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REVIEW ARTICLE

# Prognostic factors of in-hospital complications after hip fracture surgery: a scoping review

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## Abstract

Introduction: To examine prognostic factors that influence complications after hip fracture surgery. To summarize proposed underlying mechanisms for their influence. Methods: We reported according to the Preferred Reporting Items for Systematic Review and Meta-Analysis Scoping Review extension. We searched MEDLINE, Embase, CINAHL, AgeLine, Cochrane Library, and reference lists of retrieved studies for studies of prognostic factor/s of postoperative in-hospital medical complication/s among patients 50 years and older treated surgically for non-pathological closed hip fracture, published in English on January 2008–January 2018. We excluded studies of surgery type or in-hospital medications. Screening was duplicated by two independent reviewers. One reviewer completed the extraction with accuracy checks by the second reviewer. We summarized the extent, nature, and proposed underlying mechanisms for the prognostic factors of complications narratively and in a dependency graph. Results: We identified 44 prognostic factors of in-hospital complications after hip fracture surgery from 56 studies. Of these, we identified 7 patient factors—dehydration, anemia, hypotension, heart rate variability, pressure risk, nutrition, and indwelling catheter use; and 7 process factors—time to surgery, anesthetic type, transfusion strategy, orthopedic versus geriatric/co-managed care, multidisciplinary care pathway, and potentially modifiable during index hospitalization. We identified underlying mechanisms for 15 of 44 factors. The reported association between 12 prognostic factors and complications was inconsistent across studies. Conclusions: Most factors were reported by one study with no proposed underlying mechanism for their influence. Where reported by more than one study, there was inconsistency in reported associations and the conceptualization of complications differed, limiting comparison across studies. It is therefore not possible to be certain whether intervening on these factors would reduce the rate of complications after hip fracture surgery.

**Keywords** Complications · Hip fracture · Orthogeriatrics · Prognosis · Surgery

**Electronic supplementary material** The online version of this article (https://doi.org/10.1007/s00198-019-04976-x) contains supplementary material, which is available to authorized users.

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## Introduction

The age standardized rate of hip fracture ranges from lows of 2/100,000 in Nigeria (women) and 35/100,000 in Ecuador (men) to highs of 574/100,000 in Denmark (women) and 290/100,000 in Denmark (men) [1]. Patients with hip fracture often present with a reduced capacity to overcome the physiologic stress of their injury and subsequent surgery. Therefore, 30% die in the first postoperative year [2], with 7% dying in hospital [2–4]. This increased risk of death is often attributed to characteristics of the patient and structures and processes of healthcare delivery [5].

The occurrence and opportunity to prevent postoperative complications have more recently become a focus of care after hip fracture surgery [6]. Over 20 years ago, Silber and Williams argued for *death after postoperative complications* as a powerful indicator of care quality [7]. Attributing postoperative mortality to complications requires first to identify factors that might influence the occurrence of both complications and death. Failure to account for these factors could result in observing a statistical association between complications and death in the absence of causation.

We previously summarized prognostic factors for mortality after hip fracture surgery and anticipate a heterogeneous body of evidence on prognostic factors of complications [5]. Therefore, we conducted a scoping review to summarize the available literature on prognostic factors for postoperative complications. Further, we will summarize the proposed underlying mechanisms of their influence. Knowledge of the extent and nature of prognostic factors of postoperative complications will inform future interventions, quality improvement initiatives, and risk stratification.

## Methods

A scoping review framework is appropriate when summarizing a body of knowledge that is heterogeneous to identify consistencies and potential gaps for future research [8]. The review was reported in adherence to the Scoping Review extension of the Preferred Reporting Items for Systematic Review and Meta-Analysis statement [8].

### Search strategy

We searched the electronic databases MEDLINE, Embase, CINAHL, AgeLine, and the Cochrane Library. The search was developed using terms for the population (*hip fracture*) and outcome (*complications*) (see Supplementary File 1). Reference lists of retrieved studies were screened to identify additional studies that may have been missed during database searches.

### Eligibility criteria

We included studies that reported the association between a prognostic factor and any measure of postoperative in-hospital medical complication/s among patients aged 50 years and older who underwent surgery for non-pathological closed hip fracture, published in English between 1st January 2008 and 24th January 2018. We defined prognostic factors as those which relate to characteristics of the patient, structures of care, and/or processes of preoperative and postoperative care.

We excluded studies with a population of patients less than 50 years of age, treated conservatively, with pathological and/or open hip fracture, a primary exposure of surgery type or the administration of medications in hospital (as the volume of research indicated specific sub-questions for surgical type and medications are suited for their own reviews), a control/comparison group that was free of hip fracture, an outcome of surgical complications (e.g., dislocation, malunion), a study endpoint outside of the hospital setting (without explicit reporting of in-hospital complications), and those published in a language other than English and outside of the predetermined date ranges.

### Study selection

We exported citations from databases into Covidence for deduplication and screening [9]. Three reviewers independently screened all abstracts against inclusion and exclusion criteria (KS, EG, DT). Conflicts were resolved by a fourth reviewer (RMC). Full texts of potentially eligible studies were independently screened by four reviewers (KS, EG, DT, PS) with conflicts resolved by two reviewers (RMC, JAB).

### Data extraction

Data extraction was completed by two reviewers independently onto tables designed a priori (RMC, KS). Conflicts were resolved by consensus. Data extracted included the author's name, publication date, country, method, sample size, participants, prognostic factor measurement, control, outcome, duration of follow-up (length of stay), analysis type, and effect estimate. We extracted the effect of the primary study factor from multivariable analysis or from univariable analysis when multivariable analysis was not available. We included estimates from univariable analyses only, when a primary prognostic factor was not stated in the title and/or aim of the study. This was done to avoid misclassification of covariates in multivariable analyses as primary factors [10]. The proposed mechanisms for reported associations were extracted from the discussion sections by one reviewer (RMC). The extraction was checked for accuracy by a second reviewer (KS).

## Analysis

We reported findings as counts and proportions and summarized factors with a reported association and with a reported no association with complications in text and tables using a narrative review approach [11]. We also summarized the extent and the nature (modifiable vs. nonmodifiable) of these factors during an index hospitalization for hip fracture. We selected this caveat of "during an index hospitalization" to distinguish factors that are amenable to intervention during the hospital stay to reduce the occurrence of complications from those that are not. For example, while body mass index is modifiable, it is not a modifiable risk factor for in-hospital complications after hip fracture surgery as the time between surgery and the occurrence of complications is too short for a change in body mass index. Factors and their proposed underlying mechanisms were further summarized in a dependency graph. A dependency graph depicts the factors (nodes) and relationships among them (single-headed arrows) [12]. The dashed arrows indicated conflicting evidence for the presence of an association.

# Results

## Study selection

We identified 7341 studies from electronic databases after deduplication. We excluded 6731 on title and abstract screening. We excluded 554 on full-text screening for the following reasons: population ($n = 60$), exposure ($n = 42$), control ($n = 13$), outcome ($n = 168$), design ($n = 118$), follow-up after discharge from hospital ($n = 125$), publication date ($n = 26$), and language ($n = 2$). This left 56 studies for inclusion in the current review (see Fig. 1).

## Study characteristics

This scoping review of 56 studies included 2,457,050 patients with sample size ranging from 35 [13] to 2,121,215 [14]. Overall, 23 studies reported the association between prognostic factor/s and a single complication [15–37], six studies reported the association between prognostic factors/s and multiple complications [13, 38–42], and 27 studies reported the association between prognostic factor/s and a composite measure of complications (Supplementary File 2) [14, 43–68]. Length of stay ranged from 4 [13, 15, 34, 37, 48, 55, 63] to 36 [52] days across studies. Additional details related to the studies included in this review may be found in Supplementary File 3.

## Prognostic factors

### Prognostic factors of composite measures of medical complications

In total, 12 prognostic factors of composite measures of medical complications were reported by 15 studies included in this review (Table 1, Fig. 2). Of these factors, seven related to nonmodifiable patient factors—comorbidity count [63], dementia [66], Parkinson's disease [47], BMI ($\geq 30$ kg m$^2$)

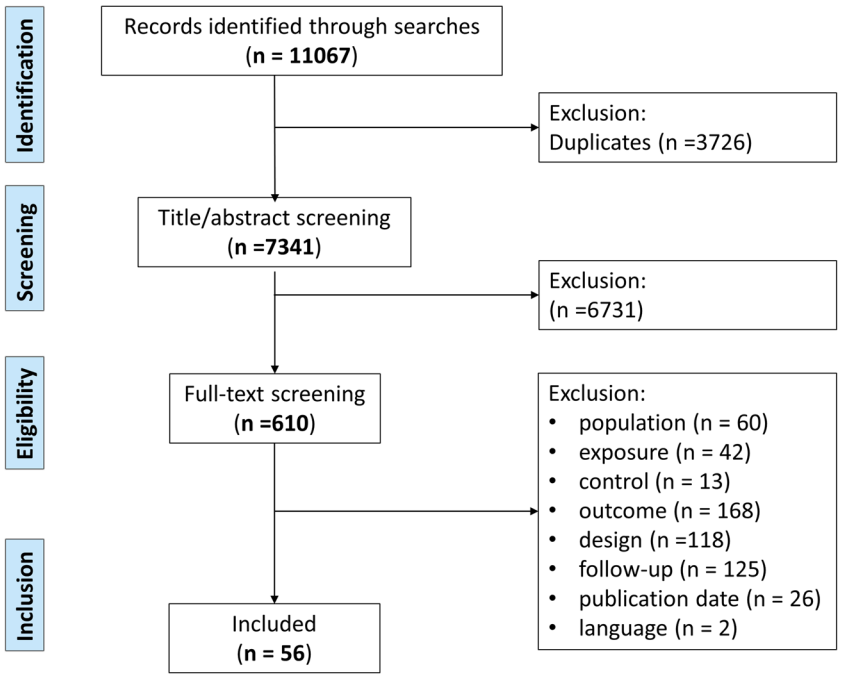


**Fig. 1** Study selection

**Table 1** Counts of a reported association or reported no association for prognostic factors of composite measure of in-hospital medical complications. Light gray cells reflect patient factors. Dark gray cells reflect care factors. √ indicates association. X indicates no association

| | comorbidities | admitted on anticoagulant | cognitive impairment | dementia | Parkinsons disease | pressure risk | nutrition | BMI/weight | frailty | serum albumin | surgical readiness | time to surgery | time of day of surgery | ortho vs. medical primary service | multidisciplinary care pathway | transfusion strategy | hospital type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Anbar 2014** | | | | | | | √ | | | | | | | | | | |
| **Batsis 2009** | | | | | | | | X | | | | | | | | | |
| **Bliemel 2015** | | | X | | | | | | | | | | | | | | |
| **Bliemel 2015b** | | | | | √ | | | | | | | | | | | | |
| **Chuang 2010** | | | | | | | | | | | | | | X | | | |
| **Foss 2009** | | | | | | | | | | | | | | | | X | |
| **Gold 2012** | | | | | | √ | | | | | | | | | | | |
| **Hirose 2008** | | | | | | | | | | | √ | | | | | | |
| **Hirose 2008b** | | | | | | | | | | | √ | | | | | | |
| **Hossain 2013** | | X | | | | | | | | | | | | | | | |
| **Judd 2015** | | | | | | | | | | | | X | | | | | |
| **Kalmet 2016** | | | | | | | | | | | | | | | √ | | |
| **Katrancha 2017** | | | | | | | | | | | | | | | √ | | |
| **Kempegowda 2017** | | | | | | | | √ | | | | | | | | | |
| **Kistler 2015** | | | | | | | | | √ | | | | | | | | |
| **Koval 2011** | | | | | | | | | | | | | | | | | √ |
| **Lefaivre 2009** | | | | | | | | | | | | √ | | | | | |
| **Menzies 2012** | √ | | | | | | | | | | | | | | | | |
| **Pimlott 2011** | | | | | | | | | | √ | | | | | | | |
| **Ryan 2015** | | | | | | | | | | | | √ | | | | | |
| **Switzer 2013** | | | | | | | | | | | | | X | | | | |
| **Tsuda 2015** | | | | √ | | | | | | | | | | | | | |
| **Verbeek 2008** | | | | | | | | | | | | X | | | | | |
| **Vidan 2011** | | | | | | | | | | | | X | | | | | |
| **Counts** | | | | | | | | | | | | | | | | | |
| **association** | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 0 | 0 | 2 | 0 | 1 |
| **no association** | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 1 | 1 | 0 | 1 | 0 |

[58], frailty (Fried Frailty Criteria) [13], serum albumin (< 35 g/L) [64], and surgical readiness (preoperative risk score incorporating the American Society of Anesthesiologists Score) [52, 53]; two related to potentially modifiable patient factors—nutrition (preoperative Mini Nutritional Assessment Short Form) [43] and pressure risk (admission Norton scale) [51]; two related to modifiable care processes—time to surgery [14, 61] and multidisciplinary care pathway [56, 57]; and one related to a nonmodifiable care structure—hospital type(teaching status) [60].

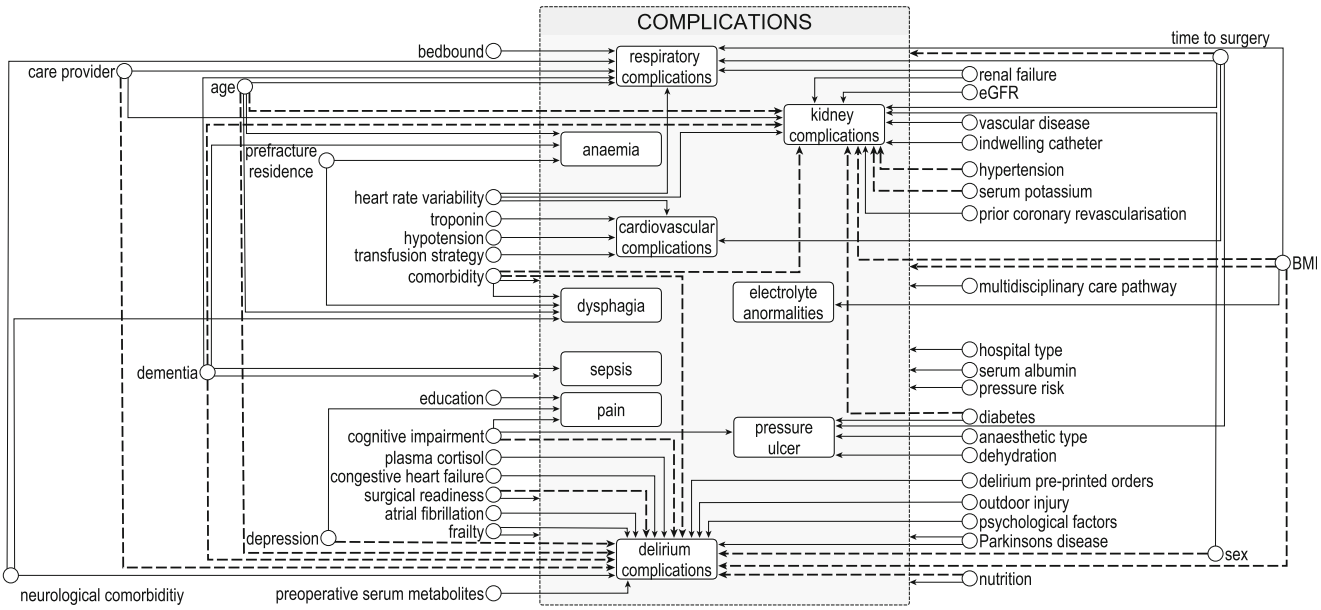


**Fig. 2** Prognostic factors of complications after hip fracture surgery. Nodes represent factors and arrows represent dependencies between nodes. Dashed arrows indicate conflicting evidences for the presence of an association

Patient factors of BMI (< 18.5 kg/m$^2$; ≥ 30 kg/m$^2$) [38], cognitive impairment [46], and time to surgery [55, 67, 68] were also reported as not associated with complications after hip fracture surgery. No association between admission on anticoagulation [54], orthopedic versus medical primary service [48], time of day of surgery [65], and liberal transfusion strategy [50] with postoperative complications were reported (Table 1).

### Prognostic factors of cardiac, respiratory, and/or kidney/urinary measures of medical complications

**Cardiac** In total, one nonmodifiable patient factor—troponin (> 0.03 ng/mL) [39]; two potentially modifiable patient factors—heart rate variability (time and frequency domains) [49] and hypotension (more than 3 occurrences of systolic pressure under 90 mmHg intraoperatively) [59]; and two modifiable process factors—time to surgery [14, 68] and transfusion strategy (liberal) [50] of cardiac complications were reported by 14 studies included in this review (Table 2, Fig. 2). No association between admission on anticoagulation [42], nutrition (preoperative Mini Nutritional Assessment Short Form score; Mini Nutritional Assessment) [41, 43], BMI (≥ 30 kg/m$^2$) [58], dementia [66], frailty (Fried Frailty Criteria) [13], orthopedic versus geriatric primary service [44], orthopedic versus co-managed service [44], and timing of orthogeriatric care [62], with cardiac complications were reported after hip fracture surgery.

**Respiratory** In total, six nonmodifiable patient factors—age [59], bedbound prefracture [59], neurological comorbidity [59], BMI (≥ 30 kg/m$^2$) [58], dementia [66], and renal failure [59]; one potentially modifiable patient factor—heart rate variability (time and frequency domains) [49]; and three modifiable process factors—time to surgery [14, 68], orthopedic versus geriatric primary service [44], and orthopedic versus co-managed service [44] of respiratory complications were reported by 11 studies included in this review (Table 2, Fig. 2). No association between admission on anticoagulation [42], nutrition (Mini Nutritional Assessment) [41], frailty (Fried Frailty Criteria) [13], and timing of orthogeriatric care [62], with respiratory complications were reported after hip fracture surgery.

**Kidney/urinary** In total, 10 nonmodifiable patient factors—age [34], sex (female [15], male [18, 34]), comorbidities (count) [15, 34], vascular disease [18], dementia [66], diabetes [18, 20], chronic kidney disease [15, 18], glomerular filtration rate (eGFR) [15, 18, 34], previous coronary revascularization [34], and serum potassium [15]; two potentially modifiable patient factors—heart rate variability (time and frequency domains) [49] and indwelling catheter (duration); [33] and two modifiable process factors—time to surgery [14, 68] and orthopedic versus co-managed service [44] of kidney/urinary complications were reported by 15 studies included in this review (Table 2, Fig. 2). Patient factors, such as age [18, 20, 33, 34], sex [20, 34], diabetes [33, 34], dementia [33], and serum potassium [34] were also reported as not associated with kidney/urinary complications after hip fracture surgery. No association between cerebrovascular disease [34], hypertension [33, 34], smoking status [34], BMI (mean) [34], history of myocardial infarction [34], neurological comorbidities [33], admission on anticoagulants [34, 42], nutrition (Mini Nutritional Assessment) [41], frailty (Fried Frailty Criteria) [13], overactive bladder [33], orthopedic versus geriatric primary service [44], and timing of orthogeriatric care [62], with kidney/urinary complications were reported after hip fracture surgery.

### Prognostic factors of delirium complications

In total, 22 prognostic factors of delirium complications were reported by 14 studies included in this review (Table 3, Fig. 2). Of these factors, 17 related to nonmodifiable patient factors—age [29, 59], sex (male) [29], frailty (Fried Frailty Criteria) [13], comorbidities (count) [29], neurological comorbidity [59], congestive heart failure [29], atrial fibrillation [29], cognitive impairment [24, 37, 40, 45], dementia [29], depression [45], neuroticism [32], Parkinson's disease [29], BMI (< 20 kg/m$^2$) [24], preoperative serum metabolites [22], plasma cortisol [23], surgical readiness (American Society of Anesthesiologists score) [29], outdoor injury [24]; two related to potentially modifiable patient factors—nutrition (postoperative cumulative energy balance) and [27] anemia (Hg level ≤ 9.7 g/dL during hospitalization) [35]; and three related to modifiable care processes—orthopedic versus geriatric care [44], orthopedic versus co-managed care [44], and delirium friendly pre-printed orders [21].

Patient factors of age [28, 45], sex [45], cognitive impairment [28], dementia [45], depression [29, 32], nutrition (preoperative Mini Nutritional Assessment Short Form) [43], and surgical readiness (American Society of Anesthesiologists score) [45]; and process factors—orthopedic versus co-managed care [16] were also reported as not associated with delirium complications after hip fracture surgery. No association between education (illiterate, elementary, middle, higher) [28], race [29], BMI [29], comorbidities (count) [28, 45], congestive heart failure [29], pulmonary disease [29], cerebrovascular disease [29], hypothyroidism [29], chronic renal insufficiency [29], syncope [29], atrial fibrillation [29], hypertension [29], cancer [29], anxiety [32, 36], psychiatric illness

**Table 2** Counts of a reported association or reported no association for prognostic factors of in-hospital cardiac, respiratory, and/or kidney/urinary complications after hip fracture surgery. Light gray cells reflect patient prognostic factors. Dark gray cells reflect care prognostic factors. √ indicates association. X indicates no association

| | age | sex | bedbound | comorbidities | vascular disease | hypertension | cerebrovascular disease | smoking status | history of myocardial infarction | dementia | neurological comorbidities | diabetes | chronic kidney disease | eGFR | previous coronary revascularisation | admitted on anticoagulant | Heart rate variability | troponin | nutrition | BMI | frailty | indwelling catheter | overactive bladder | serum potassium | hypotension | renal failure | time to surgery | ortho vs. geriatric primary service | ortho vs. comanaged service | timing of orthogeriatric care | transfusion strategy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Prognostic factors of cardiac complications** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Anbar 2014** | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | |
| **Coventry 2017** | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | X | | |
| **Dawson-Bowling 2008** | | | | | | | | | | | | | | | | | | √ | | | | | | | | | | | | | |
| **Ernst 2017** | | | | | | | | | | | | | | | | | √ | | | | | | | | | | | | | | |
| **Foss 2009** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | √ |
| **Kempegowda 2017** | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | |
| **Kim 2015** | | | | | | | | | | | | | | | | | | | | | | | | | √ | | | | | | |
| **Kistler 2015** | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | |
| **Manaqibwala 2014** | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | |
| **Mazzola 2011** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | |
| **Ryan 2015** | | | | | | | | | | | | | | | | | | | | | | | | | | √ | | | | | |
| **Tsuda 2015** | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | |
| **van Wissen 2016** | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | |
| **Vidan 2011** | | | | | | | | | | | | | | | | | | | | | | | | | | √ | | | | | |
| **Counts** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **association** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 1 |
| **no association** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| **Prognostic factors of respiratory complications** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Coventry 2017** | | | | | | | | | | | | | | | | | | | | | | | | | | | | √ | √ | | |
| **Ernst 2017** | | | | | | | | | | | | | | | | | √ | | | | | | | | | | | | | | |
| **Kempegowda 2017** | | | | | | | | | | | | | | | | | | | | √ | | | | | | | | | | | |
| **Kim 2015** | √ | | √ | | | | | | | | √ | | | | | | | | | | | | | | | √ | | | | | |
| **Kistler 2015** | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | |
| **Manaqibwala 2014** | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | |
| **Mazzola 2011** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | |
| **Ryan 2015** | | | | | | | | | | | | | | | | | | | | | | | | | | √ | | | | | |
| **Tsuda 2015** | | | | | | | | | | √ | | | | | | | | | | | | | | | | | | | | | |
| **van Wissen 2016** | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | |
| **Vidan 2011** | | | | | | | | | | | | | | | | | | | | | | | | | | √ | | | | | |
| **Counts** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **association** | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 1 | 0 | 0 |
| **no association** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **Prognostic factors of kidney/urinary complications** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Adunsky 2015** | X | X | | | | | | | | | | √ | | | | | | | | | | | | | | | | | | | |
| **Bennet 2010** | X | √ | | | √ | √ | | | | | | √ | √ | √ | | | | | | | | | | | | | | | | | |
| **Coventry 2017** | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | √ | | |
| **Eren 2012** | | √ | | √ | | | | | | | | | √ | √ | | | | | | | | | | √ | | | | | | | |
| **Ernst 2017** | | | | | | | | | | | | | | | | | √ | | | | | | | | | | | | | | |
| **Kempegowda 2017** | | | | | | | | | | | | | | | | | | | | √ | | | | | | | | | | | |
| **Kistler 2015** | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | |
| **Manaqibwala 2014** | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | |
| **Mazzola 2011** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | |
| **Ryan 2015** | | | | | | | | | | | | | | | | | | | | | | | | | | √ | | | | | |
| **Tobu 2014** | X | | | | | X | | | | X | X | X | | | | | | | | | | √ | X | | | | | | | | |
| **Tsuda 2015** | | | | | | | | | | √ | | | | | | | | | | | | | | | | | | | | | |
| **Ulucay 2012** | √ | √ | | √ | | X | X | X | X | | | X | | √ | √ | X | | | | X | | | | X | | | | | | | |
| **van Wissen 2016** | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | |
| **Vidan 2011** | | | | | | | | | | | | | | | | | | | | | | | | | | √ | | | | | |
| **Counts** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **association** | 1 | 3 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 2 | 2 | 3 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 2 | 0 | 1 | 0 | 0 |
| **no association** | 3 | 2 | 0 | 0 | 0 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |

**Table 3** Counts of a reported association or reported no association for prognostic factors of in-hospital delirium after hip fracture surgery. Light gray cells reflect patient factors. Dark gray cells reflect care prognostic factors. √ indicates association. X indicates no association

| | age | sex | race | education | frailty | comorbidities | pulmonary disease | peripheral vascular disease | cerebrovascular disease | hypothyroidism | chronic renal insufficiency | syncope | congestive heart failure | atrial fibrillation | hypertension | neurological comorbidities | cognitive Impairment | dementia | depression | anxiety | psychological factors | Parkinsons disease | psychiatric | diabetes | BMI | nutrition | preoperative serum metabolites | plasma cortisol | cerebrospinal fluid melatonin | anaemia | cancer | surgical readiness | fracture type | outdoor injury | time to admission | time to surgery | surgical duration | anaesthetic type | ortho vs. geriatric primary service | ortho vs. comanaged service | timing of orthogeriatric care | delirium friendly pre-printed orders |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Anbar 2014** | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | |
| **Coventry 2017** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | √ | √ | | |
| **Deschodt 2012** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | |
| **Dubljanin Raspopvic 2012** | | | | | | | | | | | | | | | | | √ | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Freter 2017** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | √ |
| **Guo 2017** | | | | | | | | | | | | | | | | | | | | | | | | | | √ | | | | | | | | | | | | | | | | |
| **Ji 2013** | | | | | | | | | | | | | | | | | | | | | | | | | | | √ | | | | | | | | | | | | | | |
| **Juliebo 2009** | | | | | | | | | | | | | | | | | √ | | | | | | | √ | | | | | | | | | √ | | | | | | | | |
| **Kim 2015** | √ | | | | | | | | | | | | | | | √ | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Kistler 2015** | | | | | √ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Koskderelioglu 2017** | X | X | | | | X | | | | | | | | | | | √ | X | √ | | | | | | | | | | | | X | X | | | | | X | | | | |
| **Mazzola 2011** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | |
| **Mazzola 2017** | | | | | | | | | | | | | | | | | | | | | | | | | √ | | | | | | | | | | | | | | | | | |
| **Nie 2012** | X | | | X | | X | | | | | | | | | | | X | | | | | | | | | | | | | | | X | | X | X | X | | | | | |
| **Oh 2016** | √ | √ | X | | | √ | X | X | X | X | X | X | √ | √ | X | | | √ | X | | | √ | X | X | X | | | | | X | √ | | | | | | | | | | |
| **Scholtens 2016** | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | |
| **Shin 2016** | | | | | | | | | | | | | | | | | | | X | X | √ [a] | | | | | | | | | | | | | | | | | | | | | |
| **van der Zanden 2016** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | √ | | | | | | | | | | | | | |
| **van Grootven 2016** | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | | |
| **Vidan 2011** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | |
| **Wu 2015** | | | | | | | | | | | | | | | | | √ | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Counts** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **association** | 2 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 4 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 |
| **no association** | 2 | 1 | 1 | 1 | 0 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 2 | 2 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 2 | 0 | 2 | 1 | 1 | 1 | 0 | 1 | 1 | 0 |

[a] Association for neuroticism; no association for extraversion, agreeableness, conscientiousness, or openness

[29], psychological factors—extraversion, agreeableness, conscientiousness, or openness [32]; diabetes [29], cerebrospinal fluid melatonin [31], fracture type [28, 45], time to admission [28], time to surgery [28, 68], surgical duration [28], anesthetic type (spinal, epidural, general) [45], or timing of orthogeriatric care [62], with delirium complications were reported (Table 3).

### Prognostic factors of pressure ulcers and other complications

In total, two nonmodifiable patient factors—cognitive impairment [40] and diabetes [25], and one potentially modifiable patient factors—dehydration (preoperative dry lips, thirst, and skinfold test) [25]; and two potentially modifiable process factors—time to surgery [19, 61, 68] and anesthetic type (other than general) [19], of pressure ulcers were reported by studies included in this review (Table 4, Fig. 2). No association between admitted on anticoagulant [42], and surgical duration [19], with pressure ulcers was reported after hip fracture surgery.

One study reported that education (elementary versus university degree), cognitive impairment, depression, and anemia (Hg level < 12 g/dL in women and Hg level < 13 g/dL in men during hospitalization) were prognostic of pain [30]. The same study reported that age, sex, diabetes, surgical readiness (American Society of Anesthesiologists score), anesthetic type (general versus regional), and surgical duration were not prognostic of pain [30]. Two studies reported that time to surgery was not prognostic of pain [30, 68]. One study reported that age, prefracture residence, comorbidity count, respiratory comorbidities, and neurological comorbidities were prognostic of dysphagia while cardiac comorbidities, ear, nose, and throat comorbidities, and anesthetic type were not prognostic of dysphagia [26]. One study reported that BMI ($\geq 30$ kg/m$^2$) was prognostic of electrolyte abnormalities [58]. Admission on anticoagulants [17, 42], BMI ($\geq 30$ kg/m$^2$) [58], and timing of orthogeriatric care [62] were not associated with anemia. One study reported that dementia was not prognostic of sepsis [66].

## Underlying mechanisms

We identified underlying mechanisms for 15 (34.1%) of the 44 prognostic factors of in-hospital complications (Table 5, Fig. 2).

**Table 4** Counts of a reported association or reported no association for prognostic factors of in-hospital pressure ulcer, dysphagia, pain, anemia, sepsis, and/or electrolyte abnormalities after hip fracture surgery. Light gray cells reflect patient prognostic factors. Dark gray cells reflect care prognostic factors. √ indicates association. X indicates no association

| | age | sex | prefracture function | prefracture residence | education | comorbidities | cardiac comorbidities | ear, nose and throat comorbidities | respiratory comorbidities | neurological comorbidities | cognitive Impairment | dementia | depression | diabetes | admitted on anticoagulant | dehydration | nutrition | BMI | anaemia | surgical readiness | time to surgery | anaesthetic type | surgical duration | timing of orthogeriatric care |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Prognostic factors of pressure ulcer/wound infection** | | | | | | | | | | | | | | | | | | | | | | | | |
| **Anbar 2014** | | | | | | | | | | | | | | | | | X | | | | | | | |
| **Baumgarten 2012** | | | | | | | | | | | | | | | | | | | | | √ | √ | X | |
| **Dubljanin Raspopvic 2012** | | | | | | | | | | | √ | | | | | | | | | | | | | |
| **Kempegowda 2017** | | | | | | | | | | | | | | | | | | X | | | | | | |
| **Lefaivre 2009** | | | | | | | | | | | | | | | | | | | | | √ | | | |
| **Lindholm 2008** | | | | | | | | | | | | | | √ | | √ | | | | | | | | |
| **Manaqibwala 2014** | | | | | | | | | | | | | | | X | | | | | | | | | |
| **Vidan 2011** | | | | | | | | | | | | | | | | | | | | | √ | | | |
| **Counts** | | | | | | | | | | | | | | | | | | | | | | | | |
| **association** | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 1 | 0 | 0 |
| **no association** | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| **Prognostic factors of dysphagia** | | | | | | | | | | | | | | | | | | | | | | | | |
| **Love 2013** | √ | | | √ | | √ | X | X | √ | √ | | | | | | | | | | | | X | | |
| **Counts** | | | | | | | | | | | | | | | | | | | | | | | | |
| **association** | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **no association** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **Prognostic factors of pain** | | | | | | | | | | | | | | | | | | | | | | | | |
| **Radinovic 2014** | X | X | | | √ | | | | | | √ | | √ | X | | | | | √ | X | X | X | X | |
| **Vidan 2011** | | | | | | | | | | | | | | | | | | | | | X | | | |
| **Counts** | | | | | | | | | | | | | | | | | | | | | | | | |
| **association** | 0 | 0 | 0 | | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| **no association** | 1 | 1 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 1 | 0 |
| **Prognostic factors of anaemia** | | | | | | | | | | | | | | | | | | | | | | | | |
| **Cohn 2017** | | | | | | | | | | | | | | | X | | | | | | | | | |
| **Manaqibwala 2014** | | | | | | | | | | | | | | | X | | | | | | | | | |
| **Mazzola 2011** | | | | | | | | | | | | | | | | | | | | | | | | X |
| **Kempegowda 2017** | | | | | | | | | | | | | | | | | | X | | | | | | |
| **Vidan 2011** | √ | | √ | | | | | | | | | √ | | | | | | | | | | | | |
| **Counts** | | | | | | | | | | | | | | | | | | | | | | | | |
| **association** | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **no association** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Prognostic factors of sepsis** | | | | | | | | | | | | | | | | | | | | | | | | |
| **Tsuda 2015** | | | | | | | | | | | | X | | | | | | | | | | | | |
| **Counts** | | | | | | | | | | | | | | | | | | | | | | | | |
| **association** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **no association** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Prognostic factors of electrolyte abnormalities** | | | | | | | | | | | | | | | | | | | | | | | | |
| **Kempegowda 2017** | | | | | | | | | | | | | | | | | | √ | | | | | | |
| **Counts** | | | | | | | | | | | | | | | | | | | | | | | | |
| **association** | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **no association** | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## Discussion

### Main findings

We identified 44 prognostic factors of in-hospital complications after hip fracture surgery from 56 studies included in this review. Of these, 36 related to the patient and 8 related to care processes and structures. We identified 7 patient and 7 care delivery factors that are potentially modifiable. More specifically, the presence of dehydration, anemia, hypotension, greater heart rate variability, higher pressure ulcer risk, malnutrition, prolonged indwelling catheter use, prolonged time to surgery, regional anesthetic, orthopedic (versus geriatric/co-managed) care, and multidisciplinary care pathway was

**Table 5** Proposed underlying mechanisms for the complication effects of prognostic factors

| | Factor | Underlying mechanism | Complication |
|---|---|---|---|
| Wu 2015 | Age | Younger participants might have less neurodegeneration, higher resistance to neurotoxicity, potentially caused by perioperative factors and greater brain reserve, compared to older participants. | Delirium |
| Tsuda 2015 | Anemia | Postoperative transfusion may lead to immunosuppression | Complications |
| Baumgarten 2012 | Anesthetic type | Complete lack of sensation in the lower body temporarily induced by regional anesthesia prevents small shifts to redistribute pressure, resulting in higher pressure ulcer risk than general anesthesia. | Pressure ulcer |
| Baumgarten 2012 | Anesthetic type | May be attributable to patient characteristics (such as health status). | Pressure ulcer |
| Juliebo 2009 | BMI | Malnutrition and underweight are associated with impaired immune function, and this might in part explain why low BMI and delayed surgery increase the risk of delirium. | Delirium |
| Dubljanin Raspopvic 2012 | Cognitive impairment | Older people with a hip fracture and impaired cognitive ability receive insufficient nursing care, and consequently suffer from a higher incidence of complications. | Delirium |
| Bennet 2010 | Comorbidities | This occurs following the injury due to a combination of hemorrhage, hypotension and dehydration and may be exacerbated by nephrotoxic medications or preexisting medical conditions which are known to predispose to acute renal dysfunction in the context of hypoperfusion. | Kidney |
| Lindholm 2008 | Dehydration | Patients who undergoing surgery earlier have less time to adjust to normal hydration before surgery. | Pressure ulcers |
| Tsuda 2015 | Dementia | It is possible that this relation is associated with difficulties inherent to postoperative rehabilitation in these patients, because patients with dementia often have difficulty following the instructions of the physical therapist. | Complications |
| Freter 2017 | Dementia | Individuals with dementia may receive fewer opioids after hip fracture, probably because of their greater risk of developing delirium. | Delirium |
| Radinovic 2014 | Depression | It has been noticed that psychological distress such as depression might increase postoperative analgesic consumption and have negative effects on postoperative pain. | Pain |
| Koval 2011 | Hospital type | Urban surgeons treated sicker patients undergoing more extensive procedures, and used fewer consultations, but their patients had more complications and revision surgeries. | Complications |
| Juliebo 2009 | Outdoor injury | Indoor injury is probably a combined indicator of cognitive and physical frailty. | Delirium |
| Bliemel 2015b | Parkinson's disease | Patients with Parkinson's disease need more time for mobilization under physiotherapeutic therapy. | Complications |
| Ji 2013 | Plasma cortisol | In addition to inflammation, cortisol also increases after a stress reaction, which causes detrimental effects on the brain and is associated with many psychiatric diseases. | Delirium |
| Oh 2016 | Sex | Men had poorer overall health at baseline than women. | Delirium |
| Ryan 2015 | Time to surgery | Patients delayed to surgery may be less medically stable than those who are not delayed. | Complications |
| Ryan 2015 | Time to surgery | Surgical timing was dependent on race and payer status and may indicate health care disparities. | Complications |
| Ryan 2015 | Time to surgery | Surgical timing may be influenced by variation in bed capacity (influenced by regional variation in demand, hospital teaching status and volume, and day of admission). | Complications |

associated with the occurrence of at least one in-hospital complication. The majority of factors were reported by only one study and with no proposed mechanism for their effect on complications after hip fracture surgery. Moreover, the association between 12 prognostic factors and complications was disputed across studies.

## Comparison to previous literature

From the 14 potentially modifiable factors, 3 were accompanied by a proposed underlying mechanism for their association with in-hospital complications after hip fracture surgery.

Anesthetic type was associated with the occurrence of pressure ulcers, with patients who underwent regional anesthetic more likely to develop pressure ulcers than those who underwent general anesthetic [19]. In the current review, we also reported that anesthetic type was not associated with composite measures of complications [66], delirium complications [45], or pain [30]. These findings support a 2016 Cochrane Review which indicated no difference between regional (neuraxial block) and general anesthetic on the occurrence of pneumonia, myocardial infarction, cerebrovascular accident, or acute confusion [69]. However, the authors reported that regional anesthetic may lead to lower deep venous thrombosis and operative hypotension when compared to general anesthetic [69]. Therefore, it is not clear whether recommending general anesthetic to reduce pressure risk would inadvertently increase the risk of deep venous thrombosis and operative hypotension. In the current review, the proposed

underlying mechanism for the association between anesthetic type and pressure ulcers was prolonged lack of sensation preventing small shifts to redistribute pressure with regional as compared to general anesthetic [19]. Intervening on the underlying mechanism, e.g., with higher specification foam mattresses, may mitigate the risk of pressure ulcers without changing the anesthetic strategy for patients undergoing hip fracture surgery with regional anesthetic [70].

Time to surgery was associated with the occurrence of cardiac, respiratory, and/or kidney/urinary complications [14], pressure ulcers [19], and composite measures of complications [14, 60]. Ryan et al. proposed medical instability as the underlying mechanism for their reported association between delay to surgery and postoperative complications [14]. In contrast, Lindholm et al. suggested that patients who undergo early surgery have less time to adjust to normal hydration preoperatively increasing their risk of postoperative complications [25]. These contrasting proposed mechanisms support the argument that there is an "optimal" time to surgery—one which allows preoperative medical stabilization but prevents unnecessary administrative delays. Indeed, there has been considerable debate as to the optimal time to surgery with recommendations from as early as 6 h to as late as 4 days across studies [71, 72]. Inconsistent cut-offs for *early* and *delayed* surgery may also help to explain conflicting results which reported no association between time to surgery and composite measures of complications [55, 57, 61, 67], delirium complications [28, 31], or pain [30].

Tsuda et al. proposed that postoperative blood transfusions for patients with anemia may lead to immunosuppression and subsequent complications [66]. However, a randomized controlled trial of liberal versus restrictive blood transfusion strategy on long-term survival after hip fracture surgery did not support the hypothesis that blood transfusions leads to immunosuppression [73]. We previously identified frailty and weakness (a feature of frailty) as proposed underlying mechanisms for the influence of anemia on functional recovery after hip fracture surgery [74]. Frailty could also play a role in the reported association between anemia and complications here. Indeed, anemia has been linked with inflammatory chronic diseases and frailty [75]. This morbidity burden may increase the risk of postoperative complications.

## Future research

The findings of this review are intended to inform future evidence synthesis and/or intervention development for clinical practice. From preliminary searches, we identified a large volume of research on the occurrence of postoperative complications after different surgical procedures and/or the administration of medications, after index hospitalization for hip fracture. These exposures are amenable to targeted overview of reviews to enable better understanding of their association with postoperative complications.

We identified 44 prognostic factors of which only 8 related to structures of care (hospital type) and processes of care (time to surgery, anesthetic type, transfusion strategy, orthopedic versus geriatric primary care, orthopedic versus co-managed care, delirium friendly pre-printed orders, multidisciplinary care pathway). This finding is supported by a recent review of orthogeriatric care models and outcomes after hip fracture which reported a dearth of evidence on the impact of orthogeriatric care on complications including delirium [76]. Structures and processes of care may be more amenable to intervention and should be explored in future prognostic studies.

There was limited replication of analyses of prognostic factors of complications across studies. Moreover, where replicated, we reported uncertainty of age, sex, BMI, cognitive impairment, diabetes, dementia, serum potassium, depression, nutrition, surgical readiness, time to surgery, and orthopedic versus co-managed care as prognostic factors of complications across studies. Replication should be considered prior to design of an intervention or implementation of a quality improvement initiative targeting these factors.

There was a lack of consensus across studies as to an appropriate composite measure of complications after hip fracture surgery. This may be due to different goals of a composite measure or different proposed underlying mechanisms between a given prognostic factor and composite measure of complications. However, few studies specified a goal for their composite measure or a proposed underlying mechanism for the association between prognostic factor and a composite measure of complications. It is therefore not clear whether complication selection is driven by a conceptual framework, rate of occurrence, or available data.

For elective surgical procedures, the Agency for Healthcare Research and Quality identified eight potentially fatal complications—deep vein thrombosis, pulmonary embolism, pneumonia, sepsis, shock, cardiac arrest, gastrointestinal hemorrhage, and acute ulcer [77]. We previously synthesized the evidence on complications associated with in-hospital death after hip fracture [5]. We did not synthesize the incidence of individual complications after hip fracture surgery nor explicitly synthesize the *cause* of death. More recently, a cohort study ($n = 220$) reported respiratory infections (35%), ischemic heart disease (21%), and cardiac failure (13%) as the most common causes of death listed on post-mortem reports in-hospital after hip fracture surgery [78]. This supports an earlier study of isolated limb and pelvic fractures (including hip fracture) which reported bronchopneumonia as the leading cause of death ($n = 45$) [79]. Further work should be completed to identify the most common complications causing in-hospital death after hip fracture to inform recommendations for a composite measure of complications.

We employed a scoping review adopting search terms for *complications* and not for individual complications; e.g., myocardial infarction, pneumonia, or delirium. We identified one review which focused on a specific complication after hip fracture surgery, namely delirium [80]. Their conclusion that age, overall health, and dementia were associated with postoperative delirium is reflected by the current review [80]. In the absence of a consensus as to the most appropriate composite measure of complications, it may be appropriate to generate systematic reviews and meta-analyses of specific complications informed by this review.

The dependency graph provides a framework for further discussion on intervention design [81, 82]. Therefore, we have not assessed the significance of individual factors when conflicting evidences were present. The graph depicts a network of relationships that could be statistically tested in future research. It is also important to consider the level of abstraction when considering which factors to target for intervention. Indeed, factors at a higher level of abstraction may influence the occurrence of postoperative complications through other intermediate factors and may be amenable to intervention design. In contrast, these factors may not be required for adjustment to infer causation in policy evaluations.

### Limitations of the review

There is a potential for publication bias as we limited our search to articles identified through electronic databases and to those published in English. We limited our search to complications occurring in hospital. We noted several studies that reported 30-day complications (in particular studies using the American College of Surgeons National Surgical Quality Improvement Program) but did not specify whether these complications occurred in-hospital, the community, or both [83]. Therefore, we excluded these studies from the current review. With reductions in acute length of stay, it is possible that we underestimated the extent of prognostic factors of in-hospital complications. We did not assess the quality of the reviewed articles per the scoping review framework [84]. It is therefore difficult to determine whether this uncertainty reflects different methodological qualities across studies, true variation in prognostication, or different conceptualization of the composite measures (with different prognoses based on included complications).

## Conclusion

We synthesized the evidence on prognostic factors of complications after hip fracture surgery. We identified 44 factors from 56 articles included in this review. We identified 14 potentially modifiable factors. However, with inconsistent findings, no proposed underlying mechanism, and limited replication in the evidence base due to different conceptualization of complications, it is not possible to be certain whether intervening on these factors would reduce the rate of complications after hip fracture surgery.

## Compliance with ethical standards

**Conflict of interest** Boris Sobolev and Pierre Guy report receiving grants from the Canadian Institutes of Health Research related to this work. Pierre Guy reports receiving grants from the Natural Sciences and Engineering Research Council of Canada, the Canadian Foundation for Innovation, and the British Columbia Specialists Services Committee for work regarding hip fracture care, outside the submitted work. He has also received fees from the BC Specialists Services Committee (for a provincial quality improvement project on redesign of hip fracture care) and from Stryker Orthopaedics (as a product development consultant), outside the submitted work. He is a board member and shareholder in Traumis Surgical Systems Inc. and a board member for the Canadian Orthopaedic Foundation. He also serves on the speakers' bureaus of AOTrauma North America and Stryker Canada. Katie Jane Sheehan received funding from the National Institute for Health Research (NIHR) outside of the submitted work. Evan Guerrero, David Tainter, Brian Dial, Rhian Milton-Cole, James A Blair, James Alexander, Priti Swamy, Lisa Kuramoto, and Janet Pruv Bettger have no conflicts of interest to declare.

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