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Title:

A systematic review and meta-analysis of variants of the branches of superior mesenteric artery: the Achilles heel of right hemicolectomy with complete mesocolic excision (CME)?

Short title:

Anatomy of superior mesenteric artery

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ABSTRACT

Background: Dissection with subsequent ligation and resection of arteries at their origin (central vascular ligation, CVL) is essential for adequate oncological resection during right hemicolectomy (RH) with complete mesocolic excision (CME). This technique is technically demanding due to the highly variable arterial pattern of the right colon. Therefore, this study aims to provide a comprehensive evidence-based assessment of the arterial vascular anatomy of the right colon

Methods: A thorough systematic literature search through September 2020 was conducted on the electronic databases PubMed, SCOPUS, and Web of Science (WOS) to identify studies eligible for inclusion. Data were extracted and pooled into a meta-analysis using MetaXl software.

Results: A total of 41 studies (n= 4,691 patients) were included. The ileocolic artery (ICA), right colic artery (RCA) and middle colic artery (MCA) were present in 99.7% (95% CI 99.4-99.8), 72.6% (95% CI 61.3-82.5) and 96.9% (95% CI 94.2-98.8) of patients respectively. Supernumerary RCA and MCA were observed in 3.2% and 11.4% of all cases respectively. The RCA shared a common trunk with ICA and MCA in 13.2% and 17.7% of patients respectively. A retro-superior mesenteric vein (SMV) course of the ICA and RCA was observed in 55.1% and 11.4% of all cases respectively.

Conclusion: The vascular anatomy of the right colon displays several notable variations, namely the absence of some branches (RCA absent in 27.4% of cases), supernumerary branches, common trunks, and retro-SMV courses. These variations should be taken into consideration during RH with CME to ensure adequate oncological resection while minimizing intraoperative complications.

Keywords: Superior mesenteric artery, Right hemicolectomy, Complete mesocolic excision

INTRODUCTION

Right hemicolectomy (RH) is the gold-standard treatment for cancers of the caecum, ascending colon, hepatic flexure and proximal transverse colon (1). In 2009, Hohenberger introduced the concept of complete mesocolic excision (CME), which utilizes anatomical and embryological principles in the surgical treatment of colon cancer (2). The principles of CME include a sharp dissection of the visceral plane from the retroperitoneum to remove the colon with an intact mesocolon (3,4). Additionally, the arteries supplying the right colon (ileocolic artery (ICA), right colic artery (RCA), and the right branch of the middle colic artery (MCA)) are exposed and centrally ligated at their origin to ensure adequate removal of regional lymph nodes (3,4). Compared to standard surgery, RH with CME results in a greater lymph node yield and improved oncological outcomes (2,5,6), and is therefore gaining popularity (6).

Application of the principles of CME in RH is technically challenging, especially when minimally invasive approaches (laparoscopy and robotic surgery) are used (1,7). This is principally due to the highly variable arterial supply to the right colon (8,9). A proper pre-operative understanding of the vascular anatomy of the right colon is therefore paramount to ensure adequate oncological resection with minimal intra-operative complications (8,9). This study was therefore conducted to consolidate the available literature on the arteries relevant to performing RH (ICA, RCA, MCA) and to determine their prevalence and anatomical features. This is particularly important in light of the increasingly widespread use of minimally invasive approaches in RH with CME (6)

METHODS

Study Guidelines, Protocol, and Registration

This systematic review and meta-analysis were performed as reported from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Supplement 1) (10). The protocol for this study was registered on PROSPERO, an international prospective database for reviews under the registration number CRD42020197590.

Search Strategy

A systematic literature search through September 2020 was conducted by 2 independent reviewers (RC and GA) on the electronic databases PubMed, SCOPUS, and Web of Science (WOS) to identify studies eligible for inclusion. The following search terms were used for PubMed: “Mesenteric Artery, Superior/abnormalities” [Mesh] OR “Mesenteric Artery, Superior/surgery” [Mesh] AND “Anatomy” [All Fields]. No language restriction was made. Full-texts of records remaining after initial screening by title and abstract were assessed to determine study eligibility. When the articles were published by the same study group and there was an overlap of the search period, only the most recent article was included to avoid duplication of data. The PubMed function "related articles" was used to extend the search and a reference list of all the included studies was analyzed. A search on Google Books was done for analysis of the grey literature (https://books.google.com).

Selection Criteria

To be included in the meta-analysis, a study had to satisfy the following criteria: (1) was an imaging/cadaveric or intra-operative study, (2) reported clear extractable data on the prevalence and anatomical features of the branches of the superior mesenteric artery (ICA, RCA, and MCA). Letters-to-editor, editorials, conference extracts, and studies with incomplete or irrelevant data were excluded. We did not perform any language restriction.

Data Extraction and Quality Assessment

For each study, the following information was extracted by 2 independent reviewers (RC and GA): the surname of the first author and the year of publication, the country where the study was performed, the type of study (imaging/cadaveric or intra-operative), sample size, number of patients with ICA, RCA and MCA, and the anatomical features of these vessels. Quality assessment and analysis of the risk of bias of all selected full-text articles were performed using the Anatomical Quality Assurance (AQUA) tool from the International Evidence-Based Anatomy (iEBA) working group (Supplement 2) (11).

Study Outcomes

The primary outcome was the pooled prevalence estimate (PPE) of the prevalence of the superior mesenteric artery (SMA) branches: the ileocolic artery (ICA), right colic artery (RCA), and middle colic artery (MCA). These arteries were defined based on the area they supply. The MCA and ICA were defined as the arteries arising from the SMA that approximated the transverse colon and ileocaecal valve, respectively, at their distal ends (12,13). The right colic artery (RCA) was defined as the artery arising from the SMA that ran ventral to the pancreas toward the ascending colon (12,13). The secondary outcomes were the number of each SMA branches, the anatomical variants of the RCA according to the classification reported by Yada et al. (14), and the topographical relationship between each of the SMA branches and the superior mesenteric vein (SMV).

Meta-Analytical Synthesis Methods

In general, we followed the meta-analytic guidelines of the Cochrane Collaboration (15). Binomial and multinomial pooled prevalence estimates were calculated using a DerSimoneon-Laird random-effects model with Meta-XL (v. 5.3) software. A double arc sin transformation with prevalence normalization and a continuity correction of 0.5 was applied to the data before synthesis. All estimates reported here have been back-transformed into proportions. To investigate asymmetry and publication bias we visually examined Doi and funnel plots when applicable. We conducted a leave-one-out sensitivity analysis and compared results with and without outliers on outcomes with sets of outliers. Geographic region (continent) and evaluation type (cadaveric, surgical, radiological, or mixed) were examined as a priori moderators of prevalence outcomes. We ultimately only conducted moderator analysis for the RCA prevalence outcome. We did not conduct a moderator analysis for other outcomes because they had either insufficient variance between studies and/or insufficient sample size. The definition of the location of origin of the RCA has been investigated as an ex post facto moderator as part of an exploratory analysis of significant unexplained heterogeneity in reports of RCA prevalence. In addition to the traditional meta-analytic techniques mentioned above, we conducted an unplanned exploratory analysis for the RCA prevalence outcome because of a large amount of unexplained study heterogeneity. We examined the histograms of unweighted prevalences and conducted a two-step cluster analysis, with SPSS 27.0, because we found evidence for a mixture distribution of RCA prevalence. We also created a multiattribute plot of RCA prevalence, sample size, year, and evaluation type. Following the suggestions of Wasserstein et al (16), we refrain from interpreting our results using null hypothesis significance testing. Instead, we report 95% confidence intervals, and p values for Cochran's Q are reported descriptively.

RESULTS

Study identification

The initial search produced 2,047 potentially relevant articles. Following the removal of duplicates and primary screening, 57 articles were assessed by full text for eligibility in the meta-analysis. Of these, 16 were excluded because the primary and secondary outcomes of the study did not match those of this review (Supplement 3). Thus, a total of 41 articles were included in this meta-analysis (Figure 1 & Table 1).

Figure 1: PRISMA flow diagram for the included studies

Characteristics of the studies included.

A total of 41 studies (n= 4,691 patients) were included (12–14,17–53, 69,70). In the study by Gamo et al., (28) the authors reported two different samples (a cadaveric dissection group and radiological investigation group), and for this reason, we considered this as two studies in the evaluation of vascular pattern. Most of the studies were performed in Asia (21 studies: 2,244 patients) while the rest were from Europe (13 studies: 1,441 patients) and the Americas (7 studies: 1,006 patients). The years of publication ranged from 1958 to 2019. Most of the included studies were performed during cadaveric dissections (22 studies, 1,822 patients). The rest utilized imaging techniques (11 studies, 1,889 patients), or were performed in patients undergoing surgery (8 studies, 930 patients), while one study utilized both techniques (49) (Table 1). Across 21 studies, 2 definitions of the RCA were used:

1) "independent of the origin" – these studies defined RCA as an artery supplying the ascending colon regardless of its origin (13,17,18,20,21,25,26,32,33,39,42).

2) "exclusively from the origin"- these studies defined the RCA based on its origin from the SMA (12,14,23,34,36,38,43,46,52)

Table 1: Characteristics of the included studies

Quality assessment of the included studies

The AQUA tool probes for potential risk of bias in five study domains (objectives and subject characteristics; study design; methodology characterization; descriptive anatomy; and reporting of results). The risk of bias within each domain is normally categorized as "Low", "High", or "Unclear"

(Supplement 2). Eleven studies included in this systematic review and meta-analysis revealed domain one (objectives and subject characteristics) to be at high risk of bias mainly because of the missing baseline demographic data of the study population. Sixteen studies demonstrated domain three (methodology characterization) to be at high risk of bias because the methods/techniques applied in the study were not described in enough detail for them to be reproduced. Almost all studies revealed the remaining domains (study design, descriptive anatomy, and reporting of results) to be at a low risk of bias. The summary chart of the quality and risk of bias assessment as evaluated by the AQUA tool is shown in Figure 2.

Figure 2: Summary of the AQUA assessment for the included studies

Primary Outcome

i) Pooled prevalence of the ileocolic artery (ICA)

A total of 39 studies (n=4,160 patients) reported data on the prevalence of the ICA. The pooled prevalence estimate (PPE) of the ICA was 99.7% (95% CI [99.4%, 99.8%]) (Figure 3a), with low inter-study heterogeneity, $I^2 = 21\%$, $Q(38) = 48.02$, $p = 0.13$. Spaseojovic (50) was an outlier with an ICA prevalence of 77.8% (14/18). However, the leave-one-out sensitivity analysis indicated that the effect of excluding any single study was negligible. The leave-one-out PPEs ranged from 99.6% to 99.8% (Supplement 4). The Doi and funnel plots were asymmetric and censored due to the many studies with a 100% prevalence of the ICA (Supplement 4).

Figure 3: Forest plot for PPE for ICA

ii) Pooled prevalence of the right colic artery (RCA)

The prevalence of the RCA was reported in all 41 studies (*n* = 4,691 patients) and the RCA was absent in 1,663 patients (type 4 of Yada classification) (Figure 6b). The forest plot shown in Figure 4 indicates that the random-effects pooled prevalence estimate (PPE) for the presence of the RCA was 72.6%, (95% CI [61.3%, 82.5%]) (Figure 3b, Figure 4). Leave-one-out sensitivity analysis yielded prevalence estimates ranging from 71.4 to 74.0 and a fixed-effect sensitivity analysis yielded a prevalence estimate of 69.1%, (95% CI [67.8%, 70.4%]). A visual examination of a Doi plot and forest plot exhibited no evidence of publication bias in these data (Supplement 5). The difference between the random- and fixed-effect estimates was negligible for this and all other outcomes unless otherwise noted.

When interpreting this prevalence estimate, note the extremely high degree of heterogeneity between study estimates; I^2 = 98%, $Q(41)$[1] = 2633.34, p = < .01[2]. Because of the extreme amount of heterogeneity, we conducted an exploratory analysis in addition to an analysis of a priori study moderators. We began the exploratory analysis by examining a histogram of the unweighted prevalence for each study providing evidence for a bimodal, mixture distribution of prevalence estimates (Supplement 5). The histogram appeared to contain an exponential distribution of studies with a higher prevalence of RCAs and a normal distribution of studies with a lower prevalence of RCAs. A two-step cluster analysis also provided evidence of two separate prevalence groups. We used the two-step cluster analysis algorithm to classify the cases into either the high-prevalence or low-prevalence group. The cut-point between the two groups was approximately at the point of 66% prevalence. Analyzed separately, the high-prevalence group of studies (n = 23) had a PPE of 94.8%, (95% CI 90.9% and 97.1%), I^2 = 90%, $Q(22)$ = 211.10, p = < .01; whereas, the low-prevalence group of studies (n = 19) had a PPE of 35.2% with a 95% CI between 28.7% and 42.3%, I^2 = 90%, $Q(18)$ = 182.47, p = < .01 (Supplement 5). We suggest that the definition of the location of origin of the RCA may be an important factor in explaining the reason for the mixture distribution and added it as a moderator variable in the analysis explained below.

The results of a follow-up moderator analysis of the PPE of the presence of RCA are shown in Table 2. In summary, studies in which the definition of an RCA was "independent of the origin" reported a

[1] There are 41 degrees of freedom instead of 40 because we regarded each arm of the Gamo study as a separate effect size. This creates one instance of dependent effect sizes.
[2] We are following the advice of Wasserstein, Schirm, and Lazar (2019) to report p exactly instead of using an inequality (e.g., p < .05).

lower PPE of RCA (53.7%) than studies in which the definition was "exclusively from the origin" (82.9%) or not reported (74.1%) (Table 2, Supplement 5).

Studies using a surgical evaluation technique reported a lower PPE (50.2%) than studies using a cadaveric (89.1%) or radiological technique (69.5%) (Supplement 5). Figure 5 is a multi-attribute plot showing the prevalence of RCA by year, sample size, and evaluation type. North American studies had a greater PPE of RCA presence (84.4%) than Asian (69.5%) or European studies (70.2%) (Supplement 5).

Table 2: Results of moderator analyses of the presence of the RCA

Figure 3b: Forest plot for PPE for RCA

Figure 4: Multi-attribute Plot for the presence of RCA by year, sample size, and evaluation type

Legend for Figure 4: Note Sample sizes are shown by the size of the data point from 0 (smallest) to 500 (largest). Evaluation type is shown by the darkness of the data point where surgical evaluation is darkest, cadaveric dissection is lightest, and radiology is in between.

iii) Pooled prevalence of the middle colic artery (MCA)

Of the 24 studies (n=2,993 patients) that examined the prevalence of the MCA, the PPE was 96.9% (95% CI [94.2%, 98.8%]) (Figure 5). The heterogeneity was high, I^2 = 90.6%, $Q(23)$ = 244.94, p = < .01, and there were three outlying studies (Bordei, 2006; Ferrari, 2006; Spasojevic, 2010). When these three studies were excluded the PPE increased to 98.7% (95% CI [97.6%, 99.5%]) (Figure 6). The Doi and funnel plots exhibited asymmetry due mostly to the outliers and the funnel plot showed evidence of censoring due to the studies where there was 100% prevalence (Supplement 6).

Figure 5: Prevalence of the MCA with three outlying studies excluded

Secondary Outcomes

i) Number of branches of ICA, RCA, and MCA

The ICA number, evaluated in 38 studies (n=4,602 patients), was always one (Supplement 4). Across 28 studies, of participants with at least one RCA, the PPE of having one RCA was 96.8% (95% CI [94.3, 98.6%]) compared to 3.2% (95% CI [1.4%, 5.7%]) for the PPE of having multiple RCAs (Supplement 5). Study heterogeneity was high, I^2 = 90%, $Q(27)$ = 185.13, p = < .01. Doi and Funnel plots showed asymmetry and a significant ceiling effect in prevalence (Supplement 5). Twelve studies reported the number of MCAs. The prevalence of one, two, and three MCAs was 88.6% (95% CI [83.2%, 93.1%], 10.8% (95% CI [6.5%, 16.1%], and 0.6% (95% CI [0.0%, 2.1%], respectively. There was high study heterogeneity, $I2$ = 85.0%, $Q(11)$ = 73.22, p = < .01. (Supplement 6). As in the other outcomes, the Doi and funnel plots exhibited asymmetry, outlying studies, and some censoring due to many studies reporting no cases with three MCAs (Supplement 6).

ii) Origin of RCA

The origin of the SMA branches was reported in 22 studies (n= 1,670 patients) and the rate was evaluated as reported in the Yada' classification focused on the presence of a RCA (Figure 6a, Supplement 5):

a) Type 1 (RCA independently arises from the SMA). The prevalence of this type (also described in Gamo's classification as pattern I (28)) was 68.9% (n=1,150 patients).
b) Type 2 (Common trunk for RCA and MCA). The prevalence of this variant (also described in Gamo's classification as pattern IIa (28)) was 17.7% (n=296 patients).
c) Type 3 (Common trunk for RCA and ICA). The prevalence of this variant (also described in Gamo's classification as pattern IIb (28)) was 13.2% (n=220 patients).

Another type, not reported in the Yada' classification, was the origin of MCA, RCA, and ICA from the same common trunk (prevalence=0.01%, n=4 patients) (Figure 6a); this variant was described in Gamo's classification as pattern IIc (28).

Figure 6a: Yada's classification of origin types of RCA.

iii) Topographic relationship between ICA/RCA and the superior mesenteric vein (SMV)

a) Relationships between ICA and SMV

Of the 16 studies that reported on the topographical relationship of the ICA and SMV, the multinomial PPEs for anterior, posterior, and right locations of the ICA were 44.5% (95% CI [38.1%, 51.4%), 55.1% (95% CI [48.6%, 61.8%]), and 0.4% (95% CI [0.0%, 1.5%]) respectively (Figure 6b). There was high heterogeneity in these estimates, $I^2 = 85.2\%$, $Q(15) = 101.60$, $p = < .01$. (Supplement 7). The Doi and funnel plots for anterior and posterior locations were symmetrical and exhibited significant heterogeneity apparent in the forest plots. The Doi and funnel plot for the SMA to the right was asymmetrical and censored as expected from a large number of studies with zero prevalence (Supplement 7).

Figure 6b: Topographic relationship between ICA/RCA and Superior mesenteric vein (SMV)

b) Relationships between RCA and SMV

In the 13 studies reporting on the location of the RCA, the RCA was anterior to the SMV in 87.3% (95% CI [80.7%, 92.0%] of cases, posterior to the SMV in 11.4% of cases (95% CI 6.56%, 10.72%), and to the right of the SMV in 1.3% (95% CI [0.0%, 4.0%]) (Figure 6b). The study heterogeneity was moderate, $I2 = 62\%$, $Q(12) = 31.99$, $p = < .01$. Doi and funnel plots for RCA anterior and RCA posterior showed symmetry and appropriate funneling; however, there was censoring for the SMA to the right of SMV estimate because of the preponderance of studies with zero prevalence (Supplement 7).

DISCUSSION

Proper understanding of the vascular anatomy of the colon is critical when performing RH with complete mesocolic excision (CME), with inaccurate vascular dissection often being associated with complications such as excessive intraoperative blood loss (9,44) and poor oncological outcomes (due to inadequate lymphadenectomy) (54).

The surgical significance of the right colonic vasculature has changed with the evolution of the RH technique. For example, the RCA was previously thought to have little technical importance, with surgical texts not reporting any recommendations about how to approach the RCA during RH (55). Identifying and isolating the RCA was not outlined as a crucial step during RH, from either medial (56) or lateral approaches (57). Furthermore, some texts did not report identification and ligation of the RCA (58). The colonic vasculature however started gaining a central role in colon cancer surgery with the description of the "no-touch technique" by Turnbull (59,60). This technique utilized the principles of a medial-to-lateral approach to lymphovascular isolation before colon mobilization. The rationale for this approach was based on observations that cancer cells were actively shed into the bloodstream during tumour manipulation, and that vascular ligation before colon mobilization would help minimize this (60).

The surgical significance of the colon vascular anatomy was amplified with the introduction of CME (2,6) and D3 lymphadenectomy (61,62). The principles of CME involve sharp dissection along embryological plane to ensure removal of all lymphovascular tissue in the drainage area of the tumour in a complete mesocolic envelope (2,6,62). In both techniques (CME and D3 lymphadenectomy), skeletonization with subsequent ligation and resection of colon arteries at their origin (central vascular ligation, CVL) is performed to ensure adequate removal of regional lymph nodes (2,12,62).

Preliminary reports on these techniques have documented improved oncological outcomes (2,6,61,63,64). These techniques are however technically demanding, particularly in the setting of minimally-invasive approaches (laparoscopy/ robotic surgery) due to the highly variable nature of arterial supply to the right colon. The current study, carried out on 4,691 cases, reports some robust landmarks and some critical issues related to the anatomical variants of the branches of the SMA that have been highlighted and standardized.

The presence of the ICA and MCA are the most important landmarks during RH as they are the most constant vessels that supply the right colon, being present in 99.7% (95% CI [99.4%, 99.8%]) (ICA) and 96.9% (95% CI [94.2%, 98.8%]) (MCA) respectively. Based on our analysis, there are four critical variants that must be well known and considered during RH:

- **Presence of RCA.** The PPE of RCA presence was 72.6%, (95% CI [61.3%, 82.5%]) with an extremely high degree of heterogeneity between study estimates (I^2 = 98%). During surgery, the greater rate of RCA absence (27.4%) may be a consequence of the intraoperative difficulty in identifying the artery, which has a small diameter and is therefore not easily isolated during the mesocolic mobilization and division. This difficulty is greater in obese patients, where the mesocolon is thicker and it is more difficult to identify the vascular structures (65). The higher rate of RCA absence observed in surgical studies might also be due to the fact that it might not be encountered if the vessels are divided centrally. The absence of the RCA is of great surgical significance since in such cases, the MCA may be confused for RCA and is clipped/ligated. This may compromise the blood supply to the more distal transverse colon (12). To help the surgeons, some radiological studies were performed to evaluate the presence of these vascular variations and preoperative vascular mapping with 3-D reconstruction of vascular anatomy has become applicable in the last decade. Furthermore, this high rate of heterogeneous presence of the RCA can also be linked to a non-shared definition of the origin of the RCA. The rate of RCA presence was 82.9% in "orthodox" studies ("exclusively from the origin" studies- these studies defined the RCA based on its origin/ proximal course), whilst the rate was 53.7% in studies in which the RCA was largely defined only based on their supply of the right colon (distal course) and independently from the origin.

- **The origin of the RCA from SMA.** The RCA arises from the right side of the SMA individually in about two-thirds of cases (68.9%) and the other cases from a common trunk from which the RCA and ICA originate (13.2%) or from a common trunk from which the RCA and MCA originate (17.7%). The origin of the MCA, RCA, and ICA from a shared common trunk is very rarely reported (0.2%).
- **Topographical relationships of the SMA branches with the SMV.** The retroperitoneal course of the RCA is anterior to the SMV in most cases (87.3%) and in a small number of cases the course is posterior to the SMV (11.4%); it is unusual, but not impossible, for the RCA to be located to the right of the SMV (1,3%). In comparison, the ICA crosses the SMV more commonly anteriorly (53.04%) than posteriorly (46.9%), but the variation here is very much less than for the RCA. In the relationships between the ICA and RCA with the SMV, the most common associations were the ICA anterior and RCA anterior to the SMV (42.62%) and the ICA posterior and RCA anterior to the SMV (37%). Less common variations were the ICA posterior and RCA posterior to the SMV (18.27%) and the ICA anterior and RCA posterior to SMV (2.11%). Proper understanding of the relationship between the SMV and branches of the SMA is crucial to prevent iatrogenic SMV injury, a severe and potentially fatal complication of RH (66–68).
- **The number of MCAs.** The prevalence of one, two, and three MCAs were 88.6%, 10.8%, and 0.6% respectively.

Pre-operative assessment of the vascular anatomy of the right hemi-colon may be achieved through various imaging modalities. Majority of the radiological studies utilized multidetector computed tomography (MDCT) with 3D reconstruction. This technique has been recognized as a less invasive method of evaluation of vascular anatomy of the gastro-intestinal tract, and has accuracy rates of 90%-100% (12).

This study was limited by the high level of inter-study heterogeneity that persisted despite extensive sub-group analysis. Further, although 3D MDCT/CTA have high accuracy rates, it is possible that some vessels might be missed due to their small caliber or the use of thicker slices. However, this study was strengthened by quality assessment using the AQUA tool from the International Evidence-Based Anatomy (IEBA) Working group. Further, sub-group analysis was applied, and this allowed evaluation of the influence of study characteristics on the outcomes of this study.

CONCLUSION

In surgical oncology, the primary objectives are to obtain adequate oncological resection while minimizing intra- and post-operative complications. Minimally invasive right hemicolectomy, performed according to the rules of CME with central ligation of the vessels, requires careful intraoperative dissection and isolation of the vascular structures. The vascular anatomy of the right colon displays several notable variations, namely the absence of some branches (RCA in up to 27.4% of cases), supernumerary branches, common trunks, and retro-SMV course. These should therefore be taken into consideration during RH with CME to ensure adequate oncological resection while minimizing intraoperative complications. Poor pre-operative understanding of these vascular variations may be the Achilles heel of RH with CME.

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Table 1: Characteristics of the included studies

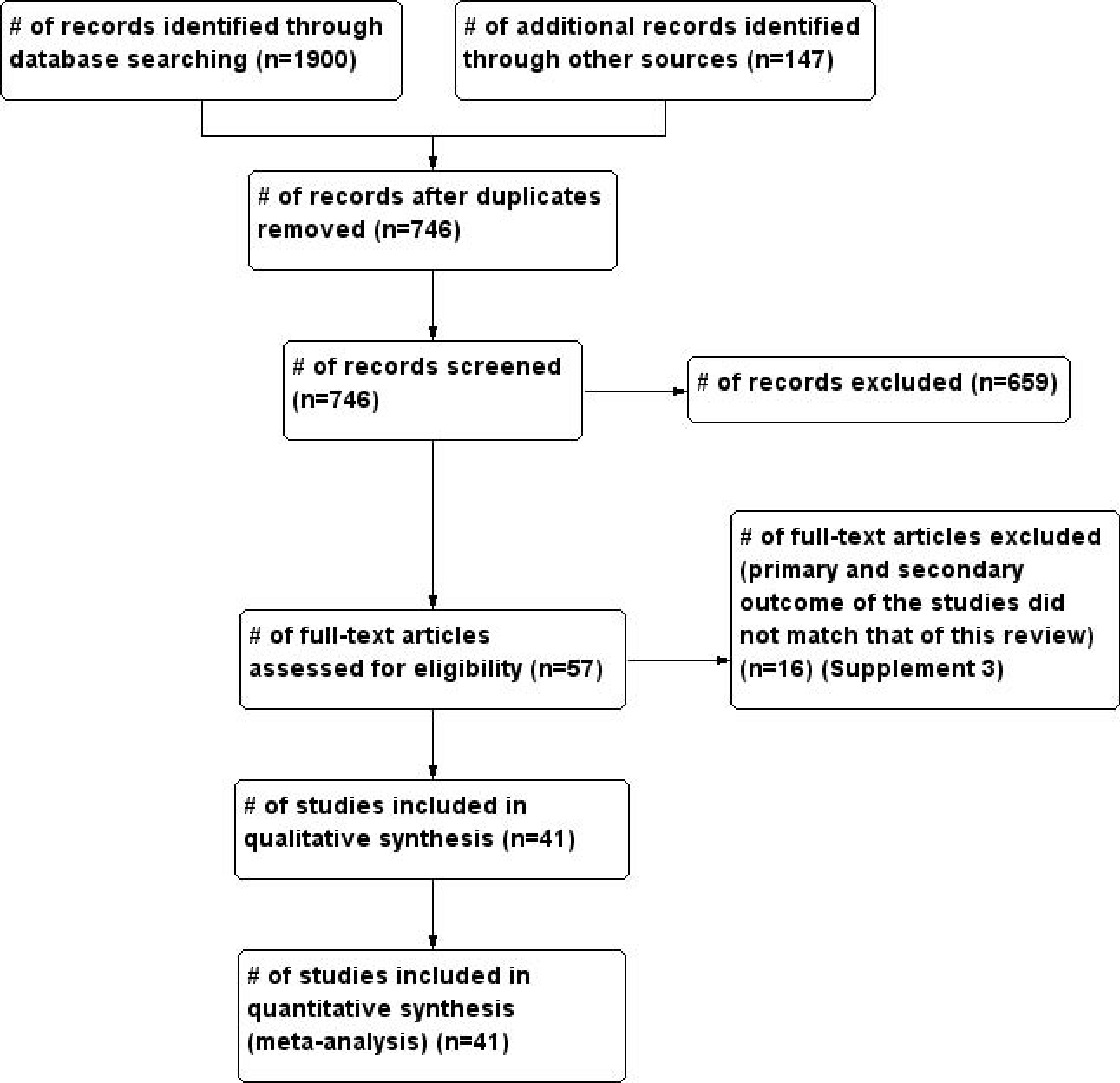
Study	Continent	Type of evaluation	Time of enrollment	Number of patients
Wu 2019	Asia	Surgery	2013-2016	60
Xiao 2019	Asia	Surgery	2016-2018	100
Alban, 2018	Asia	Cadaveric dissection	NR	50
Hiroishi 2018	Asia	Radiology	2016-2018	32
Srivastava 2018	Asia	Cadaveric dissection	NR	40
Kuzu 2017	Asia	Cadaveric dissection	2013-2015	111
Alsabilah 2017	Asia	Surgery	2016	70
Haywood 2016	Europe	Cadaveric dissection	2015-2016	25
Pereira 2016	America	Cadaveric dissection	NR	41
Deepa 2016	Asia	Cadaveric dissection	NR	50
Gamo 2016a	Europe	Cadaveric dissection	2012-2013	50
Gamo 2016b	Europe	Radiology	2012-2013	560
Lee 2016	Asia	Surgery	2014-2015	116
Murono 2016	Asia	Radiology	2012-2014	536
Nirmaladevi 2015	Asia	Cadaveric dissection	NR	50
Mane 2015	Asia	Cadaveric dissection	NR	50
Nesgaard 2015	Europe	Surgery	NR	139
Kaye 2015	Europe	Radiology	NR	151
Acar 2014	Europe	Cadaveric dissection	NR	12
Batra 2013	Asia	Cadaveric dissection	NR	30
Jain 2013	Asia	Cadaveric dissection	NR	20
Spasojevic 2013	Europe	Cadaveric dissection	NR	26
Hirai 2013	Asia	Radiology	2006-2011	100
McDermott 2012	N. America	Radiology	2001-2010	54
Spasojevic 2011	Europe	Radiology	2003-2011	14
Tajima 2011	Asia	Surgery	1999-2009	215
Oshawa 2010	Asia	Surgery	1999-2009	205
Spasojevic 2010	Europe	Radiology	NR	50
Nadu 2008	Asia	Mix*	NR	50
Ignjatovic 2007	Europe	Cadaveric dissection	NR	30
Ferrari 2007	Europe	Radiology	2006	60
Bordei 2006	Europe	Cadaveric dissection	NR	68
Shatari 2003	Asia	Cadaveric dissection	2002	27
Chung 1998	Asia	Radiology	NR	50
Yada 1997	Asia	Radiology	1985-1993	282
García-Ruiz 1996	N. America	Cadaveric dissection	NR	56
Peters 1995	N. America	Surgery	1991-1993	25
Nelson 1988	N. America	Cadaveric dissection	NR	50
Vandamme 1976	Europe	Cadaveric dissection	NR	156
Michnievichz-Nowak 1975	Europe	Cadaveric dissection	NR	100
Michels 1965	N. America	Cadaveric dissection	NR	180
Sonneland 1958	N. America	Cadaveric dissection	NR	600

NR- not reported

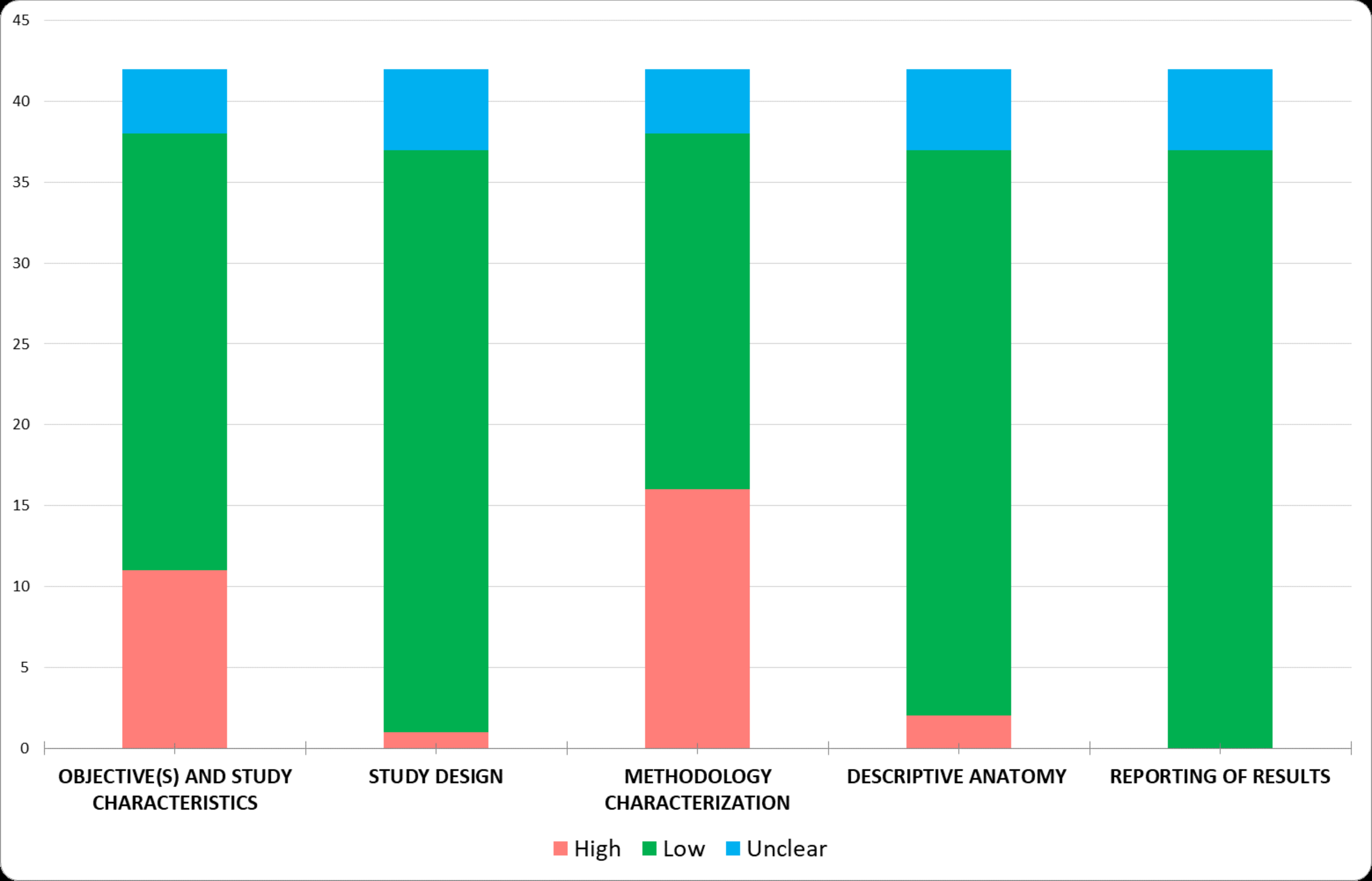
Table 2: Results of Moderator Analyses of the presence of the RCA

Moderator (*n* of studies)	**PPE(%)**	**95% CI of PPE (%)**	I^2**(%)**	***Q***
Definition of RCA Origin				
Exclusively from origin (12 studies)	82.9	57.9, 1.00	98	619.23
Independent of origin (9 studies)	53.7	30.7, 76.2	99	759.13
Not reported (21 studies)	74.1	65.4, 98.4	98	1127.90
Evaluation Type				
Cadaveric (22 studies)	81.9	67.6, 93.5	98	969.14
Radiological (11 studies)	69.5	45.2, 90.9	99	1013.56
Surgical (9 studies)	50.2	35.0, 65.6	95	
Geographic Region				
Asia (21 studies)	69.5	50.2, 80.5	97	665.36
Europe (13 studies)	70.2	42.1, 99.0	99	1293.97
North America (7 studies)	84.4	65.4, 98.4	97	217.02

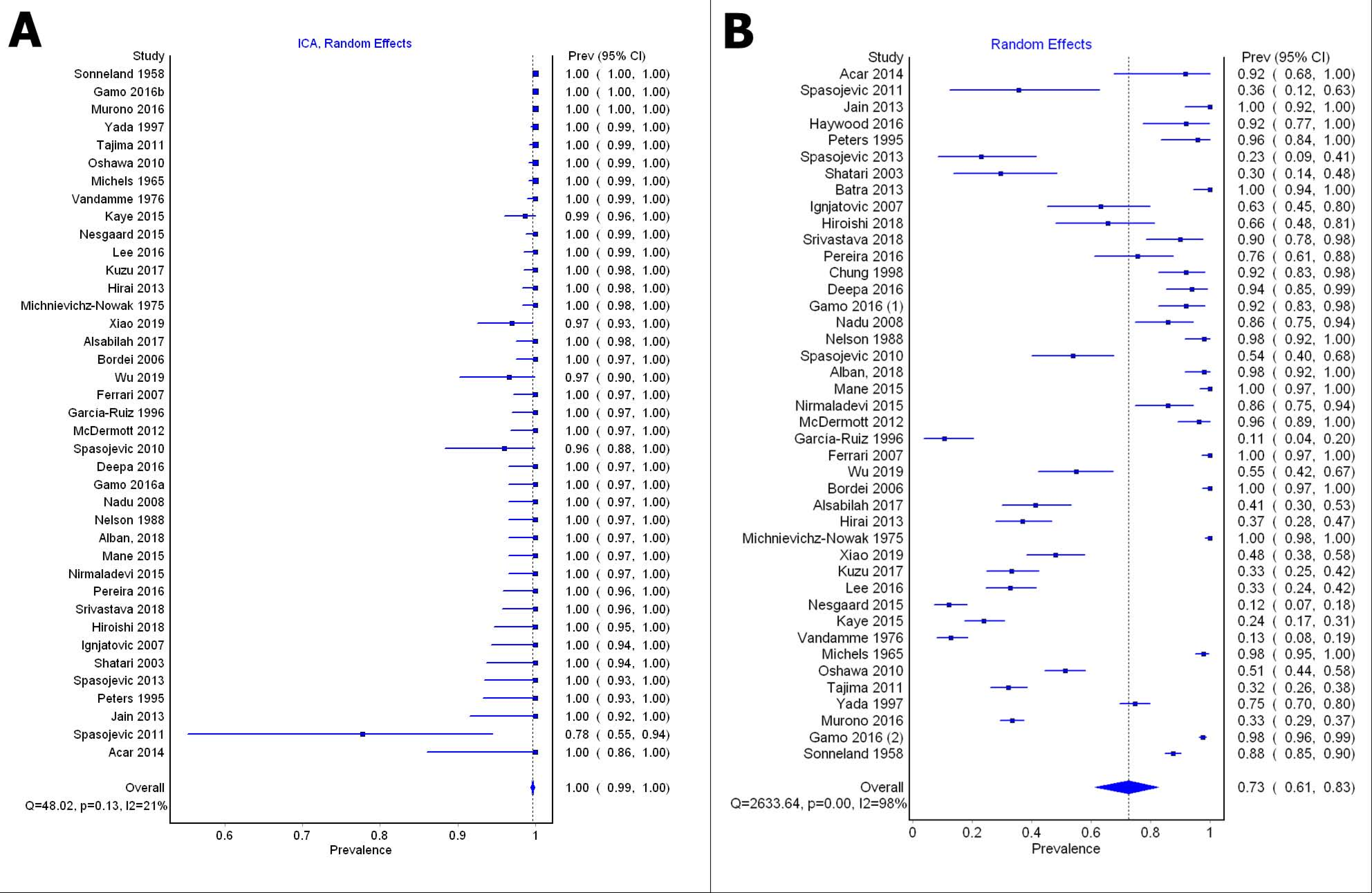
Note. A random-effects model was used for all estimates presented here. The *p* value for all *Q* statistics was 0.00.

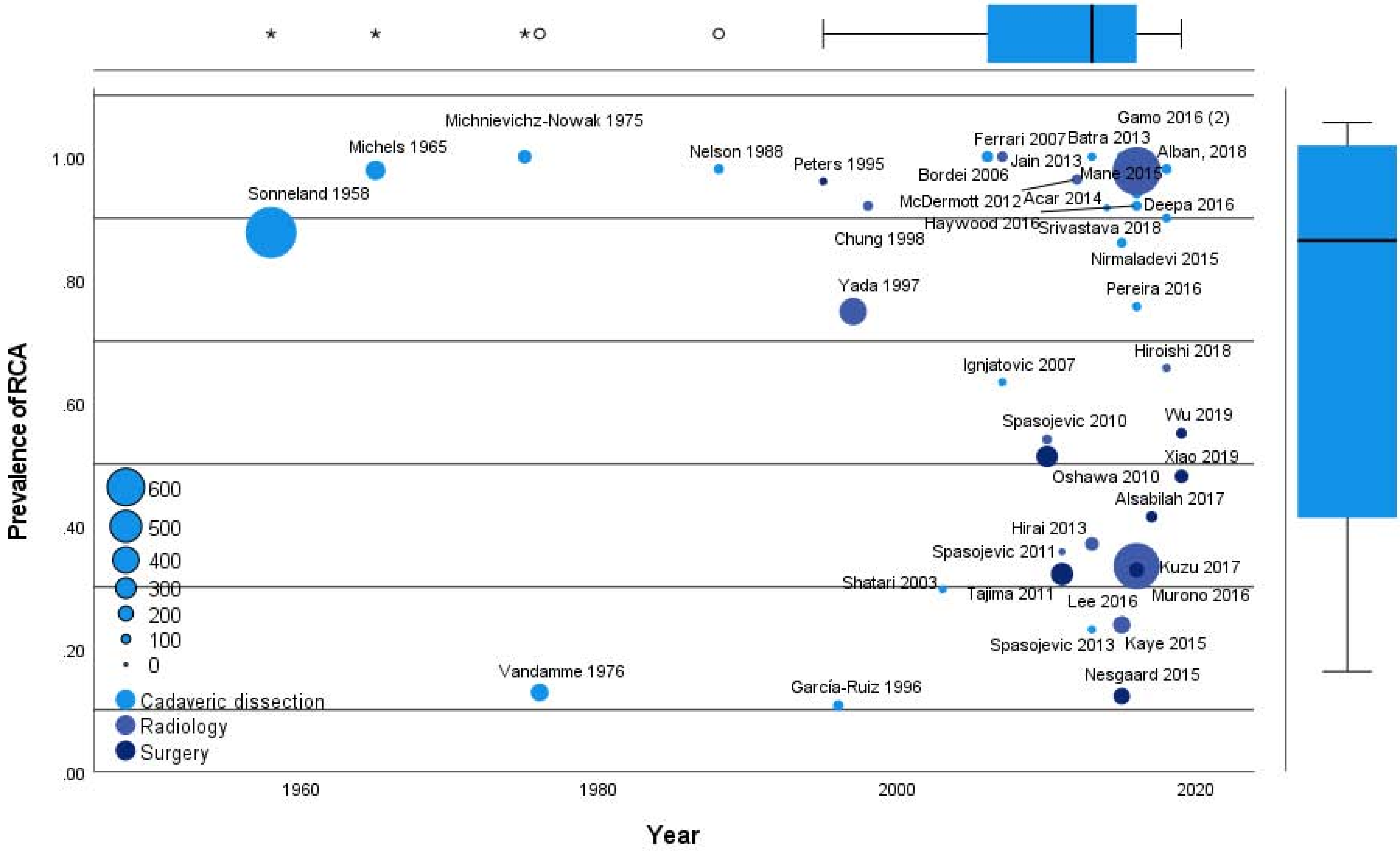


# of records identified through database searching (n=1900)
# of additional records identified through other sources (n=147)
# of records after duplicates removed (n=746)
# of records screened (n=746)
# of records excluded (n=659)
# of full-text articles assessed for eligibility (n=57)
# of full-text articles excluded (primary and secondary outcome of the studies did not match that of this review) (n=16) (Supplement 3)
# of studies included in qualitative synthesis (n=41)
# of studies included in quantitative synthesis (meta-analysis) (n=41)

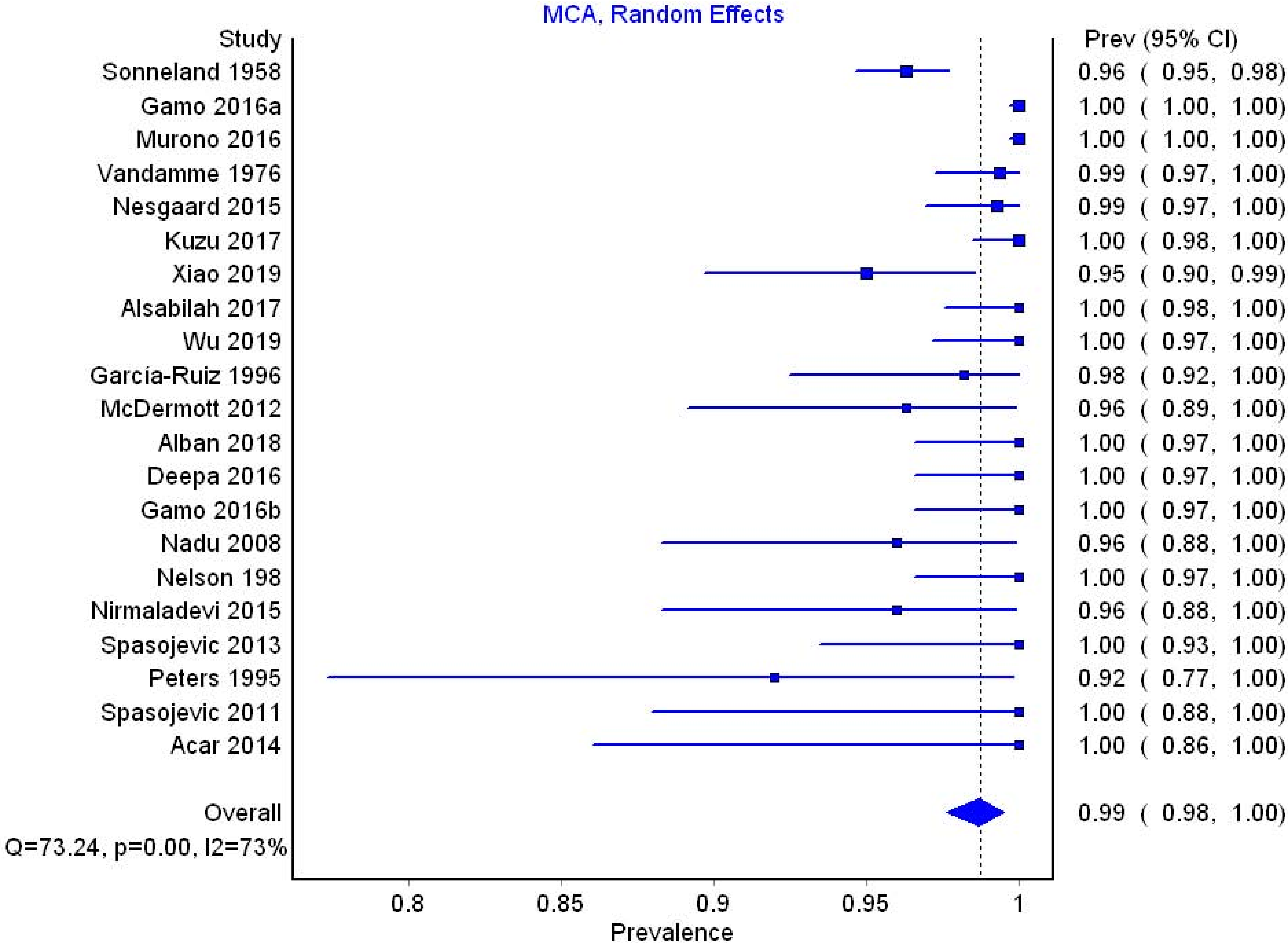


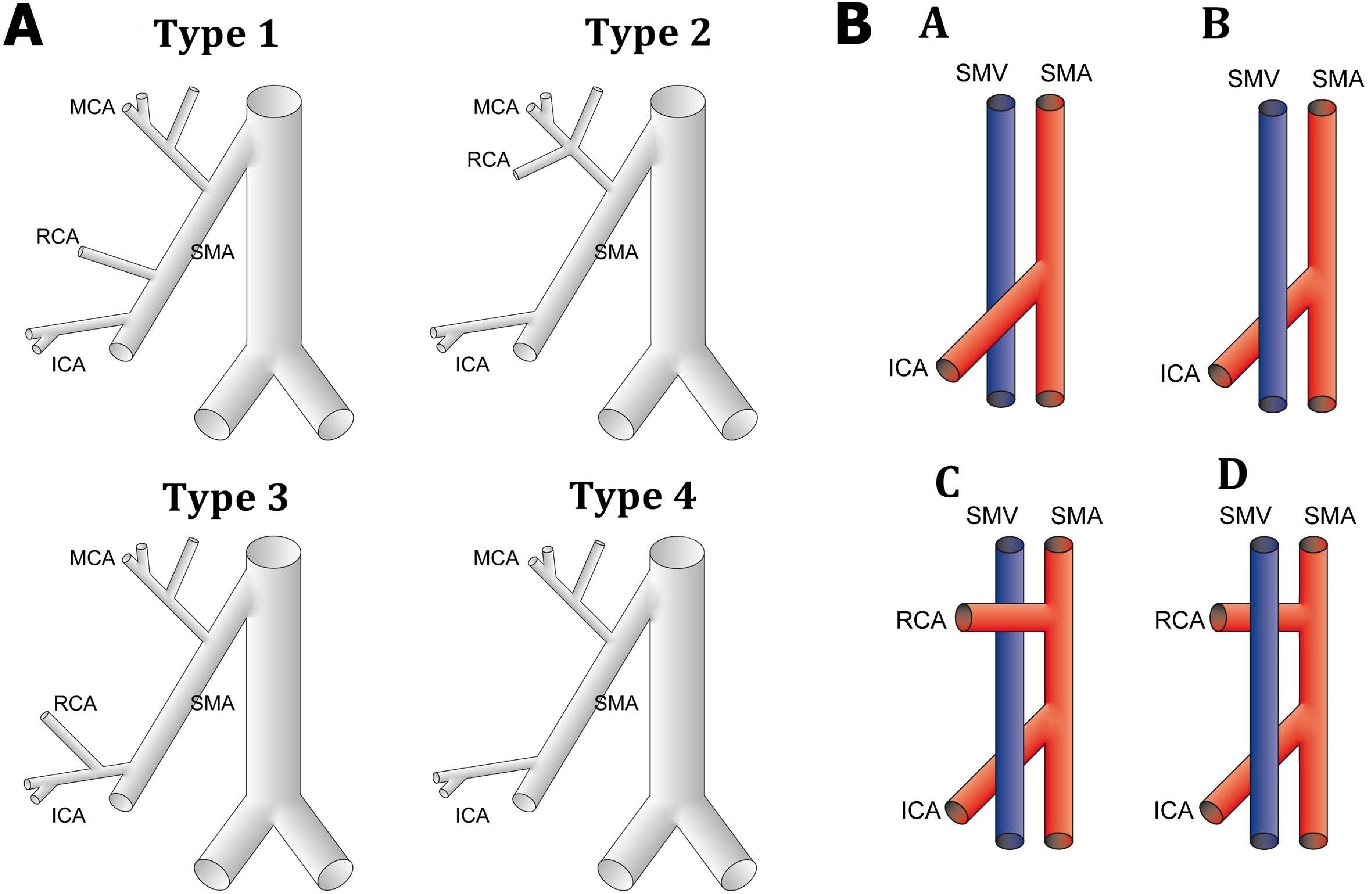
45
40
35
30
25
20
15
10
5
0
OBJECTIVE(S) AND STUDY CHARACTERISTICS
STUDY DESIGN
METHODOLOGY CHARACTERIZATION
DESCRIPTIVE ANATOMY
REPORTING OF RESULTS
High
Low
Unclear


A
ICA, Random Effects
Study
Prev (95% CI)
Sonneland 1958 1.00 (1.00, 1.00)
Gamo 2016b 1.00 (1.00, 1.00)
Murono 2016 1.00 (1.00, 1.00)
Yada 1997 1.00 (0.99, 1.00)
Tajima 2011 1.00 (0.99, 1.00)
Oshawa 2010 1.00 (0.99, 1.00)
Michels 1965 1.00 (0.99, 1.00)
Vandamme 1976 1.00 (0.99, 1.00)
Kaye 2015 0.99 (0.96, 1.00)
Nesgaard 2015 1.00 (0.99, 1.00)
Lee 2016 1.00 (0.99, 1.00)
Kuzu 2017 1.00 (0.98, 1.00)
Hirai 2013 1.00 (0.98, 1.00)
Michnievichz-Nowak 1975 1.00 (0.98, 1.00)
Xiao 2019 0.97 (0.93, 1.00)
Alsabilah 2017 1.00 (0.98, 1.00)
Bordei 2006 1.00 (0.97, 1.00)
Wu 2019 0.97 (0.90, 1.00)
Ferrari 2007 1.00 (0.97, 1.00)
García-Ruiz 1996 1.00 (0.97, 1.00)
McDermott 2012 1.00 (0.97, 1.00)
Spasojevic 2010 0.96 (0.88, 1.00)
Deepa 2016 1.00 (0.97, 1.00)
Gamo 2016a 1.00 (0.97, 1.00)
Nadu 2008 1.00 (0.97, 1.00)
Nelson 1988 1.00 (0.97, 1.00)
Alban, 2018 1.00 (0.97, 1.00)
Mane 2015 1.00 (0.97, 1.00)
Nirmaladevi 2015 1.00 (0.97, 1.00)
Pereira 2016 1.00 (0.96, 1.00)
Srivastava 2018 1.00 (0.96, 1.00)
Hiroishi 2018 1.00 (0.95, 1.00)
Ignjatovic 2007 1.00 (0.94, 1.00)
Shatari 2003 1.00 (0.94, 1.00)
Spasojevic 2013 1.00 (0.93, 1.00)
Peters 1995 1.00 (0.93, 1.00)
Jain 2013 1.00 (0.92, 1.00)
Spasojevic 2011 0.78 (0.55, 0.94)
Acar 2014 1.00 (0.86, 1.00)
Overall 1.00 (0.99, 1.00)
Q=48.02, p=0.13, I2=21%
0.6 0.7 0.8 0.9 1
Prevalence
B
Random Effects
Study
Prev (95% CI)
Acar 2014 0.92 (0.68, 1.00)
Spasojevic 2011 0.36 (0.12, 0.63)
Jain 2013 1.00 (0.92, 1.00)
Haywood 2016 0.92 (0.77, 1.00)
Peters 1995 0.96 (0.84, 1.00)
Spasojevic 2013 0.23 (0.09, 0.41)
Shatari 2003 0.30 (0.14, 0.48)
Batra 2013 1.00 (0.94, 1.00)
Ignjatovic 2007 0.63 (0.45, 0.80)
Hiroishi 2018 0.66 (0.48, 0.81)
Srivastava 2018 0.90 (0.78, 0.98)
Pereira 2016 0.76 (0.61, 0.88)
Chung 1998 0.92 (0.83, 0.98)
Deepa 2016 0.94 (0.85, 0.99)
Gamo 2016 (1) 0.92 (0.83, 0.98)
Nadu 2008 0.86 (0.75, 0.94)
Nelson 1988 0.98 (0.92, 1.00)
Spasojevic 2010 0.54 (0.40, 0.68)
Alban, 2018 0.98 (0.92, 1.00)
Mane 2015 1.00 (0.97, 1.00)
Nirmaladevi 2015 0.86 (0.75, 0.94)
McDermott 2012 0.96 (0.89, 1.00)
García-Ruiz 1996 0.11 (0.04, 0.20)
Ferrari 2007 1.00 (0.97, 1.00)
Wu 2019 0.55 (0.42, 0.67)
Bordei 2006 1.00 (0.97, 1.00)
Alsabilah 2017 0.41 (0.30, 0.53)
Hirai 2013 0.37 (0.28, 0.47)
Michnievichz-Nowak 1975 1.00 (0.98, 1.00)
Xiao 2019 0.48 (0.38, 0.58)
Kuzu 2017 0.33 (0.25, 0.42)
Lee 2016 0.33 (0.24, 0.42)
Nesgaard 2015 0.12 (0.07, 0.18)
Kaye 2015 0.24 (0.17, 0.31)
Vandamme 1976 0.13 (0.08, 0.19)
Michels 1965 0.98 (0.95, 1.00)
Oshawa 2010 0.51 (0.44, 0.58)
Tajima 2011 0.32 (0.26, 0.38)
Yada 1997 0.75 (0.70, 0.80)
Murono 2016 0.33 (0.29, 0.37)
Gamo 2016 (2) 0.98 (0.96, 0.99)
Sonneland 1958 0.88 (0.85, 0.90)
Overall 0.73 (0.61, 0.83)
Q=2633.64, p=0.00, I2=98%
0 0.2 0.4 0.6 0.8 1
Prevalence



Prevalence of RCA
Year
1.00
.80
.60
.40
.20
.00
1960
1980
2000
2020
600
500
400
300
200
100
0
Cadaveric dissection
Radiology
Surgery
Sonneland 1958
Michels 1965
Michnievichz-Nowak 1975
Vandamme 1976
Nelson 1988
Peters 1995
García-Ruiz 1996
Yada 1997
Chung 1998
Shatari 2003
Bordei 2006
Ferrari 2007
Ignjatovic 2007
Spasojevic 2010
Oshawa 2010
Spasojevic 2011
Tajima 2011
McDermott 2012
Batra 2013
Jain 2013
Hirai 2013
Spasojevic 2013
Acar 2014
Mane 2015
Nirmaladevi 2015
Kaye 2015
Nesgaard 2015
Gamo 2016 (2)
Deepa 2016
Haywood 2016
Pereira 2016
Lee 2016
Murono 2016
Kuzu 2017
Alsabilah 2017
Alban, 2018
Srivastava 2018
Hiroishi 2018
Wu 2019
Xiao 2019


MCA, Random Effects
Study
Prev (95% CI)
Sonneland 1958 0.96 (0.95, 0.98)
Gamo 2016a 1.00 (1.00, 1.00)
Murono 2016 1.00 (1.00, 1.00)
Vandamme 1976 0.99 (0.97, 1.00)
Nesgaard 2015 0.99 (0.97, 1.00)
Kuzu 2017 1.00 (0.98, 1.00)
Xiao 2019 0.95 (0.90, 0.99)
Alsabilah 2017 1.00 (0.98, 1.00)
Wu 2019 1.00 (0.97, 1.00)
García-Ruiz 1996 0.98 (0.92, 1.00)
McDermott 2012 0.96 (0.89, 1.00)
Alban 2018 1.00 (0.97, 1.00)
Deepa 2016 1.00 (0.97, 1.00)
Gamo 2016b 1.00 (0.97, 1.00)
Nadu 2008 0.96 (0.88, 1.00)
Nelson 198 1.00 (0.97, 1.00)
Nirmaladevi 2015 0.96 (0.88, 1.00)
Spasojevic 2013 1.00 (0.93, 1.00)
Peters 1995 0.92 (0.77, 1.00)
Spasojevic 2011 1.00 (0.88, 1.00)
Acar 2014 1.00 (0.86, 1.00)
Overall 0.99 (0.98, 1.00)
Q=73.24, p=0.00, I2=73%
0.8
0.85
0.9
0.95
1
Prevalence


A
Type 1
MCA
RCA
SMA
ICA
Type 2
MCA
RCA
SMA
ICA
Type 3
MCA
RCA
SMA
ICA
Type 4
MCA
SMA
ICA
B
A
SMV
SMA
ICA
B
SMV
SMA
ICA
C
SMV
SMA
RCA
ICA
D
SMV
SMA
RCA
ICA