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Acute subdural haematoma in the elderly: to operate or not to operate? A systematic review and meta-analysis of outcomes following surgery

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ABSTRACT

Objectives Acute subdural haematoma (ASDH) is a devastating pathology commonly found on CT brain scans of patients with traumatic brain injury. The role of surgical intervention in the elderly has been increasingly questioned due to its associated morbidity and mortality. Therefore, a systematic review and meta-analysis of the literature to quantify the mortality and functional outcomes associated with surgical management of ASDH in the elderly was performed.

Design/setting A multidatabase literature search between January 1990 and May 2020, and meta-analysis of proportions was performed to quantify mortality and unfavourable outcome (Glasgow Outcome scale 1–3; death/ severe disability) rates.

Participants Studies reporting patients aged 60 years or older.

Interventions Craniotomy, decompressive craniectomy, conservative management.

Outcome measures Mortality and functional outcomes (discharge, long-term follow-up (LTFU)).

Results 2572 articles were screened, yielding 21 studies for final inclusion and 15 for meta-analysis. Pooled estimates of mortality were 39.83% (95% CI 32.73% to 47.14%; 10 studies, 308/739 patients, I^2=73%) at discharge and 49.30% (95% CI 42.01% to 56.61%; 10 studies, 277/555 patients, I^2=63%) at LTFU. Mean duration of follow-up was 7.1 months (range 2–12 months). Pooled estimate of percentage of poor outcomes was 81.18% (95% CI 75.61% to 86.21%; 6 studies, 363/451 patients, I^2=45%) at discharge, and 79.25% (95% CI 72.42% to 85.37%; 8 studies, 402/511 patients, I^2=66%) at LTFU. Mean duration of follow-up was 6.4 months (range 2–12 months). Potential risk factors for poor outcome included age, baseline functional status, preoperative neurological status and imaging parameters.

Conclusions Outcomes following surgical evacuation of ASDH in patients aged 60 years and above are poor. This constitutes the best level of evidence in the current literature that surgical intervention for ASDH in the elderly carries significant risks, which must be weighed against benefits.

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INTRODUCTION

Traumatic brain injury (TBI) is among the leading causes of mortality and morbidity worldwide.[1] [2] We are currently experiencing an increasing contribution of traumatic injuries in the elderly population towards the

Strengths and limitations of this study

► Critical appraisal of studies reporting both mortality and functional outcomes following surgical evacuation of acute subdural haematoma in the elderly.
► Examination of risk factors for poor outcome in included studies.
► Heterogeneity arising from potential differences in indications for surgical intervention.
► Potential reporting bias and heterogeneity in meta-analysis from inclusion of smaller retrospective studies.

incidence of major intracranial injuries.[3–5] Statistical data from the Centers for Disease Control and Prevention demonstrated a 17% increase in accidental falls-related TBI between 2008 and 2017 in the USA.[6] Importantly, mortality rates secondary to falls-related TBI were disproportionately higher in adults aged 75 years and above, at 54.08 per 100 000 person-year, compared with 8 per 100 000 in those aged less than 75 years. With estimates of approximately 1.5 billion individuals aged above 65 years by 2050, there is an urgent need for effective and pragmatic management of elderly patients with TBI.[7] Acute subdural haematoma (ASDH) is a potentially life-threatening form of TBI encountered by emergency services, which is characterised by extra-axial collection of acute blood between the dura and underlying brain parenchyma. The elderly are particularly vulnerable due to the risks of falls-related TBI, age-related atrophic changes in the brain and the use of anticoagulants.[8] Hence, rationalisation of ASDH management in this group of patients is becoming increasingly pertinent.[9] [10] This was highlighted by a recent single centre retrospective study in the UK, which demonstrated that the odds of inpatient death were

approximately 15 times higher than its chronic counterpart in patients aged 75 years and above.[11]

In the acute setting, ASDH management consists of either urgent surgical intervention or conservative management. The former typically consists of a craniotomy and evacuation of ASDH, though a decompressive craniectomy (DC) may be required in rare instances where the brain is severely swollen intraoperatively. However, the decision for surgical intervention for ASDH in elderly patients remains a point of contention due to its associated mortality.[12] Surgical intervention is typically guided by imaging parameters including an ASDH >10 mm thickness or midline shift (MLS) >5 mm on CT imaging, neurological deterioration and/or intracranial pressure monitoring.[13] While these guidelines are applicable to the general management of adult TBI, their applicability to the elderly population is less clear. Quantifying surgical morbidity and mortality is vital for tailoring decisions to this age group and managing the expectations of relatives who may not appreciate the associated risks. Therefore, in this study, we perform a systematic review and meta-analysis of the literature to quantify the mortality associated with surgical management of ASDH in the elderly, and identify potential risk factors for poor outcome in this group.

METHODS

This study was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 Statement.[14]

Literature search

A multidatabase (PubMed, Embase and Cochrane Reviews) literature search was performed between January 1990 and May 2020 by authors OM and OE (figure 1). Conflict of opinion was settled by senior author MZ. The following search terms were used in varying combinations: "subdural h(a)ematoma", "subdural h(a)emorrhage", "outcome*", "compar*", "morbid*", "mortality*", "complication*", "reoccur*", "recur*", "surg*", "operati*", "non(-)surgical", "burrhole", "crani*", "old*", "frail*", "geri*", and "elder*" (online supplemental data 1). Eligible articles were restricted to English language only,
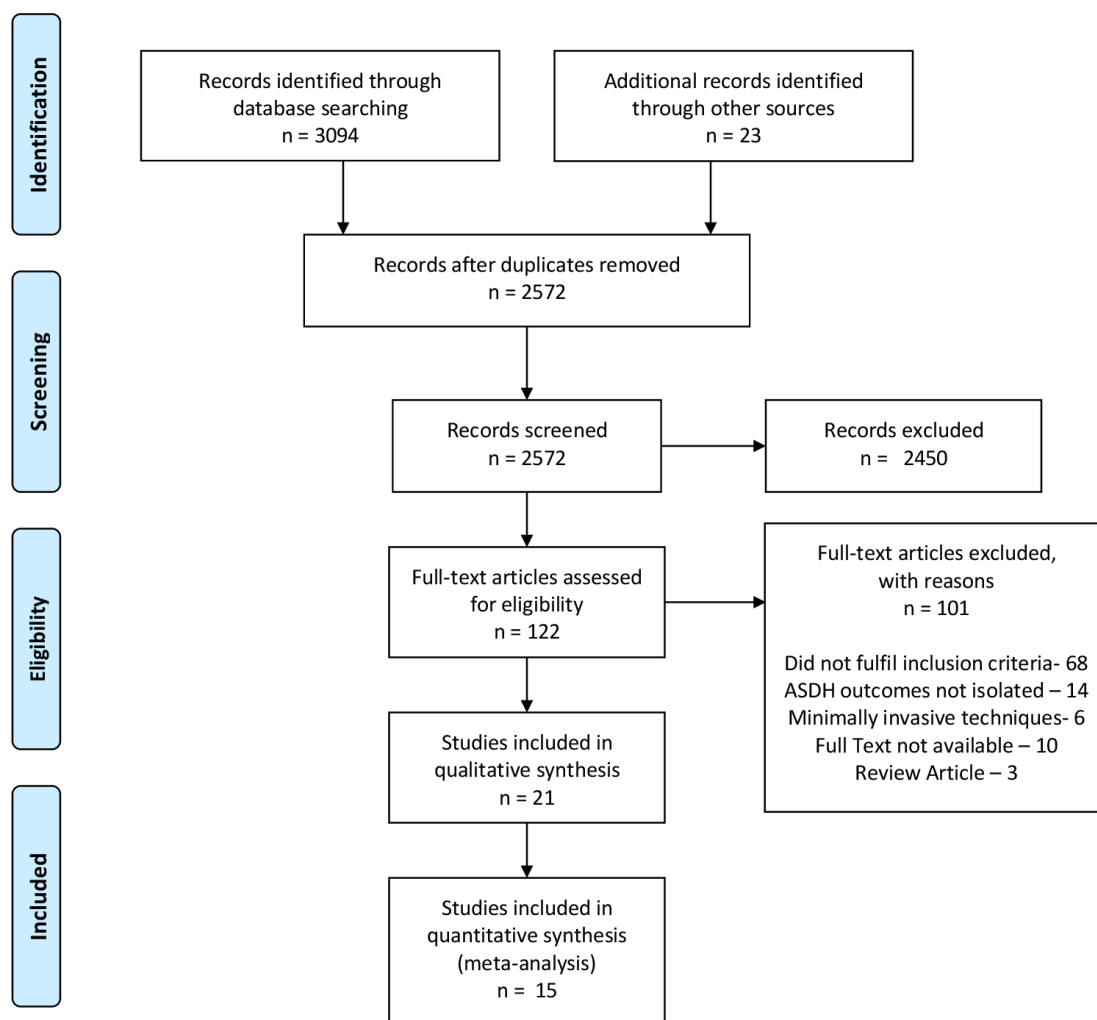

Figure 1 Search strategy for systematic literature review in accordance with PRISMA guidelines. ASDH, acute subdural haematoma; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

and the bibliographies of included studies were screened for further relevant studies.

Study selection

Studies fulfilling the following criteria were included: (1) diagnosis of traumatic ASDH (confirmed on CT imaging), (2) patient age of 60 years or above, (3) patients who underwent surgical evacuation of ASDH and (4) reported clinical outcome. Studies including patients younger than 60 years were only included if management and clinical outcomes were specifically reported for the target age group. Exclusion criteria included: (1) diagnosis of chronic subdural haematoma with no evidence of acute component; (2) significant life-threatening extracranial injuries and (3) abstracts, conference presentations, editorials and expert opinions.

Data extraction

The following variables of interest were extracted by authors SM and RS from eligible studies: number of patients, age, gender, baseline functional status, preadmission residence, comorbidities, use of antithrombotic agents (antiplatelets or anticoagulants), mechanism of injury, preoperative Glasgow Coma Score (GCS)/pupillary reaction to light, imaging findings, indications for surgical intervention, timing of surgery, intervention performed (craniotomy or decompressive craniectomy), mortality (at discharge and longer-term follow-up (LTFU)), clinical outcome (at discharge and LTFU) and duration of follow-up. Variables were summarised with respect to whether included studies examined associations with outcome. Studies reporting mortality and/or Glasgow Outcome scale (GOS) were considered for inclusion in meta-analysis (see below). When reported, GOS was used to dichotomise outcomes into good (GOS 4–5) and poor (GOS 1–3) categories. Studies reporting conservative management along with surgical management were examined for potential comparison between different treatment groups (see below). Studies reporting minimally invasive techniques for ASDH evacuation were included for narrative synthesis. All included studies were assessed for quality using the Strengthening of Reporting of Observational Studies in Epidemiology (STROBE) criteria[15] and an adaptation of the risk of bias in non-randomised studies of interventions (ROBINS-I) tool[16] by two authors independently (IM and JM) (table 1). Studies with STROBE score <13 or ROBINS-I score of critical risk of bias were deemed ineligible for inclusion in meta-analysis.

Statistical analysis

Statistical analysis was performed using R V.3.6.0, and the metafor and meta packages.[17] The percentage of patients under the following categories were pooled for meta-analysis: (1) deaths at discharge, (2) deaths at LTFU, (3) poor outcome at discharge and (4) poor outcome at LTFU. Poor outcome was defined as patients with GOS 1–3. Studies using other scoring systems were not included for meta-analysis to avoid introducing bias from definition of outcome. LTFU was defined as any time point beyond the time of discharge (specific duration of follow-up was recorded). All studies reporting mortality and/or GOS (specific score or dichotomised) in patients aged 60 years or above that underwent surgical evacuation of ASDH were included for meta-analysis. Surgical evacuation consisted of either craniotomy or decompressive craniectomy.

Heterogeneity was quantified with the following tests: DerSimonian and Laird estimator[18] to estimate between-study variance (τ^2, Cochran's Q test and the I^2 statistic. Given that $I^2 > 25\%$ in all analyses and there was potential heterogeneity between studies with respect to specific age groups, a random effects model with double-arcsine transformation[17 19] was used. Pooled estimates were reported with 95% CIs. Studies published prior to January 2000 were excluded from meta-analysis to avoid distortion of summary effect sizes due to differences in healthcare technology as a function of time. Subgroup analysis was performed using the year of the study as a moderator (pre-January and post-January 2000) with a mixed effects model[17] (online supplemental data 2). Differences between subgroup summary estimates were significantly different. Therefore, older studies were excluded on both theoretical and statistical premises. Conservative and surgical groups were not compared due to fundamental differences in treatment indications and baseline cohort characteristics, which were acknowledged by relevant studies (online supplemental data 3,4).

RESULTS

A total of 2572 articles were screened, yielding 21 studies for final inclusion[20–40] (table 1). A set of fifteen studies were suitable for meta-analysis, with varying subsets used for each separate analysis depending on available outcome data. All studies were single centre retrospective studies, except for a recent retrospective multicentre study performed in Italy involving 213 patients from 5 centres.[38]

Mortality

Mortality was generally defined as death by a specific time point, except for one study that also included death or discharge to a hospice.[34] Mortality at discharge (381/820 patients) and LTFU (322/622 patients) was reported by 13 studies, of which 10 studies were included for meta-analysis (figure 2). Duration of follow-up was provided by all studies that reported mortality at LTFU, with a mean of 7.4 months (range 2–18 months). The pooled estimate of percentage of deaths was 39.83% (95% CI 32.73% to 47.14%) at discharge, and 49.30% (95% CI 42.01% to 56.61%) at LTFU. Mean duration of follow-up in studies included for meta-analysis was 7.1 months (range 2–12 months) (table 2).

Functional outcomes

Poor outcome was defined as patients with GOS 1–3. GOS on discharge (poor outcome in 437/532 patients)

Table 1 Summary of included studies of ASDH in elderly following systematic review of the literature

Author, year	Location (period)	Country	No of hospitals/ Patients	Age for inclusion (years)	Age (years) % Male	Treatment	Outcomes measured	Risk factor analysis	STROBE criteria	ROBINS-I score
Wilberger et al, 1991[20]	Allegheny General Hospital (1982 to 1987)	USA	1/28	>65	N/A	Craniotomy	Mortality, GOS at discharge	Age, ICP, GCS, timing of surgery; descriptive analyses (not in elderly group alone)	17	Moderate
Cagetti et al, 1992[21]	University of Genoa Medical School (January 1980 to December 1988)	Italy	1/26	>80	84.2 (mean) 57.7%	Surgical evacuation	Mortality, GOS at discharge	Age, mechanism, GCS, comorbidities; descriptive analyses (not in elderly group alone)	10	Serious
Jamjoom, 1992[22]	Frenchay Hospital (1980 to 1989)	UK	1/27	≥75	79.2 (mean) 55.6%	Surgical evacuation	Mortality, GOS at 6 months	Age, sex, mechanism, GCS/ pupils, imaging, timing of surgery; χ2 test	14	Moderate
Kotwica and Jakubowski, 1992[23]	Medical University of Lodz (1984 to 1990)	Poland	1/27	>70	N/A	Surgical evacuation	Mortality, GOS at discharge	Age, gender, GCS, imaging; descriptive analyses	15	Moderate
Massaro et al, 1996[24]	Centro Traumatologico Ortopedico (1982 to 1992)	Italy	1/25	>65	N/A	DC	Mortality, GOS at 18 months	Age, gender, mechanism, GCS, timing of surgery, imaging; χ2 test/ Fisher's exact test (not in elderly group alone)	15	Moderate
Koc et al, 1997[25]	Erciyes University (January 1986 to August 1995)	Turkey	1/15	≥61	N/A	Craniotomy	Mortality, GOS at 3 months	Age, gender, presenting GCS; χ2 test (not in elderly group alone)	10	Moderate
Petridis et al, 2009[26]	UKSH Campus Kiel	Germany	1/119	>65	N/A 55.2%	Craniotomy, DC	Mortality, GOS discharge	GCS/ pupils, imaging, anticoagulation, ICP; χ2 test, ANOVA	13	Moderate
Hanif et al, 2009[27]	Beaumont Hospital (January 1999 to December 2003)	Ireland	1/29	>70	77.0 (mean) 59.7%	Surgical evacuation	Mortality, GOS at 6 months	Age, GCS; descriptive analyses (not in elderly group alone)	13	Moderate
Taussky et al, 2012[28]	Kontansspital Aarau (January 2002 to December 2007)	Switzerland	1/37	>65	73.0 (median) 46%	Craniotomy - 23 DC - 14	Mortality at discharge Mortality, GOS at 6 months	Age, pupils, timing of surgery, GCS/ pupils, anticoagulants, comorbidities; descriptive analyses	20	Moderate
Hamed et al, 2016[40]	Rheinische Friedrich-Wilhelms University (January 2010 to December 2014)	Germany	1/57	>70	N/A	Craniotomy, DC	GOS at 6 months	Age, TBI severity, timing of admission, surgical approach, antithrombotics, timing of surgery, duration of hospital stay, postoperative complications (not for elderly group alone)	17	Serious
Merzo et al, 2016[29]	Uppsala University Hospital (2008 to 2010)	Sweden	1/24	≥65	N/A	Craniotomy – 23 DC – 1	Mortality, GOS at 6 months	Age, gender, comorbidities, mechanism, imaging; χ2, unpaired Student's t-test (not for elderly group alone)	17	Moderate

Table 1 Continued

Author, year	Location (period)	Country	No of hospitals/ Patients	Age for inclusion (years)	Age (years) % Male	Treatment	Outcomes measured	Risk factor analysis	STROBE criteria	ROBINS-I score
Raj et al, 2016[30]	Helsinki University Hospital (January 2009 to December 2012)	Finland	1/44	≥75	81.0 (median) 52%	Craniotomy, DC	Mortality at 1 and 3 years	Age, baseline functional status, residence, gender, anticoagulants, mechanism, GCS/ pupils; χ2 test, unpaired Student's t-test, Mann-Whitney U test	18	Moderate
Benedetto et al, 2017[31]	Azienda Ospedaliero-Universitaria Pisana (June 2011 to December 2014)	Italy	1/67	>70	80.5 (median) 53.7%	Craniotomy	Mortality, GOS at 1 and 6 months	Age, imaging, GCS, antiplatelets; simple and multiple linear regression	17	Moderate
McGinity et al, 2017[32]	University of Texas Health Science Center (2005–2015)	USA	1/34	≥80	84.0 (mean) N/A	Craniotomy – 32 DC – 2	Mortality, GOS at 2 months (variable)	Age, mechanism, type of surgery, anticoagulants, GCS/ pupils, imaging, comorbidities; Fisher's exact test, Mann-Whitney U test	17	Moderate
Won et al, 2017[33]	Goethe-University Hospital (January 2007 to December 2016)	Germany	1/56	≥80	85.0 (mean) 43%	Craniotomy, DC	Mortality at discharge	GCS; univariate/ multivariate logistic regression	20	Moderate
Monsivais et al, 2018[34]	University of Texas Health Science Centre (January 2006 to July 2016)	USA	1/112	≥70	N/A	Craniotomy – 101 DC – 11	Mortality at discharge	Age, GCS, type of surgery; χ2 test/ Fisher's exact test	20	Moderate
Akbik et al, 2019[35]	University of New Mexico Hospital (January 2013 to December 2017)	USA	1/62	≥65	78.0 (median) 48%	Craniotomy, DC	Mortality, GOS at discharge and 3 months	Age, comorbidities, GCS/pupils, imaging, antithrombotics; Kruskal-Wallis, Fisher's exact test	15	Moderate
Bus et al, 2019[36]	Academic Medical Centre (January 2000 to October 2015)	Netherlands	1/84	≥65	75.0 (mean) 64.3%	Craniotomy – 74 DC – 10	Mortality at discharge Mortality, GOS at 1 year	Age, gender, imaging, GCS/ pupils, age of SDH, imaging, timing of surgery, anticoagulation; χ2/ Fisher's exact tests, Mann-Whitney U test, univariate logistic regression	17	Moderate
Sufaro et al, 2019[37]	Soroka University Medical Center (2006–2016)	Israel	1/28	>70	81.5 (mean) 53.6%	Craniotomy	Mortality, mRS score at discharge and 1 year	Age, gender, baseline status, antithrombotics, GCS, imaging, neurological deficit; descriptive analyses	17	Serious
Trevisi et al, 2020[38]	Ospedale Santo Spirito; Fondazione Policlinico Universitario A. Gemelli IRCSS; S. Anna University Hospital, UOC Neurochirurgia (January 2016 to December 2019)	Italy	5/147	≥70	78 (mean) 58%	Craniotomy- 133 DC- 14	Mortality, GOS at discharge and 6 months	Age, gender, comorbidities, GCS/ pupils, imaging, side of SDH, size of craniotomy, timing of surgery, anticoagulants; χ2 test, univariate/multivariate logistic regression	16	Moderate

Continued

Table 1 Continued

Author, year	Location (period)	Country	No of hospitals/ Patients	Age for inclusion (years)	Age (years) % Male	Treatment	Outcomes measured	Risk factor analysis	STROBE criteria	ROBINS-I score
Younsi et al 2020[39]	University Hospital Heidelburg (January 2006 to December 2016)	Germany	1/27	≥80	84.0 (median) 60%	Craniotomy, DC	Mortality, GOS at discharge	Age, gender, comorbidities, GCS/ pupils, imaging, surgical factors, anticoagulants; Fisher's exact test, unpaired Student's t-test	21	Serious

ANOVA, analysis of variance; ASDH, acute subdural haematoma; DC, decompressive craniectomy; GCS, Glasgow Coma Score; GOS, Glasgow Outcome Scale; ICP, intracranial pressure; IRCSS, Istituto di Ricovero e Cura a Carattere Scientifico; mRS, modified Rankin Scale; N/A, not available; ROBINS-I, risk of bias in non-randomised studies of interventions; SDH, subdural haematoma; STROBE, Strengthening of Reporting of Observational Studies in Epidemiology; TBI, traumatic brain injury; UKSH, Universitätsklinikum Schleswig-Holstein; UOC, Unità Operativa Complessa.

was reported by 9 studies, of which 6 were included for meta-analysis. GOS at LTFU (poor outcome in 459/578 patients) was reported by 11 studies, of which 8 were included for meta-analysis (figure 2). Duration of follow-up was provided by all studies that reported GOS at LTFU, with a mean of 6.8 months (range 2–18 months). Pooled estimate of percentage of poor outcomes was 81.18% (95% CI 75.61% to 86.21%) at discharge, and 79.25% (95% CI 72.42% to 85.37%) at LTFU. Mean duration of follow-up in studies included for meta-analysis was 6.4 months (range 2–12 months) (table 2). One study[37] reported modified Rankin Scale (mRS) scores at discharge and LTFU. Poor outcome was defined as mRS 5–6, and reported in 28% (8/28 patients) at discharge and 57% (16/28 patients) at LTFU.

Risk factors for poor outcome
Demographics
Inclusion age was reported by all studies, and analysed with respect to outcome in older age groups in nine studies (table 3). Of these, two studies reported a significant effect of age on outcome,[31 34] while the remainder reported no significant associations. With respect to GOS at 30 days, age was negatively associated with GOS on multivariate (regression coefficient (RC) −0.054, p=0.013; other factors included volume of ASDH, GCS, MLS and antiplatelet use) but not univariate linear regression (RC −0.043, p=0.095) analyses.[31] Age was negatively associated with GOS at 6 months on both univariate (RC −0.063, p=0.031) and multivariate (RC −0.077, p=0.002) linear regression analyses.[31] Another study[34] demonstrated a significant association between patient age group (70–79 years, 80 years and above) and mortality on univariate analysis (p=0.05; χ^2 test) and age (70–79 years vs 80 years and above) as a predictor of mortality on multivariate logistic regression (OR 2.83; 95% CI 1.18 to 6.83; p=0.02; other covariates included GCS and surgical approach). Gender was reported by 15 studies, and analysed with respect to outcome in 4 studies (table 3). A significant association with outcome was not demonstrated in any of these studies.[30 36 38 39]

Baseline functional status
Baseline functional status was reported in 11 studies, of which 5 studies examined association with outcomes (table 3). One study[39] included patients aged 80 years and above demonstrated a significant association between outcome (favourable, unfavourable) and number of comorbidities (more than 1, less than or equal to 1) (p=0.05; Fisher's exact test). This was not statistically significant on analysis with a greater number of comorbidities (more than or equal to 5, less than 5). In contrast, other studies reported no significant association between number of comorbidities and dichotomised GOS[32 38] or mortality.[34] Two studies demonstrated no statistically significant differences between survivors and non-survivors with respect to premorbid independence[30 34] or preadmission residence.[30]
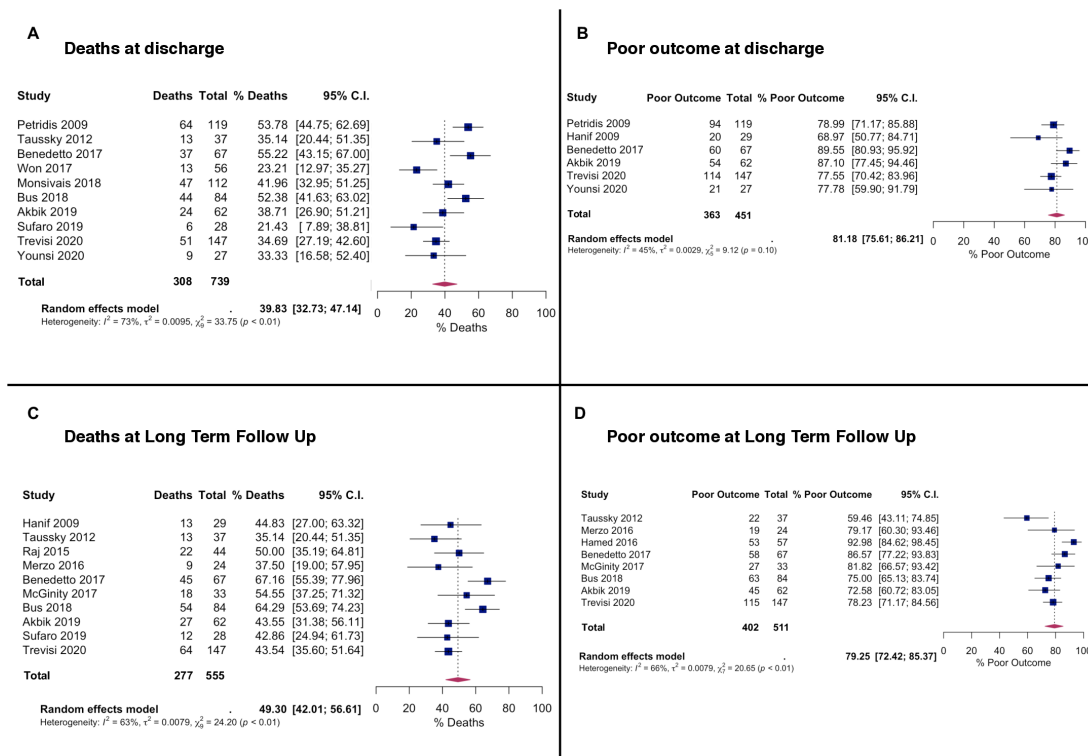
Figure 2 Forest plots depicting pooled estimates of mortality at discharge (A), poor outcome at discharge (B), mortality at discharge (C) and mortality at LTFU (D) in patients aged 65 years and above that underwent surgical evacuation of ASDH. ASDH, acute subdural haematoma; LTFU, long-term follow-up.

Use of antithrombotic agents

Use of antithrombotic agents was reported by 13 studies, of which 9 studies examined statistical association with outcome (table 3). Trevisi et al[38] demonstrated a significant association between use of anti-thrombotic agents and dichotomised GOS on univariate analysis (82 vs 57%; good vs poor outcome; p=0.01), though multivariate logistic regression demonstrated no significant effect of antithrombotic use on dichotomised GOS (OR 0.33; 95% CI 0.10 to 1.10; p=0.02; other covariates included GCS, ASDH thickness and MLS). Other studies demonstrated no significant association between antithrombotic use and GOS,[26 35] dichotomised GOS[32 36] or mortality.[30 35] Examination of antiplatelet and anticoagulant use in isolation also demonstrated no significant association with GOS[31 39] or mortality.[30 34]

Mechanism and severity of injury

Mechanism of injury was reported in seven studies.[22 26–28 30 34 35] The association between mechanism of injury and outcome was examined in five of these studies, but a significant association was not demonstrated.[22 26 28 30 34] In all seven studies reporting mechanism of injury, ground-level falls were the most common mechanism (range 65%–100%), with road traffic collisions being the second most common although much less common than falls (range 4%–30%).

Neurological status prior to surgical intervention was reported in all 21 included studies. Association between GCS or pupillary reactivity and outcome were examined in 11 studies. Of these, 10 studies demonstrated significant associations (table 3). Neurological status was reported preoperatively in two studies,[22 35] on admission and preoperatively in two studies,[36 38] and on admission in the remaining six studies. Significant heterogeneity was observed in the methodology used to assess the relationship between preoperative neurological status and outcome (online supplemental data 5, 6). Statistically significant associations between GCS and GOS[31 38 39] or mortality[26 30 33–35] were demonstrated across multiple studies. Similarly, significant associations were also demonstrated between pupillary reactivity and GOS[22 26 35 36] or mortality.[26 35] No significant relationship between GCS and GOS was demonstrated in four studies,[22 32 33 36] and between pupil reactivity and GOS/ mortality in four studies.[30 32 38 39]

Extracranial injuries were reported in four studies,[21–23 29] while patients with significant extracranial injuries were excluded from five studies.[20 24 25 31 37] There were no reports of extracranial injuries in the remaining studies. None of the included studies examined the relationship between extracranial injuries and outcome. However, early studies demonstrated poor outcomes in several patients with concomitant injuries: (1) of six patients with orthopaedic fractures (three patients with femoral fractures, two patients with rib fractures and one patient with a C2 fracture), five patients died[21] and (2) all eight patients with orthopaedic fractures had poor outcomes.[22]

Table 2 Mortality, outcomes and duration of follow-up following surgical evacuation of ASDH in patients aged 60 years and above

Author, year	No of Patients	At discharge (N, %)			At long-term follow-up (N, %)			
		Deaths	GOS 1–3	GOS 4–5	Deaths	GOS 1–3	GOS 4–5	Duration
Wilberger et al, 1991[20]	28	23	–	–	–	–	–	–
Cagetti et al, 1992[21]	26	23	23	3	–	–	–	–
Kotwica and Jakubowski, 1992[23]	27	23	–	–	–	–	–	–
Jamjoom, 1992[22]	27	–	–	–	19	23	4	6
Massaro et al, 1996[24]	25	–	–	–	15	22	3	18
Koc et al, 1997[25]	15	–	–	–	11	12	3	3
Petridis et al, 2009[26]	119	64	94	25	–	–	–	–
Taussky et al, 2012[28]	37	13	–	–	13	22	15	6
Raj et al, 2015[30]	44	–	–	–	22	–	–	12
Merzo et al, 2016[29]	24	–	–	–	9	19	5	6
Hamed et al, 2016[40]	57	–	–	–	–	53	4	6
Benedetto et al, 2017[31]	67	37	60	7	45	58	9	6
Won et al, 2017[33]	56	13	–	–	–	–	–	–
McGinity et al, 2017[32]	33	–	–	–	18	27	6	2
Monsivais et al, 2018[34]	112	47	–	–	–	–	–	–
Akbik et al, 2019[35]	62	24	54	8	27	45	17	3
Bus et al, 2019[36]	84	44	–	–	54	63	21	12
Sufaro et al, 2019[37]	28	6	–	–	12	–	–	12
Trevisi et al, 2020[38]	147	51	114	33	64	115	32	6
Younsi et al, 2020[39]	27	9	21	6	–	–	–	–

ASDH, acute subdural haematoma; GOS, Glasgow Outcome Scale.

Imaging

Imaging findings with respect to ASDH were reported in 15 included studies. The association between imaging findings and outcome was examined in eight of these studies, of which five showed significant findings (table 3). MLS was reported in seven studies,[26 31 32 35 36 38 39] while ASDH thickness or volume (estimated by volumetric analysis of CT scans) was reported in six studies.[26 31 32 36 38 39] All studies reporting these imaging parameters analysed their association with outcome.

Petridis et al[26] demonstrated a significantly greater proportion of patients with MLS>10 mm in the GOS-1 than in the GOS-5 category (χ^2 test; p<0.005). Furthermore, the difference between ASDH thickness and MLS was quantified and its association with outcome was examined. A significant association was identified between mean ASDH-MLS difference and individual GOS groups (analysis of variance (ANOVA); p<0.005), measuring 6.3 mm in the GOS-5 and 1.8 mm in the GOS-1 category. Similarly, three other studies demonstrated a significant association between mean MLS and dichotomised GOS[31 38] or mortality.[35] One study demonstrated a negative association between MLS and GOS at both 30 days (RC −0.053, p=0.015) and 6 months (RC −0.055, p=0.026) on univariate linear regression, though this did not reach statistical significance on multivariate analysis.[31] Two studies demonstrated no significant association between MLS and dichotomised[39] or trichotomised[35] GOS.

Two studies demonstrated significant associations between ASDH volume and outcome.[31 39] One study demonstrated a negative association between ASDH volume and GOS at both 30 days (RC −0.006, p=0.005) and 6 months (RC −0.005, p=0.027) on univariate linear regression, though this did not reach statistical significance on multivariate analysis.[31] Another study demonstrated a significantly smaller ASDH volume in the favourable outcome group when compared with the unfavourable outcome group (67 mL vs 118 mL; unpaired Student's t-test, p=0.05).[39] Two studies demonstrated no significant association between ASDH thickness and GOS categories[26] or dichotomised GOS.[38]

The presence of additional intracranial injuries, such as cerebral contusions and traumatic subarachnoid haemorrhage, were reported in eight studies[21–24 26 35 37–39] but only statistically analysed with respect to outcome in three studies.[22 26 35] None of these studies demonstrated significant associations between additional intracranial injuries and outcome.

Surgical factors

Timing of surgery from the time of admission or injury was reported in 10 studies, and analysed with respect to

Table 3 Potential risk factors for mortality or poor outcome following surgical evacuation of ASDH in patients aged 60 years and above

Author, Year	Outcome	Intervention	Risk factors									
			Age	Sex	Base line	GCS/pupils	Imaging	Mechanism of injury	Other intracranial injuries	Timing of surgery	Craniotomy vs DC	Antithrombotic agents
Wilberger et al, 1991[20]	Mortality GOS	Surgical	X	X	N	X	N	N	N	X	N	N
Cagetti et al, 1992[21]	Mortality GOS	Surgical	X	X	X	X	N	N	X	N	N	N
Jamjoom, 1992[22]	GOS	Surgical	NS	X	N	S	NS	NS	NS	NS	N	N
Kotwica and Jakubowski, 1992[23]	GOS	Surgical	X	X	N	X	X	N	X	N	N	N
Massaro et al, 1996[24]	Mortality GOS	DC	X	X	N	X	X	N	X	X	N	N
Koc et al, 1997[25]	Mortality GOS	Craniotomy	X	X	N	X	X	N	N	N	N	N
Hanif et al, 2009[27]	Mortality GOS	Craniotomy	X	X	N	X	N	X	N	N	N	N
Petridis et al, 2009[26]	Mortality GOS	Craniotomy, DC	X	X	N	S	S	NS	NS	N	NS	NS
Taussky et al, 2012[28]	GOS	Craniotomy, DC	X	X	X	X	N	NS	N	X	X	X
Hamed et al, 2016[40]	GOS	Craniotomy, DC	X	N	N	X	X	N	N	X	X	X
Merzo et al, 2016[29]	Mortality GOS	Craniotomy, DC	X	N	X	X	N	N	N	N	X	N
Raj et al, 2016[30]	Mortality	Craniotomy, DC	NS	NS	NS	S	N	NS	N	N	N	NS
Benedetto et al, 2017[31]	GOS	Craniotomy	S	X	X	S	S	N	N	N	X	NS
McGinity et al, 2017[32]	GOS	Craniotomy, DC	NS	N	NS	NS	NS	N	N	N	NS	NS
Won et al, 2017[33]	Mortality GOS	Craniotomy, DC	X	X	X	S	X	N	N	X	N	X
Monsivais et al, 2018[34]	Mortality	Craniotomy, DC	S	N	NS	S	N	NS	N	X	S	NS
Akbik et al, 2019[35]	Mortality GOS	Craniotomy, DC	NS	X	N	S	S	X	NS	N	N	NS
Bus et al, 2019[36]	Mortality GOS	Craniotomy, DC	NS	NS	N	S	NS	N	N	NS	NS	NS

Continued

Table 3 Continued

| Author, Year | Outcome | Intervention | Risk factors | | | | | | | | | |
			Age	Sex	Base line	GCS/pupils	Imaging	Mechanism of injury	Other intracranial injuries	Timing of surgery	Craniotomy vs DC	Antithrombotic agents
Sufaro et al, 2019[37]	Mortality mRS	Craniotomy	X	X	X	X	X	N	X	N	N	X
Trevisi et al, 2020[38]	GOS	Craniotomy, DC	NS	NS	NS	S	S	N	X	S	X	S
Younsi et al, 2020[39]	GOS	Craniotomy, DC	NS	NS	S	S	S	N	X	NS	N	NS

ASDH, acute subdural haematoma; DC, decompressive craniectomy; GCS, Glasgow Coma Score; GOS, Glasgow Outcome Scale; mRS, modified Rankin Scale; N, not reported; NS, non-significant association on statistical analysis; S, significant association on statistical analysis; X, reported but not statistically analysed.

outcome in 4 studies (table 3). No statistically significant associations were demonstrated with respect to dichotomised GOS in three studies.[22 36 39] One study demonstrated a significant association of timing of surgery after admission, divided into 6-hour increments between <6 hours and >72 hours, and GOS (χ^2 test; p<0.001).[38] However, on univariate logistic regression, timing of surgery (within 6 hours or >6 hours), demonstrated no significant effect on prediction of dichotomised GOS (p=0.20).

Choice of surgical approach included craniotomy or DC. Four studies did not distinguish between craniotomy and decompressive craniectomy, but defined surgical intervention as the surgical evacuation of ASDH.[20–23] Of the remaining studies, 12 studies included craniotomy and DC, 4 studies included craniotomies alone and 1 study defined surgical intervention as craniectomies[24] (table 1). Number of patients undergoing each surgical approach was specifically reported in six studies, however, only three studies examined association with outcome (table 3). In total, 52 patients underwent DC, but outcomes were only reported for 23 patients.[32 34 36] Two studies reported poor outcomes in in 2 out of 2, and 8 out of 10 patients.[32 36] One study reported mortality in 9 out of 11 patients.[34] Monsivais et al[34] demonstrated a significant association between surgical approach (craniotomy, DC) and mortality on univariate analysis (Fisher's exact test; p<0.01), and DC as a predictor of mortality when compared with craniotomy on multivariate logistic regression (OR 5.72; 95% CI 1.11 to 29.32; p=0.04; other covariates included age and GCS). Other studies demonstrated no significant associations between choice of surgical approach and dichotomised GOS[32 36] or mortality.[36]

DISCUSSION
Surgical outcomes
ASDH is a devastating traumatic pathology, and particularly so in the elderly. Although the significant mortality and morbidity associated with surgical intervention has been recognised for decades, there are no clear guidelines for ASDH management in this age group. With a growing elderly population worldwide and a shift in healthcare policy towards prioritising quality of life, it is essential that neurosurgical guidelines are adapted accordingly.[9 10] Indeed, the generic guidance for surgical intervention based on ASDH thickness, MLS and neurological deterioration may not necessarily be appropriate for elderly patients with ASDH.[13] In this study, we systematically reviewed the literature for studies reporting outcomes following surgical intervention in patients aged 60 years and above with ASDH. We demonstrate that the pooled estimated mortality rate in this group is 40% at the point of discharge, and 49% at LTFU (figure 2). Furthermore, the pooled estimated poor outcome (GOS 1–3) rate is 81% at discharge and 79% at LTFU. Analysis of separate age subgroups could not be performed due to insufficient reported data, and therefore inclusion age of above 60 years was used as a minimum criterion for

consideration. Only one study included patients above 60 years of age,[25] which was excluded from meta-analysis due to its date of publication. Therefore, our pooled estimated mortality and unfavourable outcome rates are generated from studies including patients aged 65 years and above. One potential source of heterogeneity was the inclusion of both craniotomy and DC within meta-analysis, as the majority of included studies did not distinguish reliably between surgical approach. Despite 11 studies including craniotomy and DC, only 7 studies reported specific numbers for each approach, and outcome could not be consistently deduced. We decided to include both procedures within the meta-analysis because: (1) we aimed to provide a pooled estimate for surgical intervention for ASDH in the elderly and (2) the decision between craniotomy and DC is intraoperative, therefore, quantification of mortality and morbidity following either procedure remains pertinent. In addition, of the three studies examining effect of surgical approach on GOS or mortality, only one study demonstrated a significant association with mortality.[34] However, this was likely due to the small proportion of patients that underwent DC. Another source of heterogeneity was the duration of follow-up. For the pooled estimate of mortality at LTFU, duration of follow-up was 6 months in five studies, 12 months in three studies, 3 months in one study and 2 months in one study. Similarly, for the pooled estimate of poor GOS at LTFU, duration of follow-up was 6 months in four studies, 12 months in two studies, 3 months in one study and 2 months in one study. Therefore, pooled mortality may have been underestimated given that a higher percentage of deaths would be expected at longer durations of follow-up. While the same concept may be true for pooled estimated poor outcomes, it is also possible that shorter durations of follow-up did not capture potential future neurological recovery. Given that included studies did not consistently report the direct cause of poor outcome or mortality, it remains difficult to extrapolate any meaningful conclusions regarding this factor. Surgical inclusion or exclusion criteria were detailed in 10 studies, and largely revolved around existing Brain Trauma Foundation Guidelines[13] (online supplemental data 4). The possibility of comparing surgical and conservative was initially evaluated, as four studies reported outcomes in conservatively managed patients.[28 33 37 38] However, indications for conservative management were due to inoperable comorbidities, good neurological status, moribund clinical status or unspecified (online supplemental data 3). Therefore, surgical and conservative groups were not feasible for comparison.

Risk factors

We also examined risk factors for mortality and poor outcome in the target cohort. Of nine studies examining the relationship between age and outcome, only two studies demonstrated a statistically significant effect.[31 34] One study demonstrated a negative association between age and GOS at 30 days and 6 months on multivariate regression.[31] Whether GOS should be modelled as a continuous variable is arguable, however, as each increment does not represent an equal difference in functional status. Another study, however, demonstrated that the odds of death were almost three times higher in patients aged 80 years and above compared with patients aged 70–79 years. While age appears intuitively likely to be associated with poorer outcomes, few studies demonstrate a significant association in the elderly cohort. Only two studies examined the relationship between baseline functional status and outcome. Neither demonstrated any difference between survivors and non-survivors with respect to premorbid independence[30 34] or preadmission residence.[30] Further studies are required to elucidate this relationship, since the use of scoring systems such as Karnofsky Performance Status[41] or Clinical Frailty Score[42] may provide a feasible method to prognosticate surgical candidates. This has been demonstrated by a recent study, which highlighted the use of the Modified Frailty Index[43] to predict 30 days mortality and 6 months unfavourable outcome.[44] Similarly, four studies reported the relationship between comorbidities and outcome, though only one study used a formal scoring system for comorbidities.[38] However, no significant association with dichotomised GOS was demonstrated.[38] In a similar fashion to baseline functional status, further studies using scoring systems such as the Charlston Comorbidity Index[45] would be useful for assessment for neurosurgical decision-making.

In contrast, the association between neurological status and outcome were examined in 11 studies. Although significant associations were demonstrated across several studies, a considerable degree of heterogeneity was observed in the approach to analysis (online supplemental data 5, 6). GCS was modelled as a continuous variable, dichotomised at various points or categorised with respect to severity of TBI. However, the emerging theme was that a lower GCS on admission was associated with a greater risk of mortality. Some studies demonstrated a similar relationship with risk of poor GOS,[31 38 39] though this did not consistently reach statistically significance.[22 32 33 36] Therefore, identifying a cut-off for admission GCS could be an important avenue for future research to help identify patients that are highly unlikely to benefit from surgery. Pupillary reactivity to light was also examined across several studies. As expected, fixed and dilated pupils were often associated with poor outcomes and mortality (online supplemental data 6), although some studies revealed no significant association. This could be due to subjective errors on reporting of pupillary reactivity, which may be remedied in future studies with use of pupillometers. In the absence of a reliable cut-off for preoperative GCS, understanding the relationship between pupillary reactivity and outcome is essential for prognosticating intubated patients. Several studies examined the relationship between imaging findings and outcome, demonstrating a significant association between MLS and outcome in four studies.[26 31 35 38] Similar

to the assessment of preoperative neurology, approaches to analysis were varied, with no reliable conclusion with respect to a prognostic cut-off value for MLS. Interestingly, while ASDH thickness was not significantly associated with outcome,[26] [38] ASDH volume was significantly associated with GOS in two studies.[31] [39] The reported negative association between ASDH-MLS differential and GOS may also warrant further investigation.[26] This has been previously reported in a retrospective cohort study of ASDH patients, which demonstrated a 75% mortality rate in patients with an ASDH-MLS differential of >5 mm.[46] In contrast, the group with an ASDH-MLS differential of 0 mm only had a 25% mortality rate. Therefore, further studies comparing different measurement approaches may yield useful information regarding prognostication.

Limitations

We acknowledge several limitations from our systematic review and meta-analysis. Although we performed a multi-database literature search, 10 full-text articles could not be accessed, which may have reported valid data for inclusion. Furthermore, non-English studies were excluded, raising the potential for geographical bias. Despite assessment of risk factors across included studies, a subgroup analysis could not be performed due to significant variation in the reporting of relevant data. Future studies should ensure that this is addressed as developing risk stratification scores will be essential to identify suitable surgical candidates. Also, duration of follow-up varied between studies with a range of 2–18 months, therefore, pooled estimates of outcomes at LTFU do not give an accurate indication of timescale. The majority of included studies were deemed at moderate risk of bias, though two studies were at serious risk (online supplemental data 7). However, none of the included studies were at critical risk of bias, and were therefore eligible for inclusion in meta-analysis. Of note, two key studies[47] [48] could not be included due to failure to meet our eligibility criteria. Shibahashi *et al*[47] compared outcomes following craniotomy and DC for ASDH across 1028 patients matched for age, gender, admission GCS and vital signs, and comorbidities. Interestingly, no differences in mortality between treatment groups in the elderly cohort were found. Indeed, this finding supports our approach to a pooled estimate for mortality on meta-analysis. This study was not included in our review due to it not presenting absolute mortality figures, rather a mean difference between groups only. While it provides some evidence of no difference in mortality when comparing craniotomy with DC, the groups were not matched for pupillary abnormalities, nor were any imaging parameters taken into account in the matching process. One recent study was published outside of the dates of our search strategy, examining a total of 2508 patients aged 65 years and older that underwent surgical evacuation of ASDH.[48] Data were collected from the USA National Trauma Data Bank registry between 2016 and 2017, which spans approximately 765 centres. Interestingly, inpatient mortality was estimated at only 30.5%. Multivariate logistic regression revealed that age, preoperative GCS, traumatic subarachnoid haemorrhage and MLS>5 mm were significant predictors of mortality. Although the risk factors are in keeping with findings from previous studies, the reported inpatient mortality was comparatively low. Given that surgical approach was not specified, as International Classification of Diseases (ICD)-10 diagnosis codes were used to extract data, and surgical indications may have varied significantly between centres, it is unclear whether inpatient mortality is truly representative of this population.

CONCLUSION

In this systematic review and meta-analysis, we demonstrate that outcomes following surgical evacuation of ASDH in patients aged 65 years and above are poor. Pooled estimated mortality rates in this group are 40% at discharge and 49% at LTFU. Estimated rates of poor GOS are 81% at discharge and 79% at LTFU. Potential risk factors for poor outcome include age, baseline functional status, preoperative neurological status and imaging parameters. While further studies are required to reliably characterise predictors of poor outcome to inform separate guidelines for surgical intervention in this cohort, this systematic review constitutes the best level of evidence in the current literature that surgical intervention for ASDH in the elderly carries significant risks, which must be weighed against benefits. We, herein, provide robust evidence that helps healthcare professional decision making and counselling of families on a contentious issue.

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