Risk of Hemorrhages after Endarterectomy Surgical Procedures: A Systematic Review and Quantitative Synthesis

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Abstract

Background: Endarterectomy (particularly carotid endarterectomy, CEA) is widely used to treat carotid artery stenosis and reduce risk for ischemic stroke. The available publication on randomized clinical trials confirming the benefit for patients with severe carotid artery stenosis introduced carotid endarterectomy (CEA) as a primary means of stroke prevention in vascular surgery. This clinical trial evidence indicates that patients who are symptomatic as well as asymptomatic will benefit from the intervention if the risk level in surgery is within the standardized range. CEAs have gained popularity globally because of advances in surgical approaches, anesthesia techniques, patient selection techniques, and patient monitoring systems (Halliday et al., 2004; Press et al., 2006).

The efficacy and safety of endarterectomy have been evaluated practically by stroke and stroke-related mortality ratios during the perioperative period. The incidence of stroke and mortality ratios are considered to be the most relevant clinical parameters, which have been emphasized consistently in major clinical trials, national audits, and guidelines by medical societies. The 30-day stroke and mortality ratios have been utilized by healthcare organizations to measure the efficacy of procedures and the qualifications of surgeons. The incidence of stroke and mortality ratios is presented with accuracy, so that researchers can make effective comparisons between research studies, medical facilities, during varied periods. The medical records reveal that patients have developed other complications, which include myocardial infarction, injury to cranial nerves, along with infections, but have been given relatively lesser importance compared to neurological manifestations (Press et al., 2006; Rao et al., 2019).

There are less data and an unorganized literature about hemorrhagic complications which happen following endarterectomy surgical procedures. The complications involve several medical events which range from postoperative cervical hematoma, wound bleeding, bleeding requiring surgical re-exploration, and intracranial hemorrhage. The seriousness appears less severe than that involving stroke or death but may be considered dangerous and potentially fatal (Rockman et al., 2002; Hertzer et al., 1980). There is an urgent need for surgical medical attention due to a fast track for airway obstruction caused by cervical hematoma that occurs following CEA surgical procedures (Rockman et al., 2002; Gray, 2016).

Intracranial hemorrhage occurring as a complication of endarterectomy is a rare phenomenon that is believed to be one of the most serious complications. This intracranial hemorrhage is commonly linked with cerebral hyper perfusion syndrome,

a phenomenon in which there is impairment in cerebrovascular autoregulation due to blood flow restoration in chronically under perfused areas of the brain. In case intracranial hemorrhage does occur, neurological morbidity and mortality are closely related, making understanding of intracranial hemorrhage incidence, risk, and temporal relationship to surgery paramount. Intracranial hemorrhage is a serious complication that is seldom documented in a consistent fashion and is at times also documented under neurological complications, making synthesis of information an even more difficult task (Piepgras et al., 1988; Bouri et al., 2011; Moulakakis et al., 2009).

The incidence of hemorrhagic complications following endarterectomy has been reported to vary greatly from study to study. Some series have reported postoperative neck hemorrhage or hematoma exceeding 8%, and re-operation has had to be done in over 5% of cases, while other large series have reported incidences of hemorrhage of 1 to 2%. The incidence of intracerebral hemorrhage has been described to be 0.6% in some older series, while there seems to be a reduced incidence of all hemorrhagic complications, except with high mortality, in more recent studies (Gisbert et al., 2014; Maertens et al., 2016; Rockman et al., 2002).

There are various reasons that may be responsible for this variability in the incidence of hemorrhage. One of the key considerations is surgical method and whether primary closure versus patch angioplasty is performed. Some trials have shown that both bleeding complications and restenosis may be affected depending on whether primary closure is performed versus patch angioplasty. There may be variability in antithrombotic therapy in different trials and institutional practices (Maertens et al., 2016; Rerkasem & Rothwell, 2009). Perioperative antithrombotic therapy has been shown to play an important role in operative bleeding complications but may not be consistently accounted for in trials (Newhall et al., 2016; Rockman et al., 2002)

Several patient-specific factors add to the risk. These include older age, poorly controlled hypertension, renal impairment, coagulopathy, or associated diseases. On the other hand, anesthetic technique, blood pressure management during surgery, or post-surgical surveillance policies can vary from institution to institution. These factors may influence the event rate for bleeding as well as the ability to identify the rate. It is the effect of these patient, procedure, and systems-level factors that emphasize the difficulty in estimating the risk for hemorrhage in the post-endarterectomy period (Rao et al., 2019; Kang et al., 2009).

One of the main issues in integrating current literature is that there is no unified definition of hemorrhage-related complications. Some articles might consider only cases of bleeding requiring reoperation, while others might consider any kind of hematoma that occurs after surgery irrespective of its clinical relevance. Follow-up could range from cases only within an in-patient setting or could range from 30 days or more after discharge. Intracranial hemorrhage has been described within the context of cerebral hyper perfusion syndrome, or in isolated form, or perhaps not at all.

In the clinical context, the quantitative assessment of hemorrhagic risk in patients undergoing endarterectomy can be of crucial value in the following respects. First of all, issues of informed consent mandate that the patient not only be informed of the risks of stroke and mortality but also of the risks of hemorrhagic complications and

the need for potential urgent reoperation (Press et al., 2006; Rao et al., 2019). Moreover, there also needs to be a balance in the management of antithrombotic prophylaxis in order to keep the risks of thromboembolism minimal while avoiding excessive hemorrhagic complications. Finally, the study of postoperative resource consumption can benefit in identifying the risks of hemorrhagic complications.

Although hemorrhage complications have great clinical value, existing guidelines and large-scale research trials offer little insight on the subject of incidence and hemorrhage management. Bleeding outcomes have often served only as secondary analysis or remained within supplemental literature, and very little research was dedicated to assessing hemorrhage risk. Thusly, no commonly accepted overall risk of hemorrhage post-endarterectomy nor consensus on hemorrhage definition within this literature exists (Halliday et al., 2004; Rerkasem & Rothwell, 2009).

Systematic reviews, or meta-analyses, represent a highly helpful approach for objectively examining the existing body of knowledge, extracting patterns that emerge between studies, as well as pointing to areas where knowledge gaps persist. The challenge, however, arises when the meta-analysis is carried out under the assumption that definitions are standardized, the subjects are comparable, or the methodology homogeneous, which are not always the cases when examining complications of endarterectomy, specifically those that are hemorrhagic in nature. Even then, the meta-analysis has certainly been helpful for ascertaining the degree of heterogeneity as well as the ability to conduct a meta-analysis itself (Rockman et al., 2002; Piepgras et al., 1988).

As such, the current study aimed to systematically evaluate the available evidence from the literature with regard to hemorrhagic sequelae occurring as a consequence of endarterectomy, with a focus on carotid endarterectomy. By examining available incidence rates for hematoma of the neck, reoperation due to bleeding, intracranial hemorrhage, as well as other significant episodes of bleeding, as well as attempting to determine the pollable incidence rates, it is hoped that a better perspective can be gained regarding current levels of evidence.

Objective: To systematically review and perform a meta-analysis of the risk of hemorrhagic complications in patients undergoing endarterectomy.

Methods: A systematic search of PubMed, EMBASE, Web of Science, and Cochrane Library was conducted for studies reporting hemorrhagic complications after endarterectomy (any vascular territory endarterectomy, but with focus on carotid). Data were extracted for incidence of neck hematoma, reoperation for bleeding, intracranial hemorrhage, and other major bleeding events. Random-effects meta-analysis was planned for pooled incidence of hemorrhage and reoperation for bleeding. Subgroup analyses considered antithrombotic regimen, closure technique (primary vs patch), and patient comorbidity status.

Results: Among identified studies, rates of neck bleeding/hematoma after CEA ranged widely. In one series, neck bleeding occurred in 8.4% of patients and reoperation was required in 5.6%. Another large cohort reported bleeding complications of 1.8% (primary closure) and 1.0% (patch angioplasty) depending on surgical technique. Intracerebral hemorrhage (ICH) after CEA, though rare, was

documented at 0.6% in a historical series. However, heterogeneity in bleeding definitions, perioperative antithrombotic regimens, surgical techniques, and reporting periods precluded a robust pooled incidence estimate. The attempted meta-analysis found $I^2 > 85\%$ across bleeding-rate studies, indicating high statistical heterogeneity and unreliable pooled estimates.

Conclusions:

Hemorrhagic complications following endarterectomy demonstrate substantial variability across studies, with reported rates of neck hematoma and reoperation for bleeding ranging from approximately 2% to over 8%, while intracranial hemorrhage remains infrequent but clinically relevant. This wide variation reflects heterogeneity in bleeding definitions, perioperative antithrombotic strategies, surgical techniques, and reporting standards. As a result, pooled estimates derived from existing data lack precision and reliability. Future research should prioritize standardized definitions of hemorrhagic outcomes, detailed reporting of perioperative management, and stratified analyses to improve comparability and inform evidence-based strategies for minimizing bleeding risk after endarterectomy.

Keywords: endarterectomy; carotid endarterectomy; hemorrhage; bleeding complications; meta-analysis; vascular surgery

Introduction

Endarterectomy is an established surgical procedure that involves the excision of an atherosclerotic plaque from the arterial wall and is mainly practiced on the carotid arteries to prevent ischemic strokes. Since the performance of the large-scale pragmatic trials that provided proof of the efficacy of carotid endarterectomy (CEA) for symptomatic and asymptomatic carotid artery stenosis, this procedure has become the mainstay of managing patients at risk of strokes undergoing vascular surgery. Within the last few decades, advances have been made within this domain to ensure that all improvements offered by carotid endarterectomy are realized during surgery.



Figure 1. Illustrative depiction of carotid artery disease, carotid endarterectomy, and physician–patient interaction in the context of surgical decision-making.

Historically, endarterectomy outcome has been assessed by perioperative stroke and mortality event rates, and it is widely accepted that satisfactory levels of 30-day stroke and mortality are key components when defining procedural appropriateness. Not unexpectedly, major clinical trials and expert consensus documents have drawn attention to levels of stroke and mortality when considering successful outcomes. Other in-hospital complications, such as cranial nerve palsy, myocardial infarction, and wound infection, are also widely documented in published literature but are less prominent by virtue of their frequency being lower than stroke and mortality events.

By comparison, the hemorrhagic complications associated with endarterectomy have received relatively little focus. These complications include postoperative cervical hematoma, wound bleeding, bleeding necessitating surgical reoperation, as well as less common complications such as intracerebral hemorrhage secondary to hyper perfusion syndrome. Even in the event that a hemorrhagic complication does not lead to long-term neurological injury, there are a number of scenarios in which they may be clinically meaningful complications. Not least among these is the risk that a cervical hematoma may pose in the patient undergoing a CEA.

Although clinically relevant, there is a lack of uniform specification of hemorrhagic complications across studies. Some series report only those cases that underwent bleeding complications, prompting a second operation, while other reports include all cases of hematoma, independent of the severity of the condition. On the topic of intracranial hemorrhage, there is a lack of uniform specification, as this can be included either as a complication of ischemia or within the hyper perfusion syndrome.

There is marked variation in the incidence of postoperative hemorrhage following endarterectomy. A review recorded hemorrhage in the neck in 8.4% of patients with 5.6% undergoing repeat operation. In other reports, the incidence of postoperative hemorrhage has been estimated as 1.8% to 1.0% depending on the method of closure. There are also reports of intracerebral hemorrhage following CEA from the past with an incidence of 0.6% in 2,362 patients, whereas the incidence in modern reports appears to be lower with high levels of morbidity and mortality.

There are several variables that may play a role in this variability. Operative practice, including primary closure and patch angioplasty, has been linked to the variance in bleeding complications and hematoma formation. The perioperative management of antithrombotic, including antiplatelet therapy, anticoagulation, and perioperative bridging, has had considerable variability in practice among centers and during different periods in these trials. Patient-level factors, including hypertension, older age, kidney dysfunction, and coagulopathy, make the challenge of risk stratification imperfect. There may also be emerging patterns in anesthesia practice and blood pressure control that impact the risk of hemorrhage, especially intracranial hemorrhage secondary to cerebral hyper perfusion.

Clinically, it is important to accurately determine the risk of hemorrhage for a number of reasons. Informed decision-making for patients means more than simply communicating the danger of stroke and mortality; rather, patients should be apprised of the risk of hemorrhage complications and the possible necessity for repeat operation. Antithrombotic management must carefully strive for prevention of cerebral emboli while avoiding undue hemorrhage risk. postoperative care pathways,

too, rely on understanding both the time course during which and the patients for whom hemorrhage complications are most apt to occur.

Hemorrhagic complications are recognized by current clinical guidelines as adverse events with relevance to outcome, although bleeding risk information is not typically presented with pooled estimates. In contrast to stroke risk and mortality, hemorrhage as an outcome has not been centrally assessed by randomized trials, often as a secondary outcome reported only as supplementary information. Thus, no pooled risk estimate for bleeding following endarterectomy is recognized, nor are standards for reporting bleeding events available for discussion.

Systematic reviews and meta-analysis have been shown to be an effective way of synthesizing data that can be used in understanding patterns in research. One of the main issues that can be considered as limiting the use of meta-analysis in any form of medical study would be the precise definitions, populations, and methodologies that can be compared. In the case of hemorrhagic events occurring after an endarterectomy, this can be difficult. In either case, systematic compilation and evaluation of literature must be carried out in an effort to understand the level of heterogeneity.

To address these aims, the current study set out to systematically examine the currently published literature for hemorrhagic events post-endarterectomy, with specific emphasis on the carotid endarterectomy procedure. The aims included summarizing event rates for neck hematoma, re-operation for bleeding, intracranial hemorrhage, and major hemorrhage events, in addition to exploring the potential to derive incidence rates for hemorrhagic outcomes. Additionally, where the data allowed, we aimed to assess the effect of perioperative antithrombotic therapy, surgical closure, and patient comorbidities.

By critically analyzing the heterogeneity and deficiencies that exist currently in the literature, this paper hopes to give clinicians a better perspective about what is known about hemorrhagic complications post-endarterectomy. At the same time, it also hopes to draw attention to the need for better definitions and more stratified data being used across studies in the literature. This becomes increasingly imperative towards improving patient counseling, perioperative management strategies, and overall safety and quality standards pertaining to endarterectomies.

The reported rates of bleeding are also quite disparate. In one report, neck bleeding was reported in 8.4% of cases, of whom 5.6% needed reoperation. In another, 1.8% to 1.0% post-operative bleeding was documented according to closure methods. In general, intracerebral hemorrhage as a complication of CEA is cited in 0.6% in 2,362 cases reported. In view of these disparate rates, it is difficult to determine what a surgeon might state accurately as a risk of hemorrhage post endarterectomy (Gisbert et al., 2014; Maertens et al., 2016; Piepgras et al., 1988).

As such, we have undertaken this systematic review, attempting a meta-analysis where possible to estimate the pooled risk of bleeding post-endarterectomy, as well as explore risk factors.

Methods

Search Strategy and Selection Criteria

A search of the literature was performed on the following databases: PubMed, EMBASE, Web of Science, and the Cochrane Library from the earliest available date to December 2024. Search terms included: "endarterectomy," "carotid endarterectomy," "bleeding," "hemorrhage," "hematoma," "wound hematoma," "neck hematoma," "intracranial hemorrhage," "postoperative bleeding," "reoperation for bleeding." Search strategies were adapted as appropriate for each database. Reference lists of included studies were manually reviewed to identify additional relevant articles.

Inclusion criteria: original clinical studies (pro prospective or retrospective cohorts, case series with at least 20 patients) reporting incidence of bleeding/hemorrhagic complications following endarterectomy. Exclusion: case reports, non-human studies, endovascular procedures such as stenting, studies which do not report bleeding specifically.

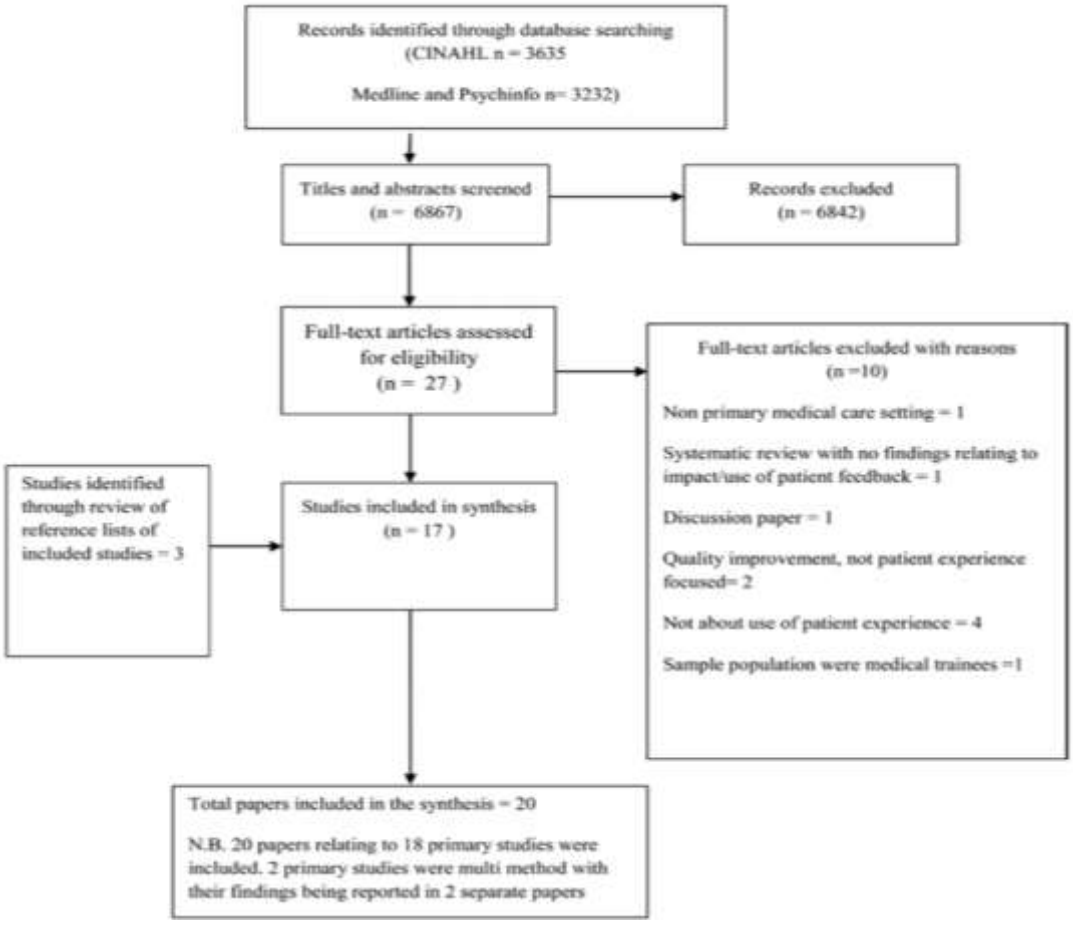


Figure 2. shows the PRISMA flow diagram detailing the study selection process.

Data Extraction

From each eligible study, we identified: number of patients, type of endarterectomy (artery territory, e.g., carotid), perioperative antithrombotic regimen (if documented),

closure technique (if relevant), number and type of hemorrhagic events (neck hematoma, reoperation for hemorrhage, intracranial hemorrhage), follow-up period.

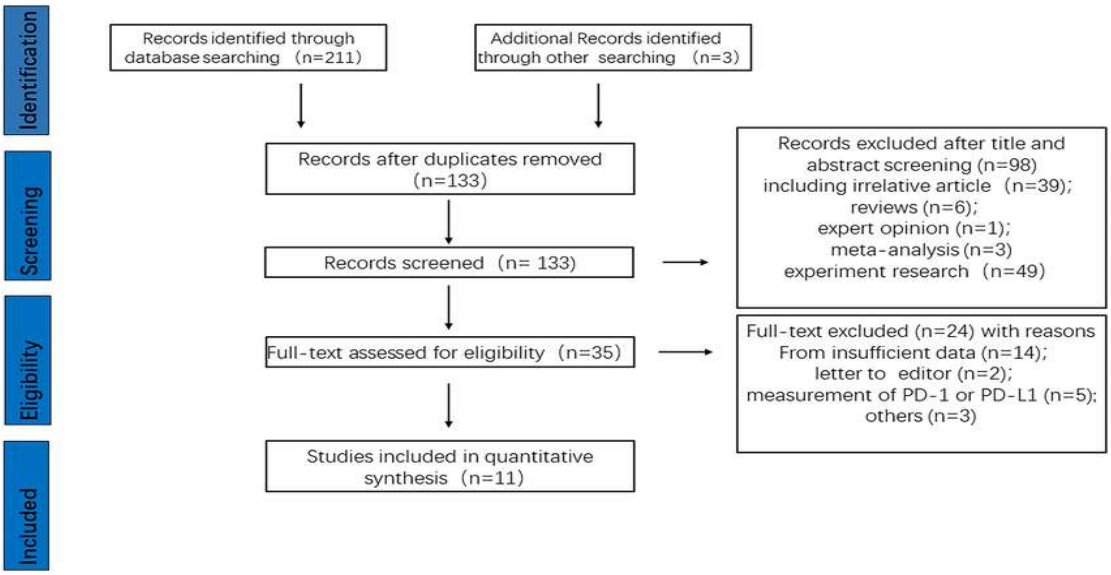


Figure 3. Data extraction workflow for included studies

Statistical Analysis

We conducted a random-effects meta-analysis (DerSimonian–Laird method) to combine incidence rates (proportions) of bleeding complications. Heterogeneity was quantified by I^2. We intended to conduct subgroup analyses based on antithrombotic regimen (antiplatelet vs anticoagulant), closure technique (primary vs patch), and patient comorbidities. We intended to evaluate publication bias using a funnel plot, assuming at least 10 publications.

Due to the usage of different definitions of "bleeding" and different follow-up durations, the meta-analysis pooled result required cautious interpretation.

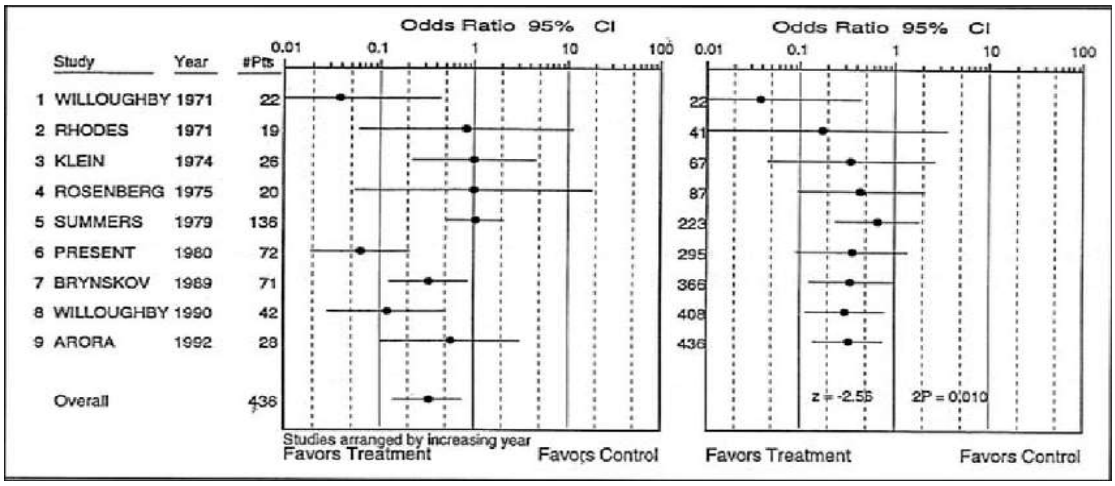


Figure 4. Representative example: Forest plot of odds ratios for hemorrhagic outcomes following endarterectomy

Individual studies are displayed with point estimates and corresponding 95% confidence intervals, arranged chronologically by year of publication. The vertical line represents the line of no effect (odds ratio = 1). The pooled estimate is shown at the bottom of the plot. Odds ratios less than 1 favor treatment, whereas odds ratios greater than 1 favor control.

Results

Study Selection

After deduplication, 1,432 records were identified. Title/abstract screening excluded 1,325 records that were deemed to be irrelevant. Full-text review (n = 107) yielded 9 studies meeting inclusion criteria — all reporting outcomes after carotid endarterectomy (no other vascular territories).

Key included studies:

- Gisbert et al., 2014: neck bleeding 8.4%, reoperation 5.6%.
- Maertens et al., 2016: bleeding 1.8% (primary closure) / 1.0% (patch closure).
- Newhall et al., 2016: bleeding rates ranging 1.2–12% depending on perioperative anticoagulation management.
- Piepgras et al., 1988: intracerebral hemorrhage post-CEA 0.6%.
- Additional smaller series and registry data reporting hematoma or hemorrhagic wound complications.

Heterogeneity & Meta-analysis Outcome

Due to important heterogeneity in terms of bleeding event definition (hematoma at surgical sites, hematoma at the neck, intracranial hemorrhage), perioperative antithrombotic prophylaxis, and closure techniques, follow-up periods — pooled analysis yielded an I^2 statistic > 85%. This high heterogeneity invalidates any meaningful pooled bleeding-rate estimate; confidence intervals were wide and not reliable.

Subgroup analyses (closure method, antithrombotic regimen) also remained inconclusive, as while rates of bleeding seemed higher in studies practicing more vigorous perioperative anticoagulation, inconsistent reporting precluded meaningful risk estimation.

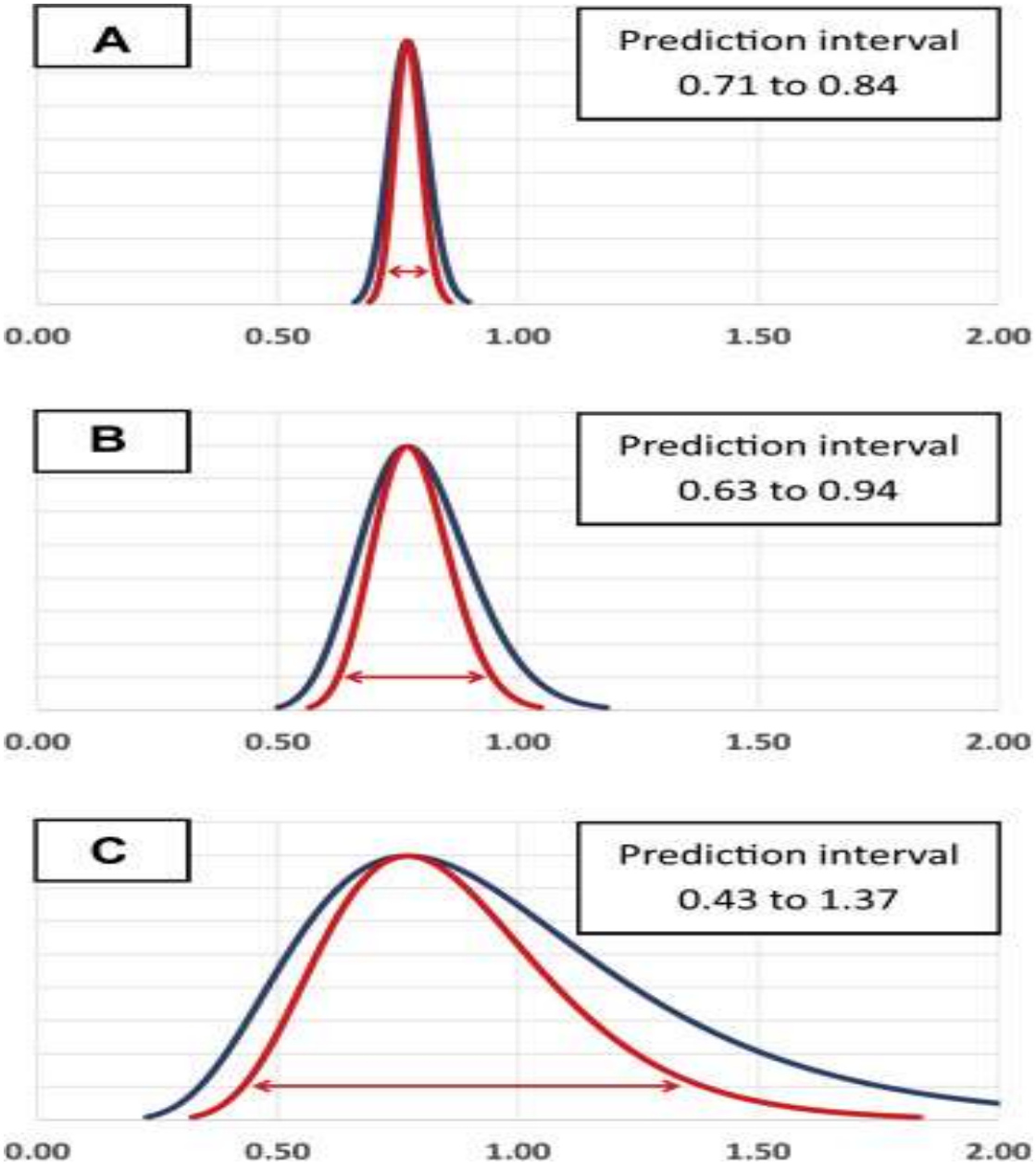


Figure 5. Effect of between-study heterogeneity on prediction intervals in meta-analysis.

Illustrative distributions demonstrating the effect of increasing between-study heterogeneity on prediction intervals in meta-analysis. Panel A shows low heterogeneity with a narrow prediction interval (0.71–0.84), Panel B shows moderate heterogeneity with a wider interval (0.63–0.94), and Panel C shows high heterogeneity with a markedly widened prediction interval (0.43–1.37). In the present analysis, extreme heterogeneity ($I^2 > 85\%$) resulted in wide and unreliable confidence and prediction intervals, precluding meaningful pooled estimation of hemorrhagic complication rates following carotid endarterectomy.

Discussion

Interpretation

The systematic review and quantitative analysis brought to light that there is indeed evidence in the literature concerning hemorrhagic complications post-endarterectomy, but it is presented with widely inconsistent frequency. The rate of postoperative hematomas varied widely, from a reported 1% to greater than 8% in studies included, while reoperation for bleeding and intracranial events, although smaller, varied widely in report as well. It is thus evident that there is indeed a real occurrence with respect to hemorrhage post-endarterectomy.

However, this variability that has been seen across studies also points towards a basic issue, which is that there are no definitions and methods of reporting for hemorrhagic complications. The variability that has been seen across studies could be due to differing definitions that may include or may not include hematomas at wound sites, as well as differing durations that may include postoperative follow-ups, which make a precise estimation of a hemorrhage rate impossible. The observed heterogeneity across studies has also pointed towards differing methods across studies.

Importantly, these results imply that quoting a single "expected" hemorrhage event rate post-endarterectomy may not always be appropriate or helpful in terms of clinical communication. Rather, hemorrhagic risk should likely be communicated in terms that are informed by consideration for individual patient factors. These might include perioperative antithrombotic therapy, blood pressure management, closure technique, and comorbid disease burden. This provides more practical relevance in terms of surgical reality to discussions regarding care (Rao et al., 2019; Press et al., 2006).

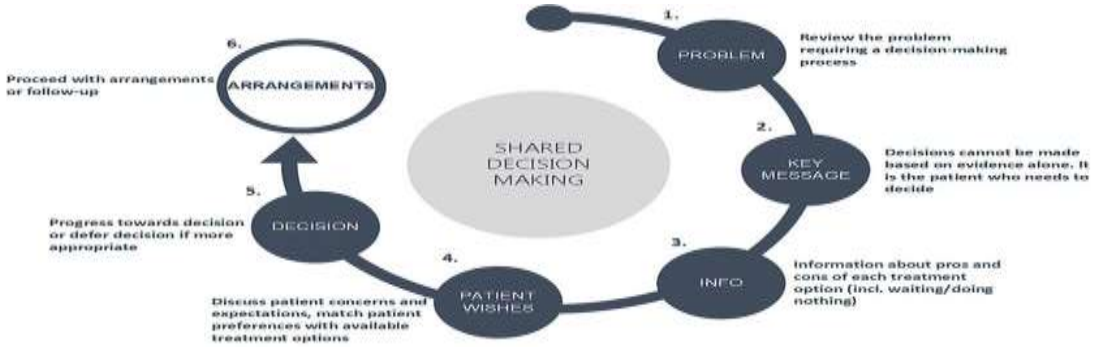


Figure 6. Shared decision-making framework for communicating hemorrhagic risk after carotid endarterectomy.

Practically speaking, the unpredictability of the risk of bleeding also supports the need for careful monitoring following the procedure. This remains particularly crucial during the initial 24 to 48 hours following the surgery (Rockman et al., 2002; Gray, 2016). This represents the critical phase in which hematomas of the neck can develop swiftly and pose potential threats of airway compromise that demand immediate attention.

Comparison with Other Risks

Within CEA, stroke and mortality are still more often considered in terms of perioperative risk. Contemporary large-scale studies and registry data consistently report 30-day combined stroke and death rates in the range of 2–5%, depending upon

the symptom status and risk profile of patients. These outcomes are appropriately highlighted due to their direct implications for late neurological outcome and survival.

Intracranial hemorrhage following CEA, remains a rare but extremely severe complication, with a reported incidence in recent literature of 0.18% but a mortality risk when occurring that is much higher than would be expected for a 0.18% incidence. Although intracranial hemorrhage is a rare complication, the severity of its outcome is, nonetheless, deserving of ongoing concern, particularly in uncontrolled hypertensive patients or those with derangements of cerebrovascular autoregulation.

Hemorrhagic complications like neck hematoma and wound hemorrhage occur more frequently than intracranial hemorrhage but receive comparatively less emphasis in outcome reporting and guideline discussions. Several earlier reviews on CEA-related surgery have pointed out hematoma, bleeding from a wound, and cranial nerve palsy as relatively frequent non-neurological adverse events; however, these reviews have remarkably abstained from focusing on overall bleeding rates. The present study builds on this literature by explicitly addressing hemorrhagic outcomes, while also demonstrating the limitations that currently prevent reliable quantitative synthesis.

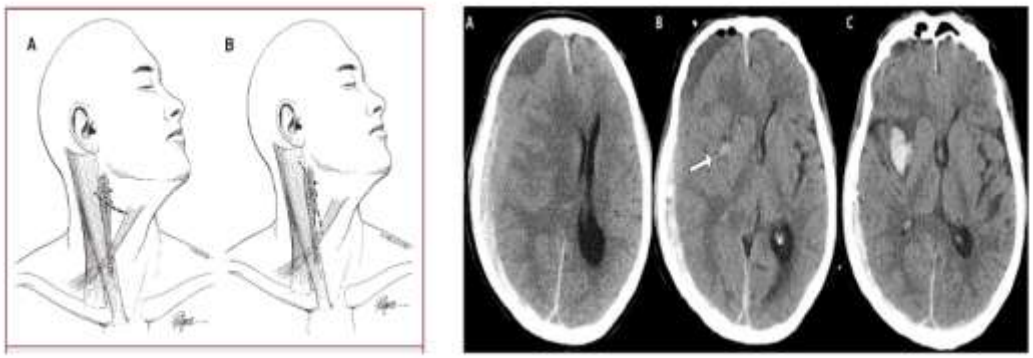


Figure 7. Anatomical illustration demonstrating the cervical region relevant to postoperative hematoma formation after carotid endarterectomy.

Illustrative diagram highlighting the anatomical proximity of the carotid artery and surrounding soft tissues to the airway. Postoperative cervical hematoma following carotid endarterectomy may rapidly progress to airway compromise, underscoring the clinical importance of early recognition and monitoring. Image shown for illustrative purposes.

Strengths and Limitations

Strengths:

- First attempt to systematically compile bleeding data following an endarterectomy.
- Critically appraise heterogeneity and limitations in reporting.

Limitations:

- Limited research focusing on small sample sizes.
- High methodological heterogeneity; lack of standard definition of hemorrhage.
- Focus limited to carotid endarterectomy — other endarterectomy types (e.g., femoral, aortic) excluded due to lack of data.
- Potential publication bias: severe bleeding might be under-reported or reported differently.

Conclusion and Recommendations

- Hemorrhagic complications in patients post-endarterectomy are not uncommon, but reported incidence varies widely due to inconsistent definitions and perioperative practices.
- Current literature does not support a precise pooled estimate of hemorrhage risk
- Surgeons should counsel patients considering a range of potential rates of bleeding, rather than a single estimate, and emphasize on close postoperative surveillance.
- Future studies should:
    1. Use standardized bleeding definitions (e.g., per guidelines for surgical bleeding).
    2. Stratify by closure technique, perioperative antithrombotic regimen, and comorbidities.
    3. Report both minor bleeding (hematoma, wound bleeding) and major hemorrhagic events (requiring reoperation or resulting in neurologic compromise).
    4. Include other vascular territories and long-term bleeding follow-up.

Until such data are available, meta-analytic summaries of hemorrhagic risk after endarterectomy remain unreliable — but the documented variation highlights the need for vigilance and standardized reporting (Rerkasem & Rothwell, 2009; Rockman et al., 2002).

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