The Journal of Nutrition, Health and Aging 28 (2024) 100357

Contents lists available at ScienceDirect

The Journal of Nutrition, Health and Aging

journal homepage: www.elsevier.com/locate/jnha

Review

Characteristics of fragility hip fracture-related falls in the older adults: A systematic review

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ARTICLE INFO

Keywords:
Accidental Falls
Aged, Fall
Frail elderly
Hip fractures

ABSTRACT

Background and objectives: With the global aging trend, the incidence of falls and hip fractures is projected to rise, leading to an increased associated burden. Over 90% of hip fractures result from falls, yet not all falls cause fractures, suggesting specific fall characteristics may contribute to hip fractures. This review provides insights into fragility hip fracture-related falls among the older adults, aiding in understanding and developing effective fall prevention strategies for this population.
Methods: Searches encompassed PubMed, OVID, EMBASE, Cochrane Library, and Web of Science, supplemented by citation checks. We included non-randomized studies detailing characteristics of fragility hip fracture-related falls in the older individuals, with or without a non-hip fracture control. Evaluated fall characteristics included height, location, direction, time, mechanism, activity during the fall, hip impact, protective responses, walking aid use, and impact surface. Results were analyzed using a narrative synthesis approach. The quality of these studies was assessed using the revised Risk of Bias Assessment tool for Non-randomized Studies 2 (RoBANS2).
Results: A total of 30 articles were reviewed, comprising 23 non-case control and 7 case-control studies, with a mean age of 75.6 years. Studies presented varied details on fall characteristics. Hip-fracture related falls typically occur indoors at or around standing height during daytime, often involving sideways or backward motions with inadequate protective responses. Slipping is predominant, yet lost balance and weakness/collapse are notable. Walking precedes many falls, but stationary activities (lack of forward motion, changing positions, sitting or standing still, transfer) also contribute. Low usage of walking aids and impact on hard surfaces are common features of these falls.
Conclusions: This review underscores fall characteristics associated with fragility hip fractures in older adults, highlighting features more aligned with age-related physical frailty than general falls. Such insights can guide healthcare providers in implementing tailored interventions to reduce hip fractures and related challenges.

1. Introduction

Falls are defined as events resulting in a person inadvertently coming to rest on the ground, floor, or another lower level [1]. The global prevalence of falls among older adults is estimated at 26.5% [2], with the frequency increasing with age. Approximately one in three individuals over the age of 65 experience at least one fall per year, and this rate rises to one in two for those aged over 80 [3]. By 2050, the global population of individuals aged 65 years or older is projected to more than double, increasing from 761 million in 2021 to 1.6 billion. Furthermore, the number of people aged 80 years or older is expected to grow even more rapidly, tripling and reaching 459 million by 2050 from around 155 million in 2021 [4]. In the United States, as the population continues to age, healthcare expenditures due to falls reached $50.0 billion in 2018 [5]

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http://doi.org/10.1016/j.jnha.2024.100357
Received 15 July 2024; Received in revised form 30 August 2024; Accepted 30 August 2024
Available online 14 September 2024
1279-7707/

and are expected to exceed $101 billion in 2030 [6]. Globally, falls are recognized as the leading cause of injuries and injury-related deaths among the older adults [7]. The rising medical expenses associated with falls in this aging demographic will significantly strain the healthcare system.

Fall injuries in older individuals range from minor conditions like soft-tissue damage, bruises, and cuts to more severe outcomes, including hip fractures, other fractures, head injuries, and damage to internal organs and the spine [8]. Hip fractures, a serious consequence of falls, contribute to an increased risk of disability, morbidity, and mortality in older people [9]. The incidence of hip fractures rises significantly with age, and associated costs during the first year after a hip fracture ($43,669) exceed those for acute coronary syndrome ($32,345) and ischemic stroke ($34,772) [10]. With the global aging trend, it is projected that the total number of hip fractures in 2050 will nearly double the 2018 figure, leading to increased costs [11]. Falls and hip fractures share common characteristics related to physical frailty, with falls accounting for over 90% of all hip fractures [12]. The fracture caused by low-energy trauma, such as falls from a standing height is defined as the fragility hip fractures. However, not all falls result in hip fractures; the most commonly reported fall injuries are superficial cuts, abrasions, bruises, and sprains [13]. More serious injuries, such as fractures, joint dislocations, and head injuries, occur in approximately 10% of falls [14]. Depending on the population studied, only 0.6%–2% of all falls reported lead to hip fractures [13,15–18].

To prevent serious injuries, sequelae, disability, and mortality from falls, understanding the associated risk factors, mechanisms, and circumstances is crucial. A study analyzing real-time falls in long-term care facilities, unlike most self-reported data studies, observed various fall types, including balance loss during walking or changing direction, self-stumbling, and loss of external support [19]. In a large cross-sectional study of community-dwelling older individuals, falls were frequent during outdoor activities such as walking, while those over 85 experienced a high frequency of indoor falls [20]. Previous research suggests that essential elements, including the orientation of the faller, fall energy, energy absorption (protective responses, local shock absorbers), and bone strength, play a role in the sequence leading from falls to hip fractures [21,22]. When these components are insufficient to halt the sequence, incidental falls are more likely to result in hip fractures. Given the very low prevalence of hip fractures after falls, it implies that specific fall characteristics may contribute to hip fractures compared to those without hip fractures.

There have been several studies analyzing the characteristics of falls in patients with hip fractures. However, the classification, definition, and number of fall characteristics varied among individual studies. Additionally, to the authors' knowledge, no systematic review has summarized the fall characteristics related to fragility hip fractures, although some brief reviews have been published [21,23]. Therefore, this study aims to provide an overview of the characteristics of fragility hip fracture-related falls in the older population and assess the quality of existing studies. This review is essential for a comprehensive understanding of the circumstances of fragility hip fractures and provides evidence for translating knowledge into clinical practice to establish effective fall prevention strategies in the older population.

2. Methods

This review protocol was prospectively registered in the PROSPERO database (registration number CRD42023454916) and follows The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [24].

2.1. Data sources and searches

We conducted a search across multiple databases, including PubMed, OVID, EMBASE, Cochrane Library, and Web of Science. The search strategy involved the utilization of a search filter developed by a clinical librarian. Furthermore, a search of 'gray' literature conducted using Google Scholar, ClinicalTrials.gov, and Google. Additionally, we manually searched reference lists of included articles to identify further potential articles meeting the inclusion criteria. The search encompassed articles published without date restrictions, and language was confined to English. All searches were performed in July 2023 and last updated in June 2024. Search strategy for all databases is provided in the supplementary data **(Supplemental material 1)**.

2.2. Study selection

We included non-randomized studies (cohort, case-control, and cross-sectional) detailing characteristics of fragility hip fracture-related falls in patients, regardless of the presence of a non-hip fracture control group. Despite several studies analyzing fall characteristics in hip fracture patients, there is significant variability in classification, definitions, and the number of characteristics, with no standardized system. Terms used to describe fall characteristics—such as pattern, circumstance, type, description, and mechanism—varied across studies, leading to inconsistency. To address this, we consolidated these concepts under the term "fall characteristics" and identified specific items based on the hypothesis by Cummings and Nevitt [21,22]. They proposed that hip fractures occur when the faller impacts near the hip and when protective responses (e.g., using an outstretched hand) and shock absorbers (e.g., soft tissue over the greater trochanter) fail to dissipate sufficient energy. These factors—impact location, protective responses, and shock absorbers—are non-skeletal determinants of fractures, while bone strength, influenced by factors such as geometry, mass, density, trabecular integrity, and fatigue damage, is a skeletal determinant. A bone fractures if the energy from a fall, influenced by these non-skeletal factors, exceeds its strength in that direction. Therefore, bone strength serves as the "last defense" against hip fractures. This means that older adults with poor bone health, typically characterized by low bone mineral density (BMD), have an elevated risk of hip fractures even from less traumatic falls.

For this review, we identified "fall characteristics" as the 10 key traits frequently mentioned in previous studies, focusing on non-skeletal determinants of fractures while excluding bone strength. These characteristics include fall height, location, direction, time of fall, mechanism, activity during the fall, hip impact, protective response, walking aid use, and impact surface. Our review included studies with participants aged 60 years and older or with a mean age in that range. We excluded reviews, conference materials, case reports, and abstracts, as well as studies focusing on: 1) high-energy incidents causing hip fractures, like falls from height or car accidents; 2) periprosthetic fractures; and 3) fractures from underlying conditions such as cancer, coxarthrosis, or femoral necrosis. There were no restrictions based on healthcare settings (community, hospital, or long-term care (LTC) facility). Duplicate entries were eliminated from the search results. Two reviewers (SK-L, K-C) independently evaluated titles and abstracts, and subsequently, reviewed full texts that met eligibility criteria or posed uncertainty. Any disagreements were resolved through discussion with a third reviewer (JY-L).

2.3. Quality assessment

The risk of bias was assessed using the revised Risk of Bias Assessment tool for Non-randomized Studies (RoBANS2) to evaluate the quality of the included studies [25,26]. The RoBANS2 tool comprises domains such as comparability of the target group (selection bias), target group selection (selection bias), confounders (selection bias), measurement of intervention/exposure (performance bias), blinding of assessors (detection bias), outcome assessment (detection bias), incomplete data outcome (attrition bias), and selective outcome reporting (reporting bias). Each domain was categorized as unclear, low risk, or high risk of bias. A quality of reporting assessment was independently conducted by two reviewers (SK-L, K-C). Any disagreements were discussed until a consensus was reached.

2.4. Data extraction

Data were extracted using a specified data extraction form that encompassed article details (author, date, publication), study particulars (design, country, data source), participant attributes (number, age, gender), inclusion/exclusion criteria, utilized control groups, between-group analyses in non-case control studies, outcomes of interest (fall characteristics), and conclusions of each study. The primary author (SK-L) performed the data extraction, which was then reviewed and verified by a third reviewer (JY-L).

2.5. Data synthesis and analysis

The study details and findings for each fall characteristic were summarized descriptively. A narrative synthesis was conducted due to the significant methodological heterogeneity in characterizing falls and the inconsistencies in the presence of control groups across studies, making a meta-analysis infeasible. Results were categorized based on the inclusion of a control group (non-hip fracture).

3. Results

3.1. Search results

A total of 1212 articles were identified in the initial search. After removing duplicates, 656 articles underwent screening based on titles and abstracts, with 8 additional records identified through abstracts and study registries. Following a thorough review of full texts, 26 articles met the inclusion criteria. Ultimately, 30 articles were eligible and included in the review, with an additional 4 articles identified through manual searches. A summary is provided in Fig. 1.

3.2. Study characteristics

The study characteristics from 1993 to 2023 are detailed in Table 1. The overview includes 17 cross-sectional studies [27–43], 3 retrospective cohort studies [44–46], 2 prospective cohort studies [18,47], and 8 case-control studies [16,48–54], spanning 21 countries with one multinational study. Seven non-case control studies explored variables like age [38,44], sarcopenia [28], dementia [30], and fracture type [42,47,52]. Sample sizes ranged from 28 to 2816 individuals, with a mean age of 75.6 years for 17,431 participants; the female proportion averaged 73.1%. One study [52] was reclassified from case-control to cross-sectional due to control definition issues. The review separately presents findings from 23 non-case control and 7 case-control studies, predominantly on community-based hip fractures, except for one focusing on LTC facilities.

3.3. Quality assessment of individual studies

The risk of biases is summarized in **Supplementary material 2**. Selection bias related to the comparability of the target group and target group selection had a low risk of bias in all studies. However, selection bias due to confounders was deemed high risk in 40% of the studies, as they did not adequately address main confounders such as age, gender, and other risk factors during the planning or analysis stages [27,29,31–33,37,38,40,41,43,45,52]. Performance bias related to the measurement of intervention/exposure was considered high risk in 36.7% of the studies. This was attributed to fall-related information obtained through self-reported data, susceptible to bias due to the extended time interval between the fall and the interview [16,27,29,30,39,48,50], or proxy interviews conducted due to dementia [29,34], potentially introducing recall bias. Additionally, recall bias was introduced through data from semi-structured interviews [36], unstructured interviews at the emergency department [46], and differences in recordkeeping methods between hospitals [33]. Four studies [18,42,53,54] specified assessor blinding, while in the others, the risk of detection bias was deemed unclear due to the absence of information on outcome assessment blinding, leaving uncertainty about its impact on results. Detection bias from outcome assessment was high in six studies [27,29,33,36,48,50] as patient-reported outcomes relied solely on simple self-responses; three studies [37,41,43] were deemed unclear. One study [27] employed mixed classifications, failing to clearly distinguish between activity and

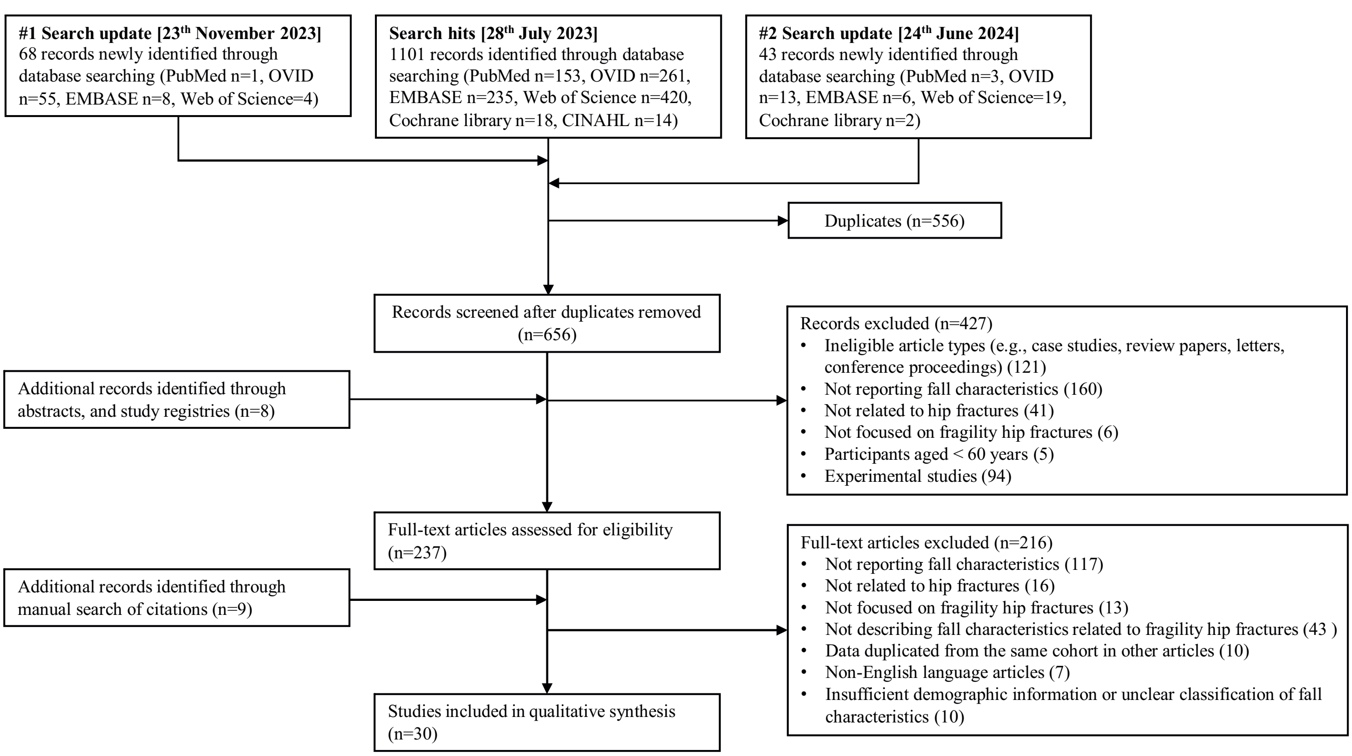

Fig. 1. Flow chart of the article inclusion process.

Table 1
Summary of study details for papers included in systematic review.

Article	Study design	Setting (Country)	Population				Inclusion criteria	Exclusion criteria	Between-group comparison*	Fall characteristics	Conclusions
			Group	n (% female)	Age (years)	Groups matched for					
Morikawa 2021 [44]	4	A single convalescent and rehabilitation center (Japan)	HF	92 (84.8)	85.3 (6.5)	NA	Age ≥ 65	NR	Age 65–84/ Age ≥ 85	Location Direction Use of walking aids	The falling direction significantly differed between HF patients in the 65–84 and 85 + age groups. In the 85 + group, there was a lower proportion of HFs from sideways falls but a higher proportion from backward falls compared to the 65–84 group.
Iolascon 2013 [27]	1	80 rehabilitation units from the PATO2 study, (Italy)	HF	419 (81.38)	79.9 (53 −97)	NA	Age ≥ 55, at least one fragility fracture in the past 12 months	Severe motor or cognitive impairments	NR	Location Direction Time Mechanism	Most HF patients fell at home, particularly in the kitchen or bathroom, in the morning, with slipping on a smooth floor being the predominant extrinsic risk factor.
Lim 2020 [28]	1	4 university hospitals from the FIRM study (South Korea)	HF	147 (78.2)	81.3 (6.7)	NA	Age ≥ 65, undergone surgery for fragility HFs	Undergone surgery unrelated to fragility HFs	Sarcopenia/ non-sarcopenia	Location Direction Mechanism	Sarcopenia is correlated with falls involving leg weakness during walking, changing positions, or standing, and it is a risk factor for these fall types in older adults with fragility HFs.
Namgung 2019 [45]	4	≥ 150 Emergency centers (South Korea)	HF	28 (NR)	NR	NA	Age ≥ 65, visited ED for nonmedical causes by LTC hospitals	Age < 65, visited ED directly, transferred from general hospitals	NR	Mechanism	HFs are more common with slips than falls from bed, often occurring in bathrooms.
Peng 2023 [29]	1	6 hospitals (China)	HF	1892 (70.0)	80.7 (7.6)	NA	Age ≥ 65, diagnosed within 21 days of fracture	Pathological fractures, periprosthetic fractures, advanced malignancies, and HFs due to non-falls	NR	Height Location Time Direction Mechanism Activity Use of walking aids	Most HFs resulted from falls in the oldest age group (≥80 years). The majority of falls occurred during the daytime, with a significant proportion happening at home. Lost balance was the primary cause of falls, with walking being the most common activity.
Formiga 2008 [30]	1	6 hospitals (Spain)	HF	1024 (77.2)	82.9 (6.5)	NA	Aged ≥ 64 for fall-related HFs	Pathological causes, high-energy trauma, suicide attempts, lack of fall evidence, cognitive decline, insufficient fall details, and institutionalized subjects	Dementia/ Non-dementia	Height Location Time	Non-demented patients predominantly fell during the day, possibly due to better mobility compared to patients with dementia.
Schwartz 1998 [48]	2	**Cases:** 34 hospitals (USA)	HF CG	214 (NR) 86 (NR)	79.7 (NR) 75.3 (NR)	Age	**Cases:** age ≥ 45 **Controls:** at least one fall in the 12 months prior to interview	Pathological fractures, uncontactable after hospital discharge, no reported fall as the immediate cause of HF, falls due to overwhelming force or seizures	NA	Height Location Mechanism Activity Impact Use of walking aids Surface	A hip/thigh impact during a fall strongly correlated with HF risk, with sideways falls posing the highest risk due to the increased likelihood of landing on the hip/ thigh.
Allander 1998 [31]	1	14 centers from The MEDOS study (France, Greece, Italy, Portugal, Spain, Turkey)	HF	2816 (74.1)	77.7 (NR)	NA	Aged >50	NR	NR	Height Location Time Mechanism Activity	Most HFs occurred indoors, with a smaller proportion outdoors in darkness. Same-level falls were predominant, whereas stairway falls contributed to a smaller portion of total fractures

Table 1 ***(continued)***

Article	Study design	Setting (Country)	Population				Inclusion criteria	Exclusion criteria	Between-group comparison*	Fall characteristics	Conclusions
			Group	n (% female)	Age (years)	Groups matched for					
Aharonoff 1998 [32]	1	A single hospital (USA)	HF	832 (78.6)	79.7 (NR)	NA	Age ≥ 65, ambulatory, cognitively intact, living at home pre-fracture, nonpathological HF	NR	NR	Location Time Activity	Fractures were mostly at home, especially in older, less healthy, and less mobile patients. The majority resulted from standing or walking falls, rather than severe trauma, with a peak in the afternoon during daylight hours.
Boyé 2014 [33]	1	2 academic and 5 regional hospitals from the IMPROve FALL study (Netherlands)	HF	468 (NR)	80 (NR)	NA	Age ≥ 65, unintentional fall on the ground or a lower level, with or without loss of consciousness	Acute medical conditions, e.g. stroke, or exogenous factors such as a traffic accident	NR	Location Activity	Indoor falls constituted two-thirds of all incidents, with variations by age and gender. Outdoor falls were more prevalent in the 65–79 age group and among men. Walking and stair use were the primary indoor fall activities, while walking and cycling were the most common outdoor activities.
Norton 1997 [35]	1	2 hospitals (New Zealand)	HF	911 (76.7)	82 (NR)	NA	Age ≥ 60	NR	NR	Height Location Direction Activity Surface	The majority of fractures resulted from falls at home, with environmental hazards implicated in a significant portion of these falls. Modifying these hazards may not be feasible, and fall circumstances varied significantly by age and residential status.
Michelson 1995 [34]	1	4 university-affiliated hospitals (USA)	HF	169 (60)	78 (10.4)	NA	Age ≥ 50, Not cancer-related and non-hospital occurrence	NR	NR	Location Direction Time Mechanism Activity Surface	HFs mainly occur indoors, often in the bedroom, living room, or kitchen. While some attribute falls to internal causes like balance loss, others recognize environmental factors.
Wei 2001 [49]	2	**Cases:** A community-based general hospital	HF	127 (73)	75.6 (5.4)	Age, sex	**Cases**: aged 65−85 with a first-time HF due to a fall	Non-ambulatory before fall, external force fall, ineligible medical conditions, dementia or mental changes affecting questionnaire response	NA	Height Location Direction Activity Protective response	Sideways falls and direct hip impact are independent predictors of HF. The prevention strategy should focus on reducing local impact force on the hip after a fall.
		Controls: Community-dwelling individuals (Taiwan)	CG	125 (71)	74.5 (4.8)		**Controls**: subjects who fell without HFs in the last 3 months				
Leavy 2015 [36]	1	A single hospital (Sweden)	HF	125 (70.3)	79.1 (9.4)	NA	Age ≥ 50, memory of the fall and verbal ability to recount details, MMSE ≥24	Reduced consciousness, post-operative confusion or medical instability	NR	Location Mechanism Activity Use of walking aids	Those fracturing during positional change had the poorest functional status, while those fracturing outdoors in snow-free environments were more similar to those fracturing indoors than to other outdoor groups.
Cummings 1994 [50]	2	**Cases:** 12 Hospitals (Australia)	HF	125 (83)	NR (65−100)	NR	Age ≥ 65, with or without a HF, Subjects providing detailed fall descriptions	Cognitive impairment, had not fallen in the past 3 years	NA	Location Mechanism Surface	There was only 1 statistically significant fall characteristic associated with risk of HF; falling while turning was much more likely to lead to a HF than falling when walking in one direction.
		Controls: Community-dwelling individuals and 9 nursing homes and hostels (Australia)	CG	84 (75)							

(continued on next page)

Table 1 *(continued)*

Article	Study design	Setting (Country)	Population				Inclusion criteria	Exclusion criteria	Between-group comparison*	Fall characteristics	Conclusions
			Group	n (% female)	Age (years)	Groups matched for					
Hwang 2011 [51]	2	A single community-based general hospital (Taiwan)	HF	306 (72.2)	M 79.1 (6.5) F 79.7 (6.4)	Gender, time of falling	**Cases:** age ≥ 65, visited the ED due to a fall with a first HF incident	Pathologic fractures and second HFs	NA	Location Direction Mechanism (mode) Protective response Surface	The direction of the fall was a strong predictor of HFs. In both men and women, backward, straight-down, and sideways falls had significantly higher risks compared to forward falls.
			CG	306 (72.2)	M 78.2 (7.1) F 76.5 (7.0)		**Controls:** older adults, visited the ED due to falls resulting in injuries other than HFs				
Burm 2021 [46]	4	A single university hospital (South Korea)	HF	1986 (71.0)	77.0 (9.4)	NA	Admitted either to the ward or ED due to HF	Age < 50, HFs from high-trauma accidents, pathological fractures, falls during hospital or LTC center admission, and unclear information on falls	NR	Location Mechanism Activity	Slips were the primary cause of falls, with indoor falls often due to incorrect shift and collapse, while outdoor falls were typically caused by trips or stumbles. Common activities during falls included walking, getting up or rising, and standing. Indoor falls were more associated with getting up or rising, while outdoor falls were more linked to walking.
Hopkinson-Woolley 1998 [37]	1	A single district general hospital (UK)	HF	321 (NR)	79 (NR)	NA	HF patients with description of the fall	Not caused by a fall (e.g., motor vehicle, cycle, pathological fractures, spontaneous fracture, fall from a height off a ladder)	NR	Location Direction Activity Use of walking aids	The majority of fractures occurred by falling directly onto the affected side, suggesting potential benefits of protective padding on the hip.
Yang 2020 [18]	3	Video-captured database of real-life falls from two LTC facilities (Canada)	HF	30 (63.3)	85.4 (7.9)	NR	All falls resulting in a person coming to rest on the floor or another lower level, with or without injury	NR	NA	Direction Activity Impact Protective response Use of walking aids	The risk of HF was higher for sideways landing and falls causing hip impact, but risk was comparable between falls initially directed sideways and forward, likely due to rotation during descent. Use of a mobility aid was associated with lower fracture risk, and a majority of HFs involved impact to the posterolateral aspect of the pelvis.
			CG	1434 (57.0)	82.3 (10.0)						
Abolhassani 2006 [38]	1	All public hospitals in 65 cities from 9 provinces from the IMSAI study (Iran)	HF	Total 572 (46.6) Aged 20–49 years 122 (21.3) Aged 50 + years 450 (53.5)	M 59.9 (20.7) F 70.2 (15.3)	NA	Admitted to emergency, surgery, and orthopedic wards due to an injurious fall event resulting in a HF	Different fall patterns leading to HFs in childhood and adolescence, aged below 20 years	Aged 20–49 years/50 + years	Height Location Activity	In patients aged 50 and older, most HFs resulted from falls from standing height or less. Older individuals predominantly experienced HFs indoors. However, falls from standing height or loss, falls during walking, and falls on stairs were identified as risk factors for HFs in older patients.
George 2021 [39]	1	A single tertiary level trauma center (India)	HF	283 (53.7)	70 (12)	NA	All HFs in individuals 50 years or older	Isolated greater trochanteric fracture and head fractures	NR	Height Mechanism Activity	Most HFs in older adults, especially in women, result from falls from standing height. Wet floors and postural changes are common causes, emphasizing the need for fall counseling that includes education on environmental safety measures and postural changes.

Table 1 ***(continued)***

Article	Study design	Setting (Country)	Population				Inclusion criteria	Exclusion criteria	Between-group comparison*	Fall characteristics	Conclusions
			Group	n (% female)	Age (years)	Groups matched for					
Ulusoy 2020 [41]	1	A single hospital (Türkiye)	HF	83 (69.9)	83 (5)	NA	Age ≥ 75, undergone surgery for HFs	NR	NR	Location Direction Mechanism Use of walking aids	Most fractures result from balance disturbances without environmental factors. Patients tend to fall on one side rather than front or back. Modifying clothes and floor materials can reduce trauma severity during falls, potentially lowering HF incidence.
Fiatarone Singh 2009 [40]	1	Three acute care hospital from the SHIP study (Australia)	HF	193 (72)	80.6 (8.4)	NA	Age ≥ 60, admitted for surgical repair of minimal-trauma HF	Residing in a nursing home, terminally ill, or severely demented	NR	Location Activity	Most commonly, HFs occurred while walking at home.
Goh 1996 [43]	1	A single university hospital (Singapore)	HF	260 (79.4)	M 76.8 (9.1) F 77.7 (8.0)	NA	HF patients	Metabolic disorders affecting skeletal integrity, bone metabolism-affecting medications, HFs from violent trauma, and previous HFs	NR	Height Location Direction Activity Protective response Use of walking aids Surface	Falls leading to direct hip impact (sideways, backwards, and straight down) comprised the majority. Most incidents occurred indoors on hard surfaces, and while walking and changing positions. Low BMD and falls were identified as critical risk factors for HFs in the older adults, highlighting susceptibility even to mild trauma, such as falling from a seated or lying position.
Aizen 2003 [52] **	2	A single rehabilitation geriatric center (Israel)	HF	101 (83.2)	TC 77.3 (8.4) Diverse 80.4 (6.7)	NA	Age ≥ 65, hospitalized for rehabilitation after a HF	Dementia, delirium or other definite age-related memory impairment	Fracture type (TC/ Diverse)	Height Direction Protective response	Both the fall direction and impact area should be considered as crucial fall characteristics for HFs. Most HFs result from falls onto the posterolateral aspect of the femur or impacts on the greater trochanter.
Cauley 2009 [47]	3	Four clinical centers from the SOF study (USA)	HF	462 (100)	FN 73.8 (5.2)/ 74 .1 (5.4) IT 75.1 (6.0)/76.4 (6.3)[a]	NA	Community-dwelling women aged 65 or older with their first HF incident	Black women, unable to walk without assistance, and a history of bilateral hip replacement	Fracture type (FN/IT)	Height Location Direction Activity Impact Protective response Surface	Except for using the hand to break the fall, none of these circumstances differentiated the severity of the fracture. A lower proportion of women who reported using their hand to break the fall experienced a severe HF.
Greenspan 1994 [42]	1	A single community-based academic hospital (USA)	HF	112 (75.9)	M: TC 88 (6) FN 87 (10) F: TC 85 (8) FN 84 (8)	NA	Age ≥ 65, previously ambulatory, HF resulting from a fall, stable for BMD measurement within 1 week of fracture	Metabolic disorders affecting skeletal integrity, bone metabolism-affecting medications, pathologic or non-fall-related fractures, a prior HF	Fracture type (TC/ FN)	Height Direction Activity Protective response	Fall characteristics and body habitus did not differentiate between HF type in older adult fallers.

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Table 1 ***(continued)***

Article	Study design	Setting (Country)	Population				Inclusion criteria	Exclusion criteria	Between-group comparison*	Fall characteristics	Conclusions
			Group	n (% female)	Age (years)	Groups matched for					
Nevitt 1993 [16]	2	Four clinical centers from the SOF study (USA)	HF WF NHF	130 (100) 294 (100) 467 (100)	74.8 (5.3) 72.0 (5.5) 71.5 (5.5)	NR	Community-dwelling, non-black women aged 65 or older with their first HF and WF incident., resulted from falls, able to report the circumstances of the fall	NR	NA	Height Location Direction Activity Impact Protective response Surface	Falls on or near the hip significantly increase the risk of HF, while falls on an outstretched hand decrease the risk of HF and increase the risk of WF. Triceps weakness independently contributes to the risk of HF, indicating that protective arm responses may be less effective in individuals with weak arm extensors.
Parkkari 1999 [53]	2	A single community-based hospital (Finland)	HF CG	206 (83) 100 (83)	80 (8) 79 (7)	Age, sex	**Cases:** HF within the past 24 h of admission **Controls:** admitted to the same hospital for a non-HF related to a fall	NR	NA	Height Direction Impact Protective response Surface	Typical HFs result from falls with subsequent impact on the greater trochanter.
Hayes 1993 [54]	2	A single rehabilitation center (USA)	HF CG	82 (77) 313 (77)	88.9 (6.2) 87.8 (5.9)	NR	**Case and controls:** aged 65 or older, previously ambulatory, experienced a fall, differing only in HF outcome	Falls on weekends and holidays without information within 24 h	NA	Height Direction Activity Impact	Impact on the hip or side of the leg was the most significant determinant of HF compared to other measured variables.

Note: Data are reported as mean (standard deviation or range).

Abbreviations: HF, hip fracture; NHF, non-hip fracture; CG, control group (Non-hip fracture); NA, data not available; NR, not reported; LTC, long-term care; ED, emergency department; MMSE, Mini-mental State Examination; BMD, bone mineral density; FN, femoral neck; TC, trochanteric; IT, intertrochanteric; WF, wrist fracture.

Study design: 1, Cross sectional study; 2, Case-control study; 3, Prospective cohort study; 4, Retrospective cohort study.

* Non-case control studies.

** This case-control study was categorized as a cross-sectional study in this review due to the absence of a non-hip fracture control group.

[a] Femoral neck fracture Gr I,II/III,IV; Intertrochanteric fracture Gr I,II/III,IV.

Table 2
Summary of fall characteristics in non-case control studies.

Article	HF (n)							
Height		< Standing height	Standing height	≥ Standing height	> Standing height	Others	Unknown	*P*-value
Formiga 2008 [30]	1024	80 (7.5) [Dementia: 18 (11.7), Non-dementia: 62 (7.1)]	905 (88.4) [Dementia: 133 (86.4), Non-dementia: 772 (88.2)]		39 (3.8) [Dementia: 3 (1.9), Non-dementia: 36 (4.1)]			0.07*
Peng 2023 [29]	1892		1725 (91.2)		167 (8.8)			
Allander 1998 [31]	2816		M: NR (66.1) F: NR (75.0)			Stairway: NR (11)	7 (1.0)	
Norton 1997 [35]	780	94 (12.1)	612 (78.5)		63 (8.1)			
Abolhassani 2006 [38]	572	Age 20–49: 2 (1.6)	Age 20–49: 26 (21.3)		Age 20–49: 91 (74.6)		Age 20–49: 3 (2.6)	
		Age > 50: 15 (3.3)	Age > 50: 263 (58.4)		Age > 50: 164 (36.4)		Age > 50: 8 (1.7)	
George 2021 [39]	283		217 (76.7)		1 (0.4)	TA 60 (21.2) Others 5 (1.8)		
Goh 1996 [43]	260	From a seated or lying position 46 (17.7) A chair or steps 32 (12.3)	182 (70)					
Aizen 2003 [52]	101		86 (85.1)					
Cauley 2009 [47]	462	NR (82.2)			NR (14.4)			
Greenspan 1994 [42]	112			NR (86.6)				

Location		Indoors	Outdoors	Others	Unknown	*P*-value
Morikawa 2021 [44]	92	72 (78.3) [Age 65–84: 24 (68.6), Age > 85: 48 (84.2)]				0.152*
Iolascon 2013 [27]	419	297 (70.88) [Kitchen 80 (26.93), Bathroom 72 (24.24), Other rooms 145 (48.82)]	122 (29.12)			
Lim 2020 [28]	147	Total: 113 (76.9) [Bedroom 70 (47.6), Kitchen 8 (5.7), Bathroom 18 (12.2), Living room 17 (11.8)] Sarcopenia: 48 (75.0) [Bedroom 36 (56.3), Kitchen 1 (1.6), Bathroom 7 (10.9), Living room 4 (6.3)] Non-sarcopenia: 65 (78.3) [Bedroom 34 (41.0), Kitchen 7 (8.4), Bathroom 11 (13.3), Living room 13 (15.7)]	Total: 30 (20.4) [Stairs 8 (5.4), On the road 22 (15.0)] Sarcopenia: 14 (21.9) [Stairs 3 (4.7), On the road 11 (17.2)] Non-sarcopenia: 16 (19.2) [Stairs 5 (6.0), On the road 11 (13.3)]			0.359*
Formiga 2008 [30]	1024		221 (21.6) [Dementia: 24 (15.6), Non-dementia: 197 (22.6)]			0.12*
Peng 2023 [29]	1892	Inside home 1451 (76.7)	342 (18.1)	Public building 99 (5.2)		0.012
Allander 1998 [31]	2816	1828 (66.9)	906 (33.1)			
Boyé 2014 [33]	468	341 (72.9)	127 (27.1)			
Aharonoff 1998 [32]	832	Home 434 (52.2) Another location 295 (35.5)	103 (12.4)			
Norton 1997 [35]	780	589 (75.5)	190 (24.4)	Home 658 (84.4) Away from home 102 (13.1) Hospital 19 (2.4)		
Michelson 1995 [34]	169	129 (76) [Bedroom 33 (20), Living room 28 (17), Kitchen 23 (14), Bathroom 13 (8), Stairs 8 (5)]	36 (21)			
Leavy 2015 [36]	125	83 (66)	42 (34)			
Burm 2021 [46]	1986	1338 (67)				
Hopkinson-Woolley 1998 [37]	321	Home 257 (80.1) [Residential home 16 (5.0), Nursing home 6 (1.8), Hospital 42 (13.1)]				
Abolhassani 2006 [38]	572	Age 20–49: 79 (64.8)	Age 20–49: 40 (32.8)		Age 20–49: 3 (2.4)	
		Age > 50: 357 (79.3)	Age > 50: 85 (18.9)		Age > 50: 8 (1.8)	

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Table 2 ***(continued)***

Location		Indoors	Outdoors	Others	Unknown	P-value
Ulusoy 2020 [41]	83	67 (80.7)	16 (19.3)			
Fiatarone Singh 2009 [40]	193	(Not on steps) NR (40)	(Not on steps) NR (30)	Steps: NR (15) Others: NR (15)		
Goh 1996 [43]	260	212 (81.5)				
Cauley 2009 [47]	462		Away from home: NR (21.5) Outdoors: NR (22.2)			0.39

Time		Morning	Afternoon	Daytime	Evening	Night	P-value
Iolascon 2013 [27]	419	152 (36.27)	122 (29.11)		82 (19.57)	49 (11.68)	
Formiga 2008 [30]	1024			739 (72.2) [Dementia: 97 (63.4), Non-dementia: 642 (73.8)]			0.008*
Peng 2023 [29]	1892	749 (39.6)	524 (27.7)		337 (17.8)	282 (14.9)	0.034
Allander 1998 [31]	2816	843 (30.8)	718 (26.3)	Midday 535 (19.6)	361 (13.2)	277 (10.1)	
Aharonoff 1998 [32]	832		NR (38.5)				
Michelson 1995 [34]	169			Daylight 101 (60)		Night 47 (28) Dusk 9 (5)	

Direction		Sideways	Forward	Backward	Oblique	Straight down/ Buttock/Back	Others/ Don't know
Morikawa 2021 [44]	92	30 (32.6) [Age 65–84: 18 (51.4), Age > 85: 12 (21.1)]	10 (10.9) [Age 65–84: 2 (5.7), Age > 85: 8 (14.0)]	52 (56.6) [Age 65–84: 15 (42.9), Age > 85: 37 (64.9)]		* P-value: Forward 0.23, Sideways 0.036, Backward 0.003	
Iolascon 2013 [27]	419	NR (54)	NR (8.1)	NR (23.2)			NR (14.7)
Lim 2020 [28]	147	77 (52.4) [Sarcopenia: 34 (53.1), Non-sarcopenia: 43 (51.8)]	19 (12.9) [Sarcopenia:7 (10.9), Non-sarcopenia 12 (14.5)]	41 (27.9) [Sarcopenia: 9 (29.7), Non-sarcopenia: 22 (26.5)]		* P-value: 0.527	
Peng 2023 [29]	1892	1493 (78.9)	91 (4.8)	96 (5.1)	Forward & sideways 91 (4.8) Backward & sideways 121 (6.4)		
Norton 1997 [35]	780	561 (71.9)	56 (7.2)	78 (10.0)			4 (0.5)/ 62 (7.9)
Hopkinson-Woolley 1998 [37]	321	270 (84.1)	8 (2.5)	43 (13.4)			
Ulusoy 2020 [41]	83	78 (94.0)	2 (2.4)	3 (3.6)			
Goh 1996 [43]	260	NR (52)	NR (4.4)	NR (21)		NR (22.6)	
Aizen 2003 [52]	101	33 (32.7)	Direct or obliquely forwards 35 (34.7) [a]	14 (13.9)		Buttock 11 (10.9) Back 7 (6.9)	
Cauley 2009 [47]	462	NR (39.4)	NR (9.7)	NR (13.6)		NR (7.2)	NR (30.1)
Greenspan 1994 [42]	112	NR (65.6)					

Mechanism		Slip	Stumble/ Trip	Lost balance[c]	Weakness/ Collapse	Standing/ Spontaneous	External force [d]	Incorrect use of stick/ Lighting/Shoes/ Dizziness/Others	Stairs/ Activity related
Iolasconjj 2013 [27] [b,k]	419	180 (47.45)	92 (21.95)					Incorrect use of the stick 50 (11.93) Shoes 46 (10.97) Insufficient lighting 78 (18.61)	
Lim 2020 [28]	147	57 (38.8) [Sarcopenia: 19 (29.7), Non-sarcopenia: 38 (45.8)]	19 (12.9) [Sarcopenia: 6 (9.4), Non-sarcopenia: 13 (15.7)]	Changing positions29 (19.7) [Sarcopenia: 15 (23.4), Non-sarcopenia: 14 (16.9)]	22 (15.0) [Sarcopenia: 11 (17.2), Non-sarcopenia: 11 (13.3)]	20 (13.6) [Sarcopenia: 13 (20.3), Non-sarcopenia: 7 (8.4)]			P-value: 0.019*
Namgung 2019 [45]	28	20 (71.4) [In or near bathroom 9 (32.1), Walking 2 (7.1), During rehabilitation 2 (7.1), Unknown 7 (25.0)]		Fall from bed 4 (14.3)			4 (14.2)		
Peng 2023 [29] **	1892	476 (25.2)	328 (17.3)	Lost balance (leg weakness, miss step) 1031 (54.5)				Others 8 (0.4) Combined 49 (2.6)	
Allander 1998 [31]	2816	1155 (46.4),	NR (6.4)						

Table 2 ***(continued)***

Mechanism		Slip	Stumble/ Trip	Lost balance[c]	Weakness/ Collapse	Standing/ Spontaneous	External force [d]	Incorrect use of stick/ Lighting/Shoes/ Dizziness/Others	Stairs/ Activity related
Michelson 1995 [34]	169	32 (19)	23 (14)				17 (10)	Others 50 (30) Weakness, moved too quickly, passed out 17 (10)	
Leavy 2015 [36] [e]	125	Indoor 8 (6.4)	Indoor 18 (14.4) Outdoor: Trips & slips [Snow 20 (16), No snow 12 (10)]	Indoor 14 (11.2)				Indoor: Inadequate footwear 7 (5.6), Reduced function/pain of the lower limb 6 (4.8), Dizziness or faintness 13 (10.4)	Indoor 8 (6) Outdoor 8 (6) [f]
Burm 2021 **	1986	569 (28.7) [Indoor 396 (30), Outdoor 173 (27)]	362 (18.2) [Indoor 189 (14), Outdoor 173 (27)]	332 (16.7) [Indoor 265 (20), Outdoor 67 (10)]	276 (13.9) [Indoor 210 (16), Outdoor 66 (10)]		65 (3.3) [Indoor 19 (1), Outdoor 46 (7)]	Loss of external support 131 (6.6) [Indoor 115 (9), Outdoor 16 (2)] Unclassified 251 (12.6)	
George 2021 [39]	283	49 (17.3)	16 (5.7)	Changing positions 35 (12.4) Loss of balance 48 (17.0)				Seizure 1 (0.4) Dizzness15 (5.3)	Stairs 32 (11.3) Activity related 21 (7.4)
Ulusoy 2020 [41]	83			62 (74.7)				Environmental factors 21 (25.3)	

Activity		Walking	Sitting [h] or standing still	Transfer	Changing positions [i]	Less physical or mobile activity [j]	Physical activity (Balance challenging activity)	Others
Iolascon 2013 [27] [b,k]	419				Getting up from the chairs 82 (19.57)			Taking objects from shelves 54 (12.88)
Peng 2023 [29] **	1892	1079 (57.0)				Housework 62 (3.3) Shower (1.4) Toilet 262 (13.8)	Physical activity 79 (4.2) Leisure activities 190 (10.0)	
Allander 1998 [31]	2816			From bed 82 (3.6) From chair 251 (11.1)	Rising from bed 280 (12.4)	Going to toilet 474 (17.2)		
Boyé 2014 [33]	468	Indoor 144 (42) Outdoor 72 (57.1)	Sitting or standing 55 (16)				Cycling 30 (24)	
Aharonoff 1998 [32]	832	Standing or walking 626 (75.2)		From stairs 29 (3.5) Out of bed or chair 58 (7.0)				Others 75 (9.0) Assault 21 (2.5) Hit by motor vehicle or bicycle 23 (2.8)
Norton 1997 [35]	780	Forward motion[g] 306 (46.9)	Standing 82 (12.6)		Turning, backing up 51 (7.8) Changing position 60 (9.2) Sitting or lying down 30 (4.6)	Reaching, bending 28 (4.3) Unknown 12 (1.8)	On stairs, steps 52 (7.8)	Other 2 (0.3) Unknown 15 (2.3) Backward motion 16 (2.5)
Michelson 1995 [34]	169	91 (54)	Standing 24 (14)	To or from a bed or chair (14)			Balance challenging activity [l] 14 (11.2)	
Leavy 2015 [36]	125	71 (56.8)	Standing 16 (12.8)		24 (19.2)			

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Table 2 ***(continued)***

Activity		Walking	Sitting [h] or standing still	Transfer	Changing positions [i]	Less physical or mobile activity [j]	Physical activity (Balance challenging activity)	Others
Burm 2021**	1986	950 (47.8) [Indoor: 494 (37), Outdoor: 456 (70)]	187 (9.4) [Indoor: Standing 117(9), Seated 28(2), Outdoor: Standing 31(5), Seated 11 (2)] Standing 31(5), Seated 11 (2)]		384 (19.3) [Indoor: Getting up or rising 234 (17), Lying in bed 55 (4), Sitting down or lowering 43 (3), Outdoor: Getting up or rising 41 (6), Lying in bed 2 (0), Sitting down or lowering 9 (1)]			Unclassified 465 (23.4)
Hopkinson-Woolley 1998 [37]	321	219 (68.2)	Standing 90 (28.0) Sitting down 12 (3.7)					
Abolhassani 2006 [38] [k]	572	Age 20–49: 41 (33.6) Age > 50:338 (75.1)			Age 20–49: Sitting/Lying 1 (0.1) Age > 50: Sitting/Lying down 17 (3.8)		Age 20–49: Working activity 74 (60.6), Recreation 16 (13.1), On stairs/steps 20 (16.4), From ladder/scaffolding 46 (37.7) Age > 50: Working activity 94 (20.8), Recreation 1 (0.2), On stairs/steps 92 (20.4), From ladder/scaffolding 48 (10.7)	
Fiatarone Singh 2009 [40]	193	NR (39)		NR (17)	Turning around (when walking) NR (9)			Others: NR (31) Backward step: NR (5)
Goh 1996 [43]	260	153 (58.8)	Standing still 18 (6.9) Sitting 13 (5.0)		Changing positions 35 (13.5) Lying down 9 (3.5) Turing around 4 (15)	Reaching 11 (4.2) Bending over 3 (1.2)	Descending steps 11 (4.2) Ascending steps 3(1.2)	
Cauley 2009 [47]	462	NR (37.7)			Sits/Lies/Bends/Reaches/Transfers NR (35.3)		Running/Climbing/Up and down stairs (10.6)	Others: NR (16.4)
Greenspan 1994 [42]	112	NR (47.6)						

Impact		Direct [m]	Others	Don't know	P-value
Michelson 1995 [34]	169	115 (68)			0.16
Cauley 2009 [47]	462	NR (51.8)	Front: NR (8.0) Back: NR (13.8)	NR (26.2)	
Greenspan 1994 [42]	112	NR (77.2)			

Protective response		Fall on hand	Break fall with hand	Don't know	P-value
Goh 1996 [43]	260		NR (18)		
Aizen 2003 [52]	101		28 (28)		
Cauley 2009 [47]	462	Yes: NR (10.2) No: NR (34.3)	Yes: NR (16.4) No: NR (26.1)	Fall on hand: NR (55.6) Break fall with hand: NR (57.5)	Fall on hand:0.007 Break fall with hand: 0.06
Greenspan 1994 [42]	112		NR (28.7)		

Use of walking aids		Yes	No
Morikawa 2021 [44]	92	20 (22.0) [Age 65–84: 9 (25.7), Age > 85: 11 (19.2)]	71 (78.0) [Age 65–84: 25 (71.4), Age > 85: 46 (80.7)]
Peng 2023 [29]	1892	739 (39.1) [M: 508 (38.3), F: 231 (40.7)]	
Leavy 2015 [36]	125	19 (15.2)	
Hopkinson-Woolley 1998 [37]	321	39 (32.1)	
Ulusoy 2020 [41]	83	47 (56.6)	36 (43.4)
Goh 1996 [43]	260		NR (97)

Impact Surface		Hard	Medium	Soft	Unknown/Others	P-value
Norton 1997 [35]	780	389 (49.9)		384 (49.2)	Unknown 7 (1.0)	
Michelson 1995 [34]	169	119 (70)		50 (30)		
Goh 1996 [43]	260	Ceramic tile/Marble 135 (51.9) Concrete/Cement 88 (33.8)		Linoleum/Soft tile 12 (4.6) Wooden floor 6 (2.3)	Others 19 (7.3)	
Cauley 2009 [47]	462	Ceramic tile/Cement: NR (23.1)		Wood/Linoleum/Carpet: NR (64.2)	Snow/Ice/Dirt: NR (5.3) Intermediary object: NR (7.4)	0.44

Note: Data are reported as number (%).
Abbreviations: HF, hip fracture group; NR, not reported; TA, traffic accident.
* Comparison within the subgroup.
** P < 0.001.
[a] Categorized as forward direction due to an inability to distinguish between them.
[b] Classified a combination of activity and mechanism as extrinsic risk factors.
[c] Including ‘changing positions, incorrect weight shift’.
[d] Namgung 2019, hit against something, excessive pull of patient's extremities by caregivers; Michelson 1995, pushing, missed seat, bumping furniture broke.

[e] Environmental conditions/objects (trips over, slips on wet surfaces inadequate footwear) and physiological factors (self-induced disequilibrium, dizziness or faintness and reduced function/pain of the lower limb).
[f] Leavy 2015, Outdoor: falls during high speeds or from ladders or bikes, Indoor: standing on one leg or on kitchen stools.
[g] 'Walking' was not classified separately.
[h] Including 'seated in wheelchair'.
[i] Utilized in both mechanism and activity classification. Including 'rising from bed, sitting down, lying down, turning, getting up or rising'.
[j] Including 'bathing, dressing, using the toilet, housework, reaching or bending'.
[k] Multiple responses.
[l] Walking on stairs or during complex activities, such as falls from bikes, stools, ladders or whilst running or sledging in slippery conditions.
[m] Impact on the hip, thigh, buttock, greater trochanter and leg on the fractured side.

Table 3
Summary of fall characteristics in case-control studies.

Article Height	Group (n)	< Standing height	Standing height	≥ Standing height	> Standing height	*P*-value*
Schwartz 1998 [48]	HF (214)	32 (15)		182 (85)		
	CG (86)	18 (21)		68 (79)		
Wei 2001 [49]	HF (127)		103 (81.1)			0.51
	CG (125)		94 (75.2)			
Nevitt 1993 [16]	HF (130)	NR (12)	NR (66)		NR (22)	
	CG (467)	NR (17)	NR (62)		NR (21)	
Parkkari 1999 [53]	HF (206)	≤ Standing: NR (96)				0.003
	CG (100)	≤ Standing: NR (86)				
Hayes 1993 [54]	HF (82)			NR (81)		0.21
	CG (313)			NR (77)		

Location		Indoors	Outdoors	*P*-value
Schwartz 1998 [48]	HF (214)	121 (57)		
	CG (86)	36 (42)		
Wei 2001 [49]	HF (127)	92 (72.4)		0.003
	CG (125)	68 (54.4)		
Cummings 1994 [50]	HF (117)	93 (79) [Bedroom 17 (15), Living room 15 (13), Kitchen 11 (9), Bathroom 10 (9), Stairs 5 (4), Garden 20 (17), Other room 15 (13)]	16 (14) [Inside shop or club 5 (4), Other 2 (2), Missing 1(1)]	0.06
	CG (84)	56 (67) [Bedroom 10 (12), Living room 8 (10), Kitchen 4 (5), Bathroom 10 (12), Stairs 1 (1), Garden 15 (18), Other room 8 (10)]	17 (20) [Inside shop or club 6 (7), Other 3 (4), Missing 2(2)]	
Hwang 2011 [51]	HF (306)	222 (72.5) [M: 50 (58.8), F: 172 (77.8)]	82 (26.8) [M: 34 (40.0), F: 48 (21.7)]	M: 0.562
	CG (306)	201 (65.7) [M: 55 (64.7), F: 146 (66.1)]	103 (33.7) [M: 28 (33.9), F: 75 (33.9))	F: 0.011
Nevitt 1993 [16]	HF (130)	Indoors: NR (68) At home: NR (54)	Outdoors: NR (32) Away from home: NR (46)	
	CG (467)	Indoors: NR (49) At home: NR (55)	Outdoors: NR (51) Away from home: NR (45)	

Direction		Sideways	Forward	Backward	Straight down/Buttock/Back	Don't know	*P*-value
Schwartz 1998 [48]	HF (214)	107 (52)	35 (17)	38 (16)			< 0.001
	CG (86)	20 (24)	41 (49)	16 (16)			
Wei 2001 [49]	HF (127)	63 (49.6)					< 0.001
	CG (125)	29 (23.2)					
Hwang 2011 [51]	HF (306)	136 (44.4) [M: 38 (44.7), F :98 (44.3)]	17 (5.6) [M: 5 (5.9), F: 12 (5.5)]	132 (43.1) [M: 34 (40.0), F: 98 (44.3)]	Straight down 18 (5.9) [M :7 (8.2), F: 11 (5.0)]		M: < 0.001
	CG (306)	75 (24.5) [M: 18 (2.2), F: 57 (25.8)]	113 (36.9) [M: 35 (41.2), F: 78 (35.3)]	96 (31.4) [M: 23 (27.0), F: 73 (33.0)]	Straight down 16 (5.2) [M: 5 (5.9), F: 11 (5.0)]		F: < 0.001
Yang 2020 [18]	HF (30)	Fall initiation stage 17 (56.7) Fall impact stage 23 (76.7)	Forward 9 (30.0) Forward or backward 7 (23.3)	Backward or straight down 4 (13.3)			Fall initiation stage: Sideways, forward vs. Backward or straight down: < 0.05
	CG (1434)	Fall initiation stage 515 (35.9) Fall impact stage 531 (37.1)	Forward 328 (22.9) Forward or backward 899 (62.9)	Backward or straight down 590 (41.2)			Fall impact state: Sideways vs. Backward or straight down: < 0.05

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Table 3 *(continued)*

Direction		Sideways	Forward	Backward	Straight down/Buttock/Back	Don't know	*P*-value
Nevitt 1993 [16]	HF (130)	NR (56)	NR (14)	NR (17)	Straight down: NR (4)	NR (9)	
	CG (467)	NR (29)	NR (44)	NR (24)	Straight down: NR (2)	NR (1)	
Parkkari 1999 [53] [a]	HF (206)	Sideways: NR (76)	Directly or obliquely forward: NR (8)	Obliquely backwards: NR (12) On back: NR (0)	On buttocks: NR (2)	NR (2)	< 0.001
	CG (100)	Sideways: NR (22)	Directly or obliquely forward: NR (38)	Obliquely backwards: NR (27) On back: NR (6)	On buttocks: NR (7)	NR (0)	
Hayes 1993 [54]	HF (82)	NR (60)					< 0.001
	CG (313)	NR (23)					

Mechanism		Slip	Stumble/Trip	Changing positions [b]	Weakness/ Collapse	Standing/ Spontaneous [b]	Dizziness	Others	*P*-value
Schwartz 1998 [48]	HF (214)		40 (20)						
	CG (86)		31 (37)						
Cummings 1994 [50]	HF (117)	11(10)	38 (36)	19 (18)	12 (11)		10 (9)	17 (16)	
	CG (84)	8(10)	35 (46)	4 (5)	6 (8)		8 (10)	15 (20)	
Hwang 2011 [51]	HF (306)	37 (12.1) [M: 12 (14.1), F: 25 (11.3)]	39 (12.7 [M: 6 (7.1), F: 33 (14.9)]	Dropping down 93 (30.4) [M: 23 (27.1), F: 70 (31.7)	55 (18.0) [M: 19 (22.4), F: 36 (16.3)]	18 (5.9) [M: 7 (8.2), F: 11 (5.0)]	47 (15.4) [M: 14 (16.5), F: 33 (14.9)	15 (4.9) [M: 4 (4.7) F: 11 (5.0)]	M: 0.017
	CG (306)	49 (16.0) [M: 9 (10.6), F: 40 (18.1)]	53 (17.3) [M: 14 (16.5), F: 39 (17.6)]	64 (20.9) [M: 14 (16.5), F: 50 (22.6)]	27 (8.8) [M: 8 (9.4), F: 19 (8.6)]	16 (5.2) [M: 5 (5.9), F: 11 (5.0)]	73 (23.9) [M: 25 (29.4), F: 47 (21.3)]	22 (7.2) [M: 8 (9.4), F: 14 (6.3)]	F: 0.028

Activity		Walking	Sitting [c] or standing still	Transfer	Changing positions [b]	Less physical or mobile activity [d]	Physical activity [e]	Others [f]	*P*-value
Wei 2001 [49]	HF (127)					66 (52.4)			0.01
	CG (125)					45 (36.3)			
Yang 2020 [18]	HF (30)	14 (46.7)	Standing or transferring 16 (53.3)						NS
	CG (1434)	801 (55.9)	Standing or transferring 631 (44.1)						
Nevitt 1993 [16]	HF (130)	NR (40)	NR (9)		NR (27)	NR (3)	NR (18)	Others: NR (2) Doesn't recall: NR (1)	
	CG (467)	NR (50)	NR (4)		NR (16)	NR (6)	NR (22)	Others: NR (2) Doesn't recall: NR (0.5)	
Hayes 1993 [54]	HF (82)	NR (59)							< 0.001
	CG (313)	NR (35)							

Impact		Direct [g]	Others	Don't know	*P*-value
Schwartz 1998 [48]	HF (214)	187 (94)	Knee 28 (14)		
	CG (86)	18 (22)	Knee 31 (36)		
Wei 2001 [49]	HF (127)	110 (86.6)			< 0.001
	CG (125)	47 (37.6)			
Yang 2020 [18]	HF (30)	22(73.3)	Knee 20 (66.7) Hand 18 (69.2)		0.05
	CG (1434)	644 (45.0)	Knee 670 (47.0) Hand 850 (81.3)		
Nevitt 1993 [16]	HF (130)	NR (91)	Hand/Wrist: NR (16)	Direct: NR (6) Hand/Wrist: NR (20)	
	CG (467)	NR (48)	Hand/Wrist: NR (46)	Direct: NR (2) Hand/Wrist: NR (6)	
Parkkari 1999 [53]	HF (206)	NR (81)			< 0.001
	CG (100)	NR (3)			
Hayes 1993 [54]	HF (82)	NR (59)			< 0.001
	CG (313)	NR (6)			

Protective response		Fall on hand	Break fall with hand	Stepping response	Others	*P*-value
Schwartz 1998 [48]	HF (214)	35(19)				
	CG (86)	28 (33)				

Table 3 *(continued)*

Protective response		Fall on hand	Break fall with hand	Stepping response	Others	*P*-value
Wei 2001 [49]	HF (127)	9 (7.1)	3 (2.4)			Fall on hand: < 0.001
	CG (125)	56 (44.8)	16 (12.8)			Break fall with hand: 0.005
Hwang 2011 [51]	HF (306)	Protective response 42 (13.7) [M: 9 (11.0), F: 33 (15.3)]				M: 1.000 F: 0.323
	CG (306)	Protective response 35 (11.4) [M: 10 (12.2), F: 25 (11.6)]				
Yang 2020 [18]	HF (30)		7 (23.3)	25 (83.3)		NS
	CG (1434)		206 (14.9)	1031 (72.0)		
Nevitt 1993 [16]	HF (130)		NR (11)		Doesn't recall (5)	
	CG (467)		NR (21)		Doesn't recall (2)	
Parkkari 1999 [53]	HF (206)		NR (17)			< 0.001
	CG (100)		NR (42)			

Use of walking aids		Yes	No	*P*-value
Schwartz 1998 [48]	HF (214)	36 (17)		
	CG (86)	7 (8)		
Yang 2020 [18]	HF (30)	3 (10)	27 (90.0)	< 0.05
	CG (1434)	347 (24.3)	1082 (75.7)	

Impact Surface		Hard	Medium	Soft	Unknown/Others	*P*-value
Schwartz 1998 [48]	HF (214)	95 (47)	50 (25)	57 (28)		
	CG (86)	33 (43)	29 (38)	14 (18)		
Cummings 1994 [50]	HF (117)	NR (58)				0.16
	CG (84)	NR (47)				
Hwang 2011 [51]	HF (306)	299 (97.7) [M: 82 (96.5), F: 217 (98.2)]		4 (1.3) [M: 2 (2.3), F: 2 (0.9)]		0.091
	CG (306)	297 (97.1) [M: 83 (97.7), F: 214 (96.8)]		7 (2.3) [M: 0 (0), F: 7 (3.2)]		
Nevitt 1993 [16]	HF (130)	NR (68)		NR (29)	NR (3)	
	CG (467)	NR (63)		NR (32)	NR (5)	
Parkkari 1999 [53]	HF (206)	NR (75)				0.25
	CG (100)	NR (69)				

Note: Data are reported as number (%). P-values were analyzed by comparing the hip fracture and control groups.
Abbreviations: HF, hip fracture group; CG, control group (Non-hip fracture); NR, not reported; NS, not significant.
[a] 'Obliquely' directions were grouped as forward and backward directions due to the absence of exact categories for these distinctions.
[b] Utilized in both mechanism and activity classification. Including 'rising from bed, sitting down, lying down, turning, getting up or rising'.
[c] Including 'seated in wheelchair'.
[d] Including 'bathing, dressing, using the toilet, housework, reaching or bending'; Wei 2001, less mobile (sitting, standing, bathing, dressing and using the toilet).
[e] Nevitt1993, jogging, stairs, descending stairs/steps/curb, ascending stairs/steps/curb, on ladder or stepstool, other vigorous exercise.
[f] Others: unknown, hit, assault.
[g] Impact on the hip, thigh, buttock, greater trochanter and leg on the fractured side.

mechanism, and presented multiple response outcomes. Six studies were ranked as high risk of attrition bias due to incomplete data [27,31,33,48,49,54]. All studies reported previously determined primary and secondary outcomes, and none exhibited selective reporting bias.

3.4. Description of fall characteristics

Many studies lacked comprehensive details on fall characteristics, with an average of 4 reported domains varying between 1 and 7 out of 10. Location was most commonly reported in 22 studies, followed by activity, direction, height, and mechanism. Detailed fall characteristics related to hip fractures are summarized in Table 2 (non-case control) and Table 3 (case-control studies).

3.4.1. Height

Fifteen studies detailed fall heights [16,29–31,35,38,39,42,43,47–49,52–54]. In 10 non-case control studies, 'standing height' (72.0%∼91.2%) [29–31,35,38,39,43] and '≥ standing height' (82.2%∼86.6%) [42,47,52] were predominant but not used concurrently. In 5 case-control studies, 'standing height' [16,49] and ≥ 'standing height' [48,54] were higher in both hip fracture and control groups, except for one study [53] where '≤ standing height' was notably higher in hip fracture cases. In the between-group analysis based on age (20∼49 years and over 50 years) [38], the percentage of 'standing height' was higher in the older age group, while the proportion of '> standing height' was lower. A disparity was noted in height classification criteria across studies, including terms like '> standing height', '≥ standing height', and others. Yet, most hip fractures occurred at or around standing height.

3.4.2. Location

Twenty-two studies addressed location [16,27–38,40,41,43,44,46–49,51]. Among 18 non-case control studies, two lacked indoor proportions [30,47] and four lacked outdoor proportions [37,43,44,46]. Indoors accounted for 40%–87.7%, often surpassing outdoor proportions significantly [29,31]. In age-based analyses (20–49 years vs. over 50 years) [38], indoor falls were more frequent among older individuals, while outdoor falls were less so. Among 5 case-control studies, indoor falls were notably higher in hip fracture groups; one study highlighted this significance [49]. Additionally, in three studies comparing both indoor and outdoor falls [16,50,51], the control group had a higher outdoor fall rate, especially notable among women [51].

3.4.3. Time

Time data were available in six non-case control studies [27,29–32,34]. Three of these studies did not categorize times (morning, afternoon, evening, night) [30,32,34]. Among those that did [27,29,31], falls were more frequent during morning and afternoon compared to evening and night. Considering morning and afternoon as daytime, approximately two-thirds of falls occurred then. In an analysis based on dementia [30], the non-dementia group experienced more daytime falls than the dementia group.

3.4.4. Direction

Direction was addressed in eighteen studies [16,18,27–29,35,37,41–44,47–49,51–54], often categorized as sideways, forward, and backward. Certain studies provided additional classifications such as combinations, oblique, or straight orientations like down, buttock, or back. Combining similar categories, sideways was predominant in 11 non-case control

Table 4
Summary of significant fall characteristics related to fragility hip fractures and adjusted risk estimates.

Article	Significant fall characteristics		Adjusted risk estimates (95% CI)
Morikawa 2021 [44]	Direction	Age ≥ 85	Backward falling: OR = 2.47 (1.04–5.84) Sideways falling: OR = 0.25 (0.10–0.63)
Lim 2020 [28]	Mechanism	Sarcopenia	Fragile falls (leg weakness during walking, changing positions or standing): OR = 2.354 (1.177–4.709)
Wei 2001 [49]	Direction		Sideways fall: OR = 2.5 (1.6–3.9)
	Impact		Direct hip impact: OR = 4.9 (2.7–8.8)
Cummings 1994 [50]	Mechanism		Turning around (postural change): OR = 7.88 (1.44–43.01)
Hwang 2011 [51]	Direction		Backward: OR = M: 10.8 (3.34–34.7), F: 10.2 (4.85–21.2) Sideways: OR = M: 15.2 (4.67–49.7), F: 12.8 (6.02–27.2) Straight-down: OR = M: 13.6 (2.72–67.9), F: 9.86 (3.10–31.4)
Yang 2020 [18]	Using a walking aid		RR = 0.30 (0.09–1.00)
	Direction		Initially falling sideways: RR = 4.62 (1.65–12.95) Initially falling forward: RR = 4.02 (1.22–13.26) (ref. backwards or straight down) Landing sideways: RR = 5.50 (2.36–12.78)
	Impact		Hip impact: RR = 3.38 (1.49–7.67) Knee impact: RR = 2.27 (1.12–4.63)
	Rotation		Backward to sideways: RR = 10.31 (1.09–100.0) Sideways to backward: RR = 0.28 (0.08–0.96)
Abolhassani 2006 [38]	Height	Age ≥ 50	Standing or less height (vs. over standing): OR = 2.67 (1.03–6.9)
	Activity		Walking during fall (vs. other activities): OR = 1.71 (1.23–2.38) Falling on stairs (vs. none): OR = 1.73 (1.25–2.37)
Schwartz 1998 [48]	Direction		Hitting the hip/thigh: OR = 97.8 (31.7–302) Hitting the knee: OR = 0.24 (0.09–0.67)
Nevitt 1993 [16]	Direction		Fall sideways, straight down: OR = 3.3 (2.0–5.6) Fell backward: OR = 0.3 (0.1–0.4)
	Impact		Fall on hip/side of leg/buttocks: OR = 32.5 (9.9–107.1) Fall on hand/wrist: OR = 20.4 (11.5–36.0)
	Protective response		Fall on hand: OR = 0.3 (0.1–0.6) Triceps weakness (−2.5 kg): OR = 1.7 (1.2–2.5)
	Impact surface		Hard surface: OR = 2.8 (1.4–5.5)
Hayes 1993 [54]	Impact		Impact hip or side of leg: OR = 21.7 (8.2–58)

Abbreviations: CI, confidence interval; OR, odds ratio; RR, relative risk ratio.

studies (39.4%∼94.0%) [27–29,35,37,41–43,47]. However, in individual studies, backward [44] and forward falls [52] also prevailed. In age-based analyses (65–84 years and over 85 years) [44], backward falls was predominant among older participants, while sideways falls were less frequent. Across 7 case-control studies, sideways falls were prevalent in hip fracture groups [16,48,49,51,53,54], whereas forward falls were more typical in control groups [16,48,51,53]. Two studies reported more backward falls in the control group [16,53], and one in the hip fracture group [51]. Notably, one study [18] differentiated direction by initiation and impact stages, observing higher sideways and forward falls in the hip fracture group and higher backward or straight down falls in the control group during impact.

3.4.5. Mechanism

Thirteen studies [27–29,31,34,36,39,41,45,46,48,50,51] explored fall mechanisms, with terms like slip, stumble/trip, and lost balance frequently used. Slip was predominant in six non-case control studies [27,28,31,36,45,46], while lost balance was highlighted in three [29,39,41]. Stumbling/tripping and weakness/collapses were also recognized as causes of falls. The influence of environmental and external factors was relatively minor compared to other mechanisms [27,41,46]. Leavy et al. [36] linked falls to environmental conditions like tripping hazards and wet surfaces, as well as physiological factors such as dizziness and lower limb issues. In sarcopenia-related analyses [28], issues like changing positions and standing still were more common, while slipping and tripping were prevalent in the non-sarcopenia group. Case-control studies revealed variations in mechanisms, with hip fracture groups often showing increased weakness/collapse [50,51], and control groups more prone to stumble/trip [48,50,51], and dizziness [51] incidents.

3.4.6. Activity

Nineteen studies explored fall mechanisms [16,18,27,29,31–38,40,42,43,46,47,49,54], with varied terms and definitions. In non-case control studies [29,33,32–38,40,42,43,46,47], walking was a common activity preceding falls, followed by changing positions, sitting/standing still, and less mobile activities like bathing or housework. Some specific studies identified standing/walking [32] or changing positions or transfer [47] as frequent fall activities. Interestingly, falls associated with physically demanding activities were less prevalent before hip fractures compared to falls resulting from less strenuous activities like changing positions, sitting/standing still, or transfer. Among case-control studies, findings varied: one reported a higher proportion of less physical or mobile activity in the hip fracture group [49], two observed reduced walking with instances of increased changing positions [16] and standing or transferring [18], and another [54] highlighted more walking in the hip fracture group than controls.

3.4.7. Impact

Nine studies [16,18,34,42,47–49,53,54] examined the impact locations of falls, categorizing them as direct (e.g., hip, thigh, buttock, greater trochanter, and leg on the fractured side) or non-direct. In three non-case control studies [34,42,47], hip fractures predominantly resulted from direct impacts on the hip. Case-control studies indicated a higher direct impact in the hip fracture group versus controls [16,18,48,49,53,54]. Conversely, non-direct impacts, like the knee or hand, were more prevalent in the control group across three studies [16,18,48]. One study [18] highlighted a higher knee impact preceding pelvic impact in the hip fracture group.

3.4.8. Protective response

Ten studies explored protective responses during falls, categorized as falling on hand, break fall with hand, and stepping response [16,18,42,43,47–49,51–53]. Among non-case control studies, less than 30% attempted protective responses in four studies [42,43,47,52]. In case-control studies, protective responses were less frequent in the hip fracture group in four studies [16,48,49,53]. However, one study [18] noted increased protective responses in this group, suggesting ineffectiveness in LTC residents possibly due to limited upper limb strength and energy absorption.

3.4.9. Use of walking aids

Eight studies [18,29,36,37,41,43,44,48] reported the use of walking aids, such as cane, walker, and wheelchair. Among non-case control studies, rates varied, with some reporting low usage [29,36,37,43,44] and others higher [41]. In one case-control study [18], less use of walking aids was observed in the hip fracture group, while another study [48] indicated higher prevalence in this group.

3.4.10. Impact surface

Nine studies [16,34,35,43,47,48,50,51,53] examined the impact surface of falls, classified as hard, medium, or soft based on floor materials. Typically, falls occurred on hard surfaces. Among non-case control studies, three [34,35,43] indicated predominantly hard surfaces, while one [47] highlighted more soft surfaces. In five case-control studies [16,48,50,51,53], the proportion of hard surfaces was slightly more frequent in the hip fracture group, with one study [48] noting more medium surfaces in controls and soft surfaces in the hip fracture group.

3.4.11. Adjusted risk estimates

Ten studies examined fall characteristics and hip fractures with risk estimates (Table 4). Sideways [16,18,49,51] and straight-down [16,51] falls increased hip fracture risk, whereas findings varied for backward falls [16,51]. Direct impacts to the hip [16,18,49,54] or knee [18] were associated with increased risks, with knee impacts often preceding those to the pelvis. However, one study [48] indicated a reduced risk of knee impact. Factors like changing positions [50], using walking aids and rotation [18], impact surfaces, and protective responses [16] were linked to hip fractures. Morikawa et al. [44] associated backward falls with those over 85 years old, while Lim et al. [28] linked falls due to leg weakness and position changes to sarcopenia. Abolhassani et al. [38] found correlations between standing or a lesser height of fall and hip fractures.

4. Discussion

This systematic review analyzed 30 studies focusing on fragility hip fracture-related falls in older adults. Predominantly occurring indoors at standing height during the daytime, these falls often involve sideways or backward movements and inadequate protective responses. While slipping is a common cause, lost balance due to position changes or weakness is also significant. Walking frequently precedes these falls, with less physical or mobile activities also common. Additionally, there's limited use of walking aids and a tendency for falls on hard surfaces. The review highlighted varied definitions across studies and identified a primarily low risk of bias, though moderate concerns existed regarding selection (uncontrolled confounding variables) and performance biases.

Cummings and Nevitt [21,22] proposed that the faller's orientation, impact near the hip, and insufficient protective mechanisms, including inadequate shock absorption by tissues like the greater trochanter, are key factors leading to hip fractures. They highlighted the importance of impact location, fall energy, energy absorption, and bone strength in determining hip fracture occurrence. The fact that falls are a primary contributor to hip fractures, yet most falls do not lead to hip fractures, supports the idea that for a fall to progress to a hip fracture, specific conditions related to fall energy generation and absorption must align and hip fractures may not occur despite a fall if any of these conditions are not met. Considering the connection of each component in the process from falls to hip fractures, understanding the interrelationship of fall characteristics, which determine the location of impact, fall energy, and absorption of energy, both within the falls themselves and with other contributing factors, is crucial in comprehending the complexities of hip fracture occurrence.

Hip fractures from falls typically occur at or around standing height. Sarvi et al. [55] noted that typical femoral strength in such instances is 3462 N. However, unexpected sideways falls, a common cause for hip fractures, can exert forces around 5200 N, surpassing typical fracture thresholds of 3500 N [56]. This strength diminishes with age; older adults show about 40% lower strength than younger ones (2888 N at age 80.9 vs. 4766 N at age 63.9). Despite falls from standing height being low-energy, they can fracture the femur in the older adults due to weakened strength. Age-related reductions in femur strength elevate hip fracture risks even with less forceful impacts, such as less than standing height. Moreover, hip fracture-related falls predominantly occur indoors and during the daytime. While outdoor falls in older adults are influenced by factors like unfamiliarity and physical activities [15,16,20], those over 85 years are more prone to indoor falls due to age-related frailty [15]. As aging progresses, activities tend to shift towards indoor tasks during the daytime, especially among the physically weaker. Indoor falls, though less severe, highlight specific indoor factors contributing to hip fractures and underscore the vulnerability of this high-risk older population. Given that most indoor falls aren't from significant heights, they reflect the activity and physical capacities of the older individuals. Importantly, during peak daytime activity, many may be unsupervised at home, necessitating caution [29].

Among the fall characteristics highlighted, direction stands out as a key factor leading to hip fractures. For substantial energy to impact the proximal femur, the individual typically lands near or directly on the hip, commonly seen in straight down, sideways, or backward falls [21]. In a finite element model study [57], peak impact force was highest during lateral impacts due to the significant force associated with sideways falls. This is influenced by variations in the thickness of soft tissues around the hip capable of absorbing the impact energy, and differences in femur boundary conditions [55]. Such sideways falls, with potential to fracture the femur [56], transmit energy directly to the hip, increasing the risk of hip fractures due to limited shock absorption. In forward falls, direct hip impact is less common as the hand/wrist [16] and knee [48] are typically engaged, unless there's a rotation or combined pelvic and knee impact [18]. During a forward fall, there is a greater chance of protective responses such as changing orientation, breaking fall with hand, and stepping movements of the feet than other fall directions, which can help prevent hip fractures. In contrast, reports on backward falls are conflicting due to various factors. In these falls, individual often lands the soft tissue of the buttocks rather than directly on the proximal femur, reducing the impact [16]. Falls with minimal forward momentum, such as those occurring during slow walking or transfers, can resemble sideways falls and may involve a combination of backward and sideways dynamics [22]. Unlike forward falls, backward falls offer fewer protective hand responses and reduced environmental awareness. The elevated occurrence of backward falls in the 85+ age group versus the 65–84 years group [44] suggests age-related factors like reduced gait speed and muscle strength may directly impact the hip and compromise hip impact absorption. Straight-down falls, similar to backward falls, risk direct hip impact and diminish protective response opportunities [16,51].

Protective responses, like changing orientation, grabbing objects, extending arms, and stepping movements, aim to reduce falling speed and minimize hip impact [22]. However, studies [16,18,42,43,47–49,51–53] show that fewer than 30% of those with hip fractures employ these defenses, indicating a failure of the defense mechanism for preventing hip fractures. Nevitt et al. [16] highlighted the importance of hand and arm function in preventing hip fractures, while Yang et al. [18] reported these protective responses less effective in LTC patients due to increased frailty. As individuals age and physical capabilities diminish, there's a heightened risk of ineffective protective responses, characterized by delayed reactions and reduced strength. Additionally, forward falls, more common in the non-hip fracture group, offer better chances for protective responses, as daily activities typically involve forward motion, enabling individuals to be more aware of the situation and use their hands for protection.

Falls result from a combination of activities and mechanisms, reflecting the individual's physical capabilities. Walking demands coordination of muscle strength, joint flexibility, agility, proprioception, balance, and other factors. Age-related functional decline increases fall and hip fracture risks during walking due to issues like slipping, stumbling, weakness, influenced by both physical abilities or environmental factors. Slips often cause backward or sideways falls, increasing the potential impact force on the hip. While lost balance and weakness are more prevalent in hip fracture cases [50,51], stumble-related falls prevail in non-fracture instances [48]. When stumbling occurs, forward falls may mitigate direct hip impact by allowing protective actions like arm extension. Balance loss and weakness usually lead to backward or sideways falls due to physical limitations rather than external factors, unlike slips and stumbles, which are more affected by elements like floor conditions and footwear. Higher fracture rates occur during less physically demanding activities like changing positions or standing, compared to more mobile activities like walking [16,18,47,49]. Factors like sarcopenia increased fall risks related to weakness and position changes [28]. Cummings et al. [50] highlighted that individuals falling while turning are more prone to side impacts on their hip than when walking straightforwardly. These insights underscore a lack of adequate physical function, protective responses, shock absorption, and bone strength, indicating the link to physical frailty. Overall, these findings emphasize how aging and diminished physical strength significantly contribute to hip fractures. While physically demanding activities heighten the risk, it's essential to note that hip fractures in the older people can also arise from everyday, less strenuous activities due to lifestyle patterns and frailty. The increased occurrence of falls due to dizziness in the non-hip fracture group may result from low-energy incidents, like orthostatic hypotension or sudden standing collapses, insufficient to cause hip fractures.

The use of walking aids among hip fracture groups varies, with studies showing both higher usage [41,48] and lower usage rates [18,29,36,37,43,44]. Reasons for this disparity include falls due to non-use, physical weakness in handling the device, or the aid itself becoming an obstacle. High usage may indicate greater frailty and elevated fall risks in the older individuals, while limited usage might signify missed fracture prevention benefits. Robinovitch et al. [19] observed that improper use of these aids could hinder protective responses during falls, heightening fracture risks. While helpful when used correctly, improper use of assistive devices can increase fracture risks. Flooring hardness affects fall severity; concrete or ceramic tiles increase impact forces compared to carpets or safety floors [58,59]. Additionally, floor stiffness impacts hip impact attenuation. In an experimental study using foam rubber layers of varying thickness to test peak hip impact force, a firm floor condition demonstrated less attenuation compared to semifirm, semi-soft, and soft conditions when compared to a rigid floor [60]. As most falls leading to hip fractures in older adults are occur indoors, proper flooring choices can reduce risks by minimizing impact forces. Caution with soft surfaces, like mats or cushions, is needed due to tripping or slipping risks. Minor differences in case-control studies suggest that various factors, beyond flooring, influence fall dynamics.

Studies have reported certain characteristics of hip fractures resulting from falls, but a comprehensive summary is lacking due to varied classifications across research, complicating effective prevention strategies [19,50,61,62]. This review provides a comprehensive summary of fall characteristics related to fragility hip fractures, and emphasizes conditions associated with age-related physical frailty. These characteristics collectively contribute to the occurrence of hip fractures.

As individuals age, they often experience declines in physical performance, such as reduced walking speed, decreased leg strength, and impaired balance, which are especially apparent during activities like walking and simple movements like changing positions. These changes increase the likelihood of falling sideways or backward, leading to direct hip impacts due to inadequate protective responses. Additionally, reduced shock absorption from muscle atrophy and diminished bone strength further heighten the risk of hip fractures, even from falls at standing height or lower.

A recent UK cohort study [63] involving 413,630 participants found that physical pre-frailty (frailty index = 1 or 2) and frailty (frailty index = 3–5), as identified by the FRAIL scale [64]—which includes weight loss, exhaustion, low physical activity, slow walking speed, and low grip strength—are associated with an increased risk of bone fractures, including hip fractures. Key indicators such as walking speed, hand grip strength, and weight loss (reflecting low muscle mass) are critical markers of muscle strength and functionality. These factors decline with age, significantly contributing to frailty and independently increasing the risk of hip fractures [65–67]. The risk is particularly high when pre-frailty or frailty is combined with a sedentary lifestyle. Frail older adults often reduce their physical activity and adopt more sedentary behaviors due to physical weakness, leading to greater engagement in less physically demanding indoor activities. Additionally, a sedentary lifestyle—characterized by reduced weight-bearing activities such as prolonged sitting or lying down—has been linked to decreased BMD [68]. As physical abilities decline, individuals become more susceptible to falls and hip fractures during routine daily activities. The characteristics of falls leading to hip fractures indicate that older adults with these traits are physically frail and at a higher risk for fractures, serving as early indicators of increased vulnerability. As the global population ages, falls and related injuries present growing challenges. However, many falls are preventable with effective interventions. Given the significant impact of hip fractures, specialized strategies to prevent these falls are essential. This review offers insights for developing tailored fall prevention strategies for the older population. By identifying modifiable factors, we can create targeted approaches to reduce the incidence of hip fractures and their associated burdens.

This review encountered challenges due to inconsistent criteria for assessing fall characteristics across studies, which prevented a meta-analysis and necessitated reliance on a narrative synthesis to systematically summarize the findings. While this approach provided a comprehensive overview, it has limitations, as the evidence remains fragmented and less generalizable. This underscores the need for more consistent, high-quality research with standardized methodologies to facilitate future meta-analyses and strengthen the evidence base. Moreover, relying on self-reported data introduces recall bias, compromising the accuracy and reliability of findings. Retrospective interviews may lead to misinterpretations, with participants potentially forgetting or altering details over time, resulting in inaccurate fall reporting. This issue is particularly pronounced in older adults with cognitive impairments, who may report fall characteristics inaccurately. To mitigate recall bias, future research should employ prospective data collection methods, such as real-time or shortly post-event reporting, standardized questionnaires, wearable technology for real-time monitoring, and shorter intervals between events and data collection.

In addition, this review focused exclusively on non-skeletal factors to identify fall characteristics, excluding bone strength, a critical aspect of fracture risk. Considering the interaction between fall determinants and bone strength in the sequence leading to hip fractures, a comprehensive fall prevention strategy that integrates both fall characteristics and bone health is essential. Future studies should combine bone health metrics with detailed fall characteristics, conduct longitudinal studies to explore these interactions, and design interventions targeting both areas. Leveraging technology like wearables, advanced imaging, and machine learning can further enhance holistic fracture prevention strategies. Furthermore, the study's results may not fully represent hip fractures in LTC settings, as the review predominantly includes community-dwelling older adults. Given the elevated physical and cognitive challenges faced by LTC patients [18], future research should specifically target hip fractures within LTC environments. As the aging population grows and reliance on LTC facilities increases, effective fall prevention management in these settings becomes increasingly crucial. LTC patients may exhibit different fall characteristics related to hip fractures compared to their community-dwelling counterparts, necessitating tailored fall prevention strategies. Including a broader range of settings, particularly LTC facilities, in future research is essential for developing more effective and context-specific fall prevention strategies. Nonetheless, the focus on community-dwelling older adults adds valuable relevance to the review. Despite its limitations, this review offers crucial insights into falls leading to hip fractures and contributing the development of effective prevention strategies.

5. Conclusions

The clear correlation between falls and hip fractures has emphasized the importance for a comprehensive understanding of both, yet this requirement remains incompletely addressed. This review highlights the characteristics of falls leading to fragility hip fractures in older adults, providing insight into the interrelated components of the process. Such falls show distinct attributes more aligned with age-related physical frailty than general falls. Given that falls leading to hip fractures can happen ordinary circumstances in daily life, there's a pressing need for enhanced care and management for the older adults, considering global aging trends. Understanding these characteristics can guide healthcare providers to implement tailored interventions, aiming to reduce hip fractures and their associated challenges.

Funding

This research was supported by a grant of Patient-Centered Clinical Research Coordinating Center (PACEN) funded by the Ministry of Health & Welfare, Republic of Korea (grant number: RS-2020-KH095863), and the Soonchunhyang University Research Fund.

Ethical approval

Ethical approval was not required for this secondary research.

Conflict of interest disclosure

No disclosures were reported.

Author contributions

Conceptualization: SK Lim, JY Lim; Data curation: SK Lim, NH Heo, Y Kim; Formal analysis: SK Lim, K Choi; Funding acquisition: JY Lim; Methodology: SK Lim, NH Heo, JY Lim; Supervision: K Choi, Y Kim; Writing – original draft: SK Lim; Writing – review & editing: JY Lim; All authors have read and agreed to the published version of the manuscript.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jnha.2024.100357.

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