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REVIEW ARTICLE

Systematic review of motor evoked potentials monitoring during thoracic and thoracoabdominal aortic aneurysm open repair surgery: a diagnostic meta-analysis

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Abstract Motor evoked potential (MEP) monitoring has been used to prevent neurological complications such as paraplegia in patients who underwent thoracic or thoracoabdominal aortic aneurysm (TAA/TAAA) surgery. The object of this study was making a systematic review to survey the performance of MEP monitoring during TAA/TAAA open repair surgery. We searched electronic databases for relevant studies. We summarized the diagnostic data with summary sensitivity, summary specificity and forest plots of pooled sensitivity, and conducted sub-group analysis. The quality of the studies was assessed using the Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) tool. We also surveyed the reporting rate of clinical key factors such as methods of anesthesia, surgery, and success rate of MEP. Nineteen studies met our criteria. The results of meta-analysis showed 89.1 % summary sensitivity (95 % confidence interval 47.9–98.6 %) and 99.3 % summary specificity (95 % confidence interval 96.1–99.9 %). Sub-group analysis of pooled sensitivity and specificity by all-or-none cut-off point were better than other cut-off points. The results of the QUADAS-2 were not good. The performance of MEP monitoring was good for detecting postoperative paraplegia in TAA/TAAA open repair surgery. The cut-off point of all-or-none may be the best, according to our review.

Keywords Motor evoked potential (MEP) monitoring · TAAA open repair · Systematic review · Diagnostic meta-analysis

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Introduction

Paraplegia is a serious complication secondary to thoracic or thoracoabdominal aortic aneurysm (TAA/TAAA) open repair because of intraoperative spinal cord ischemia. The reported incidence of paraplegia is very high, ranging from 11 to 25 % in Crawford type II repair [1, 2]. To prevent these complications, motor evoked potential (MEP) monitoring is widely used as a predictive device during TAA/TAAA open repair [3]. However, reliable MEP monitoring may be impeded by various factors such as methods of anesthesia, surgery, cardiopulmonary bypass, body temperature, success rate of MEP, and complication [4].

Appropriate methods of anesthesia, including selection of anesthetic drug and muscular relaxation monitoring are considered to be very important when conducting reliable MEP monitoring in TAA/TAAA surgery [4]. Kakinohana et al. reported that plasma propofol concentration markedly increased after induction of cardiopulmonary bypass with aortic occlusion, resulting in reduction in the bispectral index [5]. Hypothermia may have indirect effects on MEP by modulating the pharmacodynamics of anesthetic and neuromuscular agents [6].

The objective of this article was to undertake a systematic review of the literature to survey the performance of MEP monitoring in patients undergoing TAA/TAAA open repair and detecting the cut-off point of MEP monitoring in giving more sensitive, more specific evaluation, and the appropriateness of reporting on key factors including methods of anesthesia, surgery, cardiopulmonary bypass, body temperature, success rate of MEP, and complications.

Methods

We followed the recommendations of the PRISMA statement [7] and Cochrane Reviewers' Handbook version 5.1.0 [8]. We made an a priori protocol and sent it to our members in a multicenter research project to protect the spinal cord during TAA/TAAA surgery in Japan, before conducting the systematic review. We registered our protocol with PROSPERO (an international database of prospectively registered systematic reviews in health and social care http://www.crd.york.ac.uk/PROSPERO/, the PROSPERO registration number is CRD42016033475).

Eligibility criteria

We performed a literature search of all English and Japanese language reports on MEP monitoring during TAA/TAAA open repair. We included studies reporting on MEP monitoring during TAA/TAAA open repair and its relationship with clinical outcomes such as paraplegia and paralysis. We excluded animal studies, stent grafting for TAA/TAAA, reviews, commentaries, case reports, editorials, letters, proceedings, other topics, duplicated studies, studies using MEP monitoring only for D-wave monitoring, and studies published in other languages except English and Japanese.

Literature search and study selection

We searched MEDLINE, the Cochrane Central Register of Controlled Trials, EMBASE, CINAHAL, and the Japanese Central Review of Medicine (covering January 1980 to September 2015) on September 1st 2015. We identified ongoing studies by searching WHO ICTPR (http://apps.who.int/trialsearch/) and Clinical trial.gov (https://clinicaltrials.gov/).

We used a systematic search strategy (Appendix 1) and sourced relevant publications via an online information source of published literature. Moreover, the bibliographies of retrieved trials were used to identify other relevant studies. Publication bias was assessed by funnel plot and Egger test of diagnostic odds ratio.

Data collection and presentation

Two authors (MK & YT) independently selected the studies, and extracted the data. In cases of disagreement of study selection, a consensus was achieved between them, or among them and a third author. A data collection sheet was used to collate the following data: (1) basic data: authors, year of publication, name of publishing journal, study design, primary country of origin, and number of patients; (2) data for surgery and anesthesia: type of surgery, use of cardiopulmonary bypass, anesthesia methods including induction and maintenance; (3) outcome of MEP: the incidence of amplitude changes in the evoked potential wave, relationship of paraplegia to incidence of changes in MEP amplitude.

Data summary, synthesis, and meta-analysis

We summarized the data of the selected studies. The data sets included methods of anesthesia, surgery, cardiopulmonary bypass, and study country of origin, and these were extracted for diagnostic meta-analysis. We also generated a hierarchical summary receiver operating characteristic (HSROC) model to summarize global MEP monitoring performance and summary sensitivity and specificity. The methods were recommended by the Cochrane Diagnostic Test Accuracy Working Methods Group [8]. We also performed a meta-analysis using pooled sensitivity and specificity based on the random effect model. Analyses were performed by Stata (ver. 13,

Stata Corp, USA) with the metandi program and Meta-Disc version 1.4 (http://www.hrc.es/investigacion/meta-disc_en.htm). Data was expressed as summarized value [95 % confidence interval (CI)].

Sub-group analysis

We conducted sub-group analysis to determine which cut-off value of MEP amplitude reduction is better for

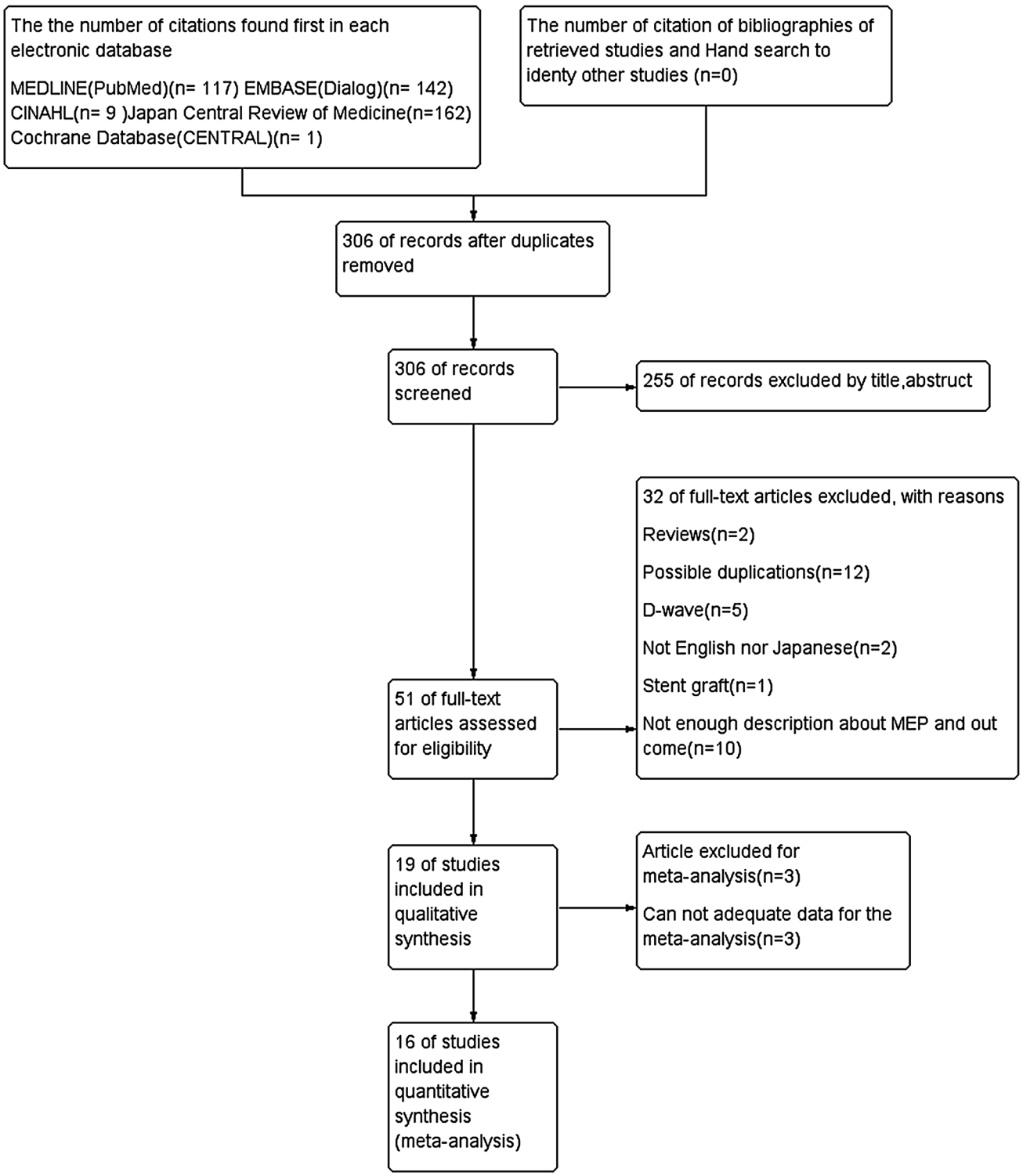

Fig. 1 PRISMA flow chart of study selection. *n*, number of studies

detecting post-operative paraplegia. We selected the cut-off points, such as 'all-or-none' (disappearance of positive wave of MEP amplitude), 75 % reduction of MEP amplitude, 50 % reduction of MEP amplitude, or 25 % reduction of MEP amplitude.

Reporting rate of key factors

We assessed the reporting rate of clinical key factors which affected the outcomes of MEP (success rate of MEP, methods of anesthesia, surgery, cardiopulmonary bypass, body temperature, and complication).

Assessment of methodological quality

Two of the authors (YT and MI) independently assessed the quality of the included studies. In cases of disagreement about the assessment, these were either resolved by discussion or by consulting a third author. To evaluate the methodological quality of the studies, the Revised Tool for the Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) [9] was used. This tool comprises 4 domains: patient selection, index test, reference standard, and flow and timing. Each domain assessed in terms of risk of bias, and the first 3 domains were assessed in terms of concerns regarding applicability. Signaling questions were also assessed in terms of concerns regarding applicability. A 'risk of bias' judgement (high, low, or unclear) was made for each domain. If the answers to all signaling questions within a domain were judged to be 'yes' (indicating low risk of bias for each question) then the domain was evaluated to be at low risk of bias. If any signaling question was judged to be 'no', indicating a high risk of bias, the domain was reported as having a high risk of bias. A judgement about concerns regarding applicability for patient selection, index test, and reference standard domain were also made. The results of the assessment of methodology quality are presented graphically.

Assessment of methodological quality of this systematic review

We rated the methodological quality of our systematic review by using the Revised Assessment of Multiple Systematic Reviews (R-AMSTER) [10]. The R-AMSTER consists of eleven items with good face and content validity for measuring the methodological quality of systematic reviews. A score of 20 or less means poor methodological quality. Scores of 21–30 mean fair methodological quality. Scores 31–35 represented good methodological quality, and scores over 35 represented studies with excellent methodological quality [11].

Results

Search results

Of the 306 relevant studies found by the search strategy, 19 [3, 12–29] studies met our inclusion criteria. One ongoing study was detected (Appendix 2). Sixteen studies [3, 12–17, 19, 21, 23–29] (Fig. 1) were finally selected for meta-analysis of MEP monitoring during TAAA open repairs.

When we assessed the full text reviews, the kappa value between the two authors was 0.973 (95 % CI 0.84–1.0). In selecting which studies to include, and which studies were suitable for meta-analysis, the kappa values were 0.954 (95 % CI 0.67–1.0) and 1.0 (95 % CI 0.55–1.0), respectively. The funnel plot of diagnostic odds ratios was symmetric, and the Egger test was not statistically significant (p value = 0.096),which indicated that there was no publication bias (Fig. 2).

Study characteristics

Characteristics of included studies

Nineteen studies were included (Table 1). The number of patients in each study varied from 13 to 210. Nine studies were prospective, another 9 studies were retrospective, and the other study was unknown. The cut-off values of MEP amplitude reduction in these studies were all-or-none, reduction to 50 % and reduction to 75 % from the baseline measurement). The incidence of paraplegia in all included studies varied from 0 to 16.7 %, with an overall rate of 3.9 % (55/1378 patients). Five studies [3, 12, 14, 21, 22], were conducted in Japan, 5 [13, 18–20, 23] in the USA, three studies [24, 26, 28] in the Netherlands, three studies [13, 14, 25] in Germany, and one each in Korea [17], Saudi Arabia [27], and Canada [28].

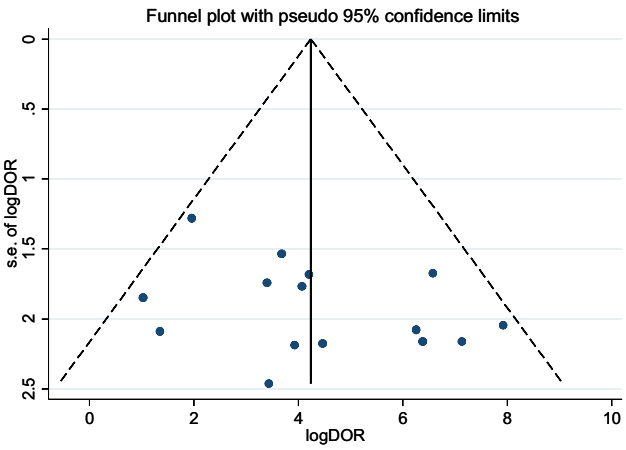

Fig. 2 Funnel plot of diagnostic odds ratios

Table 1 Characteristics of included studies

Author, year	No. of patients (M/F)	Age: mean, (SD range)	MEP success rate (%)	Induction of anesthesia	Maintenance of anesthesia	MR	MM
Ohno, 2013	Unknown	Unknown	UD	−	−	−	−
Greiner, 2012	130 (85/45)	60 (13)	100	−	−	Vecronium	+
Horiuchi, 2011	44 (33/11)	65.6 (12.1)	100	K, P	K, P	Vecronium	+
Fudicker, 2011	20 (14/6)	62.5 (9.7)	UD	K, P, Succynyl-coline	P, Sufentanyl	−	−
Estrera, 2010	105 (65/40)	60 (17–83)	96	MZ, P	Iso	Cisatracrium	+
Kawaharada, 2010	15 (12/3)	65 (52–79)	80	−	−	−	−
Min, 2010	37 (24/9)	50.7 (15.2)	80	P	−	Vecronum	–
Keyhani, 2009	233 (190/43)	67 (18–87)	UD	P, cisatracrium	Iso	Cisatracrium	+
Shine, 2008	60 (27/33)	69 (–)	96.7	Thyopenton	Sccoporamine fentanyl	Atracrium	+
Etz, 2009	13 (5/8)	59 (17.3)	100	−	−	−	−
Kawanishi, 2007	72 (52/20)	64.9 (12.8)	100	K, P, fentanyl	P, K	−	−
Ogino, 2006	92 (68/24)	67 (19–91)	UD	−	−	Vecronium	−
Etz, 2006	100 (67/33)	67 (27–86)	UD	−	−	−	−
Jacobs, 2006	112 (75/37)	62 (28–80)	100	−	−	−	−
Weigang, 2005	19 (10/9)	56 (29–81)	UD	–	MZ Fentanyl	−	−
Jacobs, 2002	210 (–)	ND	100	−	K, Sufentanyl	Vecronium	+
MacDonald, 2002	31 (16/15)	66 (37–78)	100	−	K, iso	None	None
Dong, 2002	56 (30/26)	67 (29–78)	100	P	P	None	None
de Haan, 1997	20 (–)	(22–83)	100	Etomide sufen-tanyl	K, sufentanyl	Vecronium	+

Author, year	CPB	BT (°C)	Mortality (%)	Number of pulse	Stimulation intensity	Upper arm control	Cut-off (%)	Design
Ohno, 2013	FF	35	7.8 (4/51)	5	400–600 V	−	50	Retro
Greiner, 2012	FF LHB	32–33	−	5	500 V	+	–	Pro
Horiuchi, 2011	FF	32	−	5	500 V	+	25	Retro
Fudicker, 2011	FF	34	15 (3/20)	4	200–400 V	+	50	Pro
Estrera, 2010	FF	−	5.7 (6/105)	5	400 V	−	All-or-none	Retro
Kawaharada, 2010	FF CS	−	0 (0/15)	5	500 V	−	50	Retro
Min, 2010	FF	31	6 (2/33)	5	500 V	+	50	Retro
Keyhani, 2009	LHB CS	−	−	5	400 V	−	All-or-none	Pro
Etz, 2009	LHB CS	32	−	9	10 % of MAX of MEP	+	50	Retro
Shine, 2008	LHB CSFF	26–28	−	−	−	−	25	Retro
Kawanishi, 2007	FF CS	31, DHT	5.6 (4/72)	5	500 V	+	75	Pros
Ogino, 2006	FF CS	32	0 (0/92)	−	600 V	+	25	Retro
Etz, 2006	FF CS LHB	32	6 (5/67)	9	10 % of MAX of MEP	+	50	Retro
Jacobs, 2006	FF CS LHB	30	−	5	500 V	+	50	Pro
Weigang, 2005	FF CS	30	25 (3/12)	5	Adjusted intensity	−	All-or-none	UD
Jacobs, 2002	CS LHB	31	10.8 (20/184)	9	10 % of MAX of MEP	+	25	Pro
MacDonald, 2002	−	−	3 (1/31)	3 to 5	250–1000 V	+	All-or-none	Pro
Dong, 2002	CS LHB	Oderate	5.4 (3/56)	3 to 5	250–700 V	−	All-or-none	Pro
de Haan, 1997	CS LHB FF	31	−	1	Maximal producing	−	25	Pro

K ketamine hydrochloride, *P* propofol, *Iso* isoflurane, *MZ* midazolam, *CPB* cardio-pulmonary bypass, *FF* femoral–femoral bypass, *LHB* left heart bypass, *CS* central sessation, *BT* body temperature, *Design* study design, *Retro* retrospective study, *Pro* prospective study, *MR* muscular relaxant, *MM* muscular monitoring, *Cut-off (%)* cut-off point of positive amplitude of MEP monitoring

−There is no description, +There is description

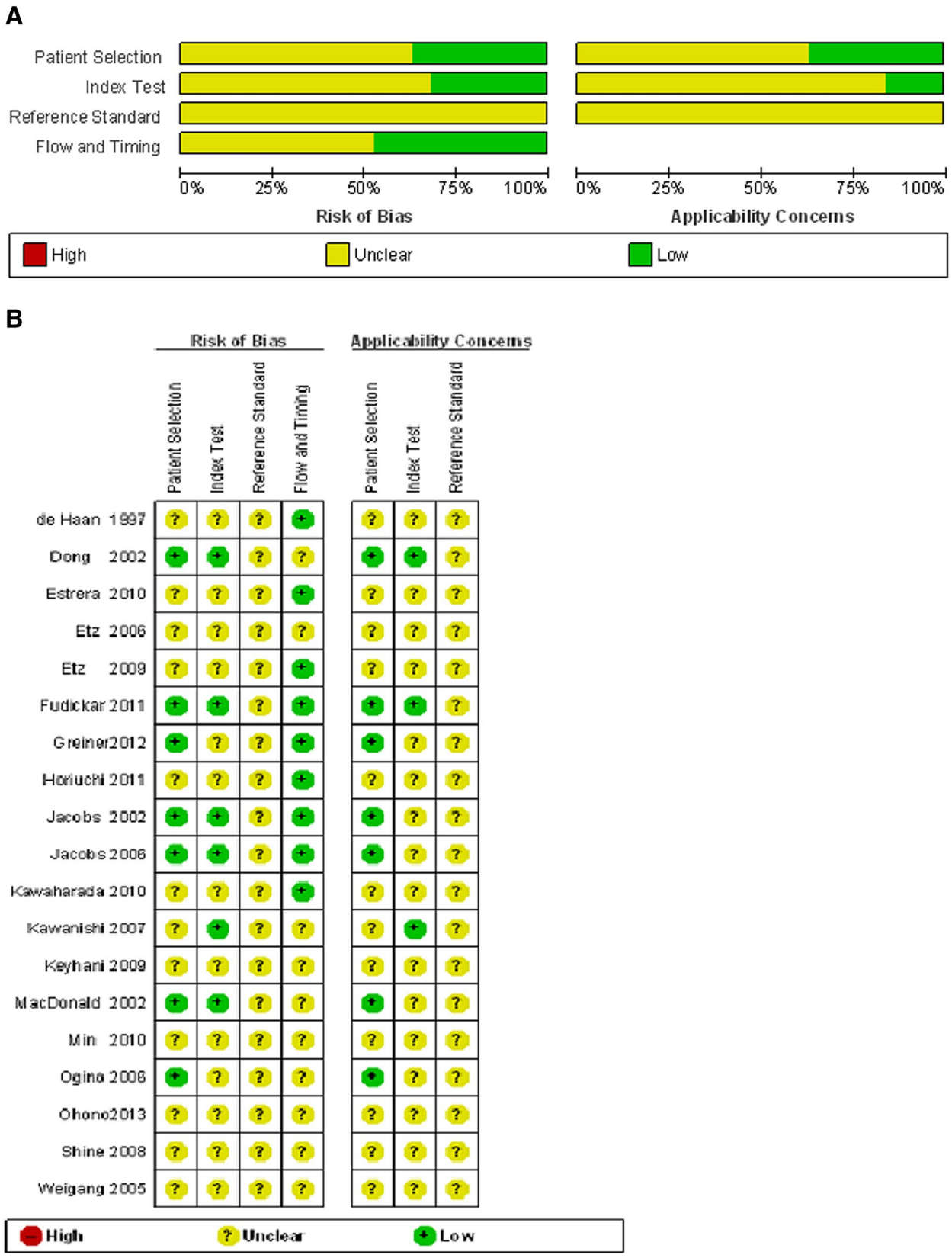

Fig. 3 **a** Summary of QUADAS-2 evaluation of included studies. **b** QUADAS-2 evaluation of each included study

Characteristics of excluded studies

Thirty-two studies [2, 30–58, 60, 61] were excluded because of various reasons (such as animal studies, probably duplications, etc.) (Appendix 3).

Methodological quality of included studies

The results of the quality assessment by QUADAS-2 of the 19 included studies are summarized in Fig. 3a. Individual assessment for each study is provided in Fig. 3b. For the patient selection domain, 7 studies [13, 14, 22, 24, 26–28] were judged to be at low risk of bias. Twelve of 19 studies [3, 12, 15–18, 20, 21, 23, 25, 28, 29] (63 %) were assessed as being at unclear risk of bias. Seven studies [13, 14, 22, 24, 26–28] were judged to be have at low applicability concern. For index test domain, 6 studies [14, 21, 24, 26–28] (32 %) were judged to be as low risk. Three studies [14, 21, 28] were judged to be low applicability concern. Another 13 studies (68 %) were assessed as studies with an unclear risk of bias. All included studies were evaluated as unclear risk in the reference standard domain. For the flow and timing domains, 9 studies (49 %) were judged to be low-risk studies. All included studies used the appropriate index because all included studies had sufficiently described the motor evoked potential. However, there were variations in the independent interpretation of the index test and timing of measurement. So all included studies were evaluated as unclear risk of bias.

Level of evidence of MEP systematic review

The R-AMSTER rating was 38. This score represented excellent methodological quality of systematic review.

Performance of MEP monitoring based on combined data by meta-analysis

Sixteen studies with relevant data were extracted for diagnostic meta-analysis. MEP monitoring showed a wide range of cut-off values (from all-or-none to 75 %) in these studies (Table 2). The total number of patients included in this analysis was 992 patients, with sample sizes ranging from 15 to 208. The diagnostic meta-analysis results using the HSROC model showed 89.2 % summary sensitivity [95 % confidence interval (CI) 47.9–98.6 %] and 99.3 % summary sensitivity (95 % CI 93.8–99.9 %). Meta-analysis of the random effect model showed 72 % pooled sensitivity of selected studies (95 % CI 57–85 % I^2 statistic = 0) and 96 % pooled specificity (95 % CI 95–97 % I^2 statistic = 91.7 %) (Fig. 4) The area under the summary ROC curve was 0.89 (Fig. 5). Sub-group analysis of pooled sensitivity and specificity for the all-or-none cut-off point were 75 % (95 % CI 35–97 % $I^2 = 0$) and 99 % (95 % CI 96–100 % $I^2 = 0$), for the 25 % cut-off point were 67 % (95 % CI 27–94 % $I^2 = 0$) and 96 % (95 % CI 93–96 % $I^2 = 93.5$), and for the 50 % cut-off point were 55 % (95 % CI 28–80 % $I^2 = 0$) and 93 % (95 % CI 90–96 % $I^2 = 70.0$) (Fig. 6).

Table 2 2 × 2 Data for meta-analysis

Study year	N	TP	FP	TN	FN	Immediate paraplegia
Ohono (2013)	37	2	2	33	0	2
Gainer (2012)	130	5	0	125	0	5
Horiuchi (2011)	44	2	9	32	1	3
Fudickar (2011)	16	0	0	13	3	0
Estrera (2010)	99	1	0	98	0	1
Kawaharada (2010)	15	0	0	15	0	0
Min (2010)	33	1	1	30	1	2
Etz (2009)	13	0	1	12	1	0
Kawanishi (2007)	72	8	1	63	0	8
Etz (2006)	100	1	0	99	0	2
Jacobs (2006)	112	3	16	93	0	3
Weigang (2005)	9	1	0	8	0	1
Jacobs (2002)	210	1	0	209	0	1
MacDonald (2002)	15	1	0	14	0	1
Dong (2002)	40	3	0	37	0	3
Haan (1997)	20	2	0	17	1	3

N number of patients, *TP* true positive, *FP* false positive, *TN* true negative, *FN* false negative

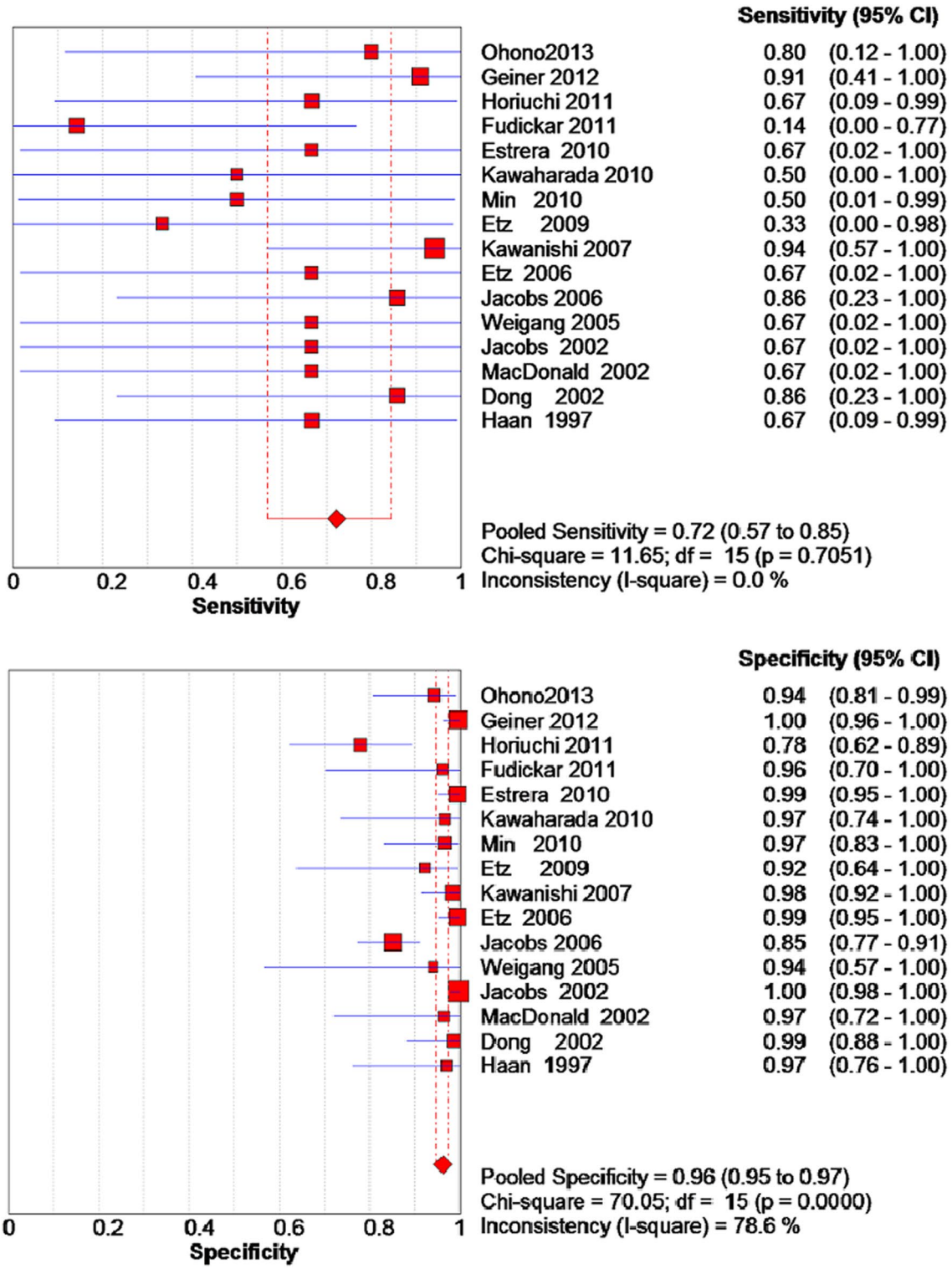

Fig. 4 Pooled sensitivity and specificity of MEP monitoring

Reporting rate of key factors

For the 19 studies selected, the reporting rate of key factors (success rate of MEP, methods of anesthesia, surgery, cardiopulmonary bypass, body temperature, and mortality) was assessed. Data on success rates of MEP monitoring were found in 13 studies [3, 15–17, 19–21, 24, 26–29]. The MEP monitoring success rate varied from 80 to 100 %. The

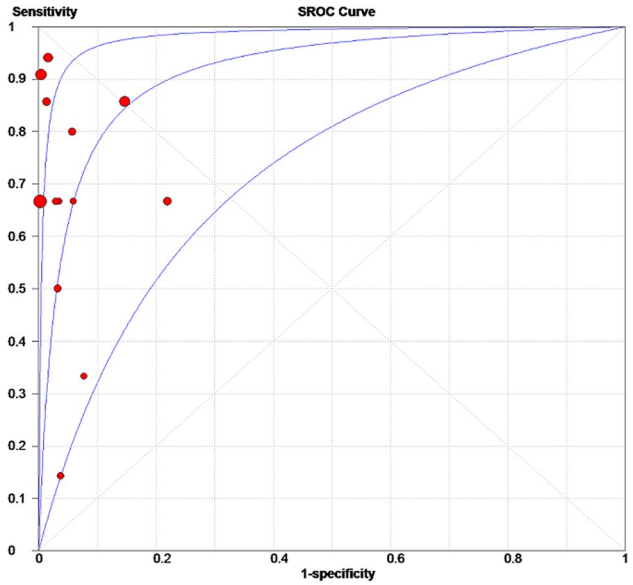

Fig. 5 SROC curve made from data from each study

overall success rate in the 13 studies [3, 13, 15–17, 19–21, 24, 26–29] was 98 % (909/925 patients). Of the 19 studies included, 11 [3, 14, 15, 18, 19, 21, 25–29] studies had descriptions of anesthesia maintenance methods, although only 7 [3, 13, 15, 18, 19, 26, 29] reported monitoring for muscle relaxant regulation. Eleven [3, 13, 14, 17, 19, 21–24, 26, 27] studies had descriptions of upper arm control of MEP. In all included studies there were descriptions of partial cardiopulmonary bypass. Body temperature was reported in 14 studies [3, 12–14, 17, 19–26, 29] and mortality rate was reported in 13 [3, 12–15, 19–26] and varied from 0 to 25 %. The total mortality rate of 13 studies was 6.9 % (54 /782 patients).

Discussion

To the best of our knowledge, our study is the first systematic review of motor evoked potentials monitoring during thoracic and thoracoabdominal aortic aneurysm open repair surgery. Based on the results of a diagnostic meta-analysis of selected studies (Fig. 4), MEP monitoring during TAAA open repair may be sufficiently sensitive and specific for detecting intraoperative spinal cord ischemia and postoperative paraplegia.

We conducted sub-group analysis of pooled sensitivity and specificity to find out which cut-off point is good for detecting postoperative paraplegia. The all-or-none cut-off point showed better pooled sensitivity and specificity than other cut-off points (Fig. 6). We excluded one study [16] which had a 75 % cut-off point in conducting sub-group analysis, so pooled sensitivity and specificity could not be made.

In 8 [12, 13, 16, 17, 20, 22–24] studies, the anesthesia methods were not clearly described, although the importance of the anesthesia regimen was recognized during MEP monitoring. The relationship between body temperature and MEP monitoring outcomes were not described quantitatively in any study selected, although body temperature may affect the reliability of MEP monitoring [19]. In future studies, the relationship between these key factors and the MEP monitoring outcomes should be investigated.

There are certain limitations in the present study. Because our search strategy was limited to only English and Japanese language articles, there is a possibility of publication (language) bias.

We searched the gray literature; however, we excluded the gray literature, such as proceedings, from our study. We also excluded 3 [18, 19, 22] studies because there were no dichotomous outcomes about MEP and paralysis. Therefore, there is a possibility of publication bias because of these factors, though explicit publication bias was not detected.

Fehlings et al. conducted a systematic review of MEP monitoring in spinal surgery [59]. They researched the evidence for intraoperative neurophysiological monitoring to improve clinical outcome, presented useful evidence on sensitivity and specificity, and answered the clinically relevant questions raised. They also pointed to the lack of evidence as to whether neuromonitoring reduces the rate of occurrence or worsening of neurological deficits in spinal surgery. In our search, we found no studies directly comparing TAAA open repair with and without MEP monitoring to detect its effectiveness in reducing neurological deficits. So we Schepens et al. investigated the factor of postoperative paraplegia after TAAA open repair by multivariate analysis [60]. In that study, MEP monitoring combined with spinal drainage was found to be a factor in reducing the rate of postoperative paraplegia (odds ratio 0.28; 95 % CI 14–56 %). Ethical issues may be involved in such controlled trials because neurophysiological monitoring is recognized as being useful in reducing such complications through physiological and clinical common practices.

Conclusion

MEP monitoring may be sensitive and specific for detecting intraoperative spinal cord ischemia and postoperative paraplegia in patients undergoing TAA/TAAA open repair. However, in some of the selected studies, we found a lack of reporting on key factors for reliable MEP monitoring, such as anesthesia methods, body temperature, and relationships between the MEP monitoring results and paraplegia. There is a need for an evidence-based consensus

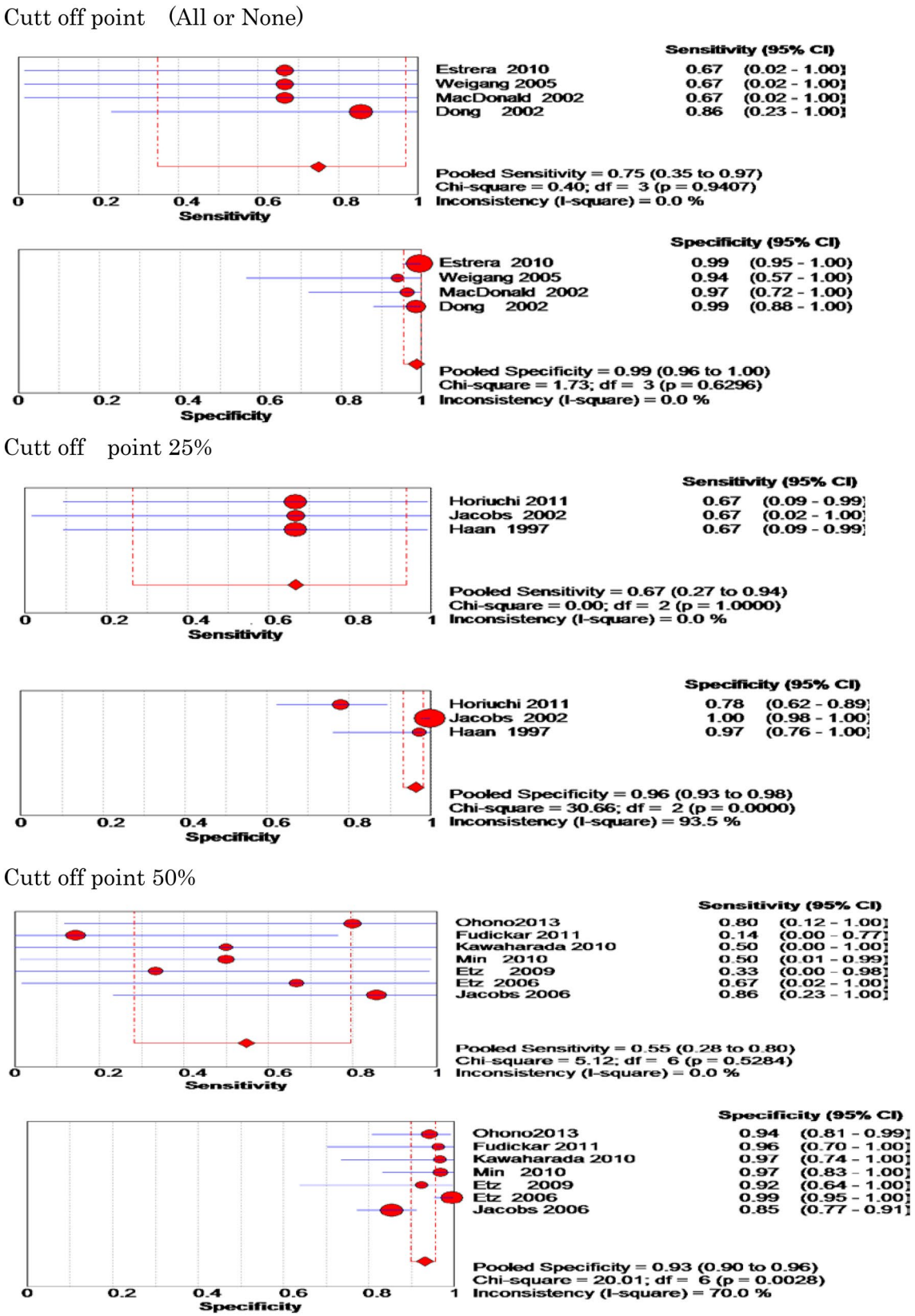

Fig. 6 Subgroup analysis of pooled sensitivity and specificity by cut-off point of MEP positive amplitude

protocol to describe the requirements in reporting items in MEP studies and to conduct better quality studies on patients undergoing TAA/TAAA open repair surgery.

Acknowledgments The authors are indebted to Mr. Takaaki Suzuki, BS for his assistance in searching the literature, abstracting the data, and proofing, and indebted to Dr. Mitsuru Ida for quality assessment of included studies by QUADAS-2. This study was conducted as part of a multicenter research project in Japan aimed at minimizing trauma to the spinal cord during TAA/TAAA surgery.

Compliance with ethical standards

Conflict of interest None of the authors have conflicts of interest with this manuscript.

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Appendix 1

Search strategy

MEDLINE

(motor evoked potential) AND ((descending thoracic aneurysm) OR (thoracoabdominal aortic aneurysm)) Limits: English, Japanese, Publication Date from 1990.

EMBASE

Set File Items Description

S1 S ABDOMINAL(W)AORTA(W)ANEURYSM
S2 S THORACIC(W)AORTA(W)ANEURYSM
S3 S DESCENDING(W)THORACIC(W)ANEURYSM
S4 S THORACOABDOMINAL(W)AORTIC(W) ANEURYSM
S5 S S1 + S2 + S3 + S4
S6 S MOTOR(W)EVOKED(W)POTENTIAL
S7 S EVOKED(W)MUSCLE(W)RESPONSE
S8 S S6 + S7
S9 S S5*S8
S10 S PY $\geq$ 1990
S11 S S9*S10

CINAHL

S9 S5 and S6
S6 S3 or S4
S5 S1 or S2
S4 (MH "Evoked Potentials, Motor")
S3 motor evoked potential
S2 (MH "Aortic Aneurysm, Abdominal") OR (MH "Aortic Aneurysm, Thoracic")
S1 Descending thoracic aneurysm or thoracoabdominal aortic aneurysm

The Japanese Central Register of Controlled Trials

Aneurysm- thoracic part/TH or Aortic aneurysm-abdominal part/TH or Descending aortic aneurysm/AL or Thoracoabdominal aneurysm/AL) and (motor evoked potential/TH or motor evoked potential/AL) and (LA = Japanese,engish and CK = human and PDAT = 1990/1/1:2011/5/31).

Cochrane database (CCTR)

#1 (Descending thoracic aneurysm) or (thoracoabdominal aortic aneurysm)
#2 MeSH descriptor Aortic Aneurysm, Thoracic explode all trees
#3 MeSH descriptor Aortic Aneurysm, Abdominal explode all trees
#4 (motor evoked potential)
#5 MeSH descriptor Evoked Potentials, Motor explode all trees
#6 (#1 OR #2 OR #3)
#7 (#4 OR #5)
#8 (#6 AND #7)

WHO ICTPR

TAAA AND motor evoked potential OR thoracic aortic aneurysm AND motor evoked potential OR abdominal aortic aneurysm AND motor evoked potential OR descending thoracic aneurysm AND motor evoked potential OR thoracoabdominal aortic aneurysm AND motor evoked potential OR thoracic aneurysm AND motor evoked potential OR abdominal aneurysm AND motor evoked potential OR thoracoabdominal aneurysm AND motor evoked potential.

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(motor evoked potential*) AND (TAAA OR "thoracic aortic aneurysm" OR "abdominal aortic aneurysm" OR "descending thoracic aneurysm" OR "thoracoabdominal aortic aneurysm" OR "thoracic aneurysm" OR "abdominal aneurysm" OR "thoracoabdominal aneurysm")

Appendix 2

On-going study

K Yoshitani et al. Motor Evoked Potential and Cerebrospinal Fluid Drainage in Thoracic and Thoracoabdominal Aneurysm Repair. National Cerebral and Cardiovascular center. Date of registration: 2014-11-01.

Appendix 3

Excluded studies	Reason for exclusion
Jacobs [2]	This is a review article
Sloan [30]	This is a review article
Takahashi [31]	MEP is D-wave monitoring
Hamanishi [32]	MEP is D-wave monitoring
Sueda [33]	MEP is D-wave monitoring
Sueda [34]	MEP is D-wave monitoring
Sueda [35]	MEP is D-wave monitoring
Zoli [36]	Possible duplicated article
Mommertz [37]	Possible duplicated article
Backes [38]	Possible duplicated article
Minatoya [39]	Possible duplicated article
Nijenhuis [40]	Possible duplicated article
Weigang [41]	Possible duplicated article
Lases [42]	Possible duplicated article
Hanafusa [43]	Possible duplicated article
Jacobs [44]	Possible duplicated article
Jacobs [45]	Possible duplicated article
Meylaerts [46]	Possible duplicated article
Jacobs [47]	Possible duplicated article
Genstofer [48]	Publication in language other than English or Japanese
Greiner [49]	Publication in language other than English or Japanese
Weigang [50]	This study involved stent-grafting procedures
Schepens [51]	Insufficient descriptions about MEP monitoring
Gloviczki [52]	Insufficient descriptions about MEP monitoring
Koja [53]	Insufficient descriptions about MEP monitoring
Kurihara [54]	Insuffficient description for MEP monitoring
Etz [55]	Insuffficient description for MEP monitoring
Dong [56]	Insuffficient description for MEP monitoring
Conrad [57]	Insuffficient description for MEP monitoring
Lancaster [58]	Insuffficient description for MEP monitoring
Sephens [60]	Insuffficient description for MEP monitoring
Dong [61]	Insuffficient description for MEP monitoring

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