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REVIEW ARTICLE

The prevalence of the extensor digiti minimi tendon of the hand and its variants in humans: a systematic review and meta-analysis

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Abstract The extensor digiti minimi (EDM) is frequently used in the case of an abduction deformity of the little finger. It is also considered as a main resource for tendon transfer. However, it shows many variations in the human hand, which include splitting into two or more slips and sending a slip to the fourth finger, named the extensor digiti minimi et quarti (EDMQ). The aim of this systematic review is to perform an evidence synthesis on the prevalence of the EDM and its variants. Twenty-six cadaveric studies met the inclusion criteria with a total of 2247 hands. Meta-analysis results yielded an overall pooled prevalence estimate (PPE) of the EDM of 99.7 % and PPEs of 11.5, 77.6, 7 and 0.6 % for the single-, double-, triple- and quadruple-slip EDM, respectively. For the single-slip EDM, the frequencies were such that Indians > Middle Eastern > Europeans > Japanese > North Americans. For the double-slip EDM, the frequencies were such that Japanese > North Americans = Europeans > Middle Eastern > Indians. No significance was found with regard to hand side. The true EDMQ prevalence was found to be at 7.3 %, whereas its crude prevalence was 8 %. This artilce offers reference values on the prevalence of the EDM and its variants, which are thought to be highly relevant to both anatomists and clinicians.

Keywords Extensor digiti minimi · Anatomy · Evidence-based medicine · Meta-analysis

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Introduction

Frequent variations occur within the extensor compartment of the forearm (Wood 1946). The extensor digiti minimi (EDM) is one that expresses such variation mainly beyond the extensor retinaculum. The apparatus extensor of the little finger usually consists of two muscles (Netter 2011): the EDM, which is quite consistent, and the less prevalent part of the extensor digitorum communis (EDC) destined to the fifth finger (EDC-V). In this article, we looked for evidence concerning the prevalence of the EDM tendon and its variants.

Anatomy of the EDM

Embryologically, the EDM, as all other extensor and supinator musculatures, rises from the mesoderm of the posterior condensation while migrating to the upper limb (Dudek and Fix 2005). The EDM is a slender muscle having a common origin with the EDC muscle; it is attached on the anterior aspect of the lateral epicondyle of the humerus, ulnar to the EDC from which it arises as a thin tendinous slip (Netter 2011). The EDM may end in a single tendon or split into two or more slips that insert into the dorsal aponeurosis of the metacarpophalangeal joint (MCPJ) of the little finger (Hollinghead 1969). Levels of tendon bifurcation can be supraretinacular, subretinacular or more frequently infraretinacular (Yoo et al. 2012). In the case of a triple- or quadruple-slip EDM, a radial slip may insert on the dorsal aponeurosis of the ring finger (Le Double 1897; Gruber 1882; 1885), sometimes called the extensor digiti minimi et quarti (EDMQ). While an EDM inserting only on the little finger is the most common variant in Hylobates, Gorilla and Pan Species, the EDMQ muscle is mostly found in various nonprimate mammals as

well in primates such as the Macaca, Papio and Pongo (Diogo and Wood 2011).

Hirai et al. (2001) reported that the EDM tended to have a smaller size in specimens where the EDC-V was present and to be more substantial, often with two slips in the absence of the EDC-V. They concluded that the growth conditions of the EDM are related to the presence or absence of the EDC-V.

However, Tanaka et al. (2007) documented an accessory retinacular band surrounding the EDM tendon at the base of the 5th metacarpal in 73 % and a septum between the EDM slips in 88 % of 30 hand specimens.

Clinical relevance

The distal bifurcation of the EDM tendon may lead to tendon impingement on the septum and could be a potential etiology of chronic tenosynovitis of the fifth compartment and of acute closed tendon injuries (Yoo et al. 2012).

As the EDM has the potential to abduct the little finger through its indirect attachment onto the abductor tubercle of the proximal phalanx (Blacker et al. 1976), its tendon is frequently used for transfer (Dickson and Manushakian 2011) and/or rerouting (Bellan et al. 1998) to correct abduction deformity of the little finger (Wartenberg's sign). Such a deformity could be caused by an ulnar nerve palsy or a traumatic avulsion of the third palmar interosseous muscle (Freeland et al. 1985), a contracture of the hypothenar muscles, or an injury of the radial collateral ligament associated with either a tear of the 4th/5th juncturae tendinum (Kilgus et al. 2003) or a lax palmar plate (Lourie et al. 1999). Rheumatoid arthritis is also known to cause abduction deformity of the little finger.

Surgeons should be aware of the EDM/EDC-V arrangement when tendon transfer procedures are required. The transfer of both slips of the EDM in the absence of the EDC-V may lead to the complete loss of little finger extension (Hirai et al. 2001).

The aim of this systematic review is to provide an evidence synthesis on the prevalence of the EDM muscle and its variants at the dorsal aspect of the hand region, exclusively limited to their distribution and arrangement distal to the extensor retinaculum because of their functional and surgical relevance.

Methods

The checklist for anatomical reviews and meta-analysis (CARMA) guidelines was followed while conducting this systematic review and meta-analysis (Yammine 2014).

Search strategy and identification of studies

A systematic literature search was conducted through a number of electronic databases such as Medline, Embase, Scielo and Google Scholar from inception to February 2014, using Boolean combinations of broad terms such as (extensor* OR "extensor digiti minimi" OR "extensor digiti quinti") AND (variation* OR variant* OR splitting OR slip*) AND (hand OR "fifth finger" OR "little finger") to locate the maximum number of relevant articles. We also searched the websites of the following journals: Acta Anatomica, Anatomical Science International, Annals of Anatomy, Clinical Anatomy, European Journal of Morphology, Folia Morphologica, International Journal of Anatomical variations, International Journal of Morphology, Journal of Anatomy, Journal of Hand Surgery [Br and Am], Journal Bone and Joint Surgery [Br and Am], Journal of Morphology, Okajimas Folia Anatomica (Japan), Romanian Journal of Morphology and Embryology, Surgical and Radiological Anatomy, and The Anatomical Record (A and B). All included articles were citation-tracked using Google Scholar to ensure that all relevant articles were identified. Duplicates were deleted.

Criteria for study selection

Literature concerning the prevalence of the variants of the EDM is infrequent, so all published or unpublished studies reporting prevalence rates were included in the review. The primary outcomes were the true and/or the crude prevalence of the EDM or its variants in cadaveric or clinical studies. The true EDM prevalence rate was defined as the number of hands affected compared to the number of hands available for study. The crude EDM prevalence was the number of individuals who had either one or two EDMs compared to the number of individuals available for study.

Secondary outcomes were the prevalence in relation to ancestry, gender, laterality and side, the interactions between those variables, and the variant types of the EDM. To ensure unbiased selection of included studies, abstracts from conferences were not included.

No restriction was imposed on date, language or age. Titles and abstracts were initially screened and full-text articles were obtained when at least one primary outcome was thought to be reported.

Data extraction and analysis

Data extracted included sample size, sample details, type of investigation (clinical or cadaveric) and the results. Analysis was performed using Stats Direct v2.7.8 (Altrincham, UK). Proportion meta-analysis (MA) and odds ratio (OR) MA was used to calculate the pooled

Table 1 Characteristics of the included studies

Studies	Population	Age (years)	Sample size: cadavers	Male	Female	Sample size: hands	Right	Left
Abdel-Hamid et al. (2013)	Egyptian	Adults	–	–	–	95	44	51
Agarwal and Tirthani (2011)	Indian	Adults	60	–	–	120	60	60
Celik et al. (2008)	Turkish	38-87	24 + 6 upper limbs	30	0	54	30	24
Dass et al. (2011)	South Indian	Adults	–	–	–	100	47	53
el-Badawi (1985)	Egyptian	Adults	–	–	–	30	–	–
el-Badawi et al. (1995)	Saudi	Adults	–	–	–	181	–	–
Godwin and Ellis (1992)	British	Adults	25	–	–	50	25	25
Gonzalez et al. (1995)	American	Adults	–	–	–	50	–	–
Govsa et al. (2011)	Turkish	38-87	19	19	0	38	19	19
Gruber (1882)	German	Adults	600	450	150	1200	600	600
Gruber (1885)	German	Adults	300	–	–	600	300	300
Hirai et al. (2001)	Japanese	Adults	–	–	–	548	276	272
Jeon et al. (2010)	Korean	Mean = 79	50 upper limbs	18	32	50	–	–
Le Double (1897)	French	Adults	82	40	32	164	82	82
Macalister Macalister (1875)	Irish	Adults	14	–	–	–	–	–
Mestdagh et al. (1985)	French	Adults	–	–	–	150	–	–
Mori (1964)	Japanese	Adults	–	–	–	205	–	–
Perkins and Hast (1993)	American	Adults	40	20	20	80	40	40
Schenck (1964)	American	Adults	–	–	–	57	–	–
Tanaka et al. (2007)	American	Adults	–	–	–	41	–	–
VanAaken et al. (2011)	Swiss	Adults	–	–	–	16	10	6
von Schroeder and Botte (1995)	American	Adults	–	–	–	43	22	21
Wehbe (1992)	American	Adults	120	–	–	240	–	–
Wood (1868)	British	Adults	102	68	34	204	102	102
Yoo et al. (2012)	Korean	Mean = 73	49	31	18	49	24	25
Zilber and Oberlin (2004)	French	Mean = 79	–	–	–	50	–	–

prevalence estimate (PPE). The two independent proportion test was used to look for significant proportion differences between studies reporting EDM frequencies in different ancestry populations. Descriptive analysis was conducted when the data were not amenable to meta-analysis. We examined heterogeneity among studies using I^2 statistics; whenever $I^2 > 50\ \%$, the random effect estimate was reported. When possible, sensitivity analysis was conducted by limiting inclusion to studies with sample size $\geq$100.

Table 2 The prevalence of the EDM

Studies	Sample size (hands)	Nb EDM (prevalence)						
		Total	Absence	Single	Double	Triple	Quad.	Slip to 4th
Abdel-Hamid et al. (2013)	95	95 (100 %)	0	8 (8.4 %)	72 (75.8 %)	15 (15.8 %)	0	4 (4.2 %)
Agarwal and Tirthani (2011)	120	119 (99.2 %)	1 (0.83 %)	91 (75.8 %)	28 (23.3 %)	0	0	0
Celik et al. (2008)	54	54 (100 %)	0	1 (1.8 %)	48 (88.9 %)	5 (9.3 %)	0	5 (9.2 %) from radial slip of the triple
Dass et al. (2011)	100	100 (100 %)	0	20 (20 %)	78 (78 %)	2 (2 %)	0	0
el-Badawi et al. (1985)	30	30 (100 %)	0	2 (6.7 %)	22 (73.3 %)	5 (16.6 %)	1 (3.4 %)	–
el-Badawi et al. (1995)	181	181 (100 %)	0	64 (35.3 %)	113 (62.4 %)	4 (2 %)	0	68
Godwin and Ellis (1992)	50	50 (100 %)	0	0	41 (82 %)	4 (8 %)	5 (10 %)	–
Gonzalez et al. (1995)	50	50 (100 %)	0	5 (10 %)	42 (84 %)	3 (6 %)	0	0
Gövsa et al. (2011)	38	38 (100 %)	0	0	33	5	0	5 (13.1 %) from radial slip of the triple
Gruber (1882)	600	–	–	–	–	–	–	57 (9.5 %)
Gruber (1885)	300	–	–	–	–	–	–	29 (9.6 %)
Hirai et al. (2001)	548	548 (100 %)	0	52 (10 %)	479 (87 %)	17 (3 %)	0	–
Jeon et al. (2010)	50	50 (100 %)	0	7 (14 %)	37 (74 %)	5 (10 %)	1 (2 %)	–
Le Double (1897)	144 cad	–	–	–	–	–	–	12 (8.3 %)
Macalister (1871)	14 cad	–	–	–	–	–	–	1
Mestdagh et al. (1985)	150	150 (100 %)	0	24 (16 %)	115 (77 %)	11 (7 %)	0	–
Mori (1964)	205	205 (100 %)	0	12 (6 %)	168 (82 %)	25 (12 %)	0	4 (2 %)
Perkins and Hast (1993)	80	80 (100 %)	0	3 (3.75 %)	70 (87.5 %)	7 (10 %)	0	–
Schenck (1964)	57	57 (100 %)	0	4	48	4	1	–
Tanaka et al. (2007)	41	39 (95.2 %)	2 (4.8 %)	1 (2.4 %)	29 (71 %)	9 (23 %)	0	5 (12.2 %)
VanAaken et al. (2011)	16	16 (100 %)	0	0	15 (93.7 %)	1 (6.35 %)	0	0
von Schroeder and Botte (1995)	43	43 (100 %)	0	1 (2 %)	36 (84 %)	3 (7 %)	3 (7 %)	1 (2 %)
Wehbe (1992)	240	240	0	19 (8 %)	209 (87 %)	12 (5 %)	0	–
Wood (1868)	106 cad	–	–	–	–	–	–	13 (12.2 %)
Yoo et al. (2012)	49	49	0	13 (26.5 %)	36 (73.5 %)	0	0	–
Zilber and Oberlin (2004)	50	50 (100 %)	0	14 (28 %)	35 (70 %)	1 (2 %)	0	1 (2 %)

Results

Search results

The search strategy yielded a total of 489 articles. Twenty-six duplicates were removed, and the initial screening of the remaining 462 articles yielded 77 as potentially relevant; of those, 6 reviews and 52 case reports were excluded. References cited in the remaining 18 studies yielded another 8 relevant studies. In total, we located 26 cadaveric studies reporting the prevalence of at least one of the primary outcomes (Wood 1868; Macalister Macalister 1875; Gruber 1882, 1885; Le Double 1897; Mori 1964; Schenck 1964; El-Badawi et al. 1985; Mestdagh et al. 1985; Godwin and Ellis 1992; Wehbe 1992; Perkins and Hast 1993; El-Badawi et al. 1995; Gonzalez et al. 1995;

von Schroeder and Botte 1995; Hirai et al. 2001; Zilber and Oberlin 2004; Tanaka et al. 2007; Celik et al. 2008; Jeon et al. 2010; Agarwal and Tirthani 2011; Dass et al. 2011; Gövsa et al. 2011; VanAaken et al. 2011; Yoo et al. 2012; Abdel-Hamid et al. 2013). We could not locate any clinical study reporting EDM prevalence. The characteristics of the included studies are described in Table 1.

Overall prevalence of the EDM

Twenty-one studies reported the overall EDM prevalence (Mori 1964; Schenck 1964; el-Badawi 1985; Mestdagh et al. 1985; Godwin and Ellis 1992; Wehbe 1992; Perkins and Hast 1993; el-Badawi et al. 1995; Gonzalez et al. 1995; von Schroeder and Botte 1995; Hirai et al. 2001; Zilber and Oberlin 2004; Tanaka et al. 2007; Celik et al. 2008; Jeon et al. 2010; Agarwal and Tirthani 2011; Dass et al. 2011; Gövsa et al. 2011; VanAaken et al. 2011; Yoo et al. 2012; Abdel-Hamid et al. 2013): 2247 hands with a PPE of 99.7 % (95 % CI 0.994–0.999, $I^2 = 0$ %). The prevalence of the EDM in the included studies is shown in Table 2.

The prevalence of the EDM slips

Twenty-one reported the slip number of the EDM tendon on the dorsum of the hand (Mori 1964; Schenck 1964; el-Badawi 1985; Mestdagh et al. 1985; Godwin and Ellis 1992; Wehbe 1992; Perkins and Hast 1993; el-Badawi et al. 1995; Gonzalez et al. 1995; von Schroeder and Botte 1995; Hirai et al. 2001; Zilber and Oberlin 2004; Tanaka et al. 2007; Celik et al. 2008; Jeon et al. 2010; Agarwal and Tirthani 2011; Dass et al. 2011; Gövsa et al. 2011; VanAaken et al. 2011; Yoo et al. 2012; Abdel-Hamid et al. 2013) with 2244 EDMs and a PPE of 11.5 % (95 % CI 0.061–0.182, $I^2 = 94.9$ %), 77.6 % (95 % CI 0.709–0.836, $I^2 = 91.9$ %), 7 % (95 % CI 0.047–0.095, $I^2 = 77.9$ %) and 0.6 % (95 % CI 0.002–0.012, $I^2 = 46.8$ %) for the single-, double-, triple- and quadruple-slip EDM, respectively.

A sensitivity analysis of the seven largest studies (Mori 1964; Mestdagh et al. 1985; Wehbe 1992; Hirai et al. 2001; Agarwal and Tirthani 2011; Dass et al. 2011) with 1543 EDMs yielded PPEs of 22 % (95 % CI 0.091–0.385, $I^2 = 98$ %), 72.3 % (95 % CI 0.572–0.852, $I^2 = 97.4$ %) and 4.1 % (95 % CI 0.018–0.071, $I^2 = 85$ %) for the single-, double-, and triple-slip EDM, respectively.

Location-based prevalence of the EDM

Only one study reported such prevalence (VanAaken et al. 2011). Of the 15 double-slip EDMs (30 slips), 12 slips (40 %) were ulnar, 8 (26.7 %) were central, and 10 (33.3 %) were radial regarding the center of the axis of abduction/adduction of the fifth finger. All other studies insinuated or presented figures of specimens showing that the double-slip EDM had one radial and one ulnar slip with no reported frequencies.

Interaction between EDM prevalence and ancestry

For the single-slip EDM, the independent proportion tests yielded the following results: Middle Eastern populations vs. European ($p = 0.0002$), European vs. North American ($p = 0.0008$), European vs. Japanese ($p = 0.0002$) and Japanese vs. North American ($p = 0.03$); all other comparisons had $p < 0.0001$. The frequencies were such that Indian > Middle Eastern > European > Japanese > North American populations.

For the double-slip EDM, the results were as follows: Japanese vs. North American ($p = 0.1$), European vs. Middle Eastern ($p = 0.02$), European vs. North American ($p = 0.55$), North American vs. Middle Eastern populations($p = 0.03$); all other comparisons had $p < 0.001$. The frequencies were such that Japanese > North American = European > Middle Eastern > Indian populations.

For the three-slip EDM, the results were as follows: Middle Eastern vs. North American ($p = 0.3$), European vs. Japanese ($p = 0.5$), Japanese vs. North American ($p = 0.4$), Japanese vs. Middle Eastern ($p = 0.3$), North American vs. Indian ($p = 0.07$), European vs. North American ($p = 0.3$) populations; all other comparisons had $p < 0.001$. The frequencies were such that Middle Eastern = European = Japanese = North American > Indian populations.

Data were not amenable to MA for the quadruple-slip variant. However, such variation in the EDM tendon was found only in European and North American populations.

Interaction between EDM prevalence and side

Five studies reported the EDM frequencies with relation to the side (Zilber and Oberlin 2004; Celik et al. 2008; Agarwal and Tirthani 2011; Dass et al. 2011; Abdel-Hamid et al. 2013) with a total of 418 EDMs (226 right, 244 left); no significant differences were found for the overall EDM prevalence (OR = 0.82; 95 % CI 0.615–1.098, $I^2 = 0$ %, $p = 0.1$), for the single-slip (OR = 0.94, 95 % CI = 0.637–1.416, $I^2 = 0$ %, $p = 0.8$), for the double-slip (OR = 0.82, 95 % CI = 0.608–1.120, $I^2 = 0$ %, $p = 0.2$) and neither for the triple-slip variant (OR = 1.04, 95 % CI = 0.456–2.372, $I^2 = 0$ %, $p = 0.9$).

Interaction with laterality

Only Celik et al. (2008) stated that bilaterality was observed in double-tendon specimens. None of the included studies reported the bilateral occurrence of the EDM.

Interaction with gender

None of the included studies reported EDM prevalence values with regard to the variable gender.

Prevalence of extensor digiti minimi et quarti

Ten studies reported the crude prevalence of the EDMQ (Wood 1868; Macalister 1875; Gruber 1882, 1885; Le Double 1897; Mori 1964; Perkins and Hast 1993; Gonzalez et al. 1995; Zilber and Oberlin 2004; Celik et al. 2008;Agarwal and Tirthani 2011) with a total of 1378 cadavers and a PPE of 7.3 % (95 % CI 0.045–0.104, $I^2 = 68.9$ %). Seven studies reported the true EDMQ prevalence (Mori 1964; Perkins and Hast 1993; el-Badawi et al. 1995; von Schroeder and Botte 1995; Gövsa et al. 2011; Abdel-Hamid et al. 2013) with a total of 692 hands and a PPE of 8 % (95 % CI 0.012–0.199, $I^2 = 95.1$ %).

Discussion

Summary of main findings

Our results showed a high consistency of the EDM with a frequency approaching 100 % in a pooled sample of 2247 hands. The most frequent presentation was the double-slip EDM with more than ¾ of cases, followed by the single-slip and the triple-slip variants. We found an association between the number of EDM slips and ancestry; the single-slip variant was significantly prevalent among Indian and Middle Eastern populations. The double-slip variant was significantly prevalent among Japanese, European and North American populations. The triple-slip variant was the least present among Indian populations. The quadruple-slip variant was present in European and North American populations only. While we found no significant differences with relation to hand side, there was a lack of data regarding the laterality and gender variables. On the other hand, the true prevalence of the EDMQ was found to be 8 %, whereas its crude prevalence was 7.3 %. To our knowledge, this is first anatomical MA exploring the prevalence of the EDM and its variants in humans.

Potential limitations and bias

Despite an extensive search strategy, no confirmation could be provided that this review located all relevant articles. However, the pooled sample sizes of 2247 hands and 1353 cadavers could be fairly considered as representative for drawing prevalence estimates of the EDM and EDMQ, respectively. On the other hand, the unexpected similarity between the true and crude EDMQ frequencies could be related to two possible issues: half of the included studies did not report the presence (or absence) of the EDMQ in their samples, and EDMQ slip to the fourth finger could have been considered as a juncturae tendinum by some authors.

Surprisingly, the majority of the included studies did not report the variation of the EDM insertion on the dorsal aponeurosis. However, based on the reported descriptions and figures, it is probable that most of the double-slip EDM tendons had one slip on each side of the axis of abduction/adduction of the fifth finger.

Another limitation is related to the fact that there were no studies reporting EDM frequency in African populations. However, we were able to compare ancestry-based prevalence values between North American, European, Japanese, Indians and Middle Eastern populations.

Conclusions

Although the prevalence of the EDM was consistent in nearly all cases, the double-slip variant was found to be its most common morphology, particularly among Japanese, European and North American populations. The single-slip variant was found to be present mainly in Indian and Middle Eastern populations. Further studies are needed to evaluate the prevalence of the EDMQ. Our results are intended to be a reference for future research on the variability of the EDM tendon anatomy.

Conflict of interest None.

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