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Extensor Hallucis Capsularis Tendon Morphometrics and its Role as a Potential Graft: A Systematic Review

Morfometría del Tendón Extensor Hallucis Capsularis y su Papel como Posible Injerto: Una Revisión Sistemática

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SUMMARY: The main goal of our study was to analyze the morphometrics of the extensor hallucis capsularis (EHC), an accessory tendon arising from the extensor hallucis longus (EHL). Despite its functional importance, there is no comprehensive data available on the prevalence, origin, insertion, and morphometrics of the EHC. Therefore, we systematically reviewed the EHC with more emphasis on its length and width. A systematic literature search using PRISMA guidelines was performed in databases such as MEDLINE, Google Scholar, SciELO, and Cochrane reviews using search terms such as "Extensor Hallucis Capsularis", AND "prevalence OR origin OR insertion OR length OR width", which yielded 315 article links. Of the nine articles that met the inclusion criteria, only six cadaveric studies comprising 260 EHC tendons from 338 lower limbs had the morphometric data. The specimens included in these six studies are in a range of 21- 82.2 years age. Pooled data (Mean±SD) of the EHC showed: total length 8.30 ±3.01cm, and width 2.26 ± 1.19mm, respectively. Our pooled analysis revealed that the EHC most commonly originated from the EHL tendon (97.6 %) followed by the tibialis anterior (2.3 %) and mainly inserted on the first metatarsophalangeal joint capsule (75.3 %), followed by the base of the proximal phalanx (23.4 %) and head of the metatarsal bone (1.3 %). Our data generated more representative values on the morphology of EHC from the available literature and this information would be of great advantage for surgeons to compare its surgical adequacy while using it as a tendinous graft in various surgeries.

KEY WORDS: Extensor hallucis capsularis; Morphometrics; Graft; Surgical; Adequacy.

INTRODUCTION

The extensor hallucis longus (EHL) is one of the muscles of anterior compartment of the leg that originates as a fleshy part from the anterior aspect of fibula and adjacent interosseous membrane. The fleshy part then becomes a long tendon, which inserts to dorsal area of the distal phalanx of hallux (Standring, 2016) (Fig. 1a). However, like any other muscle, EHL poses variations in its insertion by presenting one or more additional tendinous slips (Natsis *et al*., 2017). A wide range of supernumerary muscles and accessory tendons of both upper and lower limbs have been described in the anatomic literature from invasive and non-invasive procedures. In most cases, accessory muscles are asymptomatic but, in some cases, they may produce clinical symptoms by inserting on the adjacent structures. One such accessory extensor tendon, which is less known in the field of anatomy, is the extensor hallucis capsularis (EHC) which belongs to EHL muscle-tendon complex (Sarrafian & Kelikian, 2011) and seen on the medial side of EHL tendon (Fig. 1b) inserting to the capsule of the first metatarsophalangeal joint (1st MTPJ). Studies have described these additional extensor tendons could be of great utility as intercalary grafts in upper limbs reconstruction surgeries (Gaspar *et al*., 2017). The EHL muscle-tendon complex is long known as a good graft for variety of tendon transfer surgeries to correct equinovarus foot deformities and clawed hallux (Carda *et al*.,2010). Macalister in 1866 first described this as an extensor ossis metatarsi hallucis arising from anterior edge of the tibialis anterior (TA) tendon (Macalister, 1866). Later on, in the year 1868, Wood found a long accessory tendinous slip arising from EHL tendon inserting to the inner portion of base of the proximal phalanx of great toe either directly distal or medial to the lower attachment of extensor hallucis brevis (EHB) tendon and this was described as an extensor primi internodii hallucis (EPIH) of

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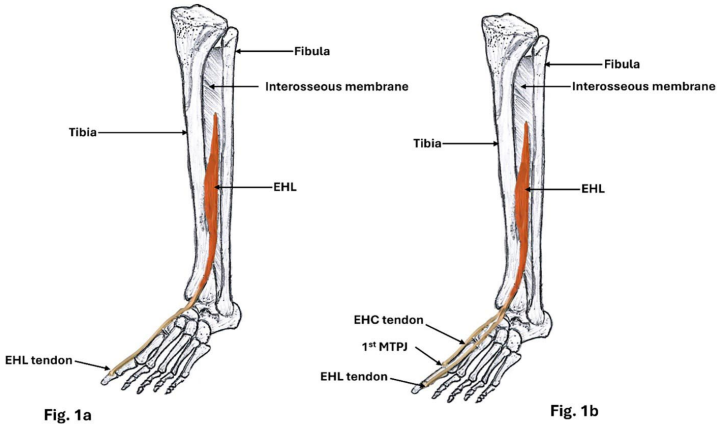

Fig. 1a. Origin and insertion of EHL muscle-tendon complex. Fig. 1b. The EHC tendon of the EHL muscle-tendon complex is inserting on 1st MTPJ capsule. EHL: Extensor hallucis longus, EHC: Extensor hallucis capsularis, 1st MTPJ: First metatarsophalangeal joint.

Wood (Wood, 1868). Although many studies reported EHC as EPIH, a study quite clearly argued that the EHC inserts on base of the proximal phalanx in minimal cases (Boyd *et al*., 2006); and to the capsule of 1st MTPJ in 80 % to 88 % of cases (Lundeen *et al*., 1983); thus, the discrepancies between these two variants exist, and this was briefly reported in a textbook (Sarrafian & Kelikian, 2011) & the compendium of anatomical variants (Lambert, 2016).

Some studies in literature even described it as a secondary EHL (Lundeen *et al*.,1983); accessory extensor tendon of the 1st MTPJ (Boyd *et al*., 2006), and a few studies described it arising from tendons of EHL, TA and EHB, respectively (Bibbo *et al*., 2004; Boyd *et al*., 2006). Regarding its insertion, EHC also showed a wide range of variations by blending with the capsule of 1st MTPJ or at the base of the first proximal phalanx (Boyd *et al*., 2006). In addition to their variant attachments, studies have also documented disparity in its size. Although a very few studies have described the characteristic features, frequency and functional importance of EHC, the data on its origin, insertion and morphometrics of EHC still remain vague and scarce. In addition, most of the modern anatomy textbooks and atlases lack its anatomical description (Hill & Gerges, 2008). Therefore, we made an attempt to systematically review the EHC to derive a standard dataset on its origin, insertion and morphology.

MATERIAL AND METHOD

Search strategy & inclusion-exclusion criteria. A thorough literature search was conducted mainly using electronic databases such as MEDLINE, Google Scholar, SciELO, and Cochrane reviews. The keywords used for search were "*Extensor hallucis capsularis*" AND "prevalence OR origin OR insertion OR length OR width". To arrive at a standard data of this underexplored area, we have confined our search criteria to the cadaveric studies and live subjects by excluding all case reports, case series, letters to editor, brief communications and studies that did not meet keywords of our search. The mean pooled data on EHC prevalence, its origin-insertion, length, and width were set to be the outcomes of our study. The references of the included articles were thoroughly checked, and duplicates were deleted. We did not set restrictions on the date and language of the studies. Initial screening on titles and abstracts of the articles were done to obtain the full-text articles (Fig. 2). The data collection was carried out using the guidelines of Preferred Reporting Items for Systematic reviews and MetaAnalyses (PRISMA) checklist (Moher *et al*., 2009).

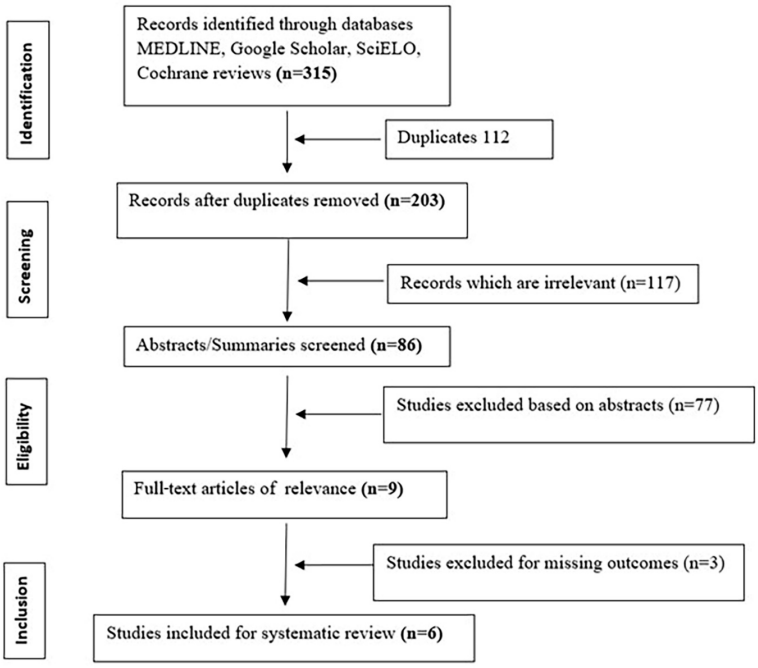

Fig. 2. Showing the application of selection criteria as per PRISMA guidelines.

Statistical Analysis. Extracted data included the country of study, sample size, and the number of EHC, their length, width, origin and insertion. The Mean±SD was calculated for the length and width of EHC. Statistical analysis was conducted using R software (version 4.3.3) with the metafor and meta packages. The prevalence of EHC tendons was extracted from six included studies. For each study, the event counts (EHC tendons origin from different sources) and total sample sizes were used to calculate prevalence (proportions) with 95 % confidence intervals (CIs). Due to the presence of extreme proportions (e.g., 0.10 and 0.98), Freeman-Tukey double arcsine transformations were applied to stabilize variances and mitigate bias in the meta-analysis. A common-effect (fixed-effect) model was initially employed to pool prevalence, as clinical homogeneity was assumed a priori. However, significant heterogeneity was detected across studies (I^2=98.9 %, T^2=0.1115, Cochran's Q-test p<0.0001), indicating substantial variability beyond sampling error. Consequently, results are presented under the common-effect model with explicit acknowledgment of heterogeneity. Study weights were derived using inverse-variance methods, prioritizing the precision of individual estimates. The pooled prevalence and 95 % CI were visualized via a forest plot. Subgroup analyses to explore geographical variations (e.g., Asia vs. Western cohorts) were conducted narratively due to insufficient statistical power for formal comparisons. Sensitivity analyses were not performed, as all studies adhered to consistent anatomical definitions. Statistical significance was set at a=0.05, and all analyses adhered to PRISMA guidelines for systematic reviews and meta-analyses.

RESULTS

Outcome of search. A total of 6 studies included 338 lower limbs with a sample of 260 EHC tendons met the inclusion criteria (Fig. 3; Table I). Although abstracts of 86 articles were initially screened, only a small portion of them (n=9) were included in our analyses because most of the articles did not report the data on keywords of our study. Three studies, two of those investigated EHL on cadavers with no obvious emphasis on EHC (Denk *et al*., 2002; Al-Saggaf, 2003), and the other one that investigated EHC tendons in the fetal sample (Aktekin *et al*.,2008) were excluded due to their insufficient elaboration or clarification on our search items. Fetal study was excluded, due to the fact that muscle-tendon growth is significant with the growth, and analyzing

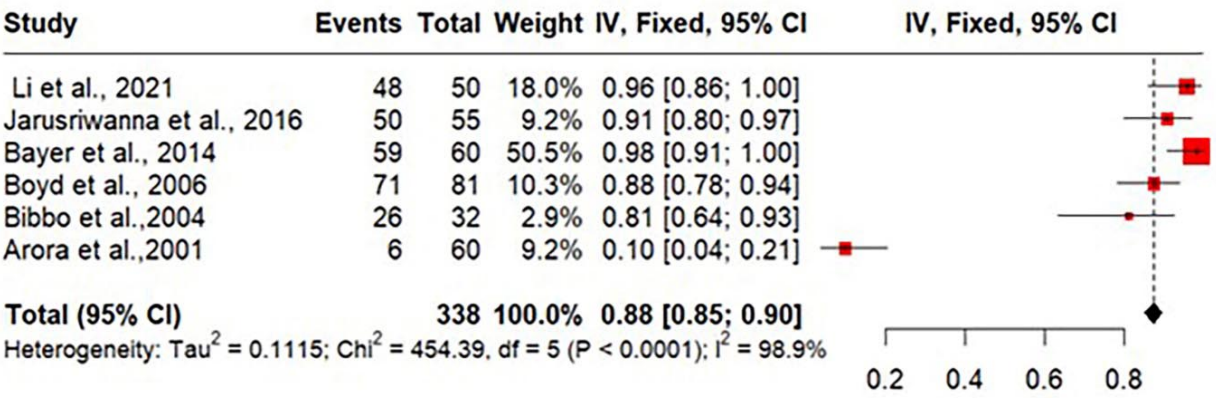

Fig. 3. Forest plot of pooled proportions and heterogeneity in the prevalence of EHC tendon. EHC: Extensor Hallucis Capsularis.

Table I. Characteristics of the included studies.

Studies (year)	Region	Sample size of limbs	Type of study	Age (Years)	Sex		Side	
					Male	Female	Left	Right
Arora *et al*., 2001	India	60	Cadaveric	NR	56	4	NR	NR
Bibbo *et al*., 2004	USA	32	Cadaveric	NR	12	22	NR	NR
Boyd *et al*., 2006	USA	81	Cadaveric	NR	NR	NR	NR	NR
Bayer *et al*., 2014	Switzerland	60	Live subjects	21-76	9	51	NR	NR
Jarusriwanna *et al*., 2016	Thailand	55	Cadaveric	33-90	36	19	29	26
Li *et al*., 2021	China	50	Cadaveric	82.2 ± 8	40	10	NR	NR

NR: not reported.

the morphometrics of fetal sample would yield procedural errors in establishing the standardized dataset. The specimens are in a range of 21- 82.2 years age. Five studies (Bibbo *et al*., 2004; Arora *et al*., 2011; Bayer *et al*., 2014; Jarusriwanna *et al*., 2016; Li *et al*., 2021) reported their gender distribution with 153 males and 106 females. One study (Jarusriwanna *et al*., 2016) reported data on 29 left and 26 right limbs. Tables I and II show the characteristics of included studies and outcomes of individual studies. Our analyses revealed the unique standardized data on EHC's origin and insertion (origin: mainly from EHL, followed by TA and in negligible cases from EHB; insertion: mainly on 1st MTPJ capsule, followed by the base of proximal phalanx and least from the head of first metatarsal bone.

EHC origin. Six studies (Bibbo *et al*., 2004; Boyd *et al*., 2006; Arora *et al*., 2011; Bayer *et al*., 2014; Jarusriwanna *et al*., 2016; Li *et al*., 2021) reported the origin of EHC tendon from different sources. Of 260 EHC tendons, 254 tendons originated from EHL tendon (97.6 %); and 6 EHC tendons from TA (2.3 %). The sample from India, China and Switzerland had 100 % origin of EHC tendon from EHL while the sample from Thailand and USA had 92-97 % of EHC tendon origin from EHL. The sample from Thailand and USA had 3-8 % of EHC tendon origin from TA while the sample from India, China and Switzerland had 0 % origin of EHC tendon from TA. None of these studies clearly specified occurrence of EHC pattern in relation with sex and sides (Table II).

EHC insertion. Six studies (Bibbo *et al*., 2004; Boyd *et al*., 2006; Arora *et al*., 2011; Bayer *et al*., 2014; Jarusriwanna *et al*., 2016; Li *et al*., 2021) reported the insertion of EHC tendon from different sources. Of 260 EHC tendons, 196 tendons inserted on 1st MTPJ capsule (75.3 %); 13 tendons inserted on the base of proximal phalanx (5 %); 3 on the head of first metatarsal bone (1.1 %) and 48 on the dorsal aspect of proximal phalanx (18.4 %). The sample from USA and Switzerland had almost 100 % insertion of EHC tendon on the 1st MTPJ capsule while the sample from Thailand had 82 % of EHC tendon insertion on the 1st MTPJ capsule. The sample from India and China had 0 % insertion of EHC tendons on the 1st MTPJ capsule. None of these studies clearly specified occurrence of EHC pattern in relation with sex and sides (Table II).

EHC length and width. Six studies (Bibbo *et al*., 2004; Boyd *et al*., 2006; Arora *et al*., 2011; Bayer *et al*., 2014; Jarusriwanna *et al*., 2016; Li *et al*., 2021) reported the mean length and width of EHC. The mean pooled data on the length and width of EHC were: 8.30 ±3.01cm and width 2.26 ± 1.19mm, respectively. Shortest length of the EHC (5.5 cm) was found in a study from the USA (Bibbo *et al*., 2004) while the longest EHC (13.5 cm) from a study conducted in Indian population (Arora *et al*., 2011). With reference to the width of EHC, minimal width (1.4 mm) was found in a study from China (Li *et al*., 2021) with the maximum width (4 mm) from USA population (Boyd *et al*., 2006) (Table II).
Overall prevalence of EHC.

The meta-analysis of six cadaveric studies (Bibbo *et al*., 2004; Boyd *et al*., 2006; Arora *et al*., 2011; Bayer *et al*., 2014; Jarusriwanna *et al*., 2016; Li *et al*., 2021) investigating the origin of EHC tendon revealed a pooled prevalence (proportion) of 0.88 (95 % CI [0.85; 0.90]). However, significant heterogeneity was observed (I^2=98.9 %, T^2=0.1115, p<0.001), indicating substantial variability across studies (Fig. 3). Geographically, samples from India, China, and Switzerland demonstrated 100 % EHL origin, whereas Thailand and the United States showed slight variability (92-97 % from EHL, 3-8 % from TA). For insertion, 75.3 % of EHC tendons attached to the 1st MTPJ capsule, though geographical disparities were notable (100 % in the U.S. and Switzerland vs. 0 % in India and China). These findings suggest that while EHL is the predominant source for the origin of EHC, regional anatomical variations exist (Table II; Fig. 3).

Table II. Outcomes of the selected studies on morphometrics of EHC.

Studies (year) & Region	Sex/side	Length (cm)	Width (mm)	Number of EHC & their source of origin	Number of EHC & their site of insertion	Prevalence
Arora *et al.*, India, 2001.	Overall	13.5	NR	6: all 6 from EHL (100 %)	2 on head of first metatarsal bone (33.3 %); 4 on base of the proximal phalanx (66.6 %)	10 %
Bibbo *et al.*, USA, 2004.	Overall	5.5	2	26: 24 from EHL (92.3 %); 2 from TA (7.7 %)	26 on I[st] MTPJ capsule (100 %)	81.25 %
Boyd *et al.*, USA, 2006.	Overall	10.8±5.0	4.0	71: 69 from EHL (97.1 %); 2 from TA (2.8 %)	70 on I[st] MTPJ capsule (99 %); 1 on base of the proximal phalanx (1 %)	87.6 %
Bayer *et al.*, Switzerland, 2014.	Overall	NR	1.8	59: all 59 from EHL (100 %)	59 on I[st] MTPJ capsule (100 %)	98.3 %
Jarusriwanna *et al.*, Thailand, 2016.	Overall	11.3±4.0	1.6±0.6	50: 48 from EHL (96 %); 2 from TA (4 %)	41 on I[st] MTPJ capsule (82 %); 8 on base of the proximal phalanx (16 %); 1 on head of the first metatarsal bone (2 %)	90.9 %
Li *et al.*, China, 2021.	Overall	5.89±0.14	1.43±0.05	48: all 48 from EHL	48 on dorsal base of proximal phalanx (96 %)	96 %

NR: not reported; EHL: Extensor hallucis longus; TA: Tibialis anterior; Ist MTPJ capsule: First metatarsophalangeal joint capsule.

DISCUSSION

Our analysis on the morphometrics of EHC tendon from cadaveric studies revealed the mean length of 8.30 cm with an average width of 2.26 mm. To our knowledge, this is the first systematic review on EHC and our findings from six different studies revealed that the EHC size differs in terms of length and width among populations. The variations we observed between the EHC length and width of different populations could be a result of anatomical dissections they performed on embalmed vs. fresh cadavers or discrepancies in the programmed cell death during the developmental processes of leg musculature (Hill & Gerges, 2008). Although such procedural bias could exist, the larger pooled data of our study could give a standard dataset about the morphometrics of EHC. Although accessory tendons of the great toe are known from ages with different terminologies as secondary extensor hallucis longus (Lundeen *et al*., 1983), accessory extensor tendon of the 1st MTPJ (Boyd *et al*., 2006), extensor ossis metatarsi hallucis, and extensor primi internodii hallucis (Macalister, 1866; Boyd *et al*., 2006), the term EHC is still underexplored and our findings on the morphometric analysis of EHC would be of great advantage for surgeons to compare its surgical adequacy while using it as a tendinous graft in various surgeries.

The presence of EHC has many functional and clinical implications. From a functional viewpoint, when EHC inserts to the base of the proximal phalanx of big toe and to the capsule of 1st MTPJ, it would facilitate the extension of great toe that usually happens during the walking and running. From a biomechanical viewpoint, EHC may exert a medial pull on the 1st MTPJ and base of the proximal phalanx and this medial pull would counteract the lateral pull exerted on distal phalanx of the great toe by main tendon of the EHL and this may increase the risk of developing hallux valgus (HV) deformity (Al-Saggaf, 2003; Fraissler *et al*., 2016) in addition to many other contributing factors of HV deformity such as wearing highheal shoes (Potu *et al*., 2023), surgical errors, and genetic factors. Nevertheless, a detailed biomechanical study is needed to assess the role of additional tendons in the occurrence of HV deformity (Zielinska *et al*., 2021).

Our pooled data on the length and width of EHC proves itself to be an adequate source of graft material for autogenous tendon transfers and ligament reconstructions. The close anatomical proximity of EHC to EHL is also an advantage for using it as a graft for repairing the hallux pathologies. Since EHC is an accessory tendon complementing the function of EHL, harvesting it has no negative outcomes (Boyd *et al*., 2006). With respect to autogenous grafting, cadaveric observations proved that the grafts cross-sectional area has a huge impact on the graft success (Hamner *et al*., 1999; Fritsch *et al*., 2017) and any tendons measuring more than 2 mm width (Boyd *et al*., 2006) with a suitable length of 8 cm are substantial and could be used as successful autogenous grafts in EHL tendon ruptures (Kurashige, 2019). As per these studies, our findings on the pooled data of width and length of the EHC are quite satisfactory for its usefulness as a successful graft.

Our study has a few limitations. First of all, we reviewed the literature strictly based on the insertion of EHC to the capsule of 1st MTPJ and the base of proximal phalanx by excluding other ambiguous debates on the EHC. Second of all, our study had high heterogeneity and insufficient data on sex- or side-specific patterns. Third of all, using keywords of our search, there was no obvious data available on the EHC's association of sex and sides with HV deformity. Future studies on these lines would be very helpful in establishing EHC as a potential graft in the field of orthopedic surgeries.

POTU, B. K. & ALMARABHEH, A. Morfometría del tendón extensor hallucis capsularis y su papel como posible injerto: Una revisión sistemática. *Int. J. Morphol., 43(4)*:1370-1375, 2025.

RESUMEN: El objetivo principal de nuestro estudio fue analizar la morfometría del *extensor hallucis capsularis* (EHC), un tendón accesorio que se origina del extensor largo del hálux (ELH). A pesar de su importancia funcional, no existen datos exhaustivos sobre la prevalencia, el origen, la inserción y la morfometría del EHC. Por lo tanto, revisamos sistemáticamente el EHC, con especial énfasis en su longitud y anchura. Se realizó una búsqueda bibliográfica sistemática, siguiendo las directrices PRISMA, en bases de datos como MEDLINE, Google Scholar, SciELO y revisiones Cochrane, utilizando términos como «*Extensor hallucis capsularis*» y «prevalencia, origen, inserción, longitud o anchura», lo que arrojó 315 enlaces a artículos. De los nueve artículos que cumplieron con los criterios de inclusión, solo seis estudios cadavéricos que comprendían 260 tendones EHC de 338 miembros inferiores tenían los datos morfométricos. Los especímenes incluidos en estos seis estudios están en un rango de edad de 21-82.2 años. Los datos agrupados (Media ± DE) del EHC mostraron: longitud total 8.30 ± 3.01 cm y ancho 2.26 ± 1.19 mm, respectivamente. Nuestro análisis agrupado reveló que el EHC se originó más comúnmente del tendón ELH (97.6 %) seguido del tendón del músculo tibial anterior (2.3 %) y se insertó principalmente en la primera cápsula articular metatarsofalángica (75.3 %), seguida de la base de la falange proximal (23.4 %) y la cabeza del hueso metatarsiano (1.3 %). Nuestros datos generaron valores más representativos sobre la morfología del EHC a partir de la literatura disponible, y esta información sería de gran utilidad para que los cirujanos comparen su idoneidad quirúrgica al utilizarlo como injerto tendinoso en diversas cirugías.

PALABRAS CLAVE: *Extensor hallucis capsularis*; Morfometría; Injerto; Quirúrgico; Idoneidad.

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