities, joint contractures, and functional dysfunctions are treated. This phase is characterized by longevity, as well as frequent poor end outcomes, which ex-

hausts patients, doctors and health insurance funds (11, 12, 13).

The etiologic factors for the occurrence of war injuries of extremity are small arms, fragments of explosives, blunt force and cold weapons. The degree of bone and soft tissue destruction of the extremities is affected by projectiles with their ballistic and injured tissue characteristics (11, 12). The effect of the projectile on the tissue and the extent of its destruction depend on the size of its kinetic energy, the length and shape of the grain path, the shape and stability of the grain, the angle of incidence and the distance of the body from the weapon (13).

The basic factor influencing the quantity and quality of the volume of destruction of living tissues is the kinetic energy of the grain (13).

In musculoskeletal surgery, there is little hope that errors in the technique can be compensated with local adaptation. The success of the operation depends on the technical competence of the surgeon and his postoperative care. There is, as a rule, only one operative chance of achieving the good function of paralyzed fist (14).

Nerve injuries can take the form of a neuropraxia, which presents as minor contusions or compression of the peripheral nerve with a temporary interruption in the transmission of electrical impulses. Axonotmesis is a more severe form of nerve injury with damage to the axons themselves and accompanying distal Wallerian degeneration, but maintaining preservation of Schwann cells and an intact endoneural nerve structure. The most severe form of damage is a neurotmesis, where there is a complete anatomical disruption to nerve continuity. Here there is no possibility of spontaneous nerve recovery, and surgery is always necessary (10).

There are two ways to treat radial nerve injury: nerve repair and neuroplasty. Repair of the nerve itself should always be done, except in very rare cases when it is not performed. There is no place for primary neuroplasty in war type injury(e.g.projectiles). Neuroplasty can be extremely rare done as neurorrhaphy, as neurolysis or, as a rule, as a (sural) nerve transplantation to replace a nerve defect.

So far, there is no generally accepted tendon transfer. In addition to irreparable upper limb nerve damage, tendon forearm transfer is a surgical method that can significantly alleviate a patient’s inability and compensate for his or her lost function. The bottom line is that three innervated tendons (median or ulnar nerve) are transposed to the patient for the above three functions. Tendon transfers represent operations of the so-called muscle balance. It is presumed that the recipient musculoskeletal unit is more important for function than the donor one and / or that it is the remaining muscle that will assume the function of the donor muscle. There is no upper time limit for the reconstruction of radial nerve palsy by tendon transfer (15-27).

## 2. AIM

To evaluate the ultimate functional results of forearm tendon transfers for irreparable radial nerve damage caused by war injuries and indicate the better opera-

tive treatment choice in accordance with the evaluation schemes.

### 3. METHODS

This is a retrospective research and included 40 patients with isolated irreparable radial nerve damage. Patients were operated from 1993 to 1996. The follow-up period is from 3.5 to 14.5 years (until 2007.). Twenty patients were operated using FCR tendon transfer method and twenty patients were operated using FCU tendon transfer method. The surgery was performed at the Clinic for Reconstructive and Plastic Surgery, Clinical Center University of Sarajevo.

The standard preoperative preparation for surgery in regional (axillary block) or general anesthesia (laboratory findings, electrocardiogram, chest X-ray, depends on interna doctor's estimation, internal doctor approval) was performed before surgery.

The intent of surgery was to transpose normally innervated tendons (by ulnar or median nerve) to a tendons that worked but was paralyzed because of RN injury.

When treating patients, standard methods to evaluate tendon transfers were used. Measurements were made with a goniometer. Measured variables were: extension, flexion, radial and ulnar deviation of the wrist, extension of the metacarpophalangeal joints (MCP) joints and distance of the tip of the II-V finger from the midpalmar crease; extension of the MCP and interphalangeal joints (IP) of the thumb joint and thumb abduction.

Three score evaluation schemes were used: Zachary (Table 3), Neumann Pertecke (Table 4) and Tajima scheme (Table 5), along with subjective evaluation of treatment (27).

Motion analyzed	Part of rating
Incomplete finger extension: for every 10 degrees minus full extension	10%
Incomplete thumb extension	10%
Incomplete extension of the wrist: inability to stretch against 20 degrees resistance	20%
Incomplete wrist flexion: inability to flex to neutral position	20%
Incomplete flexion of the fingers	moderate-10% significant-20%

Table 3. Zachary evaluation scheme

Very good	95%-100%
Good	80%-94%
Satisfies	50%-79%
Bad	<50%

Table 4. Neumann Pertecke evaluation scheme (Neumann Pertecke scheme is a modified Zachary scheme and evaluates the same variables on the same principle by grouping the results into 4 groups) (27)

The subjective rating of the patient was taken into account and evaluated as the total assessment of the hand movement. The research was conducted in accordance with the basic principles of the Declaration of Helsinki (last revision 2008) on the rights of patients involved in biomedical research. During the course of this study, the identity and all personal data of patients are permanent-

Great	complete extension of the index finger to the little finger; complete flexion of the fingers; complete extension and abduction of the thumb; wrist extension and flexion more than 10%
Good	almost complete extension of the index finger to the little finger; almost complete extension and abduction of the thumb with the wrist plate in a neutral position; near-complete fission of the index finger to the little finger, the ability to make almost complete fists volarly and with the wrist in a neutral position.
Satisfies	finger extension as in grade "Good" with wrist flexed flexibly up to 20%, ability to make fists as in grade good with wrist in extension up to 20%
Bad	results worse than described in the rate "Satisfies"

Table 5. Tajima evaluation scheme

ly protected in accordance with the regulations on the protection of identification data. For the protection of personal data, each patient was assigned an identification number used in statistical data processing. The results are presented by the number of cases, percentage, arithmetic mean and standard deviation. The software package was used for statistical analysis of the obtained data) and Microsoft Excell (version 11. Microsoft Corporation, Redmond, WA, USA). The results were analyzed by a t-test for a comparison among the examined groups. The  $p < 0.05$  was considered statistically significant.

### 4. RESULTS

In the FCR tendon transfer group, 18 patients were male, and in the FCU tendon transfer group, all 20 patients were male. In the FCR tendon transfer group, the youngest patient was 24 years old, the oldest was 77 years old, while the average age was 37.95 years. In the group where FCU tendon transfer was performed, the youngest patient was 23 years old, the oldest was 62 years old, while the average age was 38.75 years. The average time from injury to FCR tendon transfer was 452.3 days (minimum 105 days and maximum 956 days). The average time from injury to FCU tendon transfer was 340 days (minimum 109 days, maximum 712 days).

Our results were evaluated by a Zachary evaluation scheme (Table 6).

Transfer	Number of patients	Value (min-max)	Result
FCR	20	60-100%	92.25%
FCU	20	15-100%	82.20%
Total	40	15-100%	87.25%

Table 6. Analysis of the results with Zachary evaluation scheme (Flexor carpi radialis-FCR tendon transfer, Flexor carpi ulnaris -FCU tendon transfer)

Measured by the Zachary Evaluation Scheme, the overall score in patients undergoing FCR tendon transfer is 92.25%. In patients undergoing FCU tendon transfer, the total score was 82.20%. The total result of all 40 operated patients was 87.25%.

The Zachary evaluation scheme showed a significant difference between FCR and FCU results by tendon transfer ( $p < 0.05$ ). This proves significant differences in the treatment of radial nerve palsy in favor of the FCR tendon transfer.

Transfer	Great	Good	Satisfies	Bad
FCU	10	2	6	2
FCR	13	5	2	0
Total	23	7	8	2

Table 7. Analysis of results with Neuman-Pertecke scheme (Flexor carpi radialis–FCR tendon transfer, Flexor carpi ulnaris -FCU tendon transfer)

The results were also analyzed by the Neuman-Pertecke scheme (Table 7).

The Neuman-Pertecke evaluation scheme has not shown significant difference between two methods (p>0.05).

Our results were also evaluated by a Tajima evaluation scheme (Table 8).

Transfer	N	Mean	SD	SEM
FCR	20	1.55	0.60	0.13524
FCU	20	2.1	0.85	0.85224

Table 8. Analysis of results with Tajima sheme (SD- standard deviation, SEM–the standard error of the mean, Flexor carpi radialis–FCR tendon transfer, Flexor carpi ulnaris -FCU tendon transfer)

Tajima scheme proved a statistically significant difference between the two tendon transfers (p = 0.024), also in favor of FCR tendon transfers.

Subjective satisfaction after operation is very high (table 9).

Transfer	Great	Good	Satisfies
FCR	11	8	1
FCU	10	10	0
Total	21	18	1

Table 9. The patient’s subjective rating

## 5. DISCUSSION

It has been about 140 years since Nicoladoni introduced into practice clinical tendon transposition in lower leg motor paralysis and over 100 years since its massive use by Robert Jones in radial nerve palsy (4, 28).

Starr in 1922 introduced the PL muscle for thumb extension (2). Zachary in 1946 emphasized the importance of keeping at least one wrist flexor intact (15). Merle d Aubigne in 1946 announced new approach to tendon transfer (16). Burkhalter (1974) and Reid (1988) proposed a limited transfer of PT to the ECRB immediately after injury for the purpose of the so-called “internal splint” (17, 18). Bevin (1976) suggested that the RN never restores and he proposed a tendon transfer for the treatment of RN injuries (19). Brown in 1993 proposed to access full early tendon transfer in case of nerve defect over 40 mm, extensive scarring on nerve pathway, great skin loss over nerves, great nerve defect requiring long nerve grafts and high nerve damage (20). Waiting for “sufficient time” is determined by Seddon’s nerve regeneration rule (1-2 mm daily). A tendon transfer to restore muscle balance should be done 12 weeks after the expected recovery time.

There are several schemes for evaluating the results of tendon transfers in radial nerve palsy (Starr, Zachary, Neumann-Pertecke, Chuinard, Tajima) (5,9,15,27,31).

The most accepted evaluation scheme is Zachary evaluation scheme.

Evaluation of results for FCR tendon transfer was 92.25% and for FCU transfer was 82.20% by Zachary evaluation scheme. Zachary et al. through their two papers, at 5 patients (PL quit) and 19 patients (PL present) obtained results of 26% and 57% respectively. Zachary et al. for FCU had 91%, Moberg and Nachemson 91.6%, Thomsen and Rasmussen 86% (28-33).

Zachary evaluation scheme				
Author	Tendon transfer	Number of patients	Value (min to max)	Results
Zachary (15)	PT +FCR+FCU (PL missed)	5	10-40%	26%
Zachary (15)	PT +FCR+FCU (PL present)	19	20-90 %	57%
Zachary (15)	FCU	29	70-100%	91%
Moberg				
Nachemson (32)	FCU	12	80-100%	91,6%
Thomsen				
Rasmussen (29)	FCU	13	70-100%	86%
Thomsen				
Rasmussen (29)	FDS	10	70-100%	85%
Fujiwara (33)	FDS	18	60-100%	93.3%
Chuinard (31)	FDS	21	60-100%	90%

Table 10. RResults from analyzed authors: Flexor carpi radialis (FCR), Flexor carpi ulnaris (FCU), Pronator teres (PT), Palmaris longus (PL), Flexor digitorum superficialis(FDS)

Evaluation schemes differ significantly in terms of classification based on the measured active movements of the wrist, which is an additional problem. Zachary only evaluates the ability to flex to a neutral position (15). Thomsen and Rasmussen consider the Zachary method “too rigid and simplistic” and that too little attention is paid to functional results from the perspective of the subjective evaluation of the patient (32). Chuinard’s main objection to the Zachary scheme is use of “neutral position” (0 degrees) (31). Zachary measures the MCP extension at the wrist position in the neutral position (15) and does not define “mild” and “severe” loss of finger flexion for which it subtracts 10% or 20%. In the original paper Zachary states that it is not necessary and / or even desirable to achieve full finger extension when the wrist is at maximum extension; he considers this position unnatural and uncomfortable for most people. During normal open hand movement, the wrist comes in neutral or light flexion position and the goal of surgery, according to Zachary, is to reproduce this movement (15). Moberg and Nachemson, highlighted the difficulty of comparing the results of different methods and recommended the use of a Zachary evaluation scheme (conclusion were provided during 12 years follow up of patients) (32). Zachary concluded that it is necessary to maintain an active wrist flexor to stabilize the wrist. Ignoring this warning often leads to incomplete finger extension and unnecessary weakness of the wrist flexion (15). Although PL is a very weak wrist flexor, a large difference in end functional results can be observed in its presence (57%) and absence (26%). When left in situ PL and FCR, as in the case of FCU tendon transfer in 29 patients,

Zachary achieved a score of 91%. In conclusion, Zachary states that better results were achieved by transplanting only one wrist flexor (FCU) while leaving PL and FCR in situ. Moberg and Nachemson evaluated their results in 12 operated patients using FCU tendon transfer method. The overall result, evaluated by the Zachary scheme, is 91.6%. (32)

Thomsen and Rasmussen compare the results of FCU (13 patients) and FDS tendon transfer (10 patients) and present similar results. The total score achieved by FCU tendon transfer is 86% (29). The total FDS tendon transfer result is 85%. They preferred the use of FDS tendon transfer for two reasons: longer amplitude of FDS muscle movement relative to the FCU muscle and reduction of the possibility of radial deviation suggesting that the FDS muscle is transposed around the ulnar side of the forearm and not through the interosseal membrane. Thomsen and Rasmussen believed that the most appropriate muscle for pronation of the wrist is the PT (29).

Fujiwara's work published in 1970 reported results in 13 patients with radial nerve palsy and 5 patients with interosseous nerve palsy (33). All patients underwent FDS tendon transfer. The total score in all 18 patients, as measured by the Zachary evaluation scheme, was in the range is from 60-100%, with an average value of 93.3%. In a paper published in 1978, Chuinard reported results in 22 patients undergoing FDS tendon transfer over a 20-year period (31). There were 18 patients with complete radial nerve palsy and 4 patients with paralysis of the interosseous nerve. Chuinard offers its own evaluation scheme.

Forearm tendon transfer began with Murphy in 1914, who introduced the FCR muscle for finger extension and Henry in 1916 who used FCR for wrist extension. Biesalki and Mayer since 1916 recommended FDS for the wrist extension, and Jones in 1916 introduced PT muscle for wrist extension into clinical practice (2).

The transposed muscle must have sufficient motion amplitude to move the joints through the desired motion amplitude. There are two possibilities for obtaining greater effective amplitude of movement: extensive dissection of a muscle from its fascial structures and using the tenodesis effect.

Recipient tendon is significantly more important for function than is transposed donor muscle because it must remain the muscle that will perform the function of the donor muscle. With tendon transfer, a functional level of wrist and finger extension was able to be achieved, which is the goal of surgery for irreparable damage to the radial nerve (27). The most critical moment in surgery, which has the greatest repercussions on the functional result, is adequate tendon suture tension in any of these three tendon transfers (1,5).

The major difference between the operative procedure of FCR and FCU tendon transfer is in the type of donor tendon for finger extension, and as a result, the lack of finger extension (II-V) (the greatest negative effect on the final functional total result of FCU tendon transfer). In our results, the lack of finger extension (II-V) had the greatest negative effect on the final functional total result

of FCU tendon transfer. Due to lack of finger extension, an average of 10.75% was subtracted from the maximum score (100%) under the Zachary scheme for FCU tendon transfer as well as 3.25% for FCR tendon transfer. It is important to emphasize the important fact that all 20 patients in this research that were operated by FCR tendon transfer had lost three functions. Subjective satisfaction after operation is very high (21 patients rated their result as a great, 18 as a good and 1 as a satisfies; no one patient declared his/her result as a poor). The increasing incidence of gunshot wounds in extremes in peace and war necessitates a thorough knowledge of the mechanisms of their occurrence, pathomorphology, treatment modalities and possible complications (11). Optimal and timely treatment, with adequate physical treatment, is prescribed as imperative.

## 6. CONCLUSION

Forearm tendon transfer is a relevant method to compensate for the loss of function of the wrist, fingers and thumb extensions as a result of irreparable damage to the radial nerve. FCR tendon transfer provides better functional results than FCU tendon transfer in irreparable radial nerve damage. Both methods can be used for irreparable damage of radial nerve due to any etiology. The time elapsed from the injury to the performed surgery of the tendon transfer has no effect on the final functional result. There is no surgical tendon transfer procedure that can be recommended as a standard for any patient. Practically, the surgeon must tailor the surgery to the patient's needs. It is necessary to develop a unique and generally accepted evaluation scheme for the results of tendon transfers that will enable comparisons of results achieved.

- **Declaration of patient consent:** The authors certify that they have obtained all appropriate patient consent forms
- **Author's contribution:** R.K. gave substantial contribution to the conception or design of the work and in the acquisition, analysis and interpretation of data for the work. R.K. had role in drafting the work and revising it critically for important intellectual content. R.K. gave final approval of the version to be published and they agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.
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