Risk factors that predict mortality in patients with blunt chest wall trauma. An updated systematic review and meta-analysis.

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ABSTRACT

Background: Over the last 10 years, research has highlighted new emerging potential risk factors for poor outcomes following blunt chest wall trauma. The aim was to update a previous systematic review and meta-analysis of the risk factors for mortality in blunt chest wall trauma patients.

Methods: A systematic review of English and non-English articles using MEDLINE, EMBASE and Cochrane Library from January 2010 to March 2022 was completed. Broad search terms and inclusion criteria were used. All observational studies were included if they investigated estimates of association between a risk factor and mortality for blunt chest wall trauma patients. Where sufficient data were available, odds ratios with 95% confidence intervals were calculated using a Mantel-Haenszel method. Heterogeneity was assessed using the I^2 statistic.

Results: 73 studies were identified which were of variable quality (including 29 from original review). Identified risk factors for mortality following blunt chest wall trauma were: age 65 or more (OR: 2.11; CI 95%: 1.85-2.41, three or more rib fractures (OR: 1.96; CI 95%: 1.69-2.26) and presence of pre-existing disease (OR: 2.86; 95% CI: 1.34-6.09). Other new risk factors identified were: increasing Injury Severity Score, need for mechanical ventilation, extremes of Body Mass Index and smoking status. Meta-analysis was not possible for these variables due to insufficient studies and high levels of heterogeneity.

Conclusions: The results of this updated review suggest that despite a change in demographic of trauma patients and subsequent new emerging evidence over the last 10 years, the main risk factors for mortality in patients sustaining blunt chest wall trauma remained largely unchanged. A number of new risk factors however have been reported that need consideration when updating current risk prediction models used in the Emergency Department.

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https://www.crd.york.ac.uk/PROSPERO/#recordDetails

What is already known on this subject?

There are numerous reported risk factors for poor outcomes in blunt chest trauma that clinicians use to aid prognostication when managing this patient cohort in the Emergency Department. The last ten years or so has seen a change in demographic of trauma patients to an older, more frail population, which has led to emerging evidence of new potential risk factors for mortality.

What this study adds?

This updated systematic review and meta-analysis provides an overview of the research, including new emerging evidence from the last 10 years, describing the risk factors for mortality in patients with blunt chest wall trauma. The review provides an indication of the variables that should be considered in the update of current risk prediction tools used in the Emergency Department for the management of blunt chest wall trauma.

INTRODUCTION

Many trauma centres globally have adopted clinical protocols that routinely advise admission to a critical care setting where possible for elderly patients with increasing numbers of rib fractures.[1, 2] Studies have also considered whether such patients should be considered for immediate transfer to a specialist trauma unit for the appropriate level of care to be provided.[3-5] In the patient with the more minor, non-immediately life-threatening injury, management is often less protocol-driven, and many different risk stratification tools and care pathways exist.[6, 7] Although it is now well-recognised that different sub-groups of patients with blunt chest wall trauma are at risk of developing complications, to date no universally accepted guidelines exist to assist in the recognition of these high risk populations.[7, 8] As a result, clinicians still report difficulty in prognostication of patients with blunt chest wall trauma, presenting to the ED.[7]

Risk factors for mortality in patients sustaining blunt chest wall trauma have been previously investigated and include a patient age of 65 or more, three or more rib fractures, pre-existing conditions and on-set of pneumonia.[9] In the last decade, there have been numerous further studies published investigating other potential risk factors for mortality in this patient cohort, including Body Mass Index (BMI)[10-12], Injury Severity Score (ISS)[8, 13, 14], need for mechanical ventilation[15-17], smoking history[8, 18], use of pre-injury anticoagulants[19], location of rib fractures[20] and various physiological parameters[16, 21, 22]. This research is of variable quality and ranges from small, single-centre retrospective studies, to large, national prospective studies which include data for tens of thousands of patients.

There is also recent research that describes a change in the demographic of the patients sustaining trauma and subsequently presenting to EDs, to an older and more frail population.[23, 24] This change in demographic has resulted in new potentially important risk factors for this patient group and the potential need for revision of current risk stratification tools used in the ED to guide patients management. Therefore, the aim of this review was to update a previous systematic review and meta-analysis[9] in order to summarise the risk factors for mortality in blunt chest wall trauma, accounting for the change in demographic and subsequent new research studies over the last 10 or more years. For the purpose of this study, we defined blunt chest wall trauma as blunt chest injury resulting in chest wall contusion or rib fractures, with or without non-immediate life-threatening lung injury.

MATERIALS AND METHODS

Search strategy

The PRISMA guidelines were followed in the completion of this updated review.[25] A broad search strategy was employed in order to capture all relevant studies. The search filter was used for Medline and Embase Databases and the Cochrane Library from January 2010 to March 2021. The previously retrieved studies from our original review were also included in this update. The search term combinations used were Medical Subject Heading (MeSH) terms, text words and word variants for blunt chest trauma. These were combined with relevant terms for aetiological factors. The search terms used in the review are illustrated in supplementary file 1.

The reference lists of all relevant studies were hand-searched in order to identify studies missed in the electronic search. The Annals of Emergency Medicine, Emergency Medicine Journal, Injury and the Journal of Trauma were hand-searched from January 2010 to March 2021 for relevant studies. All available Trauma and Emergency Medicine Conference abstracts were searched, in addition to OpenSIGLE (System for Information on Grey Literature in Europe) to identify grey literature. Searches were international and no search limitations were used. Inclusion and exclusion criteria used for study selection can be found in supplementary file 1.

Study selection and data collection

A two-step process (in which two researchers (CB and LN) analysed each title and abstract independently and then met to discuss any discrepancies) for selecting the studies was employed in order to reduce any potential selection bias. The selected studies were obtained and the full paper analysed by the reviewers. A previously piloted data extraction form was used to record information about study design, population, sample size, risk factors investigated, primary and secondary outcome measures used and relevant results. Study authors were contacted for any missing data and response time set at six weeks. Included studies were grouped according to risk factors investigated for the analysis.

Quality assessment

The studies' methodological quality was evaluated using the Newcastle Ottawa Scale, a risk of bias assessment tool for observational studies that is recommended by the Cochrane Collaboration.[26] A 'star system' was used in which each study was judged on three broad perspectives: the selection of the study groups (maximum score of four stars); the comparability of the groups (maximum score of two stars); and the ascertainment of the outcome of interest (maximum score of three stars).[26] A description of the tool is outlined in supplementary file 2, and was undertaken using the same two-step process described for study selection.

Analysis

Meta-analysis was only completed for the risk factors that had comparable data.[25] Forest plots were presented, following guidance by Schriger et al (2010).[27] Odds ratios with 95% confidence intervals were calculated for the risk factors, using Mantel-Haenszel method with a random effect model for each outcome measure. The I^2 statistic was calculated in order to assess heterogeneity and true effect size.

Funnel plots were not produced as a measure of publication bias, as methodological guidance has suggested that they are unreliable when the included number of studies is ten or less.[28] The Cochrane RevMan 5.4 software was used for all meta-analysis[29] and STATA /IC (version 14.0) for additional pooling of continuous data.

RESULTS

Study selection

The search strategy identified 9960 citations. After screening titles and abstracts, we identified 199 potentially relevant studies for retrieval. Following full-text review, a total of 73 observational studies met the inclusion criteria, all of which were either prospective or retrospective study design. No additional citations were identified through the grey literature search. Two Chinese studies were included, from which the data in the English language abstract was extracted. No replies were received from contacted authors of individual studies. The study selection process is outlined in Figure 1.

Figure 1: Flow diagram of study selection

Study characteristics

The study design, study population, total sample size, risk factors investigated and quality assessment scores of the included studies are outlined in Table 1. Most studies included patients with blunt trauma and rib fractures. All studies designs were observational cohort studies.

Table 1: Baseline characteristics of included studies

Study	Study design	Study population	Age group	Total sample	Main risk factors investigated	Selection ****	Comparability **	Outcome ***
Abdulrahman 2013[30]	Retrospective cohort	Patients with BCT with ≥3 RFs	≥14	902	Age, RFs	***	*	*
Abid 2020[31]	Prospective cohort	Patients with BCT	12-45 & ≥65	70	Age	***	*	*
Albaugh 2000[32]	Retrospective cohort	Patients with BCT and flail chest	≥18	58	Age, ISS	***	*	*
Alexander 2000[33]	Retrospective cohort	Patients with BCT and ≥2 RFs	≥65	62	PECs	***	*	*
Athanassiadi 2004[34]	Retrospective cohort	Patients with BCT and flail chest	≥18	150	Age, ISS	***	*	*
Athanassiadi 2010[35]	Retrospective cohort	Patients with BCT and flail chest	≥18	250	Age, ISS	***	**	*
Bakhos 2006[21]	Retrospective cohort	Patients with BCT with ≥1 RF	≥65	38	Vital capacity	* *	*	*
Bankhead-Kendall 2019[36]	Retrospective cohort	Patients with BCT or RFs, presenting to ED	≥18	1303	Age	***	**	**
Barea-Mendoza 2022[37]	Prospective cohort	Patients with severe BCT, admitted to ICU	≥18	3821	Age, ISS, NISS	***	**	***
Barnea 2002[38]	Retrospective cohort	Patients with isolated RFs	≥65	77	RFs, PECs	* *	*	**
Benjamin 2018[15]	Retrospective cohort	Patients with BCT and flail chest	≥18	8098	Age, Mechanical ventilation	****	**	*
Bergeron 2003[13]	Prospective cohort	Patients with blunt trauma with RFs	Any age	405	Age, RFs, PECs, ISS	****	**	**
Borman 2006[39]	Retrospective cohort	Patients with trauma with flail chest	Any age	262	Age	***	**	**
Brasel 2006[40]	Retrospective cohort	Patients with trauma with RFs	Any age	17,308	Age, RFs, PECs, ISS	***	**	*
Bulger 2000[41]	Retrospective cohort	Patients with trauma with RFs aged ≥65	≥65	464	Age, RFs	***	**	*
Byun 2013[42]	Retrospective cohort	Patients with multiple RFs	Any age	418	Age, ISS	***	**	*
Cannon 2012[43]	Retrospective cohort	Patients with trauma with flail chest	Any age	164	Age	***	**	*
Cinar 2021[44]	Retrospective cohort	Patients with isolated thoracic trauma	≥18	683	Age, ISS, lactate level, GCS, NISS	***	**	*
Cone 2020[10]	Retrospective cohort	Patients with severe isolated BCT (chest AIS 3–5)	≥20 - <90	28,820	BMI	***	**	*
Degirmenci 2022[45]	Retrospective cohort	Patients with trauma with BCT	Any age	1020	Age, RFs, PECs, pulmonary contusions, NISS	***	**	***
Duclos 2021[46]	Retrospective cohort	Patients with BCT (chest AIS >2/ISS >15)	≥18	426	Hyperoxaemia	***	**	**
Ekpe 2014[47]	Retrospective cohort	Patients with BCT	7 -76	149	Age	***	*	*
Elkbuli 2021[48]	Retrospective cohort	Patients with ≥3 RFs, secondary to MVC	≥18	29,785	BMI	***	**	**
El-Menyar 2016 [49]	Retrospective cohort	Patients with BCT, secondary to MVC	Any age	1004	Age	***	**	***
Elmistekawy 2007[50]	Case series	Patients with BCT and isolated RFs	≥60	39	PECs	***	**	*
Emircan 2011[51]	Retrospective cohort	Patients with BCT	Any age	371	Age, ISS	***	**	*
Ferre 2021[3]	Prospective cohort	Patients with BCT and ≥1 RFs	≥18	29,780	Age, PECs	***	**	* *
Flagel 2005[52]	Retrospective cohort	Patients with BCT and ≥1RFs	Any age	64,750	RFs	***	**	*
Grigorian 2020[18]	Retrospective cohort	Patients with BCT with ≥1 RFs	≥18	282,986	PECs, ISS, Smoking	***	**	**
Gupta 2021[53]	Prospective cohort	Patients with BCT	≥12	50	Age, RFs, pulmonary contusion	****	**	*
Haines 2018[20]	Retrospective cohort	Patients with BCT with RFs	≥18	669	Location of RFs, RFs	****	**	* *
Harrington 2010[17]	Retrospective cohort	Patients with BCT with ≥1 RF	≥50	1621	Age, PECs, ISS	***	**	**
Hoff 1994[54]	Retrospective cohort	Patients with pulmonary contusions	16-49	94	RFs, Pulmonary contusion	***	**	*
Holcomb 2003[55]	Retrospective cohort	Patients with BCT with RFs	≥15	171	Age	***	**	*
Inci 1998[56]	Retrospective cohort	Patients with chest trauma	≥60	101	Age	* *	*	*
Jentzsch 2020[12]	Retrospective cohort	Patients with BCT and RFs	≥18	259	BMI	***	**	**
Jones 2011[57]	Retrospective cohort	Patients with trauma and ≥1 RFs	≥18	67,220	Age, RFs	***	**	***
Kapicibasi 2020[58]	Retrospective cohort	Patients with BCT	≥18	130	Age	***	**	* *

Khan 2020[22]	Retrospective cohort	Patients with trauma and ≥1 RFs	≥65	266	Forced vital capacity	***	**	*
Kilic 2011[59]	Case series	Patients with BCT and flail chest	16-70	23	Age	* *	*	*
Kulshrestha 2004[60]	Retrospective cohort	Patients with BCT	Any age	1359	Age, RFs	***	**	*
Lee 1989[4]	Retrospective cohort	Patients with BCT	Any age	3282	RFs	***	**	**
Lee 1990[5]	Retrospective cohort	Patients with BCT	Any age	105,493	Age	***	**	**
Lien 2009[61]	Retrospective cohort	Patients with RFs secondary to MVC	≥18	18,856	Age, RFs	***	**	*
Liman 2003[62]	Retrospective cohort	Patients with BCT	Any age	1490	Age, RFs, ISS	***	**	**
Lin 2016[63]	Retrospective cohort	Patients with BCT	≥18	1621	RFs	***	**	* *
Liu 2013[64]	Retrospective cohort	Patients with severe BCT, and penetrating	Any age	777	Age	n/a		
Marini 2019[65]	Retrospective cohort	Patients with blunt trauma with RFs, aged ≥16	≥16	1188	Age, RFs, ISS, Pulmonary contusion	***	**	*
Mentzer 2017[66]	Retrospective cohort	Patients with BCT	≥80	26,481	PECs	***	**	**
Okonta 2020[67]	Prospective cohort	Patients with BCT with RFs	Any age	73	Age, Surgical emphysema	***	**	**
Ozdil 2018[68]	Retrospective cohort	Patients with bilateral pneumothorax	≥16	181	ISS	***	**	*
Peek 2020[8]	Retrospective cohort	Patients with BCT with ≥1RF or flail chest	≥18	564,798	Age, RFs, PECs, ISS, Smoking, Obesity	***	**	**
Penasco 2017[16]	Retrospective cohort	Patients with chest trauma admitted ICU	≥65	269	Base excess	***	**	**
Penasco 2016[69]	Retrospective cohort	Patients with severe chest trauma in ICU	≥65	235	Age, Mechanical ventilation	***	**	**
Perna 2010[70]	Prospective cohort	Patients with chest trauma	≥18	500	Age, RFs, ISS, Mechanical ventilation	***	**	*
Peterson 1994[71]	Retrospective cohort	Patients with chest trauma	Any age	2073	Age	***	*	**
Sammy 2017[14]	Prospective cohort	Patient with BCT with ≥1 RFs	≥16	10,052	Age, PECs, ISS	****	**	**
Sharma 2008[72]	Retrospective cohort	Patients with BCT with ≥1RFs	Any age	808	Age, RFs	***	**	*
Shi 2017[1]	Retrospective cohort	Patients with BCT with RFs	≥65	97	Age	***	*	*
Shorr 1989[73]	Retrospective cohort	Patients with BCT	≥65	92	Age	***	*	*
Shulzhenko 2016[74]	Retrospective cohort	Patients with BCT with ≥1 RFs	≥65	67,659	Age, RFs	***	**	**
Sikander 2020[75]	Prospective cohort	Patients with BCT	≥60	80	Age, RFs, PECs	***	*	*
Sirmali 2003[76]	Retrospective cohort	Patients with chest trauma, with ≥1RF	Any age	1417	Age, RFs	***	**	*
Stawicki 2004[77]	Retrospective cohort	Patients with BCT, with ≥1RF	≥18	27,855	Age, RFs, PECs	***	**	**
Subhani 2014[78]	Cross-sectional	Patients with BCT, <48 hours of trauma	Any age	264	Number of rib fractures	***	**	*
Svennevig 1986[79]	Retrospective cohort	Patients with BCT	Any age	262	Age, RFs	* *	*	*
Testerman 2006[80]	Retrospective cohort	Patients with BCT with ≥1RFs	Any age	307	Age	****	**	*
Turcato 2021[81]	Retrospective cohort	Patients with ≥1RFs	≥75	342	Oral anticoagulants	***	**	**
Udekwu 2019[19]	Retrospective cohort	Patients with ≥3RFs, hospital LOS >3 days	≥18	383	Anticoagulants and antiplatelets	***	**	*
Van Vledder 2019[82]	Retrospective cohort	Patients with trauma with ≥1RFs	≥65	884	Age, RFs, PECs	***	**	***
Vartan 2020[83]	Retrospective cohort	Patients with blunt trauma and ≥1RFs	≥18	19,638	RFs, Smoking	***	**	**
Warner 2018[84]	Retrospective cohort	Patients with trauma RFs and FVC of >1	≥18	1106	Forced vital capacity	***	**	***
Whitson 2013[85]	Retrospective cohort	Patients with blunt trauma and ≥1 RFs	Any age	35,468	Age, RFs, PECs, ISS, BMI	***	**	**

RF: Rib fracture, BCT: Blunt chest trauma, PEC: Pre-existing conditions, OR: odds ratio, CI: confidence interval, AIS: Abbreviated Injury Score, ISS: Injury Severity Score, NISS: New Injury Severity Score, LOS: Length of stay, MVC: motor vehicle collision, GCS: Glasgow Coma Scale, ED: Emergency Department, FVC: Forced Vital Capacity

The quality of the included studies in this review was variable. A number of studies failed to clearly define the outcome mortality, omitting a description of the specific time period of follow-up over which death was studied. Most included studies used a retrospective design with data obtained from a hospital or national trauma database. Nearly all studies failed to report loss to follow-up or a statement describing the inclusion of patients with missing data. Full results of the quality assessment of the included studies are highlighted in Table 1.

Age

A total of 50 studies of varying design and quality investigated whether age was a risk factor for mortality in patients with blunt chest wall trauma. 19 studies demonstrated a higher risk of mortality in patients with blunt chest wall trauma aged 65 or more when compared with patients aged less than 65.[5, 13-16, 31, 36, 39-41, 45, 57, 58, 61, 65, 72-74, 77] Other studies demonstrated that increased risk of mortality occurred in patients aged 50 or more[17], 55 or more[59, 70], 60 or more[56, 62, 64, 71, 76], 70 or more[79], 80 or more[75] and 90 or more[82]. A number of studies demonstrated an increasing risk of mortality per additional year of age[3, 37, 60, 85] and others with an additional decade[8, 14, 32]. A total of 14 studies reported that age was not a statistically significant risk factor for increased mortality in patients with blunt chest wall trauma[1, 30, 34, 35, 42, 43, 47, 49, 51, 53, 55, 58, 67, 80], however it is worth noting that four of these studies used aged 45 or more as the cut off for increased risk.[30, 47, 55, 80] Full results are reported in Table 1 in supplementary file 3.

In line with PRISMA guidelines, meta-analysis could only be completed for the studies where the study population, dependent and independent variables were comparable. All studies investigating a patient age of 65 or more as a risk factor for mortality following blunt chest wall trauma leading to rib fractures, were combined for analysis and are illustrated in Figure 2.

Figure 2: Forest plot illustrating the odds of mortality with 95% confidence intervals in blunt chest trauma patients aged 65 or more.

Figure 2 demonstrates a combined odds ratio for mortality of 2.11 (CI 95%: 1.85-2.41) in patients with blunt chest wall trauma aged 65 or more. A moderate degree of heterogeneity between the included studies was reported (I^2 statistic: 35%). The result of the test for overall effect (Z=11.06, p<0.00001) indicated that the odds of mortality was significantly greater in patients with blunt chest wall trauma who are aged 65 or more.

Two additional subgroup analyses (Figures 2b and 2c) investigating age as a risk factor for mortality are included in supplementary file 4 (patient age of 80 or more, and increasing age).

Number of rib fractures

A total of 29 studies were included that investigated the number of rib fractures, as a risk factor for mortality. 10 studies demonstrated a higher risk of mortality in patients with blunt chest wall trauma with three or more fractured ribs, when compared with patients with less than three rib fractures.[4, 5, 13, 40, 52, 61, 62, 70, 72, 78] Other studies reported an increasing risk of mortality with each additional rib fracture [8, 38, 41, 53, 65, 77], four or more rib fractures[79], five or more rib fractures[20, 45, 60], six or more rib fractures[76], eight or more[74] and multiple rib fractures (unspecified number).[82] Five studies found no correlation between number of rib fractures and increased risk of mortality.[30, 54, 63, 83, 85] Full results are reported in Table 2 in supplementary file 3.

Meta-analysis could only be completed for the studies where the study population, dependent and independent variables were comparable. All studies investigating three or more rib fractures as a risk factor for mortality following blunt chest wall trauma leading to rib fractures, were combined for analysis and are illustrated in Figure 3.

Figure 3: Forest plot illustrating the odds of mortality with 95% confidence intervals in blunt chest trauma patients with three or more rib fractures.

Figure 3 demonstrates a combined odds ratio for mortality of 1.96 (CI 95%: 1.69-2.26) in patients with blunt chest wall trauma with three or more rib fractures. A moderate degree of heterogeneity between the included studies was reported (I^2 statistic: 45%). The result of the test for overall effect (Z=9.15, p<0.00001) indicated that the odds of mortality was significantly greater in patients with blunt chest wall trauma who have three or more rib fractures.

Pre-existing conditions

A total of 16 studies investigated pre-existing conditions as a risk factor for mortality in patients with blunt chest wall trauma. There was however substantial heterogeneity across the studies with the independent variable investigated ranging from Elixhauser Co-morbidity Count, Charlson Co-morbidity Score, cardiopulmonary disease, cardiac disease and others. Eight studies investigated the risk factor cardiopulmonary disease with six reporting it as a significant risk factor[8, 33, 50, 75, 82, 85] and two reporting no significance[18, 38]. Congestive heart failure was reported to be a significant risk factor in six studies.[8, 17, 38, 40, 82, 85] Pre-existing conditions were also reported to be a risk factor as measured by the Elixhauser Co-morbidity Count[3], and Charlson Co-morbidity Score[14, 66], One study reported co-morbidities as a significant risk factor for death, but without defining co-morbidities.[45] Full results are reported in Table 3 in Supplementary file 3.

All comparable studies investigating cardiopulmonary disease as a risk factor for mortality following blunt chest wall trauma leading to rib fractures, were combined in the meta-analysis and are illustrated in Figure 4.

Figure 4: Forest plot illustrating the odds of mortality with 95% confidence intervals in blunt chest trauma patients with cardiopulmonary disease.

Figure 4 demonstrates a combined odds ratio for mortality of 2.86 (CI 95%: 1.27-6.44) in patients with blunt chest wall trauma with cardiopulmonary disease. A low degree of heterogeneity between the included studies was reported (I^2 statistic: 0%). The result of the test for overall effect (Z=2.53, p<0.01) indicated that the odds of mortality was significantly greater in patients with blunt chest wall trauma who have cardiopulmonary disease.

Injury Severity Scale

A total of 17 studies investigated the severity of injury as a risk factor for mortality in blunt chest wall trauma, as measured using the Injury Severity Scale (ISS). General agreement was evident across the included studies with all but one[68] demonstrating increasing ISS was a significant risk factor.[13, 17, 18, 40, 42, 44, 51, 56, 62 70, 85], In patients with flail chest, conflicting results were reported, with a number of studies reporting ISS as a significant risk factor[8, 32, 35] and others reporting no significance.[34, 65] Full results are reported in Table 4 in supplementary file 3. A higher New Injury Severity Score (NISS) was reported to be a significant risk factor for mortality in three studies.[37, 44, 45]

Meta-analysis was not possible due to very high levels of heterogeneity however, pooled data for increasing ISS and a corresponding forest plot is included in supplementary file 4.

Mechanical ventilation

Four studies investigated the need for mechanical ventilation as a risk factor for mortality.[15, 17, 69, 70] Three studies demonstrated that mechanical ventilation was a significant risk factor for mortality in patients with blunt chest wall trauma, but including with varying degrees of severity ranging from rib fractures[17] to severe blunt chest trauma[69, 70] and flail chest.[15] Full results are reported in Table 5 in supplementary file 3.

Meta-analysis was not possible for this risk factor due to substantial heterogeneity in the study populations.

Body mass index

Five studies investigated Body Mass Index (BMI) as a risk factor for mortality. Three studies found no association between patient weight and mortality in patients with blunt chest wall trauma.[12, 48, 85] Peek et al (2020)[8] reported that obesity was a significant risk factor for mortality while Cone et al (2020) also found that in addition to obesity, a BMI <18.5 was also a significant risk factor.[10] Full results are reported in Table 6 in supplementary file 3. Meta-analysis was not possible due to the level of heterogeneity between the included studies.

Smoking status

Three studies investigated whether smoking is a risk factor for mortality in patients with blunt chest wall trauma. Two studies reported that the non-smokers were at higher risk of mortality. [8, 18] Vartan et al reported that patients with alcohol use disorder who also smoked, were at higher risk of mortality following blunt chest wall trauma.[83] Full results are reported in Table 7 in supplementary file 3. Meta-analysis on this risk factor was deemed not possible due to the low number of comparable studies.

Other risk factors

Time after injury (defined as increasing number of hours) to presentation at the ED was reported to lead to an increased mortality in patients with blunt chest trauma aged 12 or more.[53] The location of the rib fractures was investigated and it was found that for every lateral rib fracture, adult patients with blunt chest wall trauma had a higher risk of mortality, when controlling for age, gender and ISS.[20] Vital capacity[21] and predicted forced vital capacity (FVC)[22] were not reported to be significant risk factors for mortality. In another study however, patients whose inpatient FVC dropped to below 1 were reported to be at a higher risk of death when compared to patients whose FVC remained greater than 1 during hospitalisation.[84] Increased risk of mortality with associated complications including pulmonary contusion[54, 65] was not demonstrated, however surgical emphysema was reported to be a significant risk factor for mortality[67]. One study reported pulmonary contusions in multiple lobes to be a significant risk factor for death.[45]

Physiological parameters including early hyperoxaemia[46], lactate[44] and base excess[16] were also investigated, with base excess of <-6mmol/L demonstrating an increased risk of mortality in patients with chest trauma aged 65 or more[16] and increasing lactate demonstrating a significantly higher risk of mortality in adults with isolated thoracic trauma.[44] In patients with severe blunt chest wall trauma with three or more rib fractures, the use of pre-hospital anticoagulants or antiplatelets was not reported to be a significant risk factor for mortality.[19] In patients with rib fractures aged 75 or more, there was no reported difference in mortality rates with direct oral anticoagulants compared to vitamin K antagonists.[81] Vartan et al (2020) reported that adult patients with blunt chest wall trauma with alcohol use disorder had a higher rate of mortality, than patients with blunt chest wall trauma without alcohol use disorder.[83] Full results are reported in Table 8 in supplementary file 3.

DISCUSSION

This updated review has highlighted that despite the completion of a large number of new studies over the last decade investigating the risk factors for mortality in patients with blunt chest wall trauma, there has been limited new research that would potentially change clinical practice. Our results have demonstrated that the strongest risk factors for mortality in patients with blunt chest wall trauma after another 10 years of research continue to be; a patient age of 65 or more, three or more rib fractures and pre-existing conditions specifically cardiopulmonary disease. Other new risk factors were found to be significant in a small number of studies, but results were conflicting and meta-analysis was not possible due to heterogeneity.

An increasing ISS as a risk factor for mortality has been investigated extensively in trauma research. It would seem reasonable to assume that higher injury severity would lead to an increased risk of mortality however, this assumption is simplistic and does not always assist in the management of the patients who are less severely injured in the ED. It could be suggested that the interplay of patient characteristics, associated injuries and physiological factors will determine outcome in this patient cohort, especially the elderly patient with blunt chest wall trauma. Need for mechanical ventilation was reported to be a risk factor in a small number of studies, but needs further investigation, as this could be associated with on-set of pneumonia. The on-set of pneumonia as a risk factor for mortality was included in the original review. This has been removed from this updated review as the aim of this work is to present risk factors for inclusion in prediction models for us in the ED. At the time of presentation to the ED, the majority of patients will not have developed pneumonia and this is therefore considered more of an outcome in prognostic research, rather than a risk factor.

Extremes of BMI and smoking status were investigated in a small number of more recent studies although no definitive conclusions were possible in this review. Interestingly, the long-standing opinion of both clinicians and researchers that smokers have worse outcomes than non-smokers has been recently challenged and in two studies, the reverse was reported. To date, there is no well-established explanation as to why non-smokers may be at lower risk of mortality following blunt chest wall trauma, but it has been suggested that biologic and pathophysiologic adaptions that smokers develop may provide a survival benefit when recovering from rib fractures.[8, 18] It was also suggested that clinicians are more vigilant with smokers and consequently they receive more intensive monitoring or care.[8] Further good quality research is needed before clinicians change their practice.

These characteristics can be used to identify and risk stratify patients in the ED with blunt chest wall trauma who are at increased risk of mortality. At the time of presentation to the ED, complications are not yet apparent in this patient population, commonly not developing for up to 72 hours post-injury, and predicting which patients are high risk for morbidity and mortality is potentially difficult.[86] Knowledge of the risk factors for mortality can guide appropriate clinical management, in particular timely admission to a critical care facility, which is well-recognised in contributing to a reduction in mortality[87, 88]. Conversely,, avoiding an unnecessary admission to a resource intensive clinical area is equally as important.[86]

Dubinksy et al (1997) stated that no clear guidelines exist in the literature regarding the appropriate investigation and treatment for patients with rib fractures, and most clinicians' practice patterns are based on anecdote, individual experience, and the theoretical risk of complications.[89] In a 2020 study, it was also reported that there is still significant variation in clinical practice across EDs in how elderly patients with blunt chest trauma are assessed and investigated.[90] A recent survey study reported that there are over 20 different risk prediction tools and pathways used in the UK to manage this patient population.[7] The results of this review provide knowledge to both researchers and clinicians as to whether or not these risk prediction tools and pathways are still evidence-based or need updating or further validation.

This review has highlighted the need for a core outcome set for research in the field of blunt chest trauma management, similar to that recently developed for research regarding patients undergoing rib fracture fixation.[91] Arguably this should be a priority before further research is undertaken into risk factors in patients with blunt chest wall trauma. Similarly, although this study focussed on mortality, it is apparent that further work is also required into the development of a specific patient reported outcome measure for patients with blunt chest wall trauma. This work is currently underway and should also lead to an improvement in the quality of future research in the field and facilitate future meta-analyses.[92]

There are several limitations that need acknowledgment. Systematic reviews of observational studies are not without criticism in research. Consideration of potential forms of bias is important in observational studies, which are sensitive to both publication bias and confounding. The search strategy included a number of methods to reduce potential publication bias but no unpublished studies investigating risk factors were identified in the search. Funnel plots were not used to demonstrate the degree of publication bias as they are unreliable when less than 10 studies are included in the analysis.[28] A number of the included studies were at risk of confounding as they only reported unadjusted estimates for the associations between risk factor and mortality. We were also unsuccessful in our attempt to contact a number of authors in order to include more data in the meta-analysis. Authors of studies with incomplete data were only contacted once, whereas a reminder email may have been beneficial.

Heterogeneity between the included studies was a considerable limitation of this review, which resulted in a number of comparisons not being possible. Pooling of data (such as case series with cohort studies) has limitations and may have impacted the study findings. Standard definitions for the outcome mortality either differed or were not described in many of the studies. Definitions used for the various risk factors also differed across the studies, or how they handled the continuous variables such as age or number of risk factors. Dichotomisation of variables using a cut-off value for the point at which increased risk occurred is not recommended by methodologists, but was a common analytical technique used across the included studies.[93, 94] Despite drawing conclusions regarding cardiopulmonary disease being a risk factor for mortality, the lack of consensus scale for pre-existing conditions was a limitation of this review. As a result of the difficulty in negating the effects of bias and confounding in observational studies, it is important that the results of each individual study and this review are interpreted with caution.

There was a wealth of potential further subgroup analysis that could have been completed as part of this updated review, however due to a number of factors (as described above) this further analysis was not undertaken and the results of this study should be interpreted with caution.

In summary, the results of this updated review suggest that despite a change in demographic of trauma patients and subsequent new emerging evidence, the main risk factors for mortality in patients sustaining blunt chest wall trauma remained largely unchanged since the original review. These risk factors included; patient age of 65 or more, three or more rib fractures and the presence of pre-existing disease. Included studies were of variable quality and high levels of heterogeneity precluded further meta-analysis.

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Figure 1

PRISMA 2020 flow diagram for updated systematic reviews which included searches of databases, registers and other sources

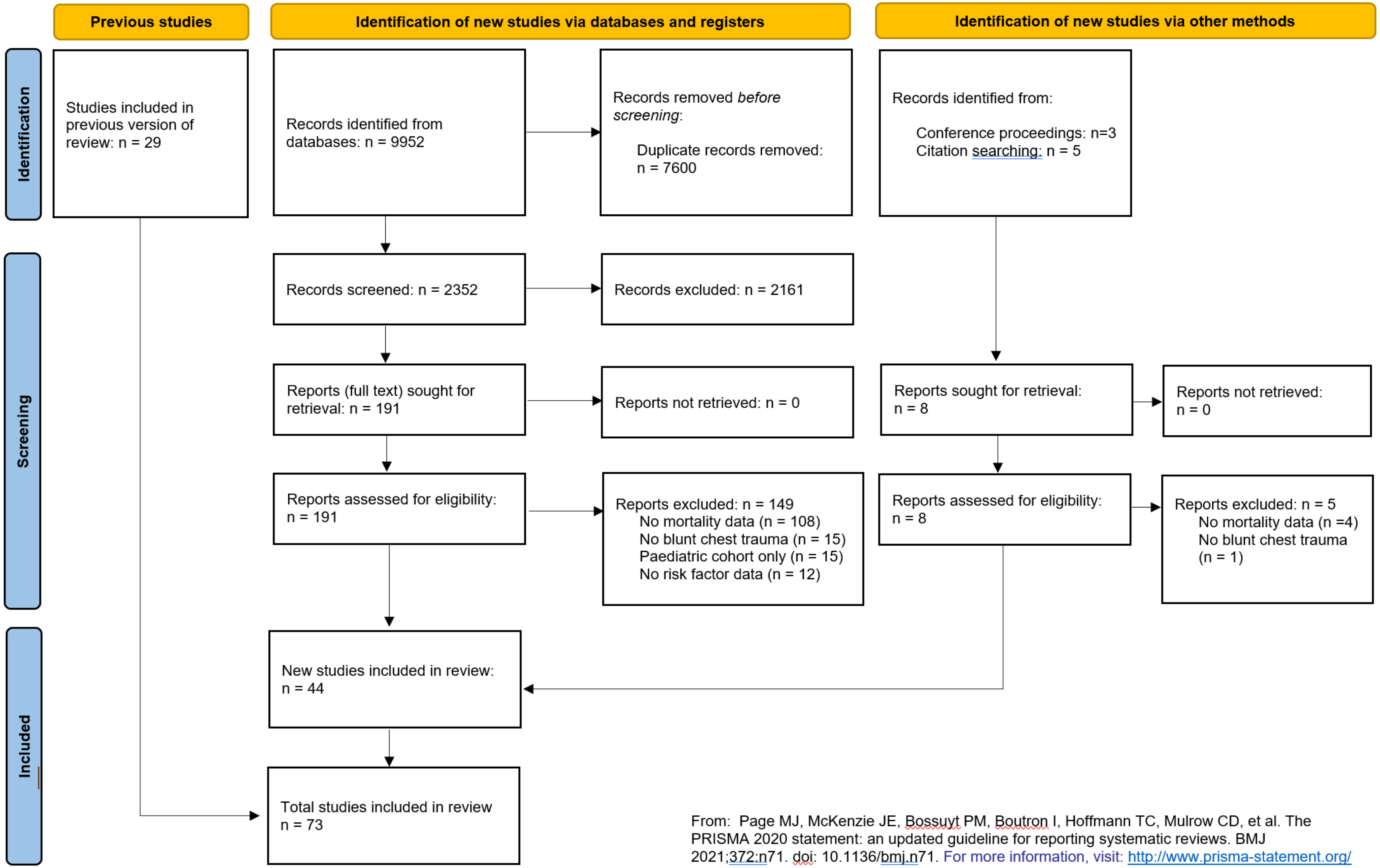

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Figure 2

Study or Subgroup	Age 65 or more Events	Age 65 or more Total	Age <65 Events	Age <65 Total	Weight	Odds Ratio M-H, Random, 95% CI
Bulger 2000	22	277	10	187	2.7%	1.53 [0.71, 3.30]
Borman 2006	17	63	37	199	3.6%	1.62 [0.84, 3.13]
Lee 1990	45	818	52	1633	8.3%	1.77 [1.18, 2.66]
Stawicki 2004	1738	8648	2190	19207	36.4%	1.95 [1.82, 2.09]
Sharma 2008	86	480	109	1136	12.8%	2.06 [1.52, 2.79]
Lien 2009	194	5079	251	13777	22.0%	2.14 [1.77, 2.59]
Bergeron 2003	22	113	27	292	4.2%	2.37 [1.29, 4.37]
Shorr 1989	17	46	66	469	3.7%	3.58 [1.86, 6.88]
Marini 2019	44	368	28	820	6.2%	3.84 [2.35, 6.28]
Total (95% CI)		**15892**		**37720**	**100.0%**	**2.11 [1.85, 2.41]**
Total events	2185		2770			

Heterogeneity: Tau² = 0.01; Chi² = 12.30, df = 8 (P = 0.14); I² = 35%

Test for overall effect: Z = 11.06 (P < 0.00001)

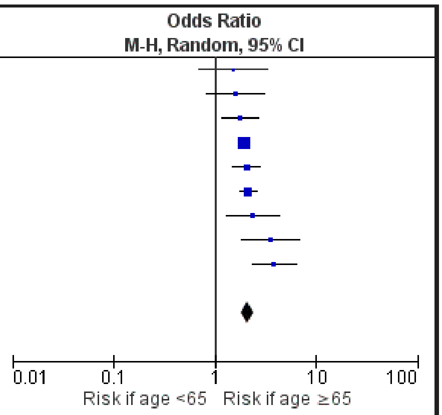


Figure 3

Study or Subgroup	≥3 RFs Events	≥3 RFs Total	<3 RFs Events	<3 RFs Total	Weight	Odds Ratio M-H, Random, 95% CI
Lin 2016	49	713	32	559	8.1%	1.22 [0.77, 1.92]
Sharma 2008	174	1208	94	1075	18.3%	1.76 [1.35, 2.29]
Flagel 2005	2222	19969	1494	25397	44.1%	2.00 [1.87, 2.14]
Lee 1990	97	2477	1837	103016	24.2%	2.24 [1.82, 2.76]
Lien 2009	43	3018	15	2691	5.3%	2.58 [1.43, 4.65]
Total (95% CI)		**27385**		**132738**	**100.0%**	**1.96 [1.69, 2.26]**
Total events	2585		3472			

Heterogeneity: Tau² = 0.01; Chi² = 7.33, df = 4 (P = 0.12); I² = 45%

Test for overall effect: Z = 9.15 (P < 0.00001)

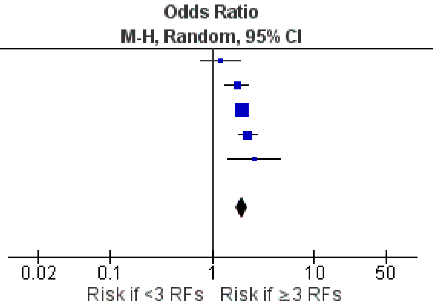
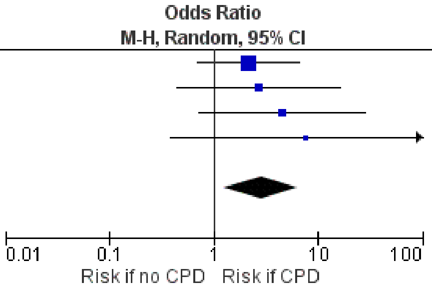


Figure 4

Study or Subgroup	CPD Events	CPD Total	No CPD Events	No CPD Total	Weight	Odds Ratio M-H, Random, 95% CI
Sikander 2020	12	38	6	34	53.0%	2.15 [0.71, 6.57]
Barnea 2002	2	13	4	63	20.0%	2.68 [0.44, 16.47]
Elmistekawy 2007	3	6	6	33	19.7%	4.50 [0.72, 28.01]
Alexander 2000	3	31	0	31	7.3%	7.74 [0.38, 156.36]
Total (95% CI)		**88**		**161**	**100.0%**	**2.86 [1.27, 6.44]**
Total events	20		16			

Heterogeneity: Tau² = 0.00; Chi² = 0.91, df = 3 (P = 0.82); I² = 0%

Test for overall effect: Z = 2.53 (P = 0.01)



Supplementary file 1
Search strategy:
All methods used in this review followed CRD guidelines. A broad search strategy was used in order to include all relevant studies. The search filters used were Medline and Embase Databases and the Cochrane Library from January 2010 until March 2021. The search term combinations were Medical Subject Heading (MeSH) terms, text words and word variants for chest trauma. These were combined with relevant terms for aetiological factors. The search terms are illustrated in Table 1.

Table 1: Keyword combinations used in the literature search.

Chest trauma	AND	Prognos*
Thora* trauma		Predictor
Rib fractures		Caus*
Thora* injury		Risk factors
Chest injury		Risk
Wounds, non-penetrating		Outcome

The asterisk indicates where the truncated version of the word was used
The references of primary studies and review articles were hand-searched in order to identify studies missed in the electronic search. In addition, the Annals of Emergency Medicine, Emergency Medicine Journal, Journal of Emergency Medicine, Injury, BMC Emergency Medicine, Trauma and the Journal of Trauma and Acute Care Surgery were hand-searched from January 2010 to March 2021 for relevant studies.
The authors of the studies selected for inclusion in this review were contacted if data was required and a deadline for response was set at three months. All available worldwide Emergency Medicine Conference abstracts were searched. In addition, OpenGrey (System for Information on Grey Literature in Europe) which include unpublished papers were searched to identify grey literature.
The searches were international and no search limitations (other than date) were imposed. Table 2 highlights the inclusion and exclusion criteria used for study selection.

Table 2. Inclusion and exclusion criteria for study selection

	Inclusion	Exclusion
Population	Studies investigating patients presenting to the ED with blunt chest wall trauma (blunt chest injury resulting in chest wall contusion or rib fractures, with or without underlying lung injury)	Studies investigating: a) Patients with penetrating trauma only b) Patients with multi-trauma only and no reference to chest trauma c) Patients with severe intrathoracic injuries only (eg. Bronchial, cardiac, oesophageal, aortic or diaphragmatic rupture) and no chest wall trauma. d) Scoring systems or prognostic tools
Outcomes	Studies investigating mortality in patients with blunt chest wall trauma	Studies investigating management or treatment strategies only
Comparators	Studies allowing estimates of association between risk factor and outcome for blunt chest wall trauma	Studies that fail to provide comparative data on risk factors and outcome.
Study Design	All observational studies, published and unpublished	Descriptive studies with no comparative data such as a narrative review or case studies

Table 3 outlines the components of the quality assessment tool used in this review.

Table 3: Quality Assessment of non-randomised studies.

Patient selection
Selected cohort was representative of the general blunt chest trauma population (1)
Cohort was a selected group or the selection was not described (0)
Comparability of groups
No differences between the groups was explicitly reported (especially in terms of age, number of rib fractures, pre-existing disease) unless it was one of the variables under investigation, or such differences were adjusted for (2)
Differences in groups were not recorded (1)
Groups differed or no comparable group used (0)
Outcomes
Mortality definition that explicitly reported, stating time period used for definition (1)
Mortality not defined (0)
Group size
>100 participants in each group (2)
<100 participants in each group (1)
Cohort design
Prospective cohort design (2)
Retrospective design / use of trauma registry or database (1)

NB: Numbers in brackets are the individual quality scores for each methodology sub-section

Supplementary file 2:

Table 1: Age as a risk factor for mortality following blunt chest wall trauma

Study	Population	Results
Abdulrahman 2013	Patients with BCT with ≥3 RFs, aged ≥14	No difference between patients aged <45 with ≥3RF (2.3%) and those aged >45 with ≥RF (6.1%) (p=0.18)
Abid 2020	Patients with BCT aged between 12-45 and ≥65	In hospital mortality significantly higher in patients aged >65 (p=0.002)
Albaugh 2000	Patients with BCT and flail chest aged ≥18	Likelihood of death increases by 132% for each decade of life
Athanassiadi 2004	Patients with BCT and flail chest aged ≥18	Age had no effect on mortality in flail chest patients
Athanassiadi 2010	Patients with BCT and flail chest aged ≥18	Age had no effect on mortality in flail chest patients
Bankhead-Kendall 2019	Patients ≥18 with BCT or RFs, presenting to ED	Age ≥65 independently associated with mortality directly related to RFs (OR: 4.1, 95% CI: 1.3–13.3, P value < .0001)
Benjamin 2018	Patients with BCT and flail chest aged ≥18	Adjusted OR of death in patients aged ≥65: 6.02 (4.8-7.5, p<0.001)
Bergeron 2003	Patients with blunt trauma with RFs, no age restriction	Adjusted OR of death in patients aged ≥65: 5.03 (1.8-13.9)
Borman 2006	Patients with trauma with flail chest, no age restriction	OR of death in patients aged 45-64: 1.7 (0.8-3.7). OR death in patients aged ≥65: 2.1 (1.0-4.6)
Brasel 2006	Patients with trauma with RFs, no age restrictions	Adjusted OR of death in patients aged 65-74: 2.7 (1.1-7.1)
Bulger 2000	Patients with trauma with RFs aged ≥65	Patients aged ≥65 had higher mortality (p<0.001)
Byun 2013	Patients with multiple RFs, no age restrictions	Age had no effect on mortality
Cannon 2012	Patients with trauma with flail chest, no age restrictions	OR of late death with increasing age (OR: 1.033, 95%CI: 0.99-1.07; p=0.067)
Ekpe 2014	Patients with BCT, no age restrictions	Age >45 had no effect on mortality (p=0.468)
El-Menyar 2016	Patients with BCT, secondary to MVC, no age restrictions	Adjusted OR of death with increasing age: 0.013 (0.997-1.029. p=0.105)
Emircan 2011	Patients with BCT, no age restrictions	On multivariate analysis, increasing age was not found to be a predictor of mortality
Ferre 2021	Patients with BCT and ≥1 RFs, no age restrictions	Adjusted OR of death with increasing age: 1.03 (1.02-1.03, p<0.001)
Harrington 2010	Patients with BCT with ≥1 RF, aged ≥50	OR death in patients aged ≥50: 1148.5 (184.9-7132.6)
Holcomb 2003	Patients with BCT with RFs, aged >15	No differences in mortality in patients aged <45 or ≥45
Inci 1998	Patients with chest trauma, no age restrictions	Patients aged ≥60 had higher mortality (p<0.001)
Jones 2011	Patients with trauma and ≥1 RFs, no age restrictions	Adjusted OR of death in patients aged ≥65: 1.47 (1.45-1.48)
Kapicibasi 2020	Patients with BCT, aged ≥18	No difference in mortality rates between patients aged <65 and ≥65
Kilic 2011	Patients with BCT and flail chest, no age restrictions	Mortality was higher in patients aged ≥55 than those aged <55 (p<0.05)
Kulshrestha 2004	Patients with BCT, no age restrictions	OR death with each 1 year increase in age: 1.04 (1.02-1.05)
Lee 1990	Patients with BCT, no age restrictions	Patients with ≥3RF aged ≥65 had higher mortality than those aged <65 with ≥ 3RF (p<0.001)
Lien 2009	Patients with RFs secondary to MVC, aged ≥18	Adjusted OR death in patients aged 65-74: 2.21 (1.63-2.99)
Liman 2003	Patients with BCT, no age restrictions	Patients aged ≥60 had higher mortality than those aged <60 (p<0.001)
Liu 2013	Patients with severe chest trauma, blunt and penetrating, no age restrictions	Adjusted OF for mortality in patients aged ≤60: 0.96 (p=0.01). Protective effect if aged <60
Marini 2019	Patients with blunt trauma with RFs, aged ≥16	Mortality increases at age 65 without a further increase until age ≥86
Okonta 2020	Patients with BCT with RFs, no age restrictions	No differences in mortality due to increasing age

Peek 2020	Patients with BCT with ≥1RF or flail chest, aged 18	Adjusted OR 30-39 years: 1.09 (1.03-1.16, p<0.001) Adjusted OR 40-49 years: 1.35 (1.28-1.43, p<0.001) Adjusted OR 50-59 years: 1.91 (1.80-2.02, p<0.001) Adjusted OR 60-69 years: 2.98 (2.81-3.17, p<0.001) Adjusted OR 70-79 years: 5.58 (5.24-5.94, p<0.001) Adjusted OR 80-89 years: 10.7 (10.1-11.4, p<0.001)
Penasco 2017	Patients with severe chest trauma admitted to ICU, aged ≥65	Adjusted OR for death increases per year from age 65: 1.08 (1.03-1.14, p=0.005)
Perna 2010	Patients with chest trauma, no age restrictions	Patients aged ≥55 had higher rate of mortality (p<0.05)
Peterson 1994	Patients with chest trauma (blunt and penetrating), no age restrictions	Patients aged ≥ 60 had higher mortality than those aged <60
Sammy 2017	Patient with BCT with ≥1 RFs, aged ≥16	Adjusted OR 45-54 years: 1.73 (1.20-2.49, p=0.003) Adjusted OR 55-64 years: 1.92 (1.31-2.82, p=0.001) Adjusted OR 65-75 years: 4.43 (3.10-6,31, p<0.001) Adjusted OR >75 years: 18.09 (13.12-24.94, p<0.001)
Sharma 2008	Patients with BCT with ≥1RFs, no age restrictions	Patients aged ≥65 had higher mortality than those aged <65 (p<0.05)
Shi 2017	Patients with BCT with RFs, aged ≥65	No difference in mortality due to age in patients aged ≥65
Shorr 1989	Patients with BCT, aged ≥65	Patients aged ≥65 had higher mortality than those aged <65 (p<0.001)
Shulzhenko 2017	Patients with BCT with ≥1 RFs, aged ≥65	Adjusted OR per year increase in age in patients ≥65: 1.059 (1.054-1.064)
Sikander 2020	Patients with BCT, aged ≥60	Mortality higher in patients aged ≥80 (p=0.001)
Sirmali 2003	Patients with chest trauma, with ≥1RF, no age restrictions	Patients aged ≥60 had higher mortality than those aged <60
Stawicki 2004	Patients with BCT, with ≥1RF, aged ≥18	Patients aged ≥65 had higher mortality than those aged <65 (p<0.001)
Svennevig 1986	Patients with BCT, no age restrictions	Patients aged ≥70 had higher mortality than those aged <70 (p<0.05)
Testerman 2006	Patients with BCT with ≥1RFs, no age restrictions	No differences in mortality in patients aged <45 and ≥45
Van Vledder 2019	Patients with trauma with ≥1RFs, aged ≥65	Adjusted OR for mortality in patients aged 81-90: 1.4 (0.6-3.2, p=0.44 and patients aged ≥91: 3.4 (1.5-7.6, p=0.003)
Whitson 2013	Patients with blunt trauma with ≥1 RFs, no age restriction	Adjusted OR per year increase in age in patients: 1.03 (1.02-1.03, p<0.0001)

RF: Rib fracture, BCT: Blunt chest trauma, OR: odds ratio, CI: confidence interval, MVC: motor vehicle collision

Table 2: Number of rib fractures as a risk factor for mortality following blunt chest wall trauma

Study	Population	Results
Abdulrahman 2013	Patients with BCT with ≥3 RFs, aged ≥14	No difference in mortality according to number of RFs (p=0.21)
Barnea 2002	Patients with isolated RFs, aged ≥65	Correlation between increasing number of RF and increased mortality (p=0.006)
Bergeron 2003	Patients with blunt trauma with RFs, no age restriction	Adjusted OR of death in patients with ≥3 RFs: 3.13 (1.3-7.6)
Brasel 2006	Patients with trauma with RFs, no age restrictions	Adjusted OR of death in patients with ≥3 RFs: 1.8(1.1-3.0)
Bulger 2000	Patients with trauma with RFs aged ≥65	OR death with each additional RF: 1.19
Flagel 2005	Patients with BCT and ≥1RFs, no age restrictions	Mortality increases with each successive RF (p<0.02)
Haines 2018	Patients with BCT with RFs, aged ≥18	Mortality higher in patients with ≥5 RFs (p<0.035)
Hoff 1994	Patients with BCT with isolated pulmonary contusions, aged 16-49	No correlation between number of RFs and mortality
Jones 2011	Patients with trauma and ≥1 RFs, no age restrictions	Adjusted OR of death in patients with ≥5 RFs: 1.05 (1.01-1.08)

Kulshrestha 2004	Patients with BCT, no age restrictions	OR death for patients with ≥5 RFs: 2.43 (1.31-4.51)
Lee 1989	Patients with BCT, no age restrictions	Patients with ≥3RFs had higher mortality than patients with 0-2 RFs
Lee 1990	Patients with BCT, no age restrictions	Patients with ≥3 RFs had higher mortality than patients with 0-2 RFs (p<0.001)
Lien 2009	Patients with RFs secondary to MVC, aged ≥18	Adjusted OR death for patients with ≥ 3 RFs: 2.44 (0.93-6.41)
Liman 2003	Patients with BCT, no age restrictions	Patients with ≥3RFs had higher mortality than patients with <3 RFs (p<0.001)
Marini 2019	Patients with blunt trauma with RFs, aged ≥16	The median number of RFs in non-survivors was higher than that in the survivors (p<0.001)
Lin 2016	Patients with BCT, aged ≥18	No difference in mortality according to number of RFs (p=0.286)
Peek 2020	Patients with BCT with ≥1RF or flail chest, aged 18	Adjusted OR of death with increasing number of RFs: 1.05 (1.04-1.06, p<0.001)
Perna 2010	Patients with chest trauma, no age restrictions	Patients with ≥3 RFs had higher mortality than patients with <3 RFs (p<0.05)
Sharma 2008	Patients with BCT with ≥1RFs, no age restrictions	Patients with ≥3 RFs had higher mortality than patients with <3 RFs (p<0.05)
Shulzhenko 2017	Patients with BCT with ≥1 RFs, aged ≥65	Adjusted OR for death for patients with ≥8 RFs: 1.51 (1.35-1.68, p<0.001)
Sirmali 2003	Patients with chest trauma, with ≥1RF, no age restrictions	Patients with ≥6 RFs had higher mortality than patients with <6 RFs
Stawicki 2004	Patients with BCT, with ≥1RF, aged ≥18	Correlation between increasing number of RF and increased mortality
Subhani 2014	Patients with BCT reporting to ED within 48 hours of trauma, no age restrictions	Statistically significant direct correlation between mortality and number of RFs. In >3RFs patients had higher mortality (p<0.001)
Svennevig 1986	Patients with BCT, no age restrictions	Patients with ≥4 RFs had higher mortality than patients with <4 RFs (p<0.05)
Van Vledder 2019	Patients with trauma with ≥1RFs, aged ≥65	Adjusted OR for death in patients with multiple (unspecified number) RFs: 2.6 (1.1-6.0, p=0.03)
Vartan 2020	Patients with blunt trauma and ≥1RFs, aged ≥18	Adjusted OR for death in patients with increasing number of RFs: 1.02 (0.97-1.08)
Whitson 2013	Patients with blunt trauma with ≥1 RFs, no age restriction	Adjusted OR for death in patients with increasing number of RFs: 0.995 (0.98-1.02, p=0.6417)

RF: Rib fracture, BCT: Blunt chest trauma, OR: odds ratio, CI: confidence interval, MVC: motor vehicle collision

Table 3: Pre-existing conditions as a risk factor for mortality following blunt chest wall trauma

Study	Population	Results
Alexander 2000	Patients with BCT and ≥2 RFs aged ≥65	Patients with cardiopulmonary disease had higher mortality than those without cardiopulmonary disease (p<0.05)
Barnea 2002	Patients with isolated RFs, aged ≥65	Patients with congestive heart failure had higher mortality than those without (p<0.001). No significant difference between patients with chronic lung disease and those without.
Bergeron 2003	Patients with blunt trauma with RFs, no age restriction	Adjusted OR for mortality in patients with co-morbidity: 2.98 (1.1-8.3)
Brasel 2006	Patients with trauma with RFs, no age restrictions	Adjusted OR for mortality in patients with congestive heart failure: 2.62 (1.93-3.55)
Elmistekawy 2007	Patients with BCT and isolated RFs, aged ≥60	Patients with chronic lung disease had higher mortality (p=0.006)
Ferre 2021	Patients with BCT and ≥1 RFs, no age restrictions	Adjusted OR for mortality in patients with an increasing Elixhauser comorbidity count: 1.35 (1.31-1.38, p<0.05)
Grigorian 2020	Patients with BCT with ≥1 RFs, aged ≥18	Adjusted OR for mortality in patients with COPD: 1.14 (0.95-1.37, p=0.160), with end-stage renal failure: 2.78 (1.84-4.20, p<0.001), with diabetes: 1.23 (1.07-1.42, p<0.001)
Harrington 2010	Patients with BCT with ≥1 RF, aged ≥50	Adjusted OR for mortality in patients with congestive heart failure: 5.7 (1.3-25.0)
Mentzer 2017	Patients with BCT, aged >80	Adjusted OR for mortality in patients an increasing Charlson Co-morbidity Index: 1.37 (1.31-1.43)

Peek 2020	Patients with BCT with ≥1RF or flail chest, aged 18	Adjusted OR for mortality in patients with congestive heart failure: 1.85 (1.72-1.99,p<0.001), with diabetes: 1.24 (1.18-1.30, p<0.001), with respiratory disease: 1.35 (1.28-1.43, p<0.001)
Sammy 2017	Patient with BCT with ≥1 RFs, aged ≥16	Adjusted OR for mortality in patients with a Charlson Score 1-5: 1.81 (1.47-2.22, p<0.001), score 6-10: 2.47 (1.83-3.32, p<0.001), score >10: 4.51 (3.11-6.54, p<0.001)
Sikander 2020	Patients with BCT, aged ≥60	Pre-existing cardiopulmonary disease was associated with mortality (p=0.032)
Stawicki 2004	Patients with BCT, with ≥1RF, aged ≥18	Effect of pre-existing conditions on patient mortality was inversely related to number of RF
Van Vledder 2019	Patients with trauma with ≥1RFs, aged ≥65	Adjusted OR for mortality in patients with cardiac disease: 2.6 (1.4-4.7, p=0.003), COPD GOLD 2 or more: 1.3 (1.4-12.7, p=0.01)
Whitson 2013	Patients with blunt trauma with ≥1 RFs, no age restriction	Adjusted OR for mortality in patients with COPD: 1.46 (1.05-2.03, p=0.024), with a history of cardiac surgery: 1.32 (1.15-1.52, p<0.0001)

RF: Rib fracture, BCT: Blunt chest trauma, OR: odds ratio, CI: confidence interval, MVC: motor vehicle collision

Table 4: On-set of pneumonia / pulmonary infection as a risk factor for mortality following blunt chest wall trauma

Study	Population	Results
Bergeron 2003	Patients with blunt trauma with RFs, no age restriction	Adjusted OR for mortality in patients with pneumonia: 3.80 (1.5-9.7)
Brasel 2006	Patients with trauma with RFs, no age restrictions	Adjusted OR for mortality in patients with pneumonia: 3.5 (2.2-5.7)
El-Menyar 2016	Patients with BCT, secondary to MVC, no age restrictions	Adjusted OR for mortality in patients with pneumonia: 0.61 (0.26-1.47, p=0.275)
Elmistekawy 2007	Patients with BCT and isolated RFs, aged ≥60	Patients with RFs with pneumonia had a higher rate of mortality than those without (p=0.015)
Grigorian 2020	Patients with BCT with ≥1 RFs, aged ≥18	Adjusted OR for mortality in patients and pneumonia: 0.50 (0.44-0.57, p<0.001)
Harrington 2010	Patients with BCT with ≥1 RF, aged ≥50	Patients with RFs with pneumonia had a significantly higher rate of mortality than those without (p<0.001)
Liu 2012	Patients with severe chest trauma, blunt and penetrating, no age restriction	Adjusted OR for mortality in patients with pneumonia: 10.94, p<0.001)
Liu 2013	Patients with severe chest trauma, blunt and penetrating, no age restriction	Adjusted OR for mortality in patients with pneumonia: 10.94, p<0.001)
Svennevig 1986	Patients with BCT, no age restrictions	Patients with pneumonia had a significantly higher rate of mortality than those without (p<0.05)

RF: Rib fracture, BCT: Blunt chest trauma, OR: odds ratio, CI: confidence interval, MVC: motor vehicle collision

Table 5: Injury Severity Score as a risk factor for mortality following blunt chest wall trauma

Study	Population	Results
Albaugh 2000	Patients with BCT and flail chest aged ≥18	Adjusted RR for mortality in patients with increasing ISS: 1.3 (1.02-1.64, p=0.021)
Athanassiadi 2004	Patients with BCT and flail chest aged ≥18	ISS was not found to be a predictor of mortality in patients with flail chest
Athanassiadi 2010	Patients with BCT and flail chest aged ≥18	ISS was the strongest predictor for mortality in patients with flail chest
Bergeron 2003	Patients with blunt trauma with RFs, no age restriction	Adjusted OR for mortality in patients with an ISS of 16-29: 1.19 (0.4-3.4), with an ISS of ≥30: 5.48 (1.7-18.1)
Brasel 2006	Patients with trauma with RFs, no age restrictions	Adjusted OR for mortality in patients with an ISS of 9-15: 1.6 (1.0-2.5), with an ISS of 16-25: 2.9 (1.5-5.5), with an ISS of >25: 18.0 (2.0-162.2)
Byun 2013	Patients with multiple RFs, no age restrictions	Adjusted OR for mortality in patients with an increasing ISS: 1.13 (1.07-1.17, p<0.001)
Emircan 2011	Patients with BCT, no age restrictions	Adjusted OR for mortality in patients with an ISS >22: 6.27 (2.48-15.88)

Grigorian 2020	Patients with BCT with ≥1 RFs, aged ≥18	Adjusted OR for mortality in patients with an ISS ≥25: 3.45 (3.07-3.88, p<0.001)
Harrington 2010	Patients with BCT with ≥1 RF, aged ≥50	Adjusted OR for mortality in patients with an increasing ISS: 43.9 (4.3-452.8, p<0.001)
Inci 1998	Patients with chest trauma, no age restrictions	In patients with an ISS >25, mortality rate was 71.4%
Liman 2003	Patients with BCT, no age restrictions	Based on ISS, there was significant difference in mortality between the patients with 0 RF, those with 1-2 RFs and those with >2 RFs (p<0.001)
Marini 2019	Patients with blunt trauma with RFs, aged ≥16	Despite a higher ISS, there was no difference in mortality of patients with flail chest, compared to those without (p=0.27)
Ozdil 2018	Patients with BCT with bilateral pneumothorax, aged ≥16	The comparison of ISS and mortality between isolated RFs and multi-trauma patients revealed no difference (p=0.22)
Peek 2020	Patients with BCT with ≥1RF or flail chest, aged 18	Adjusted OR for mortality in patients with an increasing ISS: 1.07 (1.06-1.07, p<0.001)
Perna 2010	Patients with chest trauma, no age restrictions	Mortality between the ISS groups (<25, ≥25 to <50, ≥50 to <70, >70) was statistically significant (p<0.05)
Whitson 2013	Patients with blunt trauma with ≥1 RFs, no age restriction	Adjusted OR for mortality in patients with an increasing ISS: 1.03 (1.02-1.03, p<0001)

RF: Rib fracture, BCT: Blunt chest trauma, OR: odds ratio, CI: confidence interval, MVC: motor vehicle collision

Table 6: Need for mechanical ventilation as a risk factor for mortality following blunt chest wall trauma

Study	Population	Results
Benjamin 2018	Patients with BCT and flail chest aged ≥18	Adjusted OR for mortality in patients requiring mechanical ventilation: 3.75 (2.95-4.76, p<0.001)
Harrington 2010	Patients with BCT with ≥1 RF, aged ≥50	Adjusted OR for mortality in patients requiring mechanical ventilation: 23.3 (11.9-45.2, p<0.001)
Penasco 2016	Patients with severe chest trauma admitted to ICU, aged ≥65	Adjusted OR for mortality in patients requiring mechanical ventilation: 5.36 (2.18-13.18, p<0.001)
Perna 2010	Patients with chest trauma, no age restrictions	The need for mechanical ventilation was reported a determining factor in increased mortality

RF: Rib fracture, BCT: Blunt chest trauma, OR: odds ratio, CI: confidence interval, MVC: motor vehicle collision

Table 7: Body mass index as a risk factor for mortality following blunt chest wall trauma

Study	Population	Results
Cone 2020	Patients with severe isolated BCT (chest AIS 3–5)	Adjusted OR for mortality in patients and BMI <18.5: 1.86 (1.12-3.10, p=0.017), BMI of 35.0-39.9: 1.48 (1.02-2.16, p=0.039), BMI of ≥40: 1.60 (1.03-2.50, p=0.039)
Elkbuli 2021	Patients with ≥3 RFs, secondary to MVC, aged ≥18	No significant difference in in-hospital mortality between all BMI groups, regardless of flail chest or ISS (p>0.05)
Jentzsch 2020	Patients with BCT and RFs, aged ≥18	Global and local measures of obesity were not associated with mortality in patients with RFs
Peek 2020	Patients with BCT with ≥1RF or flail chest, aged 18	Adjusted OR for mortality in patients with obesity: 1.17 (1.09-1.25, p<0.001)
Whitson 2013	Patients with blunt trauma with ≥1 RFs, no age restriction	Adjusted OR for mortality in patients with obesity: 0.91 (0.53-1.57, p=0.735)

RF: Rib fracture, BCT: Blunt chest trauma, OR: odds ratio, CI: confidence interval, MVC: motor vehicle collision

Table 8: Smoking status as a risk factor for mortality following blunt chest wall trauma

Study	Population	Results
Grigorian 2019	Patients with BCT with ≥1 RFs, aged ≥18	Adjusted OR for mortality in patients reported as smokers: 0.64 (0.56-0.73, p<0.001)
Peek 2020	Patients with BCT with ≥1RF or flail chest, aged 18	Adjusted OR for mortality in patients reported as smokers: 0.66 (0.62-0.69, p<0.001)

Vartan 2020	Patients with blunt trauma and ≥1RFs, aged ≥18	Adjusted OR for mortality in patients with Alcohol use disorder and reported as smokers: 1.42 (1.26-1.69, p<0.001)

RF: Rib fracture, BCT: Blunt chest trauma, OR: odds ratio, CI: confidence interval, MVC: motor vehicle collision

Table 9: Other risk factors for mortality following blunt chest wall trauma

Study	Population	Results
Bakhos 2006	Patients with BCT with ≥1 RF and aged ≥65	There was no significant correlation between vital capacity and mortality
Khan 2020	Patients with trauma and ≥1 RFs	There was no differences in mortality between 3 groups of Forced Vital Capacity measures (<1000mL, 1001-1500mL, >1500mL)
Duclos 2021	Patients with severe BCT, (chest AIS >2 and an ISS >15) aged ≥18	There was no significant correlation between 24 hour hyperoxemia and mortality in severe blunt chest trauma
Haines 2018	Patients with BCT with RFs, aged ≥18	For every lateral RF, patients were 1.13 (OR, p<0.001) times more likely to die, controlling for age, gender and ISS
Marini 2019	Patients with blunt trauma with RFs, aged ≥16	No association between pulmonary contusion and mortality in patients with RFs
Hoff 1994	Patients with BCT with isolated pulmonary contusions, aged 16-49	Pulmonary contusion was not associated with mortality in young, healthy patients.
Okanta 2019	Patients with BCT with RFs, no age restrictions	Adjusted OR for mortality in patients with surgical emphysema: 9.5 (1.05-86.80, p<0.045)
Penasco 2017	Patients with chest trauma admitted to ICU, aged ≥65	Adjusted OR for mortality in patients with a Base Excess of <-6mmol/L: 4.93 (1.71-14.16, p=0.002)
Udekwu 2019	Patients with BCT with ≥3RFs, hospital LOS >3 days	Adjusted OR for mortality in patients using pre-injury anticoagulants / antiplatelets: 4.29 (0.75-24.59, p=0.1021)
Vartan 2020	Patients with blunt trauma and ≥1RFs, aged ≥18	Patients with alcohol use disorder had a higher rate of mortality than those without alcohol use disorder (p<0.001)

RF: Rib fracture, BCT: Blunt chest trauma, OR: odds ratio, CI: confidence interval, MVC: motor vehicle collision

Supplementary file 3: Risk factors results tables

Table 1: Age as a risk factor for mortality following blunt chest wall trauma

Study	Population	Results
Abdulrahman 2013	Patients with BCT with ≥3 RFs, aged ≥14	No difference between patients aged <45 with ≥3RF (2.3%) and those aged >45 with ≥RF (6.1%) (p=0.18)
Abid 2020	Patients with BCT aged between 12-45 and ≥65	In hospital mortality significantly higher in patients aged >65 (p=0.002)
Albaugh 2000	Patients with BCT and flail chest aged ≥18	Likelihood of death increases by 132% for each decade of life
Athanassiadi 2004	Patients with BCT and flail chest aged ≥18	Age had no effect on mortality in flail chest patients
Athanassiadi 2010	Patients with BCT and flail chest aged ≥18	Age had no effect on mortality in flail chest patients
Bankhead-Kendall 2019	Patients ≥18 with BCT or RFs, presenting to ED	Age ≥65 independently associated with mortality directly related to RFs (OR: 4.1, 95% CI: 1.3–13.3, P value < .0001)
Barea-Mendoza 2022	Patients with severe BCT, admitted to ICU, aged ≥18 years	Adjusted OR of death in patients with increasing age: 1.03 (1.02-1.04, p<0.001)
Benjamin 2018	Patients with BCT and flail chest aged ≥18	Adjusted OR of death in patients aged ≥65: 6.02 (4.8-7.5, p<0.001)
Bergeron 2003	Patients with blunt trauma with RFs, no age restriction	Adjusted OR of death in patients aged ≥65: 5.03 (1.8-13.9)
Borman 2006	Patients with trauma with flail chest, no age restriction	OR of death in patients aged 45-64: 1.7 (0.8-3.7). OR death in patients aged ≥65: 2.1 (1.0-4.6)
Brasel 2006	Patients with trauma with RFs, no age restrictions	Adjusted OR of death in patients aged 65-74: 2.7 (1.1-7.1)
Bulger 2000	Patients with trauma with RFs aged ≥65	Patients aged ≥65 had higher mortality (p<0.001)
Byun 2013	Patients with multiple RFs, no age restrictions	Age had no effect on mortality
Cannon 2012	Patients with trauma with flail chest, no age restrictions	OR of late death with increasing age (OR: 1.033, 95%CI: 0.99-1.07; p=0.067)
Cinar 2021	Patients with isolated thoracic trauma, aged ≥18	Mean age in non-survivor group was 64 (26-75), compared to 38 (25-53) in the survivor group (p=0.002)
Degirmenci 2022	Patients with trauma with BCT, no age restrictions	Mortality was higher in the patients aged ≥65 (p<0.001)
Ekpe 2014	Patients with BCT, no age restrictions	Age >45 had no effect on mortality (p=0.468)
El-Menyar 2016	Patients with BCT, secondary to MVC, no age restrictions	Adjusted OR of death with increasing age: 0.013 (0.997-1.029. p=0.105)
Emircan 2011	Patients with BCT, no age restrictions	On multivariate analysis, increasing age was not found to be a predictor of mortality
Ferre 2021	Patients with BCT and ≥1 RFs, no age restrictions	Adjusted OR of death with increasing age: 1.03 (1.02-1.03, p<0.001)
Gupta 2021	Patients with BCT, aged ≥12 years	Mean age in non-survivor group was 51.1 (SD: 23.8), compared to 40.5 (SD: 15.9) in the survivor group (p=0.155)
Harrington 2010	Patients with BCT with ≥1 RF, aged ≥50	OR death in patients aged ≥50: 1148.5 (184.9-7132.6)
Holcomb 2003	Patients with BCT with RFs, aged >15	No differences in mortality in patients aged <45 or ≥45
Inci 1998	Patients with chest trauma, no age restrictions	Patients aged ≥60 had higher mortality (p<0.001)
Jones 2011	Patients with trauma and ≥1 RFs, no age restrictions	Adjusted OR of death in patients aged ≥65: 1.47 (1.45-1.48)
Kapicibasi 2020	Patients with BCT, aged ≥18	No difference in mortality rates between patients aged <65 and ≥65
Kilic 2011	Patients with BCT and flail chest, no age restrictions	Mortality was higher in patients aged ≥55 than those aged <55 (p<0.05)
Kulshrestha 2004	Patients with BCT, no age restrictions	OR death with each 1 year increase in age: 1.04 (1.02-1.05)
Lee 1990	Patients with BCT, no age restrictions	Patients with ≥3RF aged ≥65 had higher mortality than those aged <65 with ≥ 3RF (p<0.001)
Lien 2009	Patients with RFs secondary to MVC, aged ≥18	Adjusted OR death in patients aged 65-74: 2.21 (1.63-2.99)

Liman 2003	Patients with BCT, no age restrictions	Patients aged ≥60 had higher mortality than those aged <60 (p<0.001)
Liu 2013	Patients with severe chest trauma, blunt and penetrating, no age restrictions	Adjusted OF for mortality in patients aged ≤60: 0.96 (p=0.01). Protective effect if aged <60
Marini 2019	Patients with blunt trauma with RFs, aged ≥16	Mortality increases at age 65 without a further increase until age ≥86
Okonta 2020	Patients with BCT with RFs, no age restrictions	No differences in mortality due to increasing age
Peek 2020	Patients with BCT with ≥1RF or flail chest, aged 18	Adjusted OR 30-39 years: 1.09 (1.03-1.16, p<0.001) Adjusted OR 40-49 years: 1.35 (1.28-1.43, p<0.001) Adjusted OR 50-59 years: 1.91 (1.80-2.02, p<0.001) Adjusted OR 60-69 years: 2.98 (2.81-3.17, p<0.001) Adjusted OR 70-79 years: 5.58 (5.24-5.94, p<0.001) Adjusted OR 80-89 years: 10.7 (10.1-11.4, p<0.001)
Penasco 2017	Patients with severe chest trauma admitted to ICU, aged ≥65	Adjusted OR for death increases per year from age 65: 1.08 (1.03-1.14, p=0.005)
Perna 2010	Patients with chest trauma, no age restrictions	Patients aged ≥55 had higher rate of mortality (p<0.05)
Peterson 1994	Patients with chest trauma (blunt and penetrating), no age restrictions	Patients aged ≥ 60 had higher mortality than those aged <60
Sammy 2017	Patient with BCT with ≥1 RFs, aged ≥16	Adjusted OR 45-54 years: 1.73 (1.20-2.49, p=0.003) Adjusted OR 55-64 years: 1.92 (1.31-2.82, p=0.001) Adjusted OR 65-75 years: 4.43 (3.10-6,31, p<0.001) Adjusted OR >75 years: 18.09 (13.12-24.94, p<0.001)
Sharma 2008	Patients with BCT with ≥1RFs, no age restrictions	Patients aged ≥65 had higher mortality than those aged <65 (p<0.05)
Shi 2017	Patients with BCT with RFs, aged ≥65	No difference in mortality due to age in patients aged ≥65
Shorr 1989	Patients with BCT, aged ≥65	Patients aged ≥65 had higher mortality than those aged <65 (p<0.001)
Shulzhenko 2017	Patients with BCT with ≥1 RFs, aged ≥65	Adjusted OR per year increase in age in patients ≥65: 1.059 (1.054-1.064)
Sikander 2020	Patients with BCT, aged ≥60	Mortality higher in patients aged ≥80 (p=0.001)
Sirmali 2003	Patients with chest trauma, with ≥1RF, no age restrictions	Patients aged ≥60 had higher mortality than those aged <60
Stawicki 2004	Patients with BCT, with ≥1RF, aged ≥18	Patients aged ≥65 had higher mortality than those aged <65 (p<0.001)
Svennevig 1986	Patients with BCT, no age restrictions	Patients aged ≥70 had higher mortality than those aged <70 (p<0.05)
Testerman 2006	Patients with BCT with ≥1RFs, no age restrictions	No differences in mortality in patients aged <45 and ≥45
Van Vledder 2019	Patients with trauma with ≥1RFs, aged ≥65	Adjusted OR for mortality in patients aged 81-90: 1.4 (0.6-3.2, p=0.44 and patients aged ≥91: 3.4 (1.5-7.6, p=0.003)
Whitson 2013	Patients with blunt trauma with ≥1 RFs, no age restriction	Adjusted OR per year increase in age in patients: 1.03 (1.02-1.03, p<0.0001)

RF: Rib fracture, BCT: Blunt chest trauma, OR: odds ratio, CI: confidence interval, MVC: motor vehicle collision

Table 2: Number of rib fractures as a risk factor for mortality following blunt chest wall trauma

Study	Population	Results
Abdulrahman 2013	Patients with BCT with ≥3 RFs, aged ≥14	No difference in mortality according to number of RFs (p=0.21)
Barnea 2002	Patients with isolated RFs, aged ≥65	Correlation between increasing number of RF and increased mortality (p=0.006)
Bergeron 2003	Patients with blunt trauma with RFs, no age restriction	Adjusted OR of death in patients with ≥3 RFs: 3.13 (1.3-7.6)
Brasel 2006	Patients with trauma with RFs, no age restrictions	Adjusted OR of death in patients with ≥3 RFs: 1.8(1.1-3.0)
Bulger 2000	Patients with trauma with RFs aged ≥65	OR death with each additional RF: 1.19
Degirmenci 2022	Patients with trauma with BCT, no age restrictions	Mortality was higher in the patients with ≥5 RFs (p<0.001)

Flagel 2005	Patients with BCT and ≥1RFs, no age restrictions	Mortality increases with each successive RF (p<0.02)
Gupta 2021	Patients with BCT, aged ≥12 years	Mean number of RFs in non-survivor group was 3 (SD: 1.0), compared to 1.1 (SD: 1.1) in the survivor group (p=0.001)
Haines 2018	Patients with BCT with RFs, aged ≥18	Mortality higher in patients with ≥5 RFs (p<0.035)
Hoff 1994	Patients with BCT with isolated pulmonary contusions, aged 16-49	No correlation between number of RFs and mortality
Jones 2011	Patients with trauma and ≥1 RFs, no age restrictions	Adjusted OR of death in patients with ≥5 RFs: 1.05 (1.01-1.08)
Kulshrestha 2004	Patients with BCT, no age restrictions	OR death for patients with ≥5 RFs: 2.43 (1.31-4.51)
Lee 1989	Patients with BCT, no age restrictions	Patients with ≥3RFs had higher mortality than patients with 0-2 RFs
Lee 1990	Patients with BCT, no age restrictions	Patients with ≥3 RFs had higher mortality than patients with 0-2 RFs (p<0.001)
Lien 2009	Patients with RFs secondary to MVC, aged ≥18	Adjusted OR death for patients with ≥ 3 RFs: 2.44 (0.93-6.41)
Liman 2003	Patients with BCT, no age restrictions	Patients with ≥3RFs had higher mortality than patients with <3 RFs (p<0.001)
Marini 2019	Patients with blunt trauma with RFs, aged ≥16	The median number of RFs in non-survivors was higher than that in the survivors (p<0.001)
Lin 2016	Patients with BCT, aged ≥18	No difference in mortality according to number of RFs (p=0.286)
Peek 2020	Patients with BCT with ≥1RF or flail chest, aged 18	Adjusted OR of death with increasing number of RFs: 1.05 (1.04-1.06, p<0.001)
Perna 2010	Patients with chest trauma, no age restrictions	Patients with ≥3 RFs had higher mortality than patients with <3 RFs (p<0.05)
Sharma 2008	Patients with BCT with ≥1RFs, no age restrictions	Patients with ≥3 RFs had higher mortality than patients with <3 RFs (p<0.05)
Shulzhenko 2017	Patients with BCT with ≥1 RFs, aged ≥65	Adjusted OR for death for patients with ≥8 RFs: 1.51 (1.35-1.68, p<0.001)
Sirmali 2003	Patients with chest trauma, with ≥1RF, no age restrictions	Patients with ≥6 RFs had higher mortality than patients with <6 RFs
Stawicki 2004	Patients with BCT, with ≥1RF, aged ≥18	Correlation between increasing number of RF and increased mortality
Subhani 2014	Patients with BCT reporting to ED within 48 hours of trauma, no age restrictions	Statistically significant direct correlation between mortality and number of RFs. In >3RFs patients had higher mortality (p<0.001)
Svennevig 1986	Patients with BCT, no age restrictions	Patients with ≥4 RFs had higher mortality than patients with <4 RFs (p<0.05)
Van Vledder 2019	Patients with trauma with ≥1RFs, aged ≥65	Adjusted OR for death in patients with multiple (unspecified number) RFs: 2.6 (1.1-6.0, p=0.03)
Vartan 2020	Patients with blunt trauma and ≥1RFs, aged ≥18	Adjusted OR for death in patients with increasing number of RFs: 1.02 (0.97-1.08)
Whitson 2013	Patients with blunt trauma with ≥1 RFs, no age restriction	Adjusted OR for death in patients with increasing number of RFs: 0.995 (0.98-1.02, p=0.6417)

RF: Rib fracture, BCT: Blunt chest trauma, OR: odds ratio, CI: confidence interval, MVC: motor vehicle collision

Table 3: Pre-existing conditions as a risk factor for mortality following blunt chest wall trauma

Study	Population	Results
Alexander 2000	Patients with BCT and ≥2 RFs aged ≥65	Patients with cardiopulmonary disease had higher mortality than those without cardiopulmonary disease (p<0.05)
Barnea 2002	Patients with isolated RFs, aged ≥65	Patients with congestive heart failure had higher mortality than those without (p<0.001). No significant difference between patients with chronic lung disease and those without.
Bergeron 2003	Patients with blunt trauma with RFs, no age restriction	Adjusted OR for mortality in patients with co-morbidity: 2.98 (1.1-8.3)
Brasel 2006	Patients with trauma with RFs, no age restrictions	Adjusted OR for mortality in patients with congestive heart failure: 2.62 (1.93-3.55)
Degirmenci 2022	Patients with trauma with BCT, no age restrictions	Mortality was higher in the patients with co-morbidities (p<0.001)
Elmistekawy 2007	Patients with BCT and isolated RFs, aged ≥60	Patients with chronic lung disease had higher mortality (p=0.006)

Ferre 2021	Patients with BCT and ≥1 RFs, no age restrictions	Adjusted OR for mortality in patients with an increasing Elixhauser comorbidity count: 1.35 (1.31-1.38, p<0.05)
Grigorian 2020	Patients with BCT with ≥1 RFs, aged ≥18	Adjusted OR for mortality in patients with COPD: 1.14 (0.95-1.37, p=0.160), with end-stage renal failure: 2.78 (1.84-4.20, p<0.001), with diabetes: 1.23 (1.07-1.42, p<0.001)
Harrington 2010	Patients with BCT with ≥1 RF, aged ≥50	Adjusted OR for mortality in patients with congestive heart failure: 5.7 (1.3-25.0)
Mentzer 2017	Patients with BCT, aged >80	Adjusted OR for mortality in patients an increasing Charlson Co-morbidity Index: 1.37 (1.31-1.43)
Peek 2020	Patients with BCT with ≥1RF or flail chest, aged 18	Adjusted OR for mortality in patients with congestive heart failure: 1.85 (1.72-1.99,p<0.001), with diabetes: 1.24 (1.18-1.30, p<0.001), with respiratory disease: 1.35 (1.28-1.43, p<0.001)
Sammy 2017	Patient with BCT with ≥1 RFs, aged ≥16	Adjusted OR for mortality in patients with a Charlson Score 1-5: 1.81 (1.47-2.22, p<0.001), score 6-10: 2.47 (1.83-3.32, p<0.001), score >10: 4.51 (3.11-6.54, p<0.001)
Sikander 2020	Patients with BCT, aged ≥60	Pre-existing cardiopulmonary disease was associated with mortality (p=0.032)
Stawicki 2004	Patients with BCT, with ≥1RF, aged ≥18	Effect of pre-existing conditions on patient mortality was inversely related to number of RF
Van Vledder 2019	Patients with trauma with ≥1RFs, aged ≥65	Adjusted OR for mortality in patients with cardiac disease: 2.6 (1.4-4.7, p=0.003), COPD GOLD 2 or more: 1.3 (1.4-12.7, p=0.01)
Whitson 2013	Patients with blunt trauma with ≥1 RFs, no age restriction	Adjusted OR for mortality in patients with COPD: 1.46 (1.05-2.03, p=0.024), with a history of cardiac surgery: 1.32 (1.15-1.52, p<0.0001)

RF: Rib fracture, BCT: Blunt chest trauma, OR: odds ratio, CI: confidence interval, MVC: motor vehicle collision

Table 4: Injury Severity Score as a risk factor for mortality following blunt chest wall trauma

Study	Population	Results
Albaugh 2000	Patients with BCT and flail chest aged ≥18	Adjusted RR for mortality in patients with increasing ISS: 1.3 (1.02-1.64, p=0.021)
Athanassiadi 2004	Patients with BCT and flail chest aged ≥18	ISS was not found to be a predictor of mortality in patients with flail chest
Athanassiadi 2010	Patients with BCT and flail chest aged ≥18	ISS was the strongest predictor for mortality in patients with flail chest
Bergeron 2003	Patients with blunt trauma with RFs, no age restriction	Adjusted OR for mortality in patients with an ISS of 16-29: 1.19 (0.4-3.4), with an ISS of ≥30: 5.48 (1.7-18.1)
Brasel 2006	Patients with trauma with RFs, no age restrictions	Adjusted OR for mortality in patients with an ISS of 9-15: 1.6 (1.0-2.5), with an ISS of 16-25: 2.9 (1.5-5.5), with an ISS of >25: 18.0 (2.0-162.2)
Byun 2013	Patients with multiple RFs, no age restrictions	Adjusted OR for mortality in patients with an increasing ISS: 1.13 (1.07-1.17, p<0.001)
Cinar 2021	Patients with isolated thoracic trauma, aged ≥18	Adjusted OR for mortality in patients with an increasing ISS: 1.05 (1.01-1.08, p=0.016)
Emircan 2011	Patients with BCT, no age restrictions	Adjusted OR for mortality in patients with an ISS >22: 6.27 (2.48-15.88)
Grigorian 2020	Patients with BCT with ≥1 RFs, aged ≥18	Adjusted OR for mortality in patients with an ISS ≥25: 3.45 (3.07-3.88, p<0.001)
Harrington 2010	Patients with BCT with ≥1 RF, aged ≥50	Adjusted OR for mortality in patients with an increasing ISS: 43.9 (4.3-452.8, p<0.001)
Inci 1998	Patients with chest trauma, no age restrictions	In patients with an ISS >25, mortality rate was 71.4%
Liman 2003	Patients with BCT, no age restrictions	Based on ISS, there was significant difference in mortality between the patients with 0 RF, those with 1-2 RFs and those with >2 RFs (p<0.001)
Marini 2019	Patients with blunt trauma with RFs, aged ≥16	Despite a higher ISS, there was no difference in mortality of patients with flail chest, compared to those without (p=0.27)
Ozdil 2018	Patients with BCT with bilateral pneumothorax, aged ≥16	The comparison of ISS and mortality between isolated RFs and multi-trauma patients revealed no difference (p=0.22)
Peek 2020	Patients with BCT with ≥1RF or flail chest, aged 18	Adjusted OR for mortality in patients with an increasing ISS: 1.07 (1.06-1.07, p<0.001)
Perna 2010	Patients with chest trauma, no age restrictions	Mortality between the ISS groups (<25, ≥25 to <50, ≥50 to <70, >70) was statistically significant (p<0.05)

Whitson 2013	Patients with blunt trauma with ≥1 RFs, no age restriction	Adjusted OR for mortality in patients with an increasing ISS: 1.03 (1.02-1.03, p<0001)

RF: Rib fracture, BCT: Blunt chest trauma, OR: odds ratio, CI: confidence interval, MVC: motor vehicle collision

Table 5: Need for mechanical ventilation as a risk factor for mortality following blunt chest wall trauma

Study	Population	Results
Benjamin 2018	Patients with BCT and flail chest aged ≥18	Adjusted OR for mortality in patients requiring mechanical ventilation: 3.75 (2.95-4.76, p<0.001)
Harrington 2010	Patients with BCT with ≥1 RF, aged ≥50	Adjusted OR for mortality in patients requiring mechanical ventilation: 23.3 (11.9-45.2, p<0.001)
Penasco 2016	Patients with severe chest trauma admitted to ICU, aged ≥65	Adjusted OR for mortality in patients requiring mechanical ventilation: 5.36 (2.18-13.18, p<0.001)
Perna 2010	Patients with chest trauma, no age restrictions	The need for mechanical ventilation was reported a determining factor in increased mortality

RF: Rib fracture, BCT: Blunt chest trauma, OR: odds ratio, CI: confidence interval, MVC: motor vehicle collision

Table 6: Body mass index as a risk factor for mortality following blunt chest wall trauma

Study	Population	Results
Cone 2020	Patients with severe isolated BCT (chest AIS 3–5)	Adjusted OR for mortality in patients and BMI <18.5: 1.86 (1.12-3.10, p=0.017), BMI of 35.0-39.9: 1.48 (1.02-2.16, p=0.039), BMI of ≥40: 1.60 (1.03-2.50, p=0.039)
Elkbuli 2021	Patients with ≥3 RFs, secondary to MVC, aged ≥18	No significant difference in in-hospital mortality between all BMI groups, regardless of flail chest or ISS (p>0.05)
Jentzsch 2020	Patients with BCT and RFs, aged ≥18	Global and local measures of obesity were not associated with mortality in patients with RFs
Peek 2020	Patients with BCT with ≥1RF or flail chest, aged 18	Adjusted OR for mortality in patients with obesity: 1.17 (1.09-1.25, p<0.001)
Whitson 2013	Patients with blunt trauma with ≥1 RFs, no age restriction	Adjusted OR for mortality in patients with obesity: 0.91 (0.53-1.57, p=0.735)

RF: Rib fracture, BCT: Blunt chest trauma, OR: odds ratio, CI: confidence interval, MVC: motor vehicle collision

Table 7: Smoking status as a risk factor for mortality following blunt chest wall trauma

Study	Population	Results
Grigorian 2019	Patients with BCT with ≥1 RFs, aged ≥18	Adjusted OR for mortality in patients reported as smokers: 0.64 (0.56-0.73, p<0.001)
Peek 2020	Patients with BCT with ≥1RF or flail chest, aged 18	Adjusted OR for mortality in patients reported as smokers: 0.66 (0.62-0.69, p<0.001)
Vartan 2020	Patients with blunt trauma and ≥1RFs, aged ≥18	Adjusted OR for mortality in patients with Alcohol use disorder and reported as smokers: 1.42 (1.26-1.69, p<0.001)

RF: Rib fracture, BCT: Blunt chest trauma, OR: odds ratio, CI: confidence interval, MVC: motor vehicle collision

Table 8: Other risk factors for mortality following blunt chest wall trauma

Study	Population	Results
Bakhos 2006	Patients with BCT with ≥1 RF and aged ≥65	There was no significant correlation between vital capacity and mortality
Khan 2020	Patients with trauma and ≥1 RFs	There was no differences in mortality between 3 groups of Forced Vital Capacity measures (<1000mL, 1001-1500mL, >1500mL)
Warner 2018	Patients with trauma RFs and admission FVC of >1 aged ≥18	Mortality was higher in patients with FVC <1 during admission (3.2%), compared to patients with FVC >1 during admission (0.2%) (p<0.001)
Duclos 2021	Patients with severe BCT, (chest AIS >2 and an ISS >15) aged ≥18	There was no significant correlation between 24 hour hyperoxemia and mortality in severe blunt chest trauma
Gupta 2021	Patients with BCT, aged ≥12 years	Mean number of hours from injury to presentation in non-survivor group was 14.1 (SD: 17.5), compared to 2.0 (SD: 1.3) in the survivor group (p=0.001)

Haines 2018	Patients with BCT with RFs, aged ≥18	For every lateral RF, patients were 1.13 (OR, p<0.001) times more likely to die, controlling for age, gender and ISS
Degirmenci 2022	Patients with trauma with BCT, no age restrictions	Mortality was higher in the patients with multi-lobar pulmonary contusions (p=0.01) and in patients with high NISS values (p<0.001)
Barea-Mendoza 2022	Patients with severe BCT, admitted to ICU, aged ≥18 years	Adjusted OR of death in patients with increasing NISS value: 1.02 (1.01-1.04, p<0.001)
Cinar 2021	Patients with isolated thoracic trauma, aged ≥18	Adjusted OR of death in patients with decreasing GCS: 0.78 (0.65-0.94, p=0.010). Adjusted OR death in patients with increasing lactate: 1.19 (1.08-1.31, p<0.001)
Marini 2019	Patients with blunt trauma with RFs, aged ≥16	No association between pulmonary contusion and mortality in patients with RFs
Hoff 1994	Patients with BCT with isolated pulmonary contusions, aged 16-49	Pulmonary contusion was not associated with mortality in young, healthy patients.
Okanta 2019	Patients with BCT with RFs, no age restrictions	Adjusted OR for mortality in patients with surgical emphysema: 9.5 (1.05-86.80, p<0.045)
Penasco 2017	Patients with chest trauma admitted to ICU, aged ≥65	Adjusted OR for mortality in patients with a Base Excess of <-6mmol/L: 4.93 (1.71-14.16, p=0.002)
Turcato 2021	Patients with ≥1RFs, aged ≥75years, using oral anticoagulant therapy	No difference in mortality between direct oral anticoagulants and vitamin K antagonists in patients with RFs aged ≥75
Udekwu 2019	Patients with BCT with ≥3RFs, hospital LOS >3 days	Adjusted OR for mortality in patients using pre-injury anticoagulants / antiplatelets: 4.29 (0.75-24.59, p=0.1021)
Vartan 2020	Patients with blunt trauma and ≥1RFs, aged ≥18	Patients with alcohol use disorder had a higher rate of mortality than those without alcohol use disorder (p<0.001)

RF: Rib fracture, BCT: Blunt chest trauma, OR: odds ratio, CI: confidence interval, MVC: motor vehicle collision, NISS: New Injury Severity Score, LOS: Length of stay, ICU: Intensive Care Unit

Supplementary file 4

Figure 2b: Forest plot illustrating the odds of mortality with 95% confidence intervals in blunt chest trauma patients aged 80 or more.

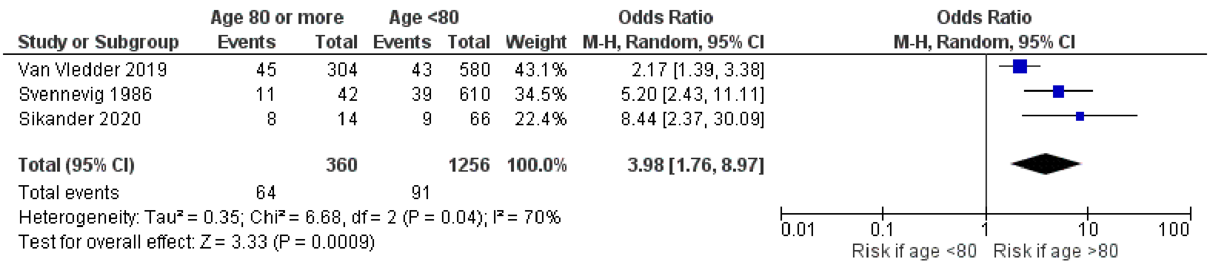


Figure 2b demonstrates a combined odds ratio for mortality of 3.98 (CI 95%: 1.76-8.97) in patients with blunt chest wall trauma aged 80 or more. A large degree of heterogeneity between the included studies was reported (I^2 statistic: 70%). The result of the test for overall effect (Z=3.33, p=0.0009) indicated that the odds of mortality was significantly greater in patients with blunt chest wall trauma who are aged 80 or more.

Figure 2c: Forest plot illustrating the odds of mortality with 95% confidence intervals in blunt chest trauma patients with increasing age.

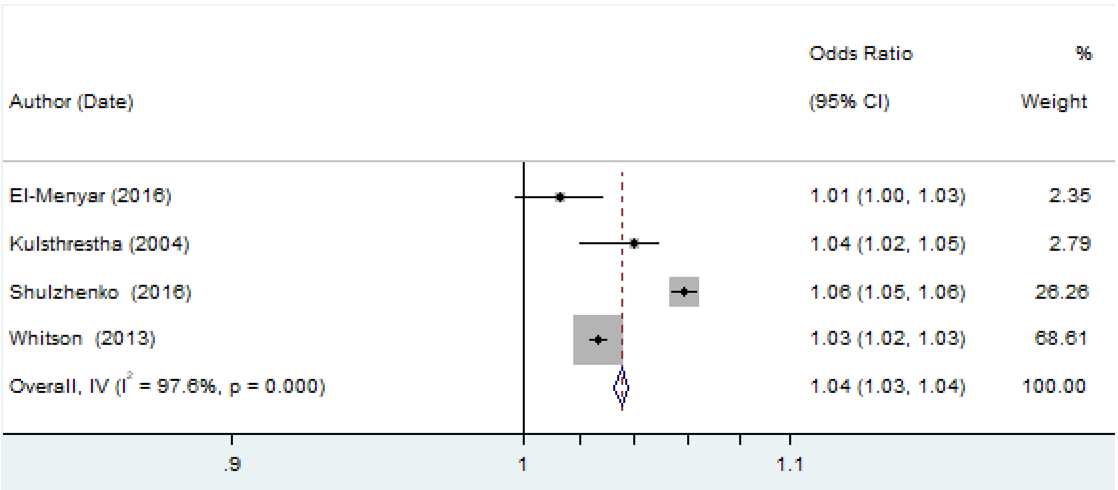


Figure 2c demonstrates a combined odds ratio for mortality of 1.035 (CI 95%: 1.033 to 1.038) per additional year of age, in patients with blunt chest wall trauma. A large very degree of heterogeneity between the included studies was reported (I^2 statistic: 97.6%). The result of the test for overall effect (Z=28.132, p<0.0001) indicated that the odds of mortality was significantly greater in patients with increasing age.

Figure 4b: Forest plot illustrating the odds of mortality with 95% confidence intervals in blunt chest trauma patients with increasing ISS.

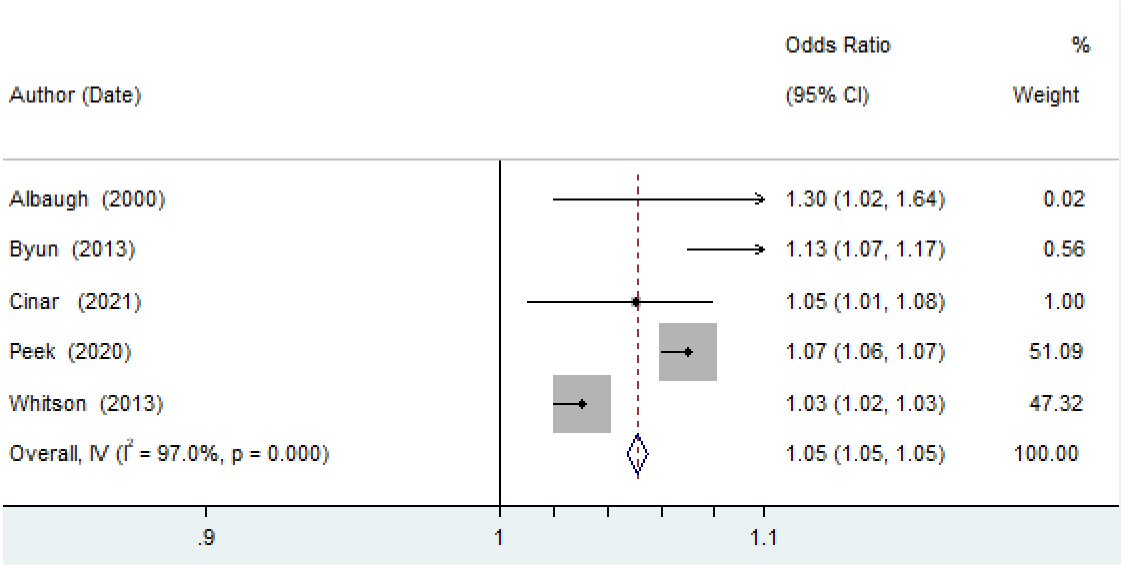


Figure 4b demonstrates a combined odds ratio for mortality of 1.05 (CI 95%: 1.05 1.06) per one ISS point, in patients with blunt chest wall trauma. A very high degree of heterogeneity between the included studies was reported (I2 statistic: 97%). The result of the test for overall effect (Z=29.08, p<0.001) indicated that the odds of mortality was significantly greater in patients with blunt chest wall trauma who have an increasing ISS.