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Evaluation of Outcome Measures of Zone V Flexor Tendon Injury: A Systematic Review

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Abstract

Background Flexor tendon injury zone V is a multicomponent soft tissue injury involving tendons, nerves, and vessels. Outcome assessment of repair thus requires evaluation of the hand as a whole rather than solely evaluating tendon function. The purpose of this Preferred Reporting Items for Systematic Reviews and Meta-Analyses -compliant systematic review was to identify and assess the components of outcome measures used in flexor zone V.

Methods A total of 3,761 studies were retrieved from four databases (PubMed, ProQuest, Cochrane Central, and Google Scholar). These studies were then screened for inclusion using a validated screening form. Fifteen articles fulfilling the eligibility criteria were included in the review. Subsequently, the included studies were assessed for methodological quality using the Joanna Brigg Institute tool.

Results Out of the 15 studies, 11 were case series, 3 were cross-sectional studies, and 1 was a randomized controlled trial. Out of 15 included studies, 13 were of low risk, whereas 2 studies suggested moderate risk when assessed for methodological quality using the Joanna Brigg Institute tool. Eight outcome measures were identified, out of which the most frequently used were Total Active Motion by the American Society for Surgery of Hand (TAM-ASSH) and Noaman's criteria. Our study found that Noaman's criteria assessed sensory-motor function and finger deformity in addition to the range of motion (ROM), which was found to be assessed by all the other outcome measures.

Conclusion We concluded that although Buck-Gramcko criteria is well suited for the ROM evaluation, Noaman's criteria, a recently developed outcome measure used exclusively for combined injuries in zone V, took into consideration the implications of nerve injury along with tendon function. Although being specifically designed for combined injuries of tendons, nerves, and vessels in zone V, there is a lack of usage of Noaman's in the literature. There still exists a lack of a consistent and appropriate choice of outcome measure.

Keywords
- zone V
- spaghetti wrist
- flexor tendon
- outcome measures
- functional outcome

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Introduction

Flexor tendon injuries continue to be one of the most commonly encountered injuries in an emergency or trauma setup. Achieving adequate digital function post flexor tendon repair remains one of the most arduous obstacles in hand surgery.[1] The flexor tendon injuries of the hand are divided into five zones with zone V extending from the proximal border of the transverse carpal ligament to the musculotendinous junctions of the flexor tendon.[2] Extensive laceration of the volar aspect of the wrist involving the median and ulnar nerves as well as radial and ulnar arteries, along with multiple flexor tendons, is termed as full house wrist or spaghetti wrist.[3,4] Puckett and Meyer coined the term spaghetti wrist as the sharp laceration of the volar surface of the wrist (between its distal skin fold and the flexor musculotendinous junction) with a minimum of three transected structures, including at least one nerve and one vessel.[5] The structures being confined in a small area can lead to adhesion formation by extrinsic healing, a common complication in this zone.[6] Range of motion (ROM) of fingers, strong grip and pinch strength, and motor dexterity depend on the excursion and tensile strength of the repaired flexor tendon. Hence, the assessment of functional outcome measures in this condition is crucial to understand the prognosis of surgical and rehabilitation protocols.

Several scoring systems have been developed for evaluating digital and composite hand function in terms of the ROM after flexor tendon repair. Some of the famous scoring systems are the Buck-Gramcko criteria, Strickland–Glogovac system, and the Total Active Motion (TAM) by the American Society for Surgery of Hand (ASSH).[2,7,8] It has been observed that diverse results are obtained when these evaluating systems are used to evaluate a particular zone of the hand.[9–11] Due to the difference in the scoring system, the results obtained are not comparable and no particular scoring system has been defined as a standard for zone V flexor tendon repair.[10,11] According to our knowledge, only the Strickland–Glogovac system was particularly tailored for the evaluation of zone II flexor tendon injuries.[8] Hence, there is a need to find the most appropriate and common outcome measure from the existing evaluation systems for the evaluation of function in zone V flexor tendon injuries.

Methods

The protocol for systematic review was registered prospectively on the international prospective register for systematic review PROSPERO (Registration Number: CRD42022329391; Date of Registration: 10th May 2022). The systematic review was reported in compliance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[12]

We included full-text articles reporting outcome measures for the digital ROM in zone V flexor tendon injuries only, English and German language, randomized controlled trials (RCTs), nonrandomized controlled trials, cohort studies, case-control studies, and case series. The reference lists of included articles were hand-searched for further relevant publications. The studies including crush injuries, fractures of forearm, wrist, and hand, tendon injuries of thumb zones, simultaneous extensor tendon injury, injuries involving multiple zones, secondary reconstruction, exclusively pediatric flexor tendon injuries, animals, cadavers, and biomechanical studies were excluded.

Two authors (K.B. and S.M.) systematically searched PubMed, ProQuest, Cochrane CENTRAL, and Google Scholar databases from the inception of the protocol to June 2022. The keywords used for searches were zone 5, zone V, flexor tendon injury, flexor tendon repair, spaghetti wrist, range of motion, functional outcome, and rehabilitation. The medical subheadings (MeSH) terms were hand injury, tendon injury, wrist injury, outcome, recovery of function, and treatment outcome. Boolean operators were used in all the searches along with the keywords. An example of a search is (((((zone V) OR (zone 5)) AND (flexor tendon injury)) AND (tendon injury)) AND (rehabilitation)) AND (treatment outcome) retrieved 27 studies on PubMed (►**Supplementary Table S1**, available in the online version). The results were merged and deduplicated prior to screening using the Zotero software (6.0.10). A screening form was devised to screen the articles for eligibility that was validated by two senior team members (M.D. and C.V.). Two team members (K.B. and I.C.) independently screened the articles using the inclusion and exclusion criteria. Disagreements were resolved by discussion with a senior member (C.V.).

The data were extracted and documented by two team members (S.M. and P.K.) independently using Microsoft Excel. Data extraction was done under the following headings: study design, number of participants, age, structures involved, repair technique for tendons, rehabilitation protocol, follow-up period, and outcome measure (evaluating system) used. The Joanna Brigg Institute (JBI) tool was used for assessing the methodological quality to identify the risk of bias in the included studies.[13] JBI for selected studies was administered by two team members (A.P. and K. B.) independently. Disagreements were resolved by a senior team member (M.D.) and discussion among all the team members.

Results

The PRISMA (2020) flowchart shows the screening process (►**Fig. 1**).[12] A total of 3,761 studies were retrieved from four databases. After deduplication, 2,008 studies were screened for titles and abstracts and 51 articles were sought for retrieval. As 15 reports could not be retrieved, we assessed 36 full-text articles for eligibility. The reasons for the exclusion of the articles are mentioned in ►**Fig. 1**. A total of 15 full-text articles met the eligibility criteria and were included in the study.

The studies included one RCT (6.66%), three cross-sectional studies (20%), and eleven case series (73.33%). The studies were published between the years 1998 and 2021. The mean follow-up duration was 11.9 months, ranging from 3 to 40 months, with no mention of the follow-up period in

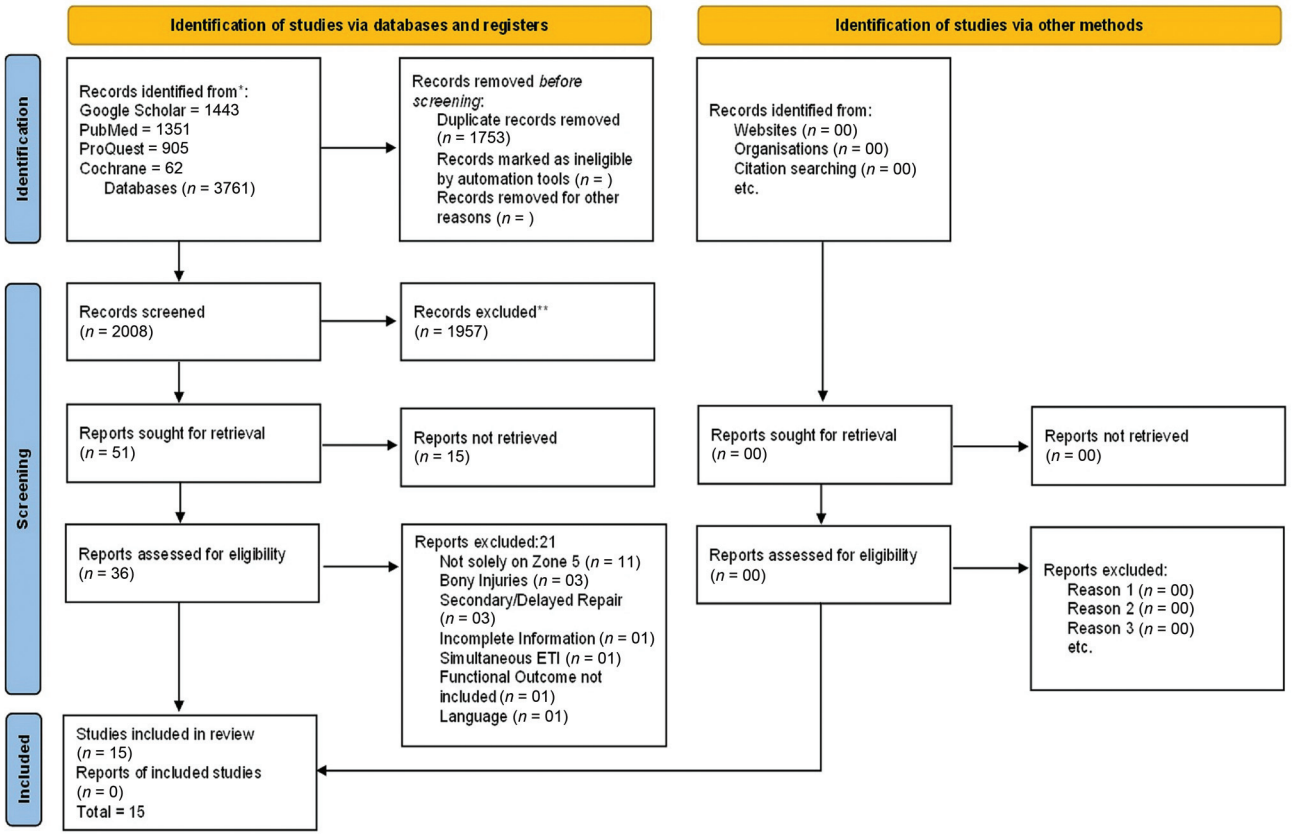

Fig. 1 PRISMA flow chart. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

one study. The total number of participants included in the reviewed articles was 617, with a sample size ranging from 11 to 153 (►**Table 1**).

►**Supplementary Table S2** (available in the online version) shows the repair technique, rehabilitation protocol, follow-up duration, and results with respect to the outcome measures. The modification of Kessler repair was used in eight studies. The other techniques mentioned are the Massachusetts General Hospital repair technique (modified Becker repair) in one study and the Tajima modification of the Kirchmayr and Kessler technique in one study. All of the studies that described the surgical technique repaired the tendon with core and reinforcing sutures. Variations of early active motion protocol were used in four studies as shown in ►**Supplementary Table S2** (available in the online version). Early passive motion protocol was used by eight studies including Kleinert, modification of Kleinert, and modified Kleinert–Duran protocol. The rehabilitation protocol was not mentioned in one study. The RCT compared Kleinert's controlled motion (early passive) versus controlled active motion (early active motion protocol; ►**Supplementary Table S2**, available in the online version).

Our review reported the use of eight different evaluating systems (►**Table 1**). Two most recent studies of the year 2021 used the TAM and Noaman criteria. The TAM, Buck-Gramcko, and Noaman evaluation systems are reported in recent studies of 5-year duration. The interpretation of results with respect to the evaluation systems in each article is shown in ►**Supplementary Table S2** (available in the online version). ►**Table 2** shows the comparison of the evaluation system in terms of the components of the ROM of joints, the method of measurement in degrees and fingertip-to-palm distance, assessment of sensory and motor function, and deformity. The angular flexion ROM is assessed in all the evaluation systems except Lister's criteria. The angular flexion ROM of the MCP, proximal interphalangeal (PIP) and distal interphalangeal joint is assessed by Buck-Gramcko, TAM, Noaman, and the modification of the Strickland formula. The adjusted Strickland does not measure the MCP joint flexion. The angular extension deficit is measured in adjusted Strickland, Buck-Gramcko, Lister's, and TAM scores. The tip-to-palm distance, a linear method of ROM, is evaluated in Buck-Gramcko, Lister's, Noaman's, and Kleinert and Verdan's criteria. Additionally, sensory and motor components of hand function as well as deformity are only assessed by Noaman's criteria.

The methodological quality of the studies was assessed by JBI critical appraisal tools (►**Supplementary Table S3**, available in the online version). A total of 13 studies were assessed as low-risk studies, whereas two studies, a cross-sectional study and RCT, were reported as moderate risk (►**Table 1**).

Discussion

Our review focused on identifying an appropriate outcome measure for the evaluation of zone V flexor tendon injuries

Table 1 Characteristics and quality assessment of the studies

Author (year)	Study design	Level of evidence	No. of participants	Mean age/ age range (years)	JBI score	Risk of the study
Boynuyogun et al[39]	Case Series	IV	20	32.7/18–47	8/10 (80%)	Low risk
Arik et al[20]	Case Series	IV	13	23.8/18–42	10/10 (100%)	Low risk
Demirdover et al[40]	Case Series	IV	125	24.8/6–61	8/10 (80%)	Low risk
Altamimy et al[19]	Case Series	IV	15	24.5/16–37	8/10 (80%)	Low risk
Hegazy et al[22]	Case Series	IV	13	30/18–46	8/10 (80%)	Low risk
Mehdi Nasab et al[23]	Case Series	IV	42	25.4/17–46	10/10 (100%)	Low risk
Raza et al[24]	Case Series	IV	31	27/17–53	10/10 (100%)	Low risk
EL-Lamie et al[21]	Case Series	IV	11	34/27–54	7/10 (70%)	Low risk
Yildirim and Nas[26]	Case Series	IV	33[a]	Group 1: 24.5 / 18–39 Group 2: 29.6 / 18–46	7/10 (70%)	Low risk
Wilhelmi et al[31]	Case Series	IV	29	28/–	9/10 (90%)	Low risk
Yii et al[41]	Case Series	IV	52	29/6–78	8/10 (80%)	Low risk
Shafiq[42]	Cross- Sectional (Observational Study)	III	30	–/0–60	6/8 (75%)	Low risk
Yazdanshenas et al[43] (2016)	Cross- Sectional (Observational Study)	III	153	28.3/–	5/8 (62.5)	Moderate risk
Al-Shanawany et al[15]	Cross- Sectional (Observational Study)	III	20	Males = 28.6 /– Females = 23.5/–	6/8	Low risk
Uday et al[25]	Randomized Controlled Trial	II	30	–/18–40	8/13 (61.53%)	Moderate risk

Abbreviation: JBI, Joanna Brigg Institute.
Note: Low risk: $\geq$ 70% of 'Yes' score
Moderate risk: 50–69% of 'Yes' score
High risk: $\leq$ 49% of 'Yes' score
[a]Group 1 = 23, Group 2 = 10

Table 2 Summary and comparison of the identified outcome measures

Evaluation system	Flexion range of motion			Extension deficit	Tip to palm distance	Opposition (median nerve)	Intrinsic hand function (ulnar nerve)	Deformity	Sensations
	MCP	PIP	DIP						
Strickland/adjusted Strickland	–	✓	✓	✓	–	–	–	–	–
Buck- Gramcko criteria	✓	✓	✓	✓	✓	–	–	–	–
Lister's criteria	–	–	–	✓	✓	–	–	–	–
Noaman's criteria	✓	✓	✓	–	✓	✓	✓	✓	✓
Total Active Motion (ASSH)	✓	✓	✓	✓	–	–	–	–	–
Kleinert and Verdan's Criteria	✓	✓	✓	–	✓	–	–	–	–
Modification of Strickland Formula	✓	✓	✓	✓	–	–	–	–	–

Abbreviations: ASSH, American Society for Surgery of the Hand; DIP, distal interphalangeal joint; MCP, metacarpophalangeal joint; PIP, proximal interphalangeal joint.
✓: Component Present
–: Component Absent

from those existing in the literature. Zone V is a flexor zone that is bound to have involvement of multiple soft tissues like the nerves, vessels, and tendons necessitating the need for wholesome evaluation involving sensory and motor assessment, in addition to tendon function. Invariably, these combined injuries have consequences on the outcome of repair and the effectiveness of rehabilitation. Apart from conventionally used outcome measures for the evaluation of flexor tendon injuries, we found Noaman's Criteria, a recently developed outcome measure, exclusively designed for the evaluation of Zone V (►**Supplementary Table S2**, available in the online version).

All the evaluation systems identified included ROM assessment; however, there was gross variation in the assessment and reporting of each. The components of the evaluating systems include angular and linear methods of ROM, sensory, motor, and deformity evaluation. According to So et al (1990) the functional outcome should include (1) integration of the measurement of tendon gliding and measurement of function; (2) the metacarpophalangeal joint measurement; (3) angular or linear measurement; and (4) representation of joint posture during motion. So et al in their study suggested the Buck-Gramcko criteria were superior to other evaluation systems because they include angular and linear flexion and extension deficits, giving a complete picture of ROM. Unlike TAM-ASSH, the Buck-Gramcko criteria do not require a normal side for comparison of ROM to assess the grading of function.[14] A modification of Strickland's formula used by Al Shanawany et al included MCP joint ROM with no evidence of its validity in the literature.[15]

Outcome assessment of a multicomponent flexor tendon injury in zone V should capture the integrity of hand function.[16] Other factors that influence the outcome of flexor tendon repair are surgical technique, immobilization period, and postoperative rehabilitation protocol.[17] Our review highlights Noaman's Criteria as being one of its kind developed solely for spaghetti wrist, and its lack of extensive use in the recent literature even though it involves wholesome evaluation of the tendon function, motor function of median and ulnar nerves, deformity, and sensations along with the ROM assessment.[18] Three of the fifteen studies after 2007 included in this review have used Noaman's criteria. Few studies in the review included separate assessments of sensations using Semmes monofilament, two-point discrimination, nerve conduction studies, and grip strength for motor assessment.[15,19–26]

Historically, there has been a shift from composite measurements such as pulp-to-distal palmar crease distances earlier to the use of the ROM of individual joints more recently.[27] The introduction of Lister's method of assessment in 1977 which measured pulp-to-distal palmar crease and extension deficit was influenced by linear measurement by Boyes in the 1950s and extension lag measurement by Van't Hof-Heiple.[28] One of the studies, Yildrim and Nas et al (2010), of our review, used Lister's criteria. According to So et al, these systems, even though simple, have disadvantages that include a wide margin of measurement error and individual variations, such as finger length and the bulk of the pulp, possibly why, these have fallen out of practice and are not favored by surgeons.[14] These disadvantages led to the development of angular measurements for the ROM such as Buck-Gramcko (1976), ASSH using TAM (1976), Lister (1977), Strickland (1980), Grossman System II (1985), and many more.

The Buck-Gramcko criteria aimed to measure function and tendon gliding, and the tip-to-crease distance represent joint posture, thus proving it to be more advantageous.[14] According to Elliot, drawbacks of this system include complex calculations, and it is also criticized as being too lenient and favored by German-speaking nations of Europe.[27]

In 1976, the ASSH Clinical Assessment Committee suggested the use of TAM and total passive motion (TPM) for assessing hand function. The difference between TAM and TPM reflected tendon adherence. Earlier (ASSH 1976), the TAM score of the unaffected side was obtained as a percentage of the TAM of the normal side (e.g. 50% of the normal side). The drawback of this system is that only the digits that have a 100% result can be graded as excellent, and it cannot be used in bilateral injuries as there was no universal TAM value.[2] As no numerical value for the score excellent was defined, some authors did not use it for statistical analysis while some authors designated excellent as a 100% score for statistical analysis.[29,30] Some have also reported the results as excellent to good as >75% as in the study by Wilhelmi et al included in this review.[31] For bilateral injuries, the TAM score is calculated as a percentage of 260 degrees. Due to the codification of excellent as 100% of the contralateral finger, Tang (2005) indicated that in comparison to the TAM method (ASSH), the modified TAM, that is, Strickland's method was more practical. There are varying degrees of joint stiffness after tendon repair and protective motion exercise, and patients who entirely satisfy the criteria as excellent are extremely rare. Although an ample TAM is required to achieve excellent functional status, it is not necessary that this range be equal to the contralateral finger. TAM of more than 85% contributes to the excellent function of the fingers.[32] Kleinert and Verdan (1983) also use a similar scoring, either the TAM or the tip-to-distal crease distance.[2] TAM is calculated by the same method as the ASSH TAM.

The original Strickland system was a combination of existing classifications and the TAM system recommended by the ASSH. Because the metacarpophalangeal joint motion was normal in all cases of zone II flexor tendon injury, he suggested that this measurement could only bias a true assessment of tendon function as reflected at the PIP and DIP joint flexion and extension lag.[8] The score was expressed as a percentage of a hypothetical normal finger for which the range of PIP plus DIP was 175 degrees. The lack of complexity of this system is advantageous; however, it doesn't represent joint posture during motion, which adds to its disadvantage. In 1985, Strickland modified the scoring system of their assessment (adjusted Strickland), which is criticized to be too lenient and effectively moves all results up by one grade.[27] The difference between Strickland's original system and the adjusted system exists only in the definition of the categories, not in what is being measured.[29]

A relatively recent evaluation system was developed by Noaman in 2007 for combined injury of the flexor tendon, nerves, and vessels at the wrist. The goal of their study was to present a new functional outcome score to be able to evaluate the results of both tendon and nerve repair.[18] This study assessed 42 patients with combined injuries of tendons, nerves, and vessels in zone V. The repair technique used was modified Kessler along with early passive mobilization for rehabilitation.[18] The scoring system stratified the results as excellent, good, fair, and poor depending on tendon function, opposition, intrinsic, deformity, and sensation.[18]

Buck-Gramcko, Lister, Klienert, and Verdan and TAM-ASSH criteria are based on the ROM assessment making them easier to administer as compared to Strickland, modified Strickland criteria which involve the calculation of final scoring using formulae. Noaman's criteria gave a direct description of each component; however, assessment of five components makes it more time-consuming than others.

Healing the flexor tendon and collagen remodeling takes about 2 to 3 months or more, and correction of interphalangeal joint contracture may take even longer. Therefore, the evaluation of flexor tendon repair and the outcomes should be measured at around 3 months after surgery when rehabilitation is complete making the follow-up period an important factor.[32,33] The follow-up duration in our review ranged from 3 months to 40 months. A recent review by Peters et al recommended the outcomes be measured for a longer duration that is greater than 6 months to identify the adverse effects and long-term effectiveness of the prescribed treatment.[34]

The comparison of the results between the studies depends on the congruency and comparability of the outcome measures. The difference in the grading of each system and the lack of comparability among the outcome measures is supported in a study done by Hahn et al.

The authors deduced that for the results to be compared among different studies either the same outcome measure should be used or if different systems are used, they need to be convertible from one system to another.[11] The functional outcomes used for the evaluation of zone V lack congruence in terms of the method of assessment and reporting the scores. Hence, the need arises to standardize the outcome measures that has been raised by several authors.[14,30,35,36] Our review illustrates that these differences still exist and that Noaman's criteria which is developed solely for zone V has not been extensively explored. As a solution to this variability, Peters et al (2021) suggested the use of goniometric measurement for affected digits that is individual joint flexion/extension measurements and TAM as it is easier to compare and interpret the clinical significance across groups within a study and across studies comparing the same interventions.[34] Additionally, the validity and reliability of these evaluation systems have not been established due to a lack of consensus on the gold standard.[30] Therefore, the need arises to evaluate the psychometric properties of outcome measures used in the literature used to evaluate zone V flexor tendon repair and to further explore the potential of recently developed criteria such as Noaman's for its appropriateness.

There may be other outcome measures used by various authors in their research and clinical practice that could not be found in this review due to the specific eligibility criteria. In our review, we found paucity in randomized trials, one of the reasons for this could be, in the surgical field, that randomization would either not be feasible or possible at all.[37] Another limitation of our review was that most of the studies were case series (level 4 evidence) which is in sync with the finding of the study done by Sugrue et al on the level of evidence in plastic and reconstructive surgery in the past 10 years.[38] The literature does magnify the efforts of researchers in the field toward the development of criteria centralizing the evaluation to particular zones such as Noaman's criteria for zone V and Strickland's criteria for zone II. Our review does emphasize further use of Noaman's criteria in order to assess its universal applicability for repairs in flexor zone V.

Conclusion

This study gives us an overview of the clinician-rated outcome measures used for the assessment of zone V flexor tendon injuries in the literature. Our review identified eight such outcome measures. The most common among these were TAM-ASSH and Noaman's criteria, which were applied in three studies each. Kleinert and Verdan, and Buck-Gramcko, which are among the more familiar ones, were applied in two studies each. Even though the well-established Buck-Gramcko system gives a better evaluation of the ROM and the recently developed Noaman's criteria evaluates the hand more comprehensively, all these outcome measures lack validity and reliability. There has been no consensus on the use of an outcome measure, and there still exists a lack of a consistent and appropriate choice of outcome measure to be used for zone V flexor tendon injuries. This systematic review thus highlights the need for further research to help standardize the outcome assessment of zone V flexor tendon injuries.

PROSPERO Registration: CRD42022329391
The protocol was submitted on April 30, 2022 according to PRISMA (2020) guidelines and was approved on May 10, 2022. The review was conducted from April 30 to November 24, 2022.

Presentation
This review was awarded first rank in paper presentation section of the SHTICON 2022, 9th Annual Conference of the Society for Hand Therapy, India in collaboration with 45th Annual Conference of the Indian Society for Surgery of the Hand. The conference was held on 7 to 8 October 2022 in Jaipur, Rajasthan.

Author Contributions
C.V. was involved in formulating the idea of this systematic review, resolving disagreements on the inclusion of studies, writing of the manuscript, and expert guidance throughout the review process. M.D. initiated the idea of

this systematic review, resolving disagreements on the inclusion of studies, and writing of the manuscript. K.B. was involved in drafting the review, literature search, screening process, risk of bias assessment, and writing of the final manuscript. I.C. was responsible for drafting the review, screening process, and writing of the manuscript. S.M. was involved in drafting the review protocol, literature search, data extraction from the studies included, and writing of the manuscript. P.K. was involved in drafting the review protocol, extracting data, and suggestions for writing the manuscript. A.P. was involved in drafting the review protocol, assessing the risk of bias, and writing of the manuscript.

Conflict of Interest
None declared.

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