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The prevalence and distribution of the variants of Gantzer's muscle: a meta-analysis of cadaveric studies

Adil Asghar[1], Rakesh Kumar Jha[1], Apurba Patra[2], Binita Chaudhary[1], Brijendra Singh[3]
[1]Department of Anatomy, All India Institute of Medical Sciences Patna, Patna, [2]Department of Anatomy, All India Institute of Medical Sciences Bathinda, Bathinda, [3]Department of Anatomy, All India Institute of Medical Sciences Rishikesh, Rishikesh, India

Abstract: The Gantzer's muscle is often present in the flexor compartment of the forearm. It lies underneath flexor digitorum superficialis and compresses the anterior interosseous nerve. Furthermore, this muscle frequently bestows an accessory muscle of flexor pollicis longus or flexor digitorum profundus, or sometimes together. The current meta-analysis aims to compute the prevalence of subtypes of Gantzer's muscle. Major electronic databases (PubMed, Scopus, Google Scholar, etc.) were searched for title and abstract. After removing the duplicate citations, the titles/abstracts were shortlisted with the help of inclusion and exclusion criteria. The shortlisted titles/abstracts were downloaded or collected from the library. The data of all subtypes of Gantzer's muscle were pooled from shortlisted published manuscripts for meta-analysis. The pooled estimate of other anatomical characteristics was also observed. A total of 59 cadaveric studies of sample size 5,903 were evaluated for pooled prevalence of flexor pollicis longus (accessory head). Similarly, the authors evaluated 14 studies of 1,627 upper limbs for flexor digitorum profundus (accessory head). The unit of analysis was per 100 upper limbs. The Pooled prevalence of accessory muscle of flexor pollicis longus and flexor digitorum profundus were 48% (95% CI, 44%–52%) and 17% (95% CI, 13%–21%), respectively. The Gantzer's muscle is present in 2/3rd of the upper limbs. Accessory head of flexor pollicis longus is almost three times more common than the accessory head of flexor digitorum profundus. A classification of Gantzer's muscle is needed to reduce the ignorance of these variants.

Key words: Forearm, Prevalence, Hand, Skeletal muscle, Cadaver

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Introduction

Gantzer's muscle refers to a group of accessory muscles of the flexor compartment of the forearm. It descends beneath with flexor digitorum superficialis (FDS) up to mid-forearm. It takes origin from at the medial epicondyle of humerus (ME) (common flexor origin) or coronoid process of the ulna or fascial sheath of FDS or pronator teres. It inserts onto the deep flexors, *i.e.*, flexor pollicis longus (FPL) and flexor digitorum profundus (FDP) [1]. This muscle was first reported by Albinus in the 18th century and described by Gantzer [2], a German anatomist, in 1813. Based on initial observations, the authors identified two main variants of Ganzter's muscle, *i.e.*, accessory head of FPL (ahFPL) and accessory head of FDP (ahFDP) [3]. Underneath the FDS, Gantzer's muscle follows an oblique path from the medial to the lateral aspect of the forearm before joining the FPL [4]. Furthermore, the Gantzer's muscle can contribute to the FDP muscle through a second tendon. The presence of ahFPL and ahFDP could

Corresponding author:
Binita Chaudhary
Department of Anatomy, All India Institute of Medical Sciences Patna, Phulwari Sharif, Patna, Bihar 801507, India
E-mail: binitachaudhary18@gmail.com

be explained by the embryological events of the common flexor muscle mass, which splits into two strata: deep and superficial during differentiation [1]. The FPL, FDP, and pronator quadratus muscles are all derived from the deep layer. Gantzer's muscle is the product of an imperfect cleavage of the deep layer [4]. The human gained the FPL during its evolution. The introduction of FPL into the flexor compartment allowed the thumb to move independently in three different planes [5]. A detailed meta-analysis was conducted by Roy et al. (2015) [6] on the ahFPL variant of Gantzer's muscle. The authors did not include ahFDP. There was at least a dozen of the manuscript which dealt with ahFDP. So, the pooled prevalence of Gantzer's muscle in the previous meta-analysis may be considered inaccurate. Finding such deficiency in the previous meta-analysis forced us to conduct the current study to elucidate the pooled estimate of both variants (ahFPL and ahFDP) and unfold the more comprehensive picture. This research aimed to determine the pooled prevalence of these accessory muscles in various populations and their morphometry and relation to the anterior interosseous nerve (AIN). It will be helpful in clinical diagnosis and surgical approaches to the forearm.

Materials and Methods

Search strategy

The authors have conducted a thorough search of the electronic databases PubMed, Google Scholar, Scopus, ScienceDirect, and EMBASE to find papers suitable for inclusion in the meta-analysis. Gantzer's muscle or accessory head of FPL or ahFPL and accessory head of FDP or ahFDP were among the keywords used in the quest. There were no time or language limitations. We thoroughly reviewed relevant studies or publications to identify potentially qualified articles for the meta-analysis.

Inclusion and exclusion criteria

Studies with extractable data on the occurrence of Gantzer's muscle in the upper limbs were deemed suitable for inclusion in the meta-analysis. The meta-analysis excluded publications that were case reports, letters to the editor, or conference abstracts, original articles which had insufficient data. During the eligibility appraisal, any disputes among the reviewers are resolved by consensus among all reviewers. The appraisal of quality of each study was conducted with the help of the Anatomy Quality Assessment tool [7].

Data extraction

The authors have collected information on the prevalence of ahFPL or ahFDP, origin, insertion, nerve supply, laterality, relation with nerves of the forearm, and morphological variation from included studies. In addition, we contacted the manuscript authors for more information via email if necessary information was missing.

Statistical analysis

Statistical analysis was performed by R statistical package 4.2.0 (R Foundation for Statistical Computing, Vienna, Austria). The Higgin's I^2 test was used to determine study heterogeneity. A fixed-effects model was used if heterogeneity (Higgin's I^2 statistics) was less than 50%. A random-effects model was used if the heterogeneity (I^2 statistics) was greater than 50%. To investigate the causes of heterogeneity, subgroup analysis, sensitivity, and cumulative analysis were used when needed. The unit of analysis was per 100 upper limbs examined.

Results

Characteristics of included studies

Fifty-eight studies in the current review have been undertaken to explore the prevalence of Gantzer's muscle (Fig. 1) [3, 4, 8-55]. These studies examined 5,903 upper limbs for ahFPL variant (Table 1). Only 14 studies have been explored for the prevalence of ahFDP, including the data of 1,627 limbs (Table 1) [3, 8-14, 54]. A total of 5,903 limbs were included in the meta-analysis, which has data from 1868 to 2021. The data of Wagenseil (1936) [54] was bifurcated according to the population because they estimated the prevalence of Gantzer's muscle in Mongoloid and European populations. These data were collected from June 2020 to February 2021. The study population was predominantly adult cadavers, except for one study, *i.e.*, Kara et al. (2012) [32]. The majority of manuscripts included in the review had wide geographical distribution, and it included data from all subcontinents except Australia.

Prevalence

The pooled prevalence of Gantzer's muscle (ahFPL and ahFDP) was found to be 65% (95% confidece interval [CI], 57%–73%) in 5,903 upper limbs. Fifty-eight cadaveric studies (n=5,903 upper limbs) reported the pooled prevalence of only ahFPL to be 48% (95% CI, 44%–52%) (Fig. 2). The

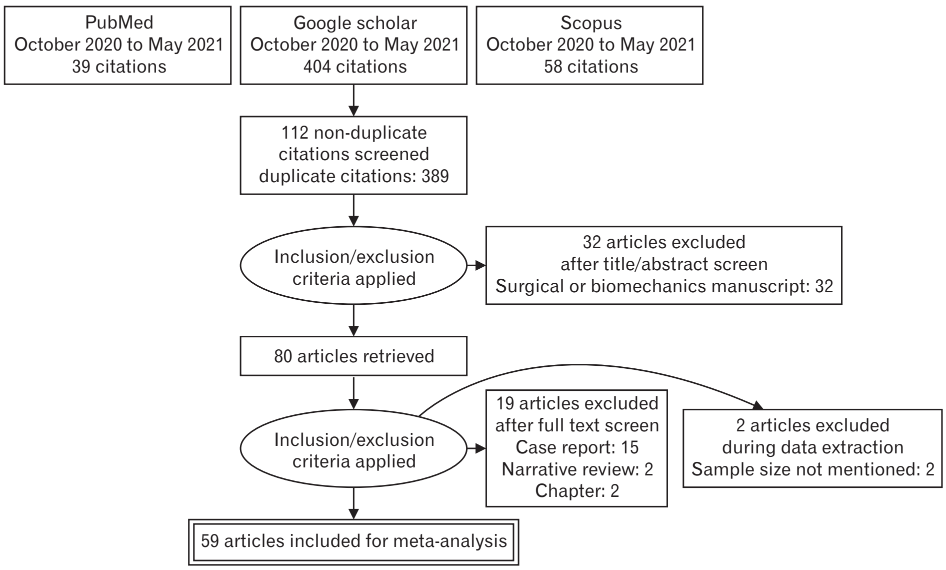

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram of search strategy for Gantzer's muscle.

sensitivity analysis was conducted to capture the fluctuation in the prevalence after excluding each study. The range of variability of prevalence was 1% (47%–48%). The cumulative analysis was executed to examine the maximum variations in the prevalence estimates by adding each study.

The pooled estimate of the only ahFDP in 1,627 limbs from 14 studies was 17% (95% CI, 13%–21%) (Fig. 3). The variability of the pooled estimate was 2% in sensitivity analysis and 8% in cumulative analysis. Thus, the heterogeneity of the estimate was 74.3%.

Ethnic and geographical distribution

African studies have demonstrated the highest prevalence, 73% (95% CI, 53%–87%) of ahFPL in 157 limbs with nil heterogeneity. The Mongoloid population 56%, (95% CI, 47%–65%) in 2,532 limbs and North American population 51%, (95% CI, 40%–61%) in 589 limbs have similar prevalence. South American studies, including 521 limbs, have a prevalence of 44% (95% CI, 29%–60%). The Caucasian population (Asian 41% in 1,447 limbs and European 39 % in 657 limbs) has a lower prevalence of ahFPL than the ethnicities mentioned earlier. No studies were reported from the Australian population. The heterogeneity among studies of other ethnic groups varied from 76% to 94%.

The prevalence of ahFDP was 24% (95% CI, 22%–27%) in Mongoloid population without any heterogeneity of estimate. The same prevalence in African, Caucasian of Asian and European origin were 9% (95% CI, 3%–23%), 17% (95% CI, 11%–26%) and 11% (95% CI, 7%–18%), respectively. The prevalence in North and South American populations were based on only a single study, and they were 3% (95% CI, 0.7%–10%) and 3% (95% CI, 0.41%–18%), respectively. Most of the estimates have wider confidence intervals due to the low sample size.

Laterality and sex distribution

The laterality of ahFPL was examined in 1,275 limbs (Table 2). The occurrence of ahFPL was more frequent in right side (49%) (95% CI, 46%–53%) than left side (45%) (95% CI, 42%–49%) with rate difference of 5% (95% CI, 0.2%–11%, P=0.043). Almost, similar occurrences of ahFDP were in right and left upper limbs, *i.e.*, 9% (95% CI, 5%–14%) and 10% (95% CI, 6%–15%), respectively. The unilateral occurrence of ahFDP was 8%, and bilateral occurrence was slightly higher, *i.e.*, 10%. The data on sex distribution was inadequate. The prevalence of ahFPL was 38% in males and 13% in females in 402 limbs which would be misleading. The distribution of ahFDP in males and females was 12% and 23%, respectively. So, females have a double prevalence rate of ahFDP.

Anatomical distribution

The origin of ahFPL was evaluated in 1,283 limbs (Table 2). The commonest site of its origin was ME in 37% (95% CI, 35%–40%) followed by coronoid process of ulna (CP) in 24% (95% CI, 22%–26%), and muscle sheath of FDS in 15% (95% CI, 13%–17%). The dual origin from ME and CP has been observed in 8% (95% CI, 7%–10%). Antebrachial fascia also

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Table 1. Study characteristics of Gantzer's muscle

Reference	Year	Prevalence (%)	95% confidence interval	ahFPL/ ahFDP	No. and ethnicity of sample	Risk of bias
Adachi [53][a)]	1910	63	54–70	84	134 Asian Mongoloid	Unclear
Afroze et al. [18]	2020	24	14–38	12	50 Asian Caucasian	High
al-Qattan [15]	1996	52	33–70	13	25 Asian Caucasian	Low
Bagoji et al. [16]	2017	29	19–42	17	58 Asian Caucasian	Moderate
Bajpe et al. [17]	2015	24	14–38	12	50 Asian Caucasian	High
Ballesteros et al. [19]	2019	32	24–42	34	106 South American	Low
Bando [53][a)]	1956	64	59–69	217	340 Asian Mongoloid	Unclear
Bangarayya et al. [20]	2018	40	24–58	12	30 Asian Caucasian	Moderate
Bilecenoglu et al. [21]	2005	20	9–38	6	30 Asian Caucasian	Low
Burute and Vatsalaswamy [22]	2017	36	29–44	56	156 Asian Caucasian	High
Caetano et al. [23]	2015	68	57–77	54	80 South American	Low
Chakravarthi et al. [24]	2014	72	59–83	39	54 Asian Caucasian	Moderate
Dubois de Monto-Marin et al. [55]	2021	11	4–26	4	36 European Caucasian	Moderate
Dellon and Mackinnon [25]	1987	33	20–48	14	43 North American	Low
Desai et al. [26]	2017	58	46–70	35	60 Asian Caucasian	High
Dolderer et al. [27]	2011	26	11–50	5	19 European Caucasian	Low
Dykes and Anson [28]	1944	53	45–61	80	150 North American	Moderate
El Domiaty et al. [8]	2008	62	47–75	26	42 African	Low
Gunnal et al. [29]	2013	51	44–58	92	180 Asian Caucasian	Moderate
Hemmady et al. [30]	1993	67	53–78	36	54 Asian Caucasian	Low
Herrold et al. [31]	2020	55	49–60	148	271 South American	High
Inoue [53][a)]	1934	71	61–79	71	100 Asian Mongoloid	Unclear
Jones et al. [3]	1997	45	34–56	36	80 European Caucasian	Low
Kara et al. [32] (adult)	2012	38	26–52	20	52 Asian Caucasian	Low
Kara et al. [32] (fetal)	2012	32	23–43	29	90 Asian Caucasian	Low
Khade et al. [33]	2020	53	36–70	16	30 Asian Caucasian	Moderate
Kida [34]	1988	62	54–70	82	132 Asian Mongoloid	Low
Kudo and Obata [53][a)]	1957	55	48–61	118	216 Asian Mongoloid	Low
Kumari et al. [35]	2017	42	29–56	20	48 Asian Caucasian	Moderate
Le Double and Berry [36]	1897	33	28–39	100	300 European Caucasian	Moderate
Loth [53][a)]	1912	89	78–95	50	56 African	Low
Mahakkanukrauh et al. [37]	2004	62	56–68	149	240 Asian Mongoloid	Moderate
Malhotra et al. [38]	1982	54	48–60	130	240 North American	Moderate
Mangini [10]	1960	74	63–82	56	76 North American	Low
Matsunaga et al. [39]	2000	35	27–43	50	144 Asian Mongoloid	Low
Mohammed [9]	2018	64	52–76	38	59 African	Low
Mori [41]	1964	50	43–57	103	205 Asian Mongoloid	Low
Mustafa et al. [40]	2016	45	25–66	9	20 Asian Caucasian	Moderate
Oh et al. [51]	2000	67	55–77	48	72 Asian Mongoloid	Moderate
Oliveira et al. [11]	2021	50	34–66	17	34 South American	Low
Pai et al. [12]	2008	46	38–55	58	126 Asian Caucasian	Low
Philip and Dakshayani [13]	2018	22	13–36	11	50 Asian Caucasian	Moderate
Ravi Prasanna et al. [42]	2019	36	24–50	18	50 Asian Caucasian	High
Riveros et al. [43]	2015	10	3–27	3	30 South American	Moderate
Sano [53][a)]	1931	70	38–90	7	10 Asian Mongoloid	Unclear
Sato [44]	1969	25	22–29	151	604 Asian Mongoloid	Moderate
Sekizawa [53][a)]	1960	54	43–64	45	84 Asian Mongoloid	Unclear
Sharma et al. [45]	2008	40	28–53	24	60 Asian Caucasian	Moderate
Shayo et al. [46]	2015	42	30–54	26	62 Asian Caucasian	Low
Shirali et al. [47]	1998	55	42–67	33	60 North American	Moderate
Tamang et al. [48]	2013	25	16–37	15	60 Asian Caucasian	High
Tomizawa [53]	1986	54	35–73	13	24 Asian Mongoloid	Moderate
Tubbs et al. [49]	2006	20	8–43	4	20 North American	Low
Uyaroglu et al. [50]	2006	52	39–65	27	52 Asian Caucasian	Moderate
Wagenseil [54]	1936	73	65–79	103	142 Asian Mongoloid	Moderate
Wagenseil [54]	1936	55	47–62	82	150 European Caucasian	Moderate

Table 1. Continued

Reference	Year	Prevalence (%)	95% confidence interval	ahFPL/ ahFDP	No. and ethnicity of sample	Risk of bias
Wood [14]	1868	61	49–72	44	72 European Caucasian	Low
Yang et al. [4]	2017	48	37–59	35	73 Asian Mongoloid	Moderate
Yu et al. [52]	2018	58	31–82	7	12 Asian Mongoloid	Moderate
Pooled weighted prevalence		48	44–52	2,844	5,903 random effect model	
Bando [53][a]	1956	25	21–30	86[b]	340 Asian Mongoloid	Moderate
El Domiaty et al. [8]	2008	14	7–28	6[b]	42 African	Unclear
Inoue [53][a]	1934	29	21–39	29[b]	100 Asian Mongoloid	Unclear
Jones et al. [3]	1997	18	11–27	14[b]	80 European Caucasian	Low
Kudo and Obata [53][a]	1957	20	16–26	44[b]	216 Asian Mongoloid	Low
Mohammed [9]	2018	5	2–15	3[b]	59 African	Low
Mangini [10]	1960	3	1–10	2[b]	76 North American	Low
Oliveira et al. [11]	2021	3	0–18	1[b]	34 South American	low
Pai et al. [12]	2008	14	9–22	18[b]	126 Asian Caucasians	Low
Philip and Dakshayani [13]	2018	22	13–36	11[b]	50 Asian Caucasians	Moderate
Sano [53][a]	1930	23	14–36	13[b]	56 Asian Mongoloid	Unclear
Sekizawa [53][a]	1960	21	14–31	18[b]	84 Asian Mongoloid	Unclear
Wagenseil [54]	1936	26	20–34	37[b]	142 Asian Mongoloid	Moderate
Wagenseil [54]	1936	10	6–16	15[b]	150 European Caucasian	Moderate
Wood [14]	1868	7	3–16	5[b]	72 European Caucasian	Low
Pooled weighted prevalence		17	13–21	302[b]	1,627 random effect model	

ahFPL, accessory head of flexor pollicis longus; ahFDP, accessory head of flexor digitorum profundus. [a]Secondary reference was used because the data collected from secondary reference due to inaccessibility of original manuscript. [b]ahFDP.

gave origin to ahFPL in 4% (95% CI, 3%–5%). The fascial sheath of FDS was the predominant site of origin for ahFDP, which was 74% (95% CI, 65%–82%). The origin ahFDP from ME, CP, and pronator teres were 15% (95% CI, 9%–23%), 6% (95% CI, 3%–13%) and 4% (95% CI, 2%–10%), respectively in 214 samples.

Gantzer's muscle was inserted either in the muscle belly or tendon of FPL and FDP. The insertion of ahFPL was examined in 345 limbs (Table 3). The ahFPL was inserted in the muscle belly of FPL in 1/2nd to 2/3rd of the sample, and remaining samples were inserted on the tendinous part of FPL. The extent of ahFPL in the upper 1/3rd of the forearm was observed in 71% of the sample, followed by 23% in the middle 1/3rd and the remaining 6% extended up to the lower 1/3rd of the forearm. The insertion of ahFDP was predominantly on the tendon of the index finger, *i.e.*, 47% (95% CI, 37%–57%), followed by the tendon of middle finger, *i.e.*, 20% (95% CI, 13%–29%) (Table 3).

The innervation of ahFPL was examined in 1,237 limbs (Table 2). AIN was the predominant supply of ahFPL in 2/3rd of samples (95% CI, 64.1%–69.3%). The median nerve supplied ahFPL in 1/3rd samples (95% CI, 30.6%–35.9%). Ulnar nerve innervated it in 0.1% samples (95% CI, 0%–4%). The innervation of ahFDP was AIN in 55.6% and medial nerve (MN) in 44.4% (Table 1).

Morphological distribution

The morphology of ahFPL was examined in a sample of 655 limbs (Table 2). The fusiform shape was the predominant shape of muscle which was observed in almost 3/4th of samples. The length of ahFPL varied from 6.9 to 12 cm, and width varied from 0.3 to 0.7 cm. The adequate data was unavailable to estimate the morphological distribution of ahFDP. However, the Fusiform shape was predominant in ahFDP.

Risk of bias

Most of the studies did not provide adequate information about sex distribution. The studies may have a high risk of bias (ROB) because the authors did not report adequate anatomical and morphological details [16, 17, 20, 25, 30, 41, 47]. The studies with a higher ROB reported less prevalence of ahFPL, *i.e.*, 37% (95% CI, 27%–48%) than moderate and low ROB studies, *i.e.*, 47% and 52%. The prevalence of ahFDP was similar in both moderate and low risk. None of the studies was categorized into a high ROB for ahFDP.

Publication bias

The funnel plot of the current meta-analysis was symmetrical. Egger's linear regression test for publication bias was conducted, refuting the possibility of publication bias

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	ES	95% CI	W	N
El Domiaty et al 2008 [8]	0.62	0.47, 0.75	34.23%	42
Loth 1912 [53][a]	0.89	0.78, 0.95	29.90%	56
Mohammed 2018 [9]	0.64	0.52, 0.76	35.87%	59
African	0.73	0.53, 0.87	100.00%	157
Afroze et al 2020 [18]	0.24	0.14, 0.38	4.08%	50
al-Qattan 1996 [15]	0.52	0.33, 0.70	3.54%	25
Bagoji et al 2017 [16]	0.29	0.19, 0.42	4.43%	58
Bajpe et al 2015 [17]	0.24	0.14, 0.38	4.08%	50
Bangarayya et al 2018 [20]	0.40	0.24, 0.58	3.75%	30
Bilecenoglu 2005 [21]	0.20	0.09, 0.38	3.15%	30
Burute & Vatsalaswamy 2017 [22]	0.36	0.29, 0.44	5.40%	156
Chakravarthi et al 2014 [24]	0.72	0.59, 0.83	4.30%	54
Desai et al 2017 [26]	0.58	0.46, 0.70	4.65%	60
Gunnal et al 2013 [29]	0.51	0.44, 0.58	5.52%	180
Hemmady et al 1993 [30]	0.67	0.53, 0.78	4.43%	54
Kara et al (adult) 2012 [32]	0.38	0.26, 0.52	4.46%	52
Kara et al (fetal) 2012 [32]	0.32	0.23, 0.43	4.95%	90
Khade et al 2020 [33]	0.53	0.36, 0.70	3.80%	30
Kumari et al 2017 [35]	0.42	0.29, 0.56	4.39%	48
Mustafa et al 2016 [40]	0.45	0.25, 0.66	3.20%	20
Pai et al 2008 [12]	0.46	0.38, 0.55	5.31%	126
Philip & Dakshayani 2018 [13]	0.22	0.13, 0.36	4.00%	50
Ravi Prasannna et al 2019 [42]	0.36	0.24, 0.50	4.38%	50
Sharma et al 2008 [45]	0.40	0.28, 0.53	4.64%	60
Shayo et al 2015 [46]	0.42	0.30, 0.54	4.69%	62
Tamang et al 2013 [48]	0.25	0.16, 0.37	4.35%	60
Uyaroglu et al 2006 [50]	0.52	0.39, 0.65	4.52%	52
Asian Caucasean	0.41	0.36, 0.47	100.00%	1,447
Dolderer et al 2011 [27]	0.26	0.11, 0.50	11.96%	19
Jones et al 1997 [3]	0.45	0.34, 0.56	18.43%	80
Le Double & Berry 1897 [36]	0.33	0.28, 0.39	20.18%	300
Wagenseil 1936 [54]	0.55	0.47, 0.62	19.56%	150
Wood 1868 [14]	0.61	0.49, 0.72	18.08%	72
Dubois de Monto-Marin et al 2021 [55]	0.11	0.04, 0.26	11.78%	36
European Caucasean	0.39	0.28, 0.53	100.00%	657
Adachi 1910 [53][a]	0.63	0.54, 0.70	6.69%	134
Bando 1956 [53][a]	0.64	0.59, 0.69	6.95%	340
Inoue 1934 [53][a]	0.71	0.61, 0.79	6.48%	100
Kida 1988 [34]	0.62	0.54, 0.70	6.68%	132
Kudo & Obata 1957 [53][a]	0.55	0.48, 0.61	6.87%	216
Mahakkanukrauh et al 2004 [37]	0.62	0.56, 0.68	6.88%	240
Matsunaga et al 2000 [39]	0.35	0.27, 0.43	6.71%	144
Mori 1964 [41]	0.50	0.43, 0.57	6.85%	205
Oh et al 2000 [51]	0.67	0.55, 0.77	6.31%	72
Sano 1931 [53][a]	0.70	0.38, 0.90	3.59%	10
Sato 1969 [44]	0.25	0.22, 0.29	7.00%	604
Sekizawa 1960 [53][a]	0.54	0.43, 0.64	6.49%	84
Tomizawa 1986 [53]	0.54	0.35, 0.73	5.29%	24
Wagenseil 1936 [54]	0.73	0.65, 0.79	6.64%	142
Yang et al 2017 [4]	0.48	0.37, 0.59	6.40%	73
Yu et al 2018 [52]	0.58	0.31, 0.82	4.17%	12
Asian Mongoloid	0.56	0.47, 0.65	100.00%	2,532
Dellon & Mackinnon 1987 [25]	0.33	0.20, 0.48	15.16%	43
Dykes & Anson 1944 [28]	0.53	0.45, 0.61	20.15%	150
Malhotra et al 1982 [38]	0.54	0.48, 0.60	21.03%	240
Mangini 1960 [10]	0.74	0.63, 0.82	17.21%	76
Shirali et al 1998 [47]	0.55	0.42, 0.67	17.24%	60
Tubbs et al 2006 [49]	0.20	0.08, 0.43	9.21%	20
North American	0.51	0.40, 0.61	100.00%	589
Ballesteros et al 2019 [19]	0.32	0.24, 0.42	22.17%	106
Caetano et al 2015 [23]	0.68	0.57, 0.77	21.58%	80
Herrold et al 2020 [31]	0.55	0.49, 0.60	23.50%	271
Oliveira et al 2021 [11]	0.50	0.34, 0.66	19.31%	34
Riveros et al 2015 [43]	0.10	0.03, 0.27	13.43%	30
South American	0.44	0.29, 0.60	100.00%	521

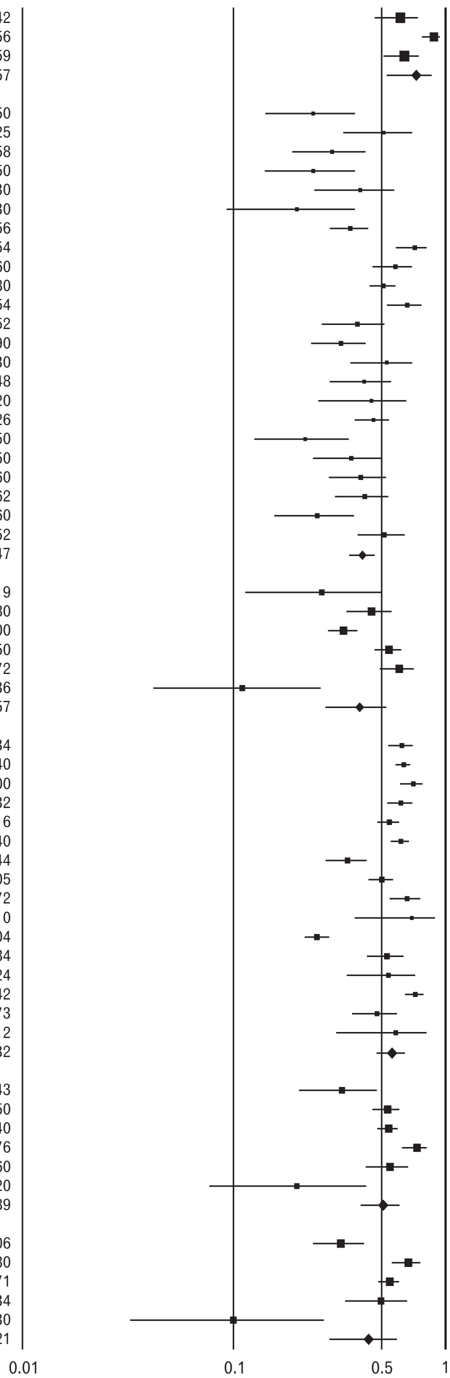

Fig. 2. Pooled weighted prevalence of accessory head of flexor pollicis longus variant. ES, effect size (log-odds ratio); CI, confidence interval; W, weight of study (inverse variance); N, sample size. [a]Secondary reference was used because the data collected from secondary reference due to inaccessibility of original manuscript.

(*P*-value=0.858). Trim and fill analysis was undertaken to estimate pooled prevalence. The observed pooled prevalence was similar to the estimated pooled prevalence.

Discussion

Summary of findings

In the current meta-analysis, the prevalence of Gantzer's muscle was 65% in 5,903 upper limbs, which is inconsistent with the results of the prior meta-analysis. The pooled prevalences of ahFPL and ahFDP variants were 48% and 17%, re-

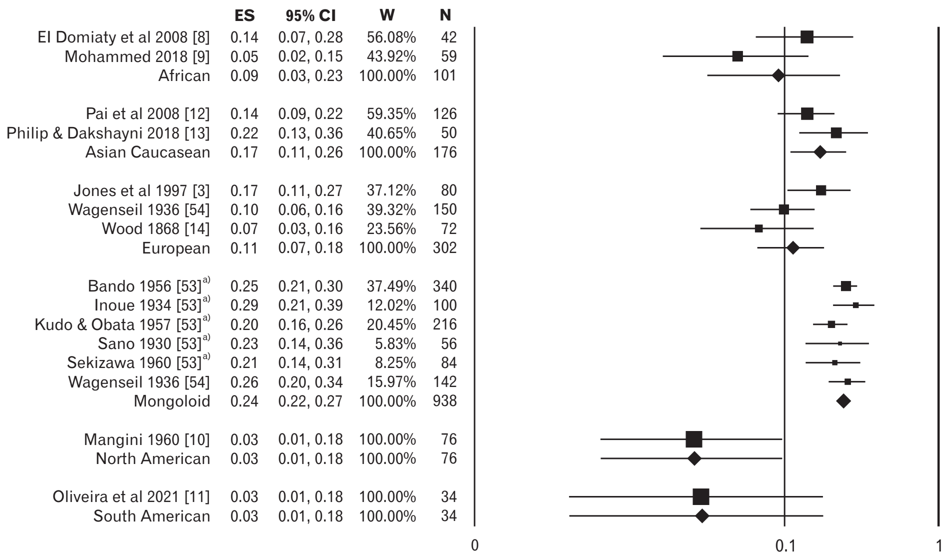

Fig. 3. Pooled weighted prevalence of accessory head of flexor digitorum profundus variant. ES, effect size (log-odds ratio); CI, confidence interval; W, weight of study (inverse variance); N, sample size. [a]Secondary reference was used because the data collected from secondary reference due to inaccessibility of original manuscript.

Table 2. Characteristics of variants of Gantzer's muscle: laterality, sex, anatomical and morphological distribution

Characteristic	ahFPL		ahFDP	
	P (%)	95% CI (%)	P (%)	95% CI (%)
Laterality				
Right	49	46–53	9	5–14
Left	45	42–49	10	6–15
Unilateral	47	43–51	8	4–16
Bilateral	53	49–57	10	6–16
Sex				
Male	38	32–44	12	7–18
Female	13	8–18	23	14–36
Origin				
Flexor digitorum superficialis	15	13–17	74	65–82
CP	24	22–26	6	3–13
ME	37	35–40	15	9–23
Antebrachial fascia	4	3–5	NA	NA
Dual origin (CP & ME)	8	7–10	NA	NA
Pronator teres	NA	NA	4	2–10
Innervation				
Anterior interosseous nerve	66.7	64.1–69.3	55.6	46–65
Median nerve	33.2	30.6–35.9	44.4	36–55
Ulnar nerve	0.1	0.1–0.2	NA	NA
Morphology				
Fusiform	72	69–75	NA	NA
Voluminous	2	1–4	NA	NA
Slender	10	8–13	NA	NA
Voluminous & fusiform	1	0–1	NA	NA
Triangular	5	3–6	NA	NA
Strap-like	4	3–6	NA	NA
Papillary like	6	4–8	NA	NA

ahFPL, accessory head of flexor pollicis longus; ahFDP, accessory head of flexor digitorum profundus; P, prevalence; CI, confidence interval; CP, coronoid process of ulna; ME, medial epicondyle of humerus; NA, not applicable.

spectively. The pooled prevalence that varied in the cumulative analysis was 4% (48% to 52%). The overall heterogeneity was 89%, which was much lower than earlier meta-analysis. The African, Mongoloid, and North American ethnicities had a higher prevalence than other ethnic groups for ahFPL. It was more frequent on the right side. ME was the commonest site of origin for ahFPL, and the muscle belly of FPL was the most common site of its insertion.

Similarly, the fascial sheath of FDS was the commonest site of origin, and FDP tendon for the index finger was the commonest insertion site for ahFDP. AIN predominantly innervated both variants. The fusiform shape was most frequent in both variants.

The ahFPL is a wide variation in modern humans, and it has clinical significance, especially in AIN and median nerve compression. For example, the Gantzer's muscle, or ahFPL, which acts as an additional head of the FPL, would enhance thumb flexion, indicating a functional difference from other primates [12]. Similarly, authors speculate that ahFDP might be improving pinching action or flexion of other fingers.

Agreement or disagreement with other studies

The prevalence of Gantzer's muscle has been shown to be 44.2%, with a 95% confidence interval of 34.7% to 54% in a previous meta-analysis conducted by Roy et al. (2015) [6]. The authors have computed only the prevalence of the ahFPL variant in 2,358 upper limbs. We considered both variants for pooled estimation. The prevalence of ahFPL in the present meta-analysis was 48% (95% CI, 44%–52%) in 5,903 upper limbs. The difference in prevalence between both meta-

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Table 3. Characteristics of variants of Gantzer's muscle: insertion of both variants

ahFPL			ahFDP		
Insertion	P (%)	95% CI (%)	Insertion	P (%)	95% CI (%)
Muscle	61	52–70	Index finger tendon	47	37–57
Tendon	13	7–20	Middle tendon	20	13–29
Proximal third of forearm	71	66–76	Ring finger tendon	0	0–7
Middle third of forearm	23	18–27	Little finger tendon	10	5–18
Lower third of forearm	6	3–8	Middle & ring finger tendon	20	13–29
			Middle, ring & little finger tendon	3	1–9

ahFPL, accessory head of flexor pollicis longus; ahFDP, accessory head of flexor digitorum profundus; P, prevalence; CI, confidence interval.

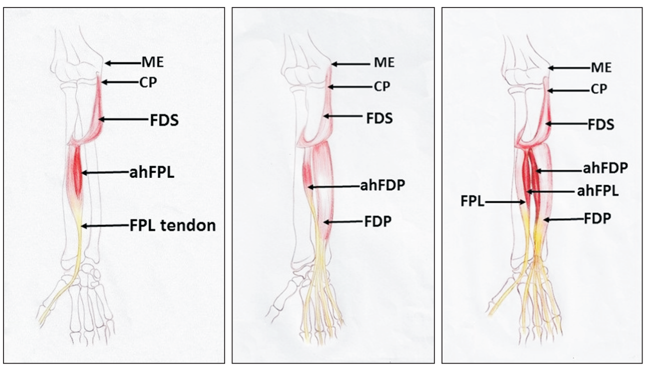

Fig. 4. Classification of Gantzer's muscle. ME, medial epicondyle of humerus; CP, coronoid process of ulna; FDS, flexor digitorum superficialis; ahFPL, accessory head of flexor pollicis longus; ahFDP, accessory head of flexor digitorum profundus.

analyses is attributed to higher sample size. The present meta-analysis examined more than double the sample size of the previous meta-analysis. The authors [3, 12, 37, 53] reported Gantzer's muscle prevalence, which varied from 60% to 71%. These authors reported both variants. The studies [14, 15, 25, 28, 38, 41, 47] reported lower prevalence (39%–55%) and they only included ahFPL variant. The second variant, *i.e.*, ahFDP, might have been missed due to ignorance. Such ignorance may be dealt with in the classification of these variants. The variants of Gantzer's muscle may be classified as per its morphology and attachment (Fig. 4). They were classified into three types. The suggested classification is as follows, based on the review of various literatures, which could be helpful in the future to study the relationship with the nearby structure.

Type I: ahFPL

Type Ia: Insertion into the belly of FPL

Type Ib: Insertion into the tendon of FPL

Type II: ahFDP

Type IIa: Insertion into the first tendon of FDP (index finger)

Type IIb: Insertion into the second tendon of FDP (middle finger)

Type IIc: Insertion into the third tendon of FDP (ring finger)

Type IId: Insertion into the fourth tendon of FDP (little finger)

Combination of any of two or more may be denoted as IIbcd or IIab, etc.

Type III: ahFPL and ahFDP

The sub-category of type III will be developed in the future with the availability of adequate data.

Type III is rare, and this subtype was not included for the pooled prevalence of variants of Gantzer's muscle due to inadequate description and data. The forearm muscle blastema develops from Interzone blastema over cartilage of developing radius and ulna at the 4th week of intrauterine life [6, 8]. The superficial muscle blastema migrates earlier than the blastema of the deeper muscle. FDS, FDP, and FPL are phylogenetically newer muscles that develop from volar hand blastema, and they ascend upwards to reach the definitive origin [12]. The fascial sheath of superficial muscles like FDS or pronator teres a guide for deeper FPL and FDP. The variants of Gantzer's muscle might be developmental errors [3, 12]. The FPL is the newer muscle (phylogenetically) among the forearm flexors, which could be the reason for the higher prevalence of ahFPL.

Clinical implications

These muscles generally lie deep to MN and are innervated by AIN [56]. The Gantzer's muscle has long been debated as a cause of neurological compression of AIN or MN. Tabib et al. [57] documented AIN syndrome caused by Gantzer's muscle. The patient had isolated weakness of the FPL and was unable to pinch between thumb and index finger. The pronated and extended elbow may cause characteristic pain in front of the mid-forearm. Electrodiagnostic investigation revealed moderate slowing of conduction velocity. On surgical exploration, Gantzer's muscle along with swollen AIN.

The surgical removal led to the resolution of pain within a month. Similar reports were also noted in many other literatures [57-60]. Such syndrome was named as Kiloh–Nevin syndrome or AIN syndrome. This disorder also often leads to loss of pinching [12, 56].

Limitation & potential bias

The high heterogeneity of pooled prevalence and inadequate data of sex distribution were the significant limitations. The high heterogeneity was mainly attributed to the variable population of studies. Most old studies lack sex-based data, and retrieving such data from the author's communication was impossible. It is the scope of further research. The strength of the current meta-analysis is that the present study has a double sample size than the previous one.

Conclusion

The prevalence of Gantzer's muscle is 65%. It has two major variants: ahFPL and ahFDP. Both variants have population and sex variations. The origin of both variants is almost similar, but their insertions vary. Accessory head of FPL inserts on belly or tendon of FPL. Still, the other variant (ahFDP) inserts on the tendon of the FDP for the index and middle finger.

ORCID

Adil Asghar: https://orcid.org/0000-0002-1404-1298
Rakesh Kumar Jha:
https://orcid.org/0000-0003-1292-5927
Apurba Patra: https://orcid.org/0000-0002-1107-4481
Binita Chaudhary: https://orcid.org/0000-0002-1922-7630
Brijendra Singh: https://orcid.org/0000-0002-3501-0896

Author Contributions

Conceptualization: AA, RKJ. Data acquisition: AA, RKJ, BC. Data analysis or interpretation: AA, AP. Drafting of the manuscript: AA, RKJ, BC. Critical revision of the manuscript: AP, BC. Approval of the final version of the manuscript: all authors.

Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

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