INVESTIGATING THE ECONOMIC IMPACT OF CARECLIP AUTOMATIC FALL DETECTION DEVICE

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Foreword

Falls can have a large impact on both an individual's health and wellbeing, as well as an economic impact on the national health service. Taking this into consideration, many health services have introduced fall prevention programmes in community settings. These are programmes where a person is assessed for fall risk and a programme is then designed to help prevent them from having a fall. These programmes are needs based and often include exercise regimes, education and support with aids etc.

Not being able to get up and thus lying on the floor for a long period of time after the fall (a long lie) has further clinical consequences for the elderly faller. Evidence is now emerging that a body worn fall detection device could also have a clinical benefit. Here a fall is not prevented but rather, when a fall does occur that an alarm is sent to a nominated carer, who can then come to the fallers aid quickly, so that the faller does not have to experience a long lie thus avoiding further clinical consequences.

Fall prevention programmes and fall detection programmes are complementary and both may support the elderly (as one example of a cohort who could benefit) in reducing falls and preventing long lies which will maintain their independence and quality of life for longer. The potential economic benefit for avoiding these falls and long lies for an already stretched health service is worth investigating.

The Health Innovation Hub, supported by Small Business Innovation Research (SBIR) funding awarded by Cork County Council and Enterprise Ireland to ADA Security, commissioned this investigation into the feasibility of the economic impact of CareClip, an automatic fall detection device. The benefit of this study signals that from the perspective of the health service (payer), the cost of investing in a national roll out of such a device could avoid future costs of falls and assumed long lies.

This study also informs on areas for future research design to build and clarify the economic impact to the health service, on reducing falls and long lies by using all programmes that are available to them.

Executive Summary

As the global population ages, challenges arise as how to maintain quality of life and independent living for as long as possible and how to manage the increasing burden on already stretched health care systems. Innovative technologies are emerging for this cohort to assist in maintaining their independence. One area where technology may have an impact in improving independence and quality of life for elders is in fall detection.

CareClip is a body worn fall detection device that aims to maintain independence and quality of life of the wearer. It does this by being able to detect if the wearer has fallen and if this does occur, then being able to alert a nominated person/carer to come to the faller's aid quickly. Thus, hopefully reducing the clinical impact of the fall, and associated health resource use. Thus, CareClip has the potential to improve both fallers' health outcomes and the economic impact on the health care system.

This report investigates the economic impact of adopting CareClip in a community setting, in the elderly user group. It consists of two sections. The first, presents an overview of what is known in the literature on the economic impact of falls; the clinical and economic consequences of long lies from falls and the cost effectiveness of wearable sensors. The second section investigates the economic impact of CareClip. This will be informed by findings from the literature review in Part 1 and cost of CareClip provided by ADA Healthcare Solutions to conduct a cost benefit analysis and a budget impact analysis of rolling out CareClip to all in this cohort and an alternative scenario of rolling out to half this cohort assuming a falls risk assessment to have been conducted and CareClip given to those most at risk of falling.

The literature review reveals the cost of falls in 2018Euros varies:

- €227.95 to €2,265 per individual for a fall that does not require hospitalisation,
- €2,171 to €7,005 for injurious falls,
- €3,585 to €24,690 per individual hip fracture or hospitalisation.

Lying on the floor for a long period of time after the fall, has an additional clinical impact on the faller. This can vary but an increase the probability of the faller not being able to conduct activities of daily living themselves, and of being hospitalised and, they are more likely to die. The evidence for the clinical benefit for the use of wearables or sensor equipment in detecting

falls or alerting falls is beginning to emerge. However, there is a dearth of evidence of cost effectiveness on body worn detection devices.

The second section of this report examines the economic impact of CareClip. Using the estimates extracted from the literature review in Part one and the costs of CareClip the following data is used in the economic analyses:

- The Central Statistics Office projects there will be over 850,000 people over 65 years of age by 2026 and this will rise to 1.45 million by 2046 [29].
- 30% of these people can expect to experience a fall (this is widely cited in research) [30].
- Average cost of falls, without using a detection device such as CareClip = €13,809 per person.
- Using 2016 population estimates cost of falls without a detection device such as CareClip is calculated at €2.6 billion.
- Owing to aging population this is expected to increase to €6 billion by 2046.

Cost Benefit Analysis

- CareClip annually costs €624.25 in year one and €340.50 in subsequent years for monitoring.
- It is anticipated CareClip will detect falls quickly thereby reducing long lies. This will have a positive economic impact on the health service. This care avoided (owing to long lies prevented) is employed as an estimate of the benefits of CareClip in this Cost Benefit Analysis.
- Owing to absence of primary effectiveness data assumptions were made around the reductions in long lies attributable to CareClip ranging from 25% to 99%.
- The cost of fall estimates extracted from the literature are applied to these benefits so as to measure them in monetary terms.
- The costs and benefits of CareClip are compared in a Cost Benefit Analysis.
- Results of the Cost Benefit Analysis reveal there is a positive net benefit of providing CareClip (the benefits of providing CareClip are greater than the costs of providing CareClip). This result holds when effectiveness of CareClip is varied between 25% and 99% (where effectiveness refers to reducing long lies).

There are several limitations to the analysis:

- The perspective adopted for the analysis was that of the health service provider. However, only direct health care costs were included. We acknowledge there are wider cost implications of falls too which should be incorporated.
- The choice of comparator (no detection device) may not be an accurate reflection of usual care. We acknowledge for example the "Senior Alert Scheme" is currently available but no effectiveness data were available on this to incorporate into the evaluation.
- No primary data on the effectiveness of CareClip was available so several assumptions had to be made.
- There are multiple potential benefits of CareClip, in the absence of primary data one benefit was chosen to measure effectiveness in this analysis – the prevention of long lies.
- In the absence of primary data on resource utilisation estimates from the literature had to be relied upon.
- Health care resources were valued using historical estimates sourced from the literature. These may not reflect current costs.
- Single estimates from the Central Statistics Office and the literature were employed.
- One-way sensitivity analyses are included to examine the impact of the assumptions surrounding CareClip's effectiveness. A probabilistic sensitivity analysis was not concluded. This could facilitate an examination of joint parameter and decision uncertainty.
- Cost Benefit Analyses are a useful and valid type of economic evaluation. However, they measure health benefits in monetary terms, not in terms of quality of life as advocated in national and international guidelines.

Study results demonstrate, a fall detection device such as CareClip, could bring savings to an already stretched health care system by preventing fall consequences such as long lies. From a health care service perspective, the economic benefit of avoiding the consequences of long lies and therefore reducing the pressure in the system could be worth the investment in the device, particularly if it was managed in tandem with existing falls risk assessments so those most at risk of falling will be identified and provided with the device.

While there are several limitations to this analysis it does demonstrate there is potential for CareClip to be considered cost effective from a public health service perspective. However, further analysis with primary data is warranted for definitive conclusions regarding its cost effectiveness can be made.

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1. Introduction

As the global population ages, challenges arise as how to manage the increasing burden on already stretched health care systems and how to maintain quality of life and independent living for as long as possible in this population. Innovative technologies are emerging for this age group to assist in maintaining their independence. One area where technology may have an impact in improving independence and quality of life for elders is in fall detection.

CareClip is a body worn fall detection device that aims to maintain independence and quality of life of the wearer. It does this by being able to detect if the wearer has fallen and if this does occur, then being able to alert a nominated person/carer to come to the faller's aid quickly. Thus, hopefully reducing the clinical impact of the fall, and associated health resource use. Thus, CareClip has the potential to improve fallers' health outcomes and the economic impact on the already burdened health care system.

This report investigates the economic impact of adopting CareClip in a community setting, in the elderly user group. It consists of two sections. The first, presents an overview of what is known in the literature on the economic impact of falls; the clinical and economic consequences of long lies from falls and the cost effectiveness of wearable sensors. The second section investigates the economic impact of CareClip. This will be informed by findings from the literature review in Part 1 and cost of CareClip provided by ADA Healthcare Solutions to conduct a clinical benefit analysis and a budget impact analysis.

2.Review Of Economic Literature On Fall Detection Devices.

2.1 Introduction To Economic Literature On Fall Detection Devices.

A series of literature reviews were conducted systematically to examine the economic literature on fall detection devices. Four specific areas in the literature were considered:

1.Economic costs of falls.

2.Clinical consequences of lying on the floor for a long period of time after a fall.

3.Strategies to detect falls.

4.Cost effectiveness of body worn fall detection devices.

Section 2.2 presents the methodology employed to conduct the four literature reviews. Section 2.3-2.6 presents the results of each of the literature reviews and Section 2.7 provides a summary of the information extracted from the research conducted.

2.2 Method For Conducting Literature Reviews.

Four separate literature reviews were conducted in a systematic way. The methodology for these systematic reviews was guided by the principles of conducting systematic reviews [1,2]. This included using the PICOCS framework (i.e. population, intervention, comparators, outcomes, context, studies) proposed by Davies to support inclusion criteria. Separate PICOS frameworks were designed for each specific literature review (presented below). A full search strategy using draft guidelines for the retrieval and interpretation of economic evaluations of health technologies in Ireland developed by Health information and Quality Authority, Ireland (HIQA) [2] was developed using search strings for each literature review (presented below). The systematic literature search was completed in several databases including EBSCO, CINAHL, MEDLINE, EMBASE etc. The economic search for grey literature was conducted using the following repositories: Cochrane Library (www.cochrane.org), Grey Literature: Guideline Websites were searched. Google Scholar and Google. As per HIQA guidelines data extraction included the following elements: setting, perspective and time horizon; Intervention, country, type of study, population targeted, and outcome. The evidence was combined and summarised using a narrative synthesis. The following sections (2.2.1-2.2.4) describe in more detail the methodology employed for each of the four systematic literature reviews.

2.2.1. Literature Review On Cost Of Falls In The Elderly.

Table 1 presents the PICOS framework for the literature review on the cost of falls in the elderly. Economic studies from 2000-2018 that focussed on cost of falls in the elderly in Ireland, United Kingdom or Europe were included. No limits were applied regarding the type of study for inclusion in the review to ensure identification of all the evidence for cost of falls. A full search strategy was developed using search strings categorised into four groups; terms associated with “elderly” and “economic filters” and “fall” and “Ireland or Europe” (Table 2). The search was conducted on 9th February 2018. A total of 11,523 papers/studies, were identified in the initial search. The time filter from 2000-2018 was then applied with the result reducing to 10,051. Using English language as a filter this reduced to 8,881. Using the “fall” terms as title terms returned a value of 2,222. Using “Ireland or Europe” search string resulted in 113 articles. Screening the titles of these 113 articles for context resulted in a literature search result of 52. 52 articles were further screened by abstract to identify if they fulfilled the inclusion criteria. This resulted in 10 articles that underwent full review and the data extracted was placed in the extraction table in section 2.3.

Table 1. PICOS Framework Cost Of Falls In The Elderly.

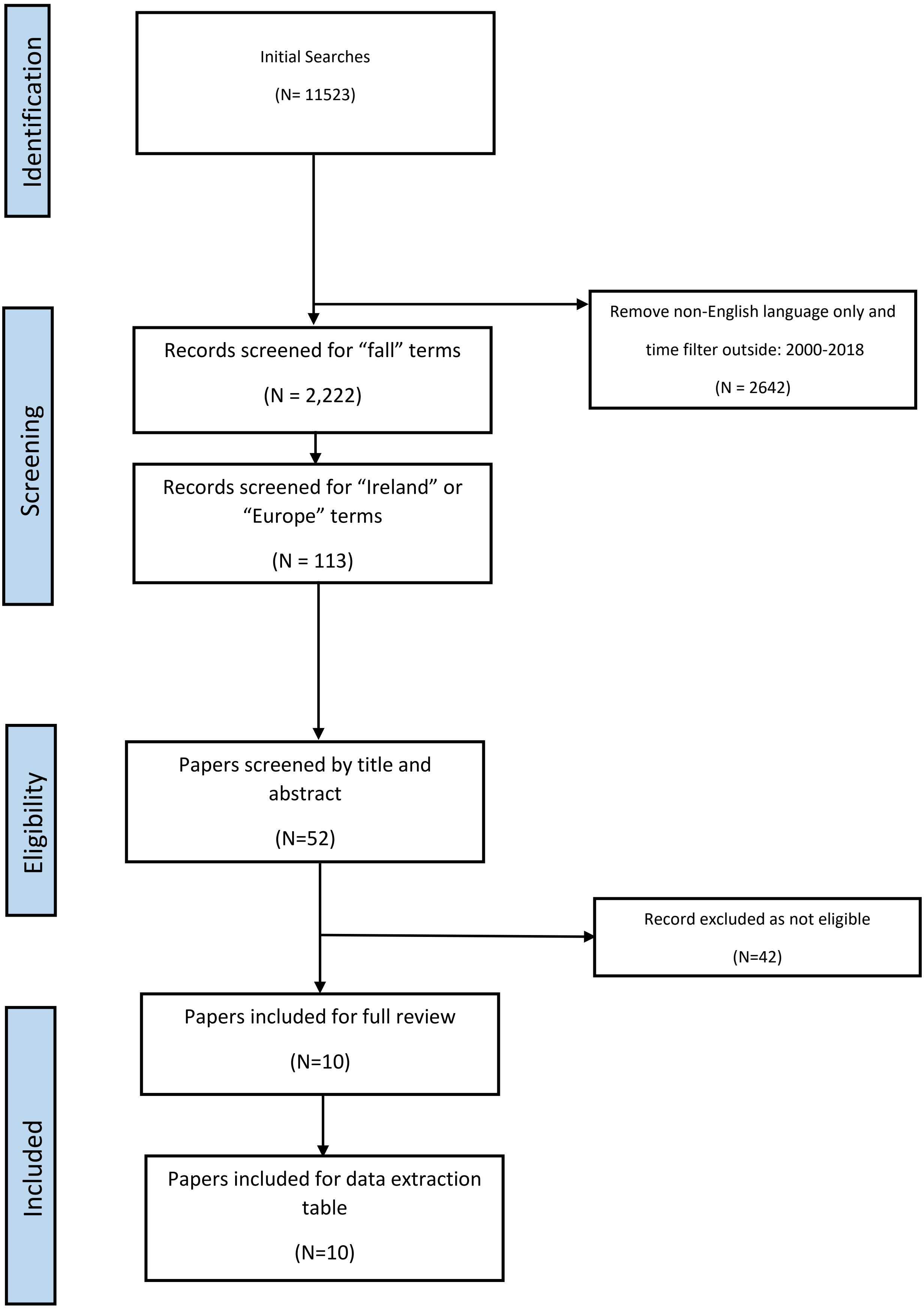
PICOS Framework	**Broad Areas**	**Specific search terms**	**Inclusion criteria**	**Exclusion criteria**
Population	**Adult patient**	“elderly” OR “senior” or “aged” or “geriatric”	Adult patient (i.e. ≥ 18 years of age)	Adolescents
Intervention	**Cost of falls**	**General (in {Title/Abstract})** “fall” OR “falling” or “trips” AND “cost” or “economics” or “financial”	Intervention in a community setting	Protocol for intervention, telephone intervention
Comparison	Comparison against other interventions or with no intervention	No specific search terms		
Outcome		No specific search criteria	Outcomes relating to fall outcomes	no outcome measures
Setting	Country specific	“Ireland” or “Europe” or “United Kingdom”	Europe	United states or Australia or non-European
Publication type/level of evidence		**Databases searched** EBSCO host Online Research Databases were used to simultaneously search relevant health and economic databases (Academic Search *Complete, CINAHL (the Cumulative Index to Nursing and Allied Health Literature),*	**Time:** Publication date within timeframe of 2000-2018 **Publication types:** Systematic reviews, Full economic evaluations;	**Publication quality** Publication of study did not contain sufficient detail regarding intervention or outcome measures.

PICOS Framework	Broad Areas	Specific search terms	Inclusion criteria	Exclusion criteria
		Medline, and UK/Eire Reference Centre). *Embase* and the Trip database were also searched. ***Cochrane Library*** (www.cochrane.org) ***Grey Literature: Guideline Websites*** were searched.	partial economic evaluations	**Publication types:** Literature reviews, discussion papers, integrative reviews, opinion pieces or study protocols. Oral/poster conference abstracts (as limited data available for data extraction).

Table 2. Search String.

Elderly	"elderly" OR "Senior" OR "aged" OR "geriatric"
Intervention	fall" OE "falls" OR "falling" OR "trips" AND "cost" OR "economics" OR "financial"
Location	"Ireland" OR "Europe" OR "United Kingdom"

Figure 2. 1. Flow Chart Of Search Process And Results**.** Cost Of Falls In The Elderly.



2.2.2 Literature Review On Clinical Consequences Of Lying On Floor For A Long Time After A Fall In The Elderly.

Table 3 presents the PICOS framework for assessing the clinical consequences of lying on the floor for a long period of time after a fall in the elderly. Economic studies from 1980-2018 that focussed on clinical consequences of lying on the floor for a long period of time after a fall in the elderly in Ireland, the United Kingdom or Europe were included. No limits were applied in the type of study for inclusion in the review to ensure identification of all the evidence for cost of falls. A full search strategy was developed using search strings categorised into four groups; terms associated with “elderly” and “fall” and “Ireland or Europe” (Table 4). The search was conducted on 9th February 2018. A total of 416 papers/studies, were identified in the initial search. The time filter from 1980-2018 was then applied with the result reducing to 415. Using English language as a filter this reduced to 409. Using the “consequences” terms in the search terms returned a value of 199. Using “Falls “terms in the title string resulted in 56 articles. Screening the titles of these 56 articles for context resulted in a literature search result of 30. These 30 articles were further screened by abstract to identify if they fulfilled the inclusion criteria. This resulted in 5 articles that underwent full review and the data extracted was placed in the extraction table in section 2.4.

Table 3. PICOS Framework Of Clinical Consequences Of Lying On The Floor For A Long Period Of Time After A Fall In The Elderly.

PICOS Framework	**Broad Areas**	**Specific search terms**	**Inclusion criteria**	**Exclusion criteria**
Population	**Adult patient**	“elderly” OR “senior” or “aged” or “geriatric”	Adult patient (i.e. ≥ 18 years of age)	Adolescents
Intervention	**Cost of falls**	**General (in {Title/Abstract})** “fall” OR “falling” or “trips” or “slips” AND “Long lie(s)” or “length of time on floor” or “inability to get up after	Intervention in a community setting	Protocol for intervention, telephone intervention

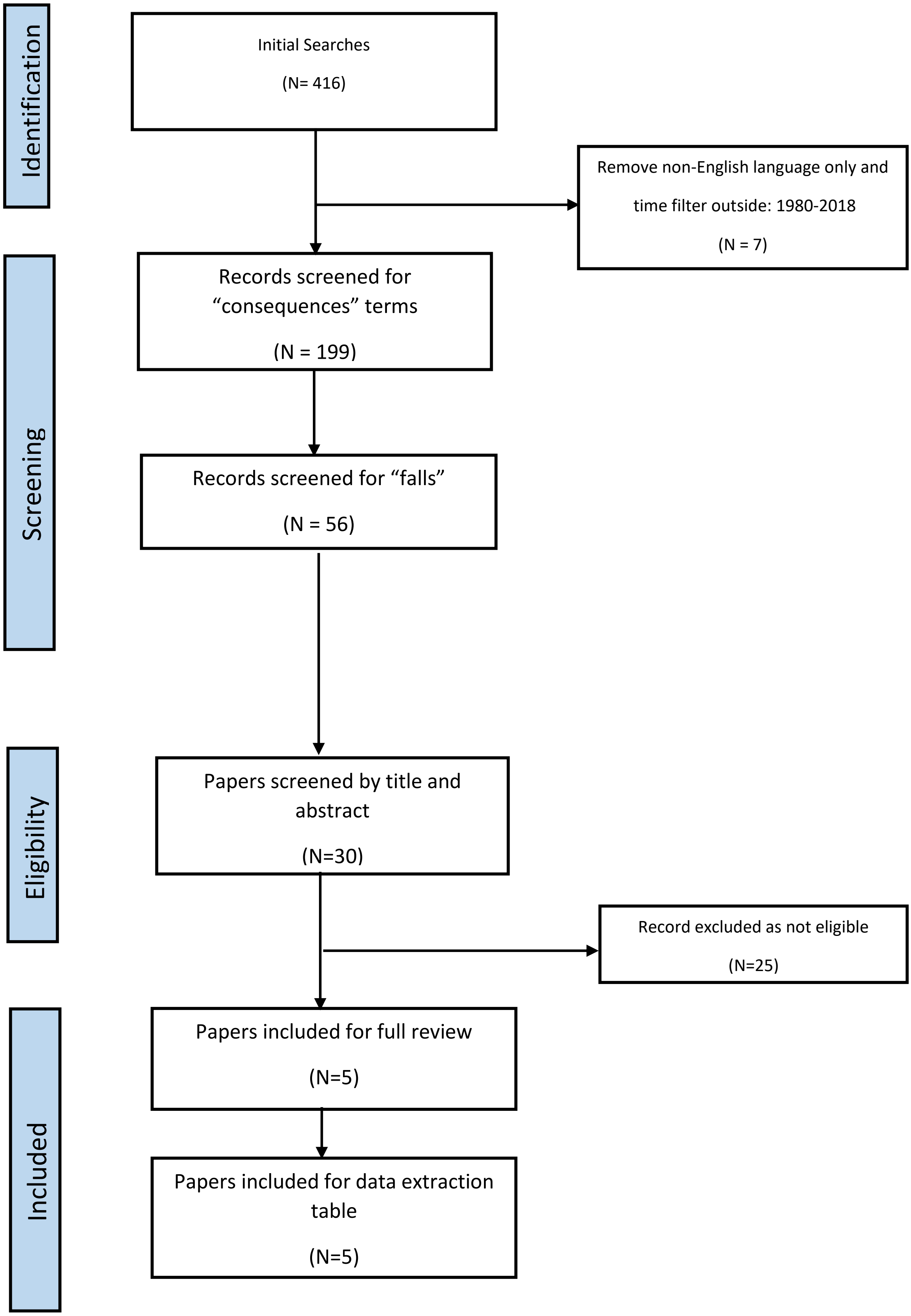
PICOS Framework	Broad Areas	Specific search terms	Inclusion criteria	Exclusion criteria
		a fall" or "response time after fall"		
Comparison	Comparison against other interventions or with no intervention	No specific search terms		
Outcome		No specific search criteria	Outcomes relating to fall outcomes	no outcome measures
Setting	Country specific	"Ireland" or "Europe" or "United Kingdom"	Europe	United states or Australia or non-European
Publication type/level of evidence		**Databases searched** EBSCO host Online Research Databases were used to simultaneously search relevant health and economic databases (Academic Search *Complete, CINAHL (the Cumulative Index to Nursing and Allied Health Literature), Medline, and UK/Eire Reference Centre).* *Embase* and the Trip database were also searched. ***Cochrane Library*** (www.cochrane.org) ***Grey Literature: Guideline Websites*** were searched.	**Time:** Publication date within timeframe of 1980-2018 **Publication types:** Systematic reviews, Full economic evaluations; partial economic evaluations	**Publication quality** Publication of study did not contain sufficient detail regarding intervention or outcome measures. **Publication types:** Literature reviews, discussion papers, integrative reviews, opinion pieces or study protocols. Oral/poster conference

PICOS Framework	Broad Areas	Specific search terms	Inclusion criteria	Exclusion criteria
				abstracts (as limited data available for data extraction).

Table 4. Search String

Elderly	"elderly" OR "Senior" OR "aged" OR "geriatric"
Intervention	fall" OR "falls" OR "falling" OR "trips" OR "slips" AND "consequences" OR "impact" OR "effects" OR "repercussions" AND "time on floor" OR "long lies(s)" OR "response time" OR "inability to get up"
Location	"Ireland" OR "Europe" OR "United Kingdom"

Figure 2.2. Flow Chart Of Search Process And Results**.** Clinical Consequences Of Lying On The Floor For A Long Period Of Time After A Fall In The Elderly.



2.2.3. Literature Review On Fall Detection Sensors In The Elderly.

Table 5 presents the PICOS framework for clinical outcome studies with a ten-year (2008-2018) time limit that focussed on sensors for fall detection in the elderly in the community setting were included. No limits were applied regarding the type of study for inclusion in the review to ensure identification of all the evidence for sensor fall detection. A full search strategy was developed using search strings categorised into four groups; terms associated with "elderly" and "fall" and "wearables" (Table 6). The search was conducted on 9th February 2018. A total of 362 references, were identified in the initial search. Using English language as a filter this reduced to 346. The ten-year time filter (2008-2018) was then applied with the result reducing to 339. Using all the search terms as subject terms returned a value of 10. These 10 articles were further screened by abstract to identify if they fulfilled the inclusion criteria. Articles that did not state a clinical outcome were eliminated from review. This resulted in four articles that underwent full review and the data extracted was placed in the extraction table in section 2.5.

Table 5. PICOS Framework On Clinical Outcomes On Fall Detection Sensors In The Elderly.

PICOS Framework	**Broad Areas**	**Specific search terms**	**Inclusion criteria**	**Exclusion criteria**
Population	**Adult patient**	"elderly" OR "senior" or "aged" or "geriatric"	Adult patient (i.e. ≥ 18 years of age)	Adolescents
Intervention	**Falls detection**	**General (in {Title/Abstract})** "fall" OR "movement" or "prevention" or "detection" AND "wearables" or "sensors" or "accelerometers" or "panic buttons"	Intervention in a community setting	Protocol for intervention, telephone intervention
Comparison	Comparison against other interventions	No specific search terms		

PICOS Framework	Broad Areas	Specific search terms	Inclusion criteria	Exclusion criteria
	or with no intervention			
Outcome		No specific search criteria	Outcomes relating to fall outcomes	no outcome measures
Setting	No specific terms	No specific search criteria	Community	Hospitals, prisons
Publication type/level of evidence		**Databases searched** EBSCO host Online Research Databases were used to simultaneously search relevant health and economic databases (Academic Search *Complete, CINAHL (the Cumulative Index to Nursing and Allied Health Literature), Medline, and UK/Eire Reference Centre).* *Embase* and the Trip database were also searched. ***Cochrane Library*** (www.cochrane.org) ***Grey Literature: Guideline Websites*** were searched.	**Time:** Publication date within timeframe of 2008-2018 **Publication types:** Systematic reviews, Full economic evaluations; partial economic evaluations	**Publication quality** Publication of study did not contain sufficient detail regarding intervention or outcome measures. **Publication types:** Literature reviews, discussion papers, integrative reviews, opinion pieces or study protocols. Oral/poster conference abstracts (as limited data available for data extraction).

Figure 2.3. Flow Chart Of Search Process And Results**.** Fall Detection Sensors In The Elderly.

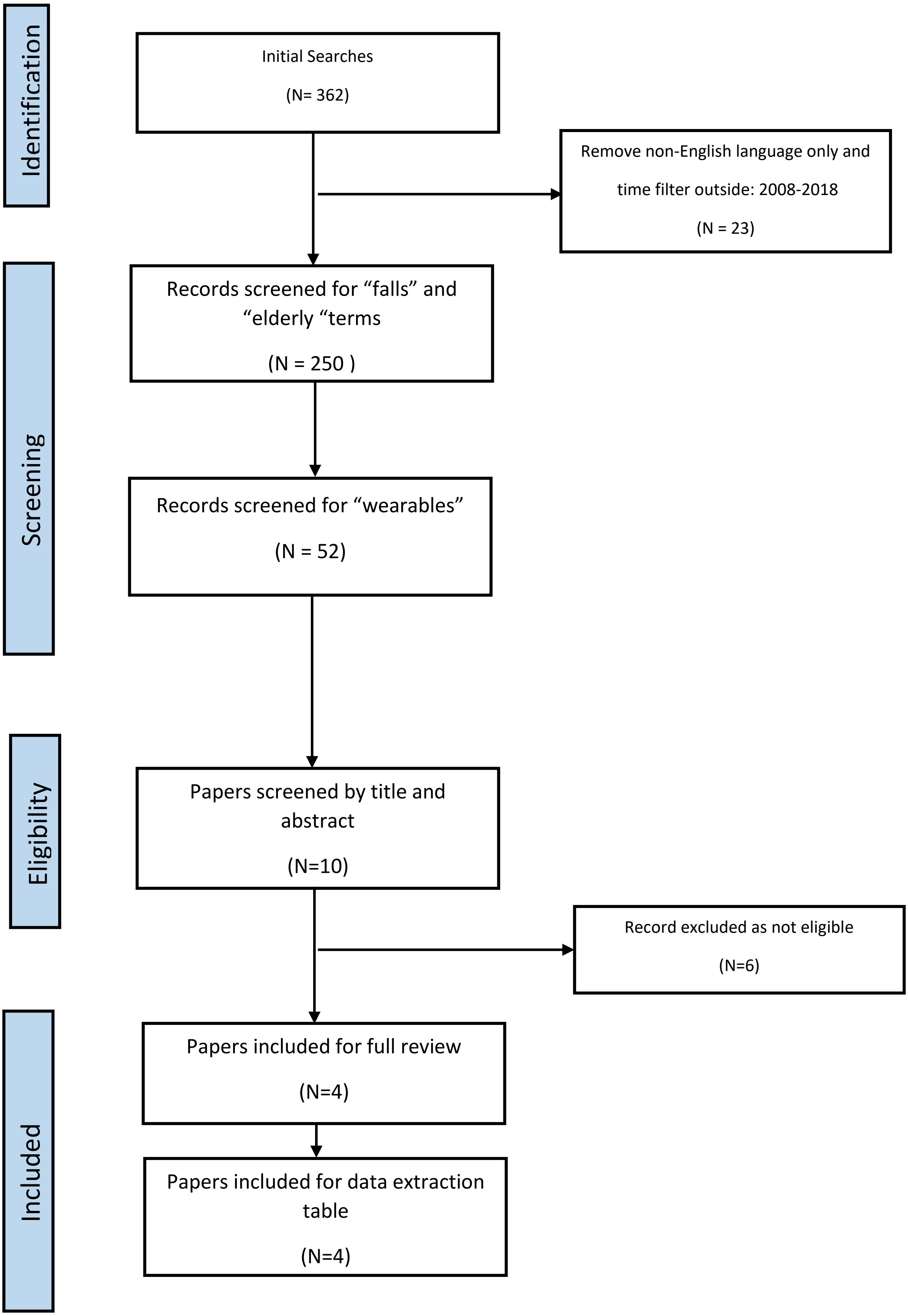


Table 6. Search String

Elderly	"elderly" OR "Senior" OR "aged" OR "geriatric"
Intervention	""fall" OR "movement" OR "detection" OR "prevention" AND "wearables" OR "sensors" OR "accelerometers" OR "panic buttons"

2.2.4. Literature Review On Cost Effectiveness Of Assistive Technologies In The Elderly.

Table 7 presents the PICOS framework for economic studies on fall detection sensors in the elderly in the community setting. A ten-year (2008-2018) time limit was used. No limits were applied regarding the type of study for inclusion in the review to ensure identification of all the economic evidence for sensor fall detection. A full search strategy was developed using search strings categorised into four groups; terms associated with "elderly" and "fall" and "wearables" and "economics" (Table 8). The search was conducted on 9th February 2018. A total of 11,067 references, were identified in the initial search. Using English language as a filter this reduced to 9907. The ten-year time filter (2008-2018) was then applied with the result reducing to 6133. Using all the search terms as subject terms returned a value of 509. Using the "Fall" search string in the title resulted in 39 articles. Screening the titles of these 39 articles for context resulted in a literature search result of 24. These 24 articles were further screened by abstract to identify if they fulfilled the inclusion criteria. Exercise programmes or cognitive development programmes or changes to physical environment interventions were eliminated from review. This resulted in one article that underwent a full review and the data extracted was placed in the extraction table in 2.6.

Table 7. PICOS Framework On Economic Studies For Fall Detection Sensors In The Elderly.

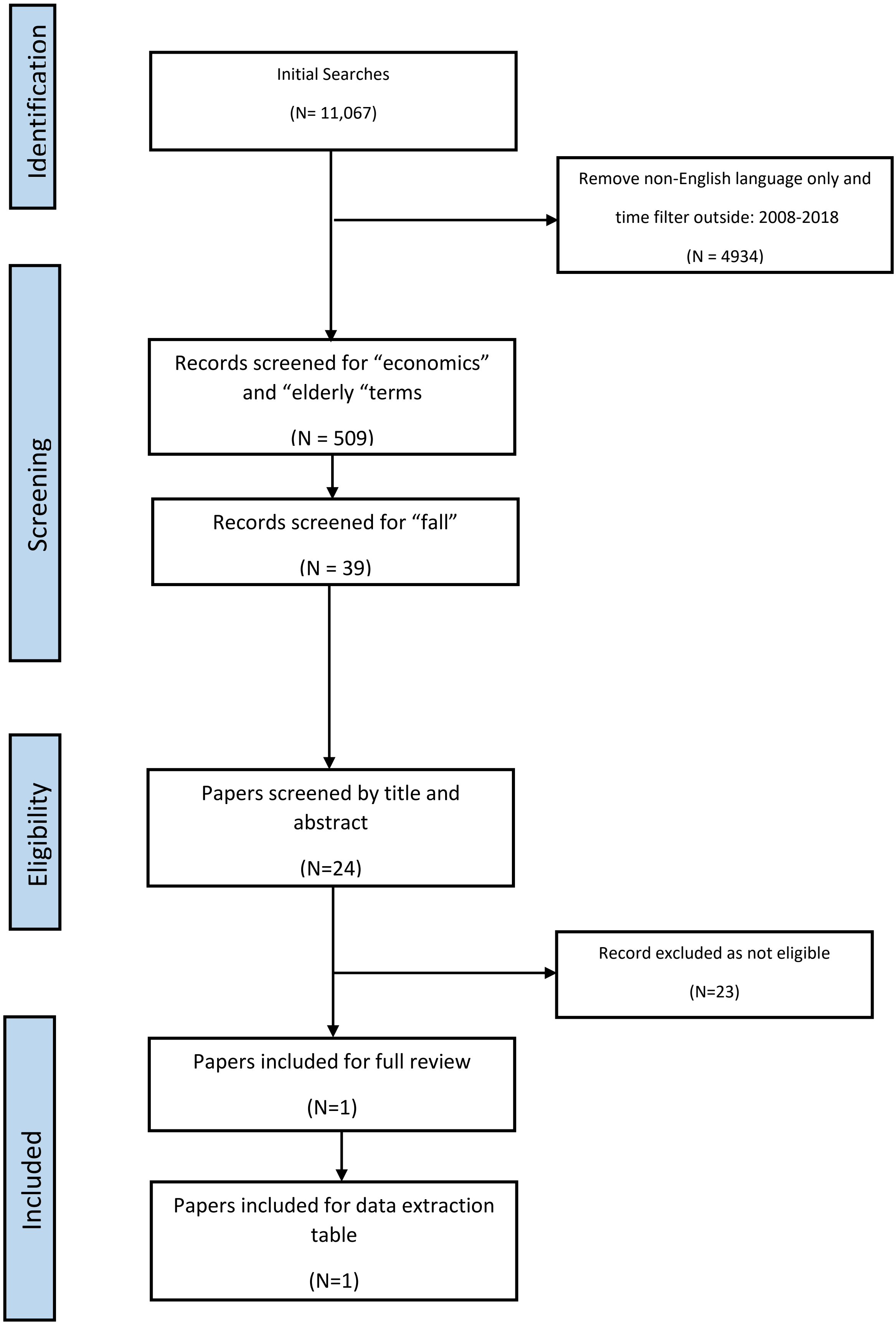
PICOS Framework	**Broad Areas**	**Specific search terms**	**Inclusion criteria**	**Exclusion criteria**
Population	**Adult patient**	“elderly” OR “senior” or “aged” or “geriatric”	Adult patient (i.e. ≥ 18 years of age)	Adolescents
Intervention	**Falls detection**	**General (in {Title/Abstract})** “fall” OR “movement” AND “detection” OR “monitor” OR “sensor” OR “alert” OR “alarm” OR “help button” or “telemedicine” OR “assistive technologies” OR “wearables” or “panic button” or “accelerometer” AND "Economics" OR "cost* and benefit*" OR "cost analysis" OR "cost management" OR “cost saving” OR "additional resources" OR "cost effectiveness"	Intervention in a community setting	Protocol for intervention, telephone intervention
Comparison	Comparison against other interventions or with no intervention	No specific search terms		
Outcome		No specific search criteria	Outcomes relating to fall outcomes	no outcome measures
Setting	No specific terms	No specific search criteria	Community	Hospitals, prisons

PICOS Framework	Broad Areas	Specific search terms	Inclusion criteria	Exclusion criteria
Publication type/level of evidence		**Databases searched** EBSCO host Online Research Databases were used to simultaneously search relevant health and economic databases (Academic Search *Complete, CINAHL (the Cumulative Index to Nursing and Allied Health Literature), Medline, and UK/Eire Reference Centre).* *Embase* and the Trip database were also searched. ***Cochrane Library*** (www.cochrane.org) ***Grey Literature: Guideline Websites*** were searched.	**Time:** Publication date within timeframe of 2008-2018 **Publication types:** Systematic reviews, Full economic evaluations; partial economic evaluations	**Publication quality** Publication of study did not contain sufficient detail regarding intervention or outcome measures. **Publication types:** Literature reviews, discussion papers, integrative reviews, opinion pieces or study protocols. Oral/poster conference abstracts (as limited data available for data extraction).

Table 8. Search String

Elderly	"elderly" OR "Senior" OR "aged" OR "geriatric"
Intervention	""fall" OR "movement" AND "detection" OR "monitor" OR "sensor" OR "alert" OR "alarm" OR "help button" or "telemedicine" OR "assistive technologies" OR "wearables" or "panic button" or "accelerometer"
Cost effectiveness	"Economics" OR "cost* and benefit*" OR "cost analysis" OR "cost management" OR "cost saving" OR "additional resources" OR "cost effectiveness"

Figure 2.4. Flow Chart Of Search Process And Results. Cost Effectiveness Of Fall Detection Sensors In The Elderly.



2.3 Cost Of Falls

As the population ages, falls and their impact are of growing concern to both the people who suffer the fall, and to the stretched health care system which must cope with treating the falls. The subsequent cost to health care systems and Governments, which have a limited health budget have been reported frequently in the literature. A systematic literature review preformed found 10 papers on the cost of falls in the elderly population. The data from these papers were extracted, synthesised and placed in a table (Appendix A1). The results demonstrated a large variation in costs of falls depending on type of fall and jurisdiction. To provide consistency and applicability to the current environment, the findings from these results are presented here in 2018 Euros. The studies considered were from Ireland, the United Kingdom, United States, Norway, Italy, and the Netherlands.

Table 9 reports the estimates from the literature. There is a wide range of costs associated with falls depending on the type of fall and how serious the consequence of the fall is. From the literature evaluated, the cost of a "fall only that does not require hospitalisation" can vary from €227.95 to €2,265 per individual in current times. "Injurious falls" can vary from €2,171 to €7,005. However, if a fall results in a hip fracture and/or hospitalisation the costs can vary from €3,585 to €24,690 per individual fracture or hospitalisation. Therefore, even falls that do not require hospitalisation have a cost impact for health care systems.

In summary, using data extracted from this literature review, the cost of falls in 2018Euros varies from €2,265 per individual for a fall that does not require hospitalisation, to €2,171 to €7,005 for injurious falls and finally, from €3,585 to €24,690 per individual hip fracture or hospitalisation.

Table 9. Analysis Of Cost Per Individual Fall In 2018€X,000.

Study	Year	Country	Cost/Population	Cost/individual 2018€ *
Iglesias. et al [3]	2009	United Kingdom	Not stated Data from 2003	1.€1,775.61fall only 2. €24,690.9 fall leading to hip fracture 3. €4,491.96 fall leading to wrist fracture 4. €3,039.83 fall leading to arm fracture 5. €2,171.65 fall leading to vertebral fracture 6. €5,707.41 fall leading to other fracture
Davis, J.C. et al [4]	2010	Literature review of International estimates from: United States Australia Europe United Kingdom	US non-fatal and fatal falls =2008 US$23.3billion/yr. UK non-fatal and fatal falls 2008$ 1.6billion data from 2008	Type of fall: 1.Faller €2,265.36 2.Injurious fall €7,005.88 3.Hospitalisation due to fall €17,262.84
Tian, Y. et al [5]	2013	United Kingdom	£2billion/year 2010 Cohort of 421 patients followed: 1.£5m spent on both care associated with the fall itself and in the ear following the fall. 2.£1.2m spent on core event of fall for 421 patients.	Cost of fall and one year follow up = €13,796 2.Core event €3,309.87
Sartini et al [6]	2009	Italy	Domestic fall hospitalisation 2006€395m/year	Fall requiring hospitalisation €5,874.97
Hartholt K, A. et al [7]	2012	The Netherlands	2007-9 Elderly falls to A&E. €674.5m/yr Fractures €540m/yr	Mean cost/fall €9,477.91

Hektoen, L.F. et al [8]	2009	Norway	Not stated	€1,270.49
Cotter, P.E. et al [9]	2006	Ireland	Total cost of one year of fall related admissions to an acute hospital =€10.8m	Typical hip fracture hospital admission =€17,543.59
Gannon. et al [10]	2008	Ireland	WHO fall rates to Ireland 30% of older pop over 65 falls =130000 1.Baseline cost of falls and fractures =2004€404m 2.Fractures estimate 2004€225m 3.Falls only =2004€19m	1.€3,585.44
Carey et al [11]	2005	Ireland	Total inpatient cost of 1760 hospitalisations (unintentional injury due to fall) =2002 €9.2m Hip fractures =€5.9m of this.	Type of injury 1.Fractured hip= €10,612.03 2.Intracranical injury = €4,600.59
Schuffham, P. et al [12]	2003	United Kingdom	2000 total cost £981m. 1.Cost per fall per 10000 population, started from 2000£300k in 60-64age group 2.2000 £1.5m >70age group	1. €45.59 2.€227.95

*Estimates reached using the following steps: 1. Calculating the cost per type of fall in currency and year of data used. 2.Converting that figure to euros in year of data. 3. Index linking to current (2018) rates.

2.4 Clinical Consequences Of Lying On The Floor For A Long Time After A Fall.

Another consideration explored in the literature is the clinical consequence of lying on the floor for a period after a fall (referred to as long lies). A systematic literature review was conducted and found 4 papers on the consequence of lying on the floor for a long period of time in the elderly. The data was extracted from these papers synthesised and placed in a table (Appendix A2).

A meta-analysis by Ryanen [13], determined that 12% of men and 19% of women aged over 65 years of age who sought medical attention after a fall lay there for 15 minutes or more after falling. The occurrence of a fall followed by a long lie was associated with a high body temperature, low serum potassium concentration and severe injury. A meta-analysis conducted by Bloch [14] found that healthy elderly adults require twice as long to stand as younger patient. 25% of elderly adults were unable to rise from an accidental fall and reaching the age of 80 is a risk factor independently associated with inability to rise from the ground after a fall. Bloch also showed that lying on floor for a long period of time nearly doubles the risk of death. In the elderly a minor fall can be fatal if on the floor for a long period of time due to development of pressure ulcers, dehydration and hypothermia, rhabdomyolysis or renal failure.

Another study by Fleming [15] showed that in a cohort of over 90-year olds that 15% who had a fall, remained on the floor for an hour or more. This study showed that if the person had more falls it led to longer times being on the floor. All the incidents in which people lay on the floor for over an hour arose from unwitnessed falls. 60% had a fall related hospital admission during the follow up year and 36% moved into long term care with a year. There was a threefold increase admission to a care home.

Whilst Gurleys [16] population-based study of patients who were found in their homes either helpless or dead by paramedics over a twelve-week period in San Francisco showed that a longer time spent being helpless was associated with being found dead or being transported to hospital and being admitted or discharged to other care rather than independent living. 67 % of deaths in this study were of those immobilised for more than 72 hours, which contrasted with 12% of deaths with those that were found lying for less than one hour. This is in line with Tinetti [17] who identified that prognosis for fallers who are unable to get up after falling were more likely to die, to be hospitalised and to suffer a lasting decline in activities of daily living. Table 10 illustrates the probability of a consequence occurring after a long lie post fall as stated from the literature review. In summary, findings from this literature review show that lying on the floor for a long period of time after the fall has clinical impact on the faller. The impact can vary but it can increase their probability of not being able to conduct activities of daily living themselves, to being hospitalised even resulting in the fact that they are more likely to die.

Table 10. Probability Of Consequence Occurring After Long Lie Post Fall.

Time on floor	Consequence	probability	reference	Sample population patients	Country
Mean floor time > 30mins	1-year outcome death	11%	Tinetti [17]	1103	U.S.
< 1 hour	dead	12%	Gurley [16]	367	U.S.
> 72 hours	dead	67%	Gurley [16]	367	U.S.
Long time	death	50%	Bloch [14]	Meta-analysis	Meta-analysis
Mean floor time > 30mins	Severe injury	65%	Tinetti [17]	1103	U.S.
>1 hour	Fall related hospital admission during one year follow up.	60%	Fleming [15]	20	U.K.
≥72 hours	Admitted to hospital	62%	Gurley [16]	367	U.S.
Mean average = 19mins	Nursing home placement	7%	Tinetti [17]	1103	U.S.

>1 hour	Long term care facility within study time frame	36%	Fleming [15]	14	U.K.
>1hour	Long term care facility by end of study censoring (everyone patient had conducted a year since interview).	53%	Fleming [15]	15	U.K.
≥72 hours	Not return to independent living	62%	Gurley [16]	367	U.S.
Mean average = 19mins	Decline in basic activity of daily living for greater than 3 days	12%	Tinetti [17]	1103	U.S.
Mean floor time > 19 mins	Decline in at least one daily activities living and instrumental activities of daily living	35%	Tinetti [17]	1103	U.S.
Mean floor time > 30mins	Immediate post fall hospitalized (not serious injury but unable to get up)	12%	Tinetti [17]	1103	U.S.

2.5 Technologies To Detect Falls.

Taking into consideration the impact of falls in the elderly population from a health and economics perspective, the importance of detecting falls as quickly as possible can be seen, to avoid the faller from lying on the floor for a long period of time. Introducing technology in the form of wearable sensors may aid in the detection of falls and thus be of clinical benefit. Some studies have been conducted to attempt to predict and or detect falls in the elderly who are wearing the sensors through building algorithms which will predict when a fall is about to occur. If a fall has occurred the sensor can send signals to alert a nominated carer of the fall that has occurred. Wearable sensors may now also be used as part of a fall risk assessment.

The systematic literature review conducted here found 4 papers on use of wearables to detect or predict falls in the elderly. The data from these studies were extracted and synthesised and placed in a table (Appendix A3). These studies are discussed here.

Mohler et al [18] evaluated the use of wearables to assess if their measures could be a predictor of falls in the Arizona frailty cohort study. They concluded that sensor derived parameters may be a useful fall risk predictor in populations with indicators of frailty. Nyan [19] found that a sensor device could detect accurately a fall about to happen, which gave the person lead time to activate an air bag device and Ejupi [20] developed a wavelet-based algorithm that accurately detected sit to stand movements during activities of daily living in older people and discriminated significantly between fallers and non-fallers. While Lee [21] concluded that wearables can be an effective way of measuring falling behaviour in community dwelling elderly and are a low cost and ordinary method of prevention.

Danielsen (22) and Shany (23) both have discussed how wearables can be integrated into a fall risk assessment protocol. The challenges issues and trends in fall detection systems have been described by Igual (24) from the literature review that was conducted. Klenk (25) describes the FARSEEING real world depository that is collecting real world falls data derived from sensor technology.

In summary, findings from this literature review illustrates that the evidence for the clinical benefit for the use of wearables or sensor equipment in detecting falls or alerting falls is beginning to emerge. It suggests that body worn devices may have a clinical benefit by detecting falls early and being able to alert carers to come to the fallers aid quickly. The result of which avoids long lies and the subsequent health consequences of that event.

2.6 Cost Effectiveness Of Body Worn Fall Detection Devices.

Evidence is emerging on the clinical benefit of wearables as described in section 2.5. A systematic literature review was conducted to ascertain cost effectiveness of fall detection devices. This review found no papers on the cost effectiveness of wearables illustrating the dearth of evidence in this setting.

As no observations on the cost effectiveness of wearable sensors were found the literature search was expanded to review cost effectiveness in early alert or fall prevention programmes. The review found one paper that described a cost analysis in an early alert non-wearable system. Rantz [26] (Appendix A4 (Table A4i)) study examined the use of an alarm that was incorporated into beds and other areas in the homes of elderly who were living in an assisted community setting in the United States. The system detected health status changes in the elderly and sent early signals to health care providers. The health care providers then had the opportunity to react quickly to the changes in health status that were being monitored. The results showed that those that were using the technology and thus receiving assistance earlier had a benefit in some health status measures in comparison to those that were not using the technology, but this was found not to be statistically significant. The study concluded that the intervention is cost effective. However, on further analysis of the study it was evident that the ICER (Incremental cost effectiveness ratio, a measurement of cost effectiveness) was not calculated, and no formal economic evaluation was performed.

Many fall prevention programmes have been devised and some have examined their cost and /or cost effectiveness. Some include exercise programmes, involving Tai-Chi or the Otago (exercise based) programme to be introduced to elderly people to partake in on a regular basis to build up muscle and balance and thus prevent the likelihood of falling. Others document assistive technologies such as aids and home visits by occupational and physical therapist. Farag [27] and Smith [28] (Appendix A4(Table A4ii)) are examples of exercise programmes to help prevent falls where a cost analysis has been conducted.

In summary, findings from this literature review on cost effectiveness on body worn detection devices show that there is a dearth of evidence in this area with no relevant literature being found. This suggest an area for future research.

2.7 Summary Of Literature Reviews

In summary from this review, the cost of falls in 2018Euros varies from €227.95 to €2,265 per individual for a fall that does not require hospitalisation, to €2,171 to €7,005 for injurious falls and finally, from €3,585 to €24,690 per individual hip fracture or hospitalisation. Lying on the floor for a long period of time after the fall, has a clinical impact on the faller separate to the fall itself. The impact can vary but it can increase their probability of not being able to conduct activities of daily living themselves, and of being hospitalised and also, they are more likely to die. The evidence for the clinical benefit for the use of wearables or sensor equipment in detecting falls or alerting falls is beginning to emerge. It suggests that body worn devices may have a clinical benefit by detecting falls early and being able to alert carers to come to the fallers aid quickly. The result of which avoids long lies and the subsequent health and cost consequences of that event. Finally, whilst the clinical benefit for wearing fall detection devices is beginning to emerge there is a dearth of evidence of cost effectiveness on body worn detection devices.

3 Investigating The Economic Impact Of CareClip.

3.1. Introduction

Owing to limited resources for health and social initiatives, choices regularly must be made between different uses of the same resources. One means of comparing between alternatives is health economic evaluations. The aim of which is to investigate the cost effectiveness of an intervention compared to a comparator (often status quo). This involves estimating the additional costs and benefits of the intervention and comparing it to that of the comparator. If the intervention is less costly and more beneficial than the comparator (positive net benefit) it can be considered cost effective.

This section of the report attempts to estimate the cost effectiveness of CareClip. In the absence of primary data on CareClip the secondary evidence presented in the previous section is synthesised and incorporated into an economic model to investigate the cost effectiveness of CareClip and the budget impact of rolling it out.

A public payer perspective is taken because falls are a public health issue. The analysis is conducted comparing the cost of a national roll out of the device to the future savings for the health service in not having to treat the clinical consequences of the falls and long lies that the device may detect.

3.2. Methods For Investigating The Cost Effectiveness Of CareClip.

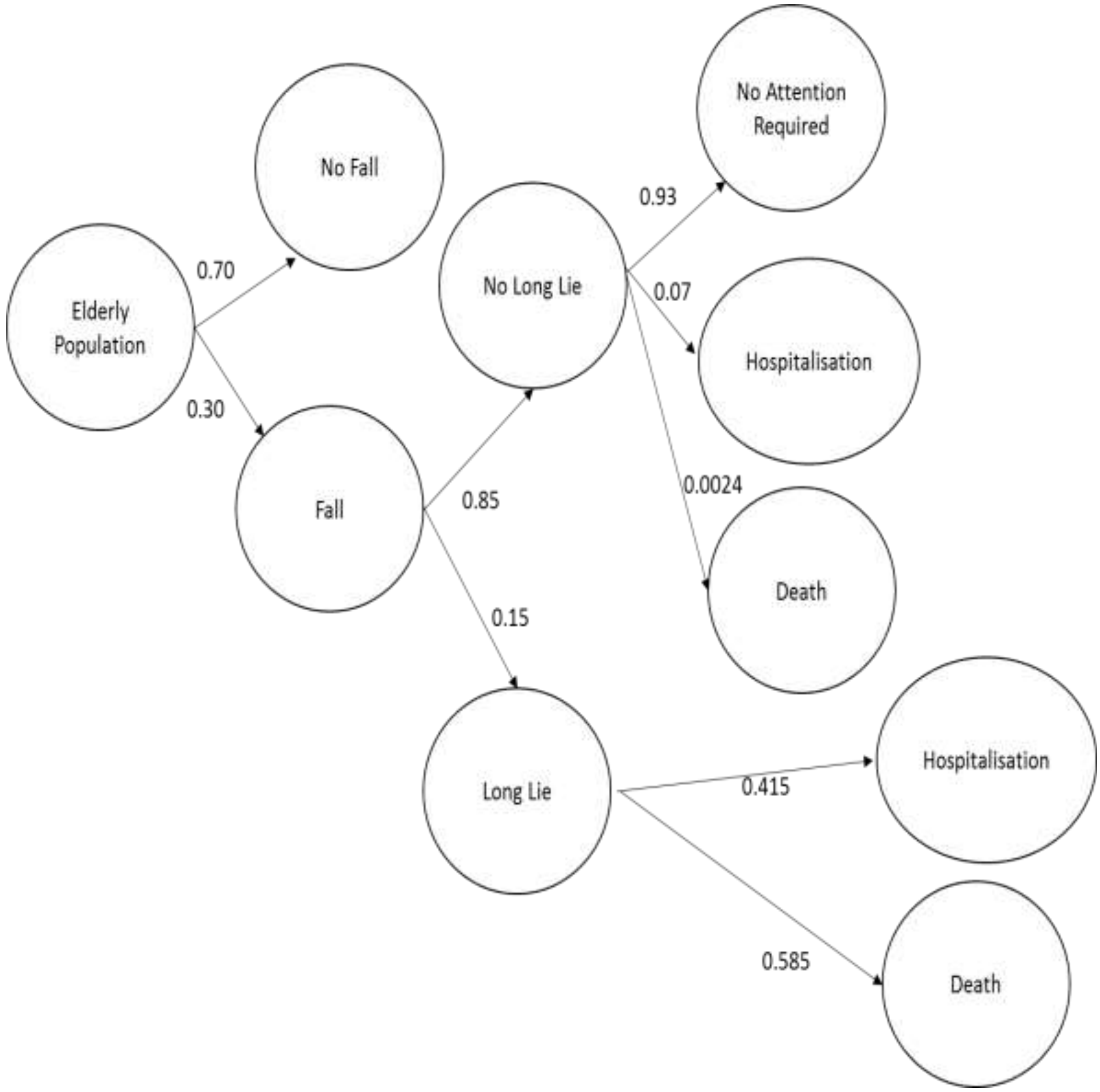
Standard methods as advocated by HIQA (34) are employed to conduct the health economic evaluation and budget impact analysis. For conducting the health economic evaluation, the intervention is CareClip and the comparator considered is "do nothing" and the perspective of the health service is considered. Therefore, this analysis is considering the cost effectiveness of CareClip should it be rolled out on a national basis through the public health care system.

The premise underlying the benefit of CareClip is that earlier detection of falls reduces long lies therefore reducing risk of death, hospitalisations, need for long term care and reduction in decline in activities of daily living. Evidence from the literature review (table 10) is adopted here to estimate the probability of adverse events arising from falls where there is no fall detection device in use. These estimates are used in the construction of an economic model.

Economic Model.

As illustrated in Figure 3.1 and presented in Table 11, the probability of falls amongst the elderly is 30%; death from a fall is 0.24% and hospitalisations arising owing to a fall 7% (Gannon et al 2007 [33]). Furthermore, there is on average a 15% likelihood of a long lie resulting from a fall (14,17,31). Following a long lie the average likelihood of death is 59%. This is represented on a flow diagram (Figure 3.1).

Figure 3.1. Flow Diagram Of Probabilities Of Consequences Arising From A Fall In The Elderly.



Effectiveness of CareClip.

In the absence of primary data on CareClip a range of assumptions (Table 11) about the effectiveness of CareClip are used to investigate its cost effectiveness compared to having no sensor, i.e. estimate the value of events avoided. It is assumed that when CareClip is present a fall is detected thereby reducing the likelihood of a long lie. Assumptions were made surrounding the reduction in long lies from using CareClip, ranging from 99% effective to 25% effective. Using these assumptions, the probability of long lies occurring whilst wearing CareClip is reduced to between 1% and 11%.

Table 11. Probabilities Of Adverse Events After Falls.

	Probabilities	Source
Fall	0.30	Skelton et al 2004
Death from Fall	0.0024	Gannon et al 2007
Hospitalisations from Falls	0.07	Gannon et al 2007
Long Lie	0.15	Bloch 2012, Tinetti et al 1993, Wilde et al 1981. Literature indicates 10-20% average = 15%
Death from A Long Lie	0.59	Literature indicates 50-67%, average = 59%
Hospitalisations from a Long Lie	0.42	Inverse of death from long lie
Assumptions re Long Lie with CareClip		
CareClip 99% Effective in avoiding long lies	0.01	
CareClip 75% Effective in avoiding long lies	0.04	
CareClip 50% Effective in avoiding long lies	0.08	
CareClip 25% Effective in avoiding long lies	0.11	

Costs

Monetary values were assigned to falls using the Irish evidence on the economic impact of falls extracted from the literature review (Table 13). Cost of death from a fall is €472,808 (Gannon et al 2007 inflated to 2018 euros). Hospitalisations owing to falls are valued at €30,332 (weighted average from Gannon et al 2007 inflated to 2018 euros). This estimate includes costs relating to: inpatient, ambulance, emergency department, long term care, outpatients, GP, informal care and quality of life. With respect to the cost of CareClip, ADA Healthcare Solutions provided costs of the CareClip device and associated costs.

Table 12. Costs

Category	**€**	**Source**
Death following a fall	472,808.22	Gannon et al 2007[1] (2018 prices[2])
Hospitalisations associated with a fall	30,331.59	Gannon et al 2007[1] (2018 prices[2])
CareClip Year 1	624.25	ADA Healthcare Solutions
CareClip Subsequent Years	340.50	ADA Healthcare Solutions

[1] Weighted average for falls resulting in factures and non-fractures. Includes cost relating to: inpatient, ambulance, emergency department, long term care, outpatients, GP, informal care and quality of life. [2] CSO (2018) http://www.cso.ie/en/interactivezone/visualisationtools/cpiinflationcalculator/

Estimating Cost Effectiveness

Using the estimates described above, the benefits of CareClip, aka long lies avoided, can be valued in monetary units (Euros). Thus, the benefits can be directly compared to the cost of CareClip to estimate net benefit (benefit – costs). This type of economic evaluation is a Cost Benefit Analysis.

Using the estimates presented above in Tables 11 and 12, an economic model is developed, for the comparator (No CareClip) and the intervention (CareClip) under the four alternative assumptions. The results of which are illustrated in Figures 3.2 (a-f) below. The models 2A-2D are in Appendix A5. The information obtained from these models inform the basis of the Cost Benefit Analysis in Section 3.3.

Figure 3.2. (A). Probability Of Occurrence Of Adverse Event From Falls In The Elderly With No CareClip Being Used.

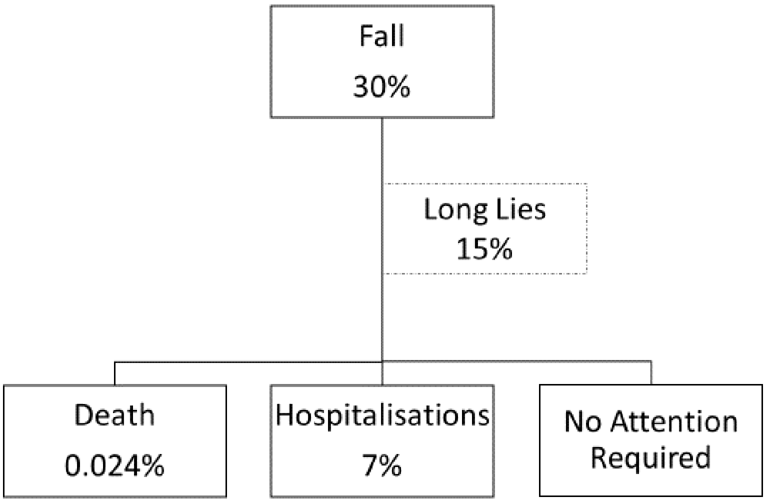


Figure 3.2. (B). Numbers And Cost Of Adverse Events From Falls In The Elderly Per 1000 Cohort With No CareClip Being Used.

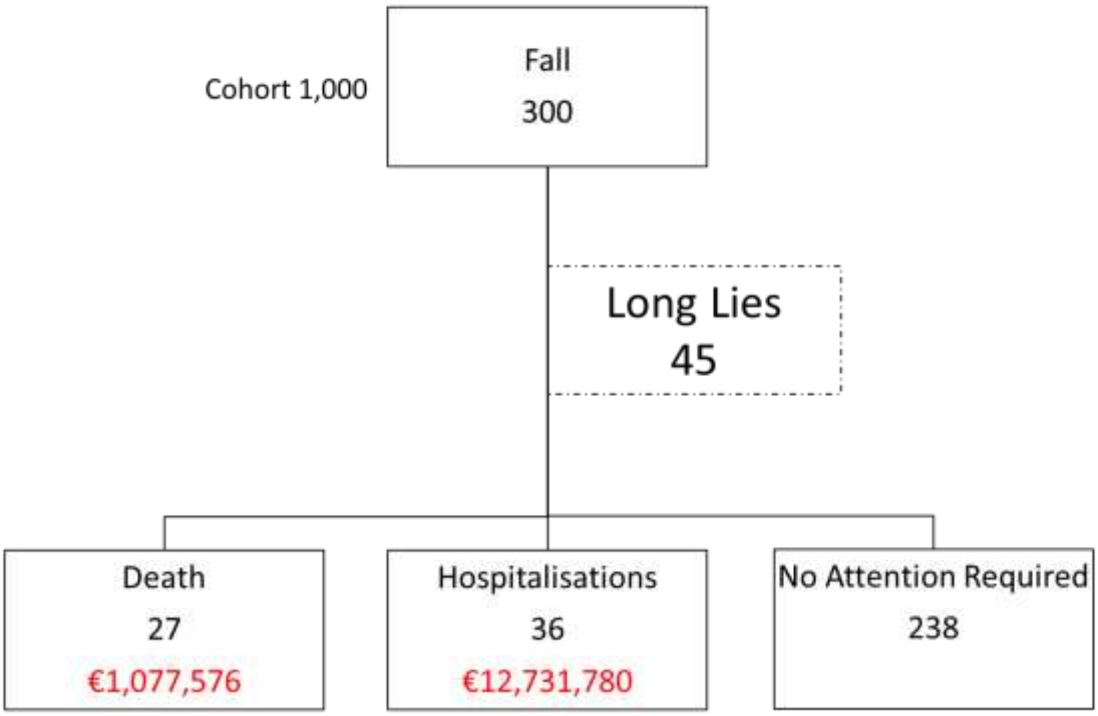
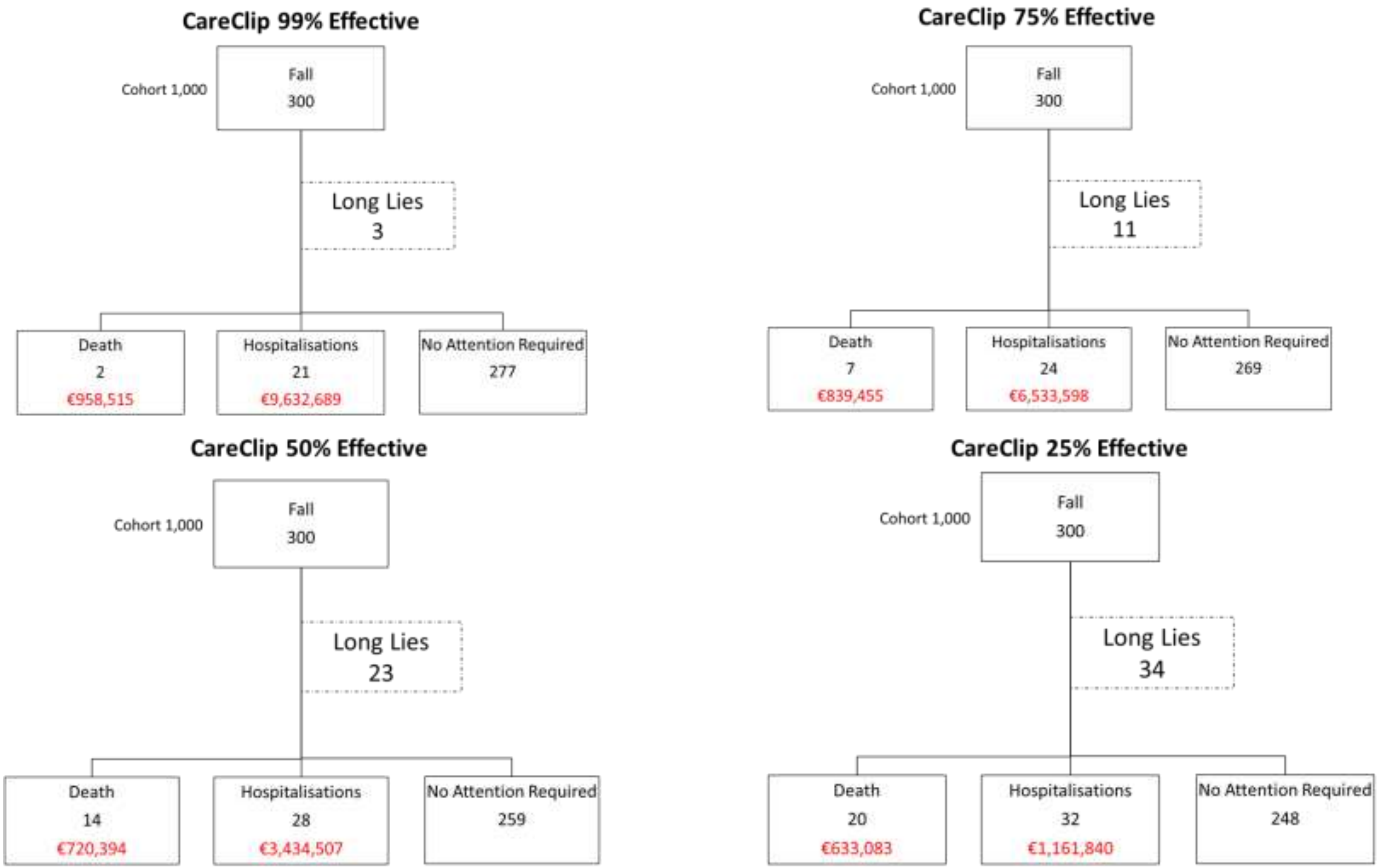


Figure 3.2 (C-F). Probability Of Occurrence Of Adverse Event From Falls In The Elderly With No CareClip Being Used.



3.3. Economic Analysis Of CareClip

3.3.1. Cost Benefit Analysis Of CareClip

The results of the models (Figures 3.2(a-f) are presented alongside the cost of the intervention in Table 13 to conduct the cost benefit analysis for the first year of implementation.

Where CareClip is not used, falls are not detected, and long lies are not avoided. The cost of these falls as estimated using economic model above are €13,809,356 for a cohort of 1000 which is €13,809 per person.

Where CareClip is employed there is a device cost as well as cost of falls. However, with fewer long lies some care is avoided. These costs are estimated for various levels of effectiveness corresponding with the economic models above.

Net benefit is estimated by comparing costs with and without CareClip. The incremental net benefit varies depending on how effective CareClip is at alerting a carer to assist a faller and thus avoid a long lie from the fall. If CareClip is 99% effective the incremental net benefit is €11,390 in year one. Even if CareClip is effective at preventing long lies 25% of the time there is still an incremental net benefit of €2,594 in year one. The cost benefit analysis demonstrates that if long lies are reduced because of CareClip, then the cost of falls declines and even when the device costs are considered CareClip has a positive net benefit compared to having no CareClip (Table 16) from the perspective of the health service.

Table 13. Cost Benefit Analysis Year 1

	Device Cost[1]	Average Cost Falls €[2]	Net Cost €[3]	Incremental Net Benefit [4]
No CareClip	-	13,809	13,809	
CareClip 25% Effective	624.25	10,591	11,215	2,594
CareClip 50% Effective	624.25	7,373	7,997	5,812
CareClip 75% Effective	624.25	4,155	4,779	9,030
CareClip 99% Effective	624.25	1,795	2,419	11,390

[1] €250 device cost + €25 per month service fee, inclusive of 13.5% VA T [2] Average cost per person estimated using total costs produced in Economic Models 1, 2A-D divided by 1,000 cohort. [3] Device costs plus fall cost. [4] Difference in net costs between No CareClip and with CareClip (under various assumptions).

3.3.2. Budget Impact Analysis of CareClip

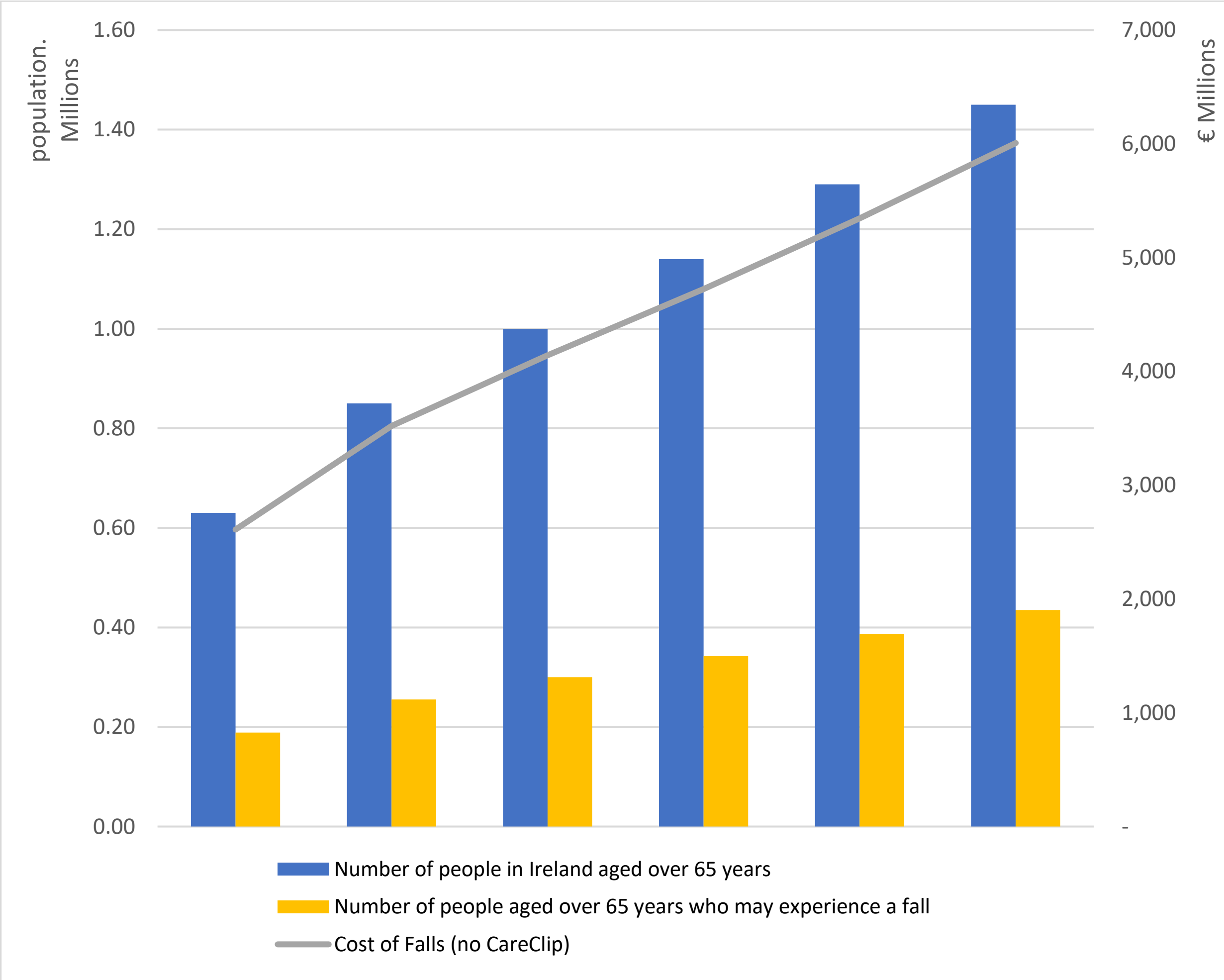
The Irish population is aging and the population over 65 is expected to grow from 0.63 million in 2016 to 1.45m in 2046 (Table 14). Research estimates suggests 30% of this population can expect to have a fall [30] (Figure 3.3). As revealed from the literature review, falls are estimated to cost €13,809 on average per person (Figure 3.2. (b)). Applying this cost estimate to expected population estimates reveals the expected cost of falls increases from €2.6b in 2016 to €6b in 2046 (Figure 3.3).

Table 14. Projections for Irelands' aging population and numbers who may have a fall.

Year	Number of people in Ireland aged over 65 years [29]. Millions.	Number of people aged over 65 years who may experience a fall. 30% [30] millions.	Cost of falls. €b.
2016	0.63	0.19	2.6
2026	0.85	0.25	3.5
2031	1	0.30	4.1
2036	1.14	0.34	4.7
2041	1.29	0.38	5.3
2046	1.45	0.43	6.0

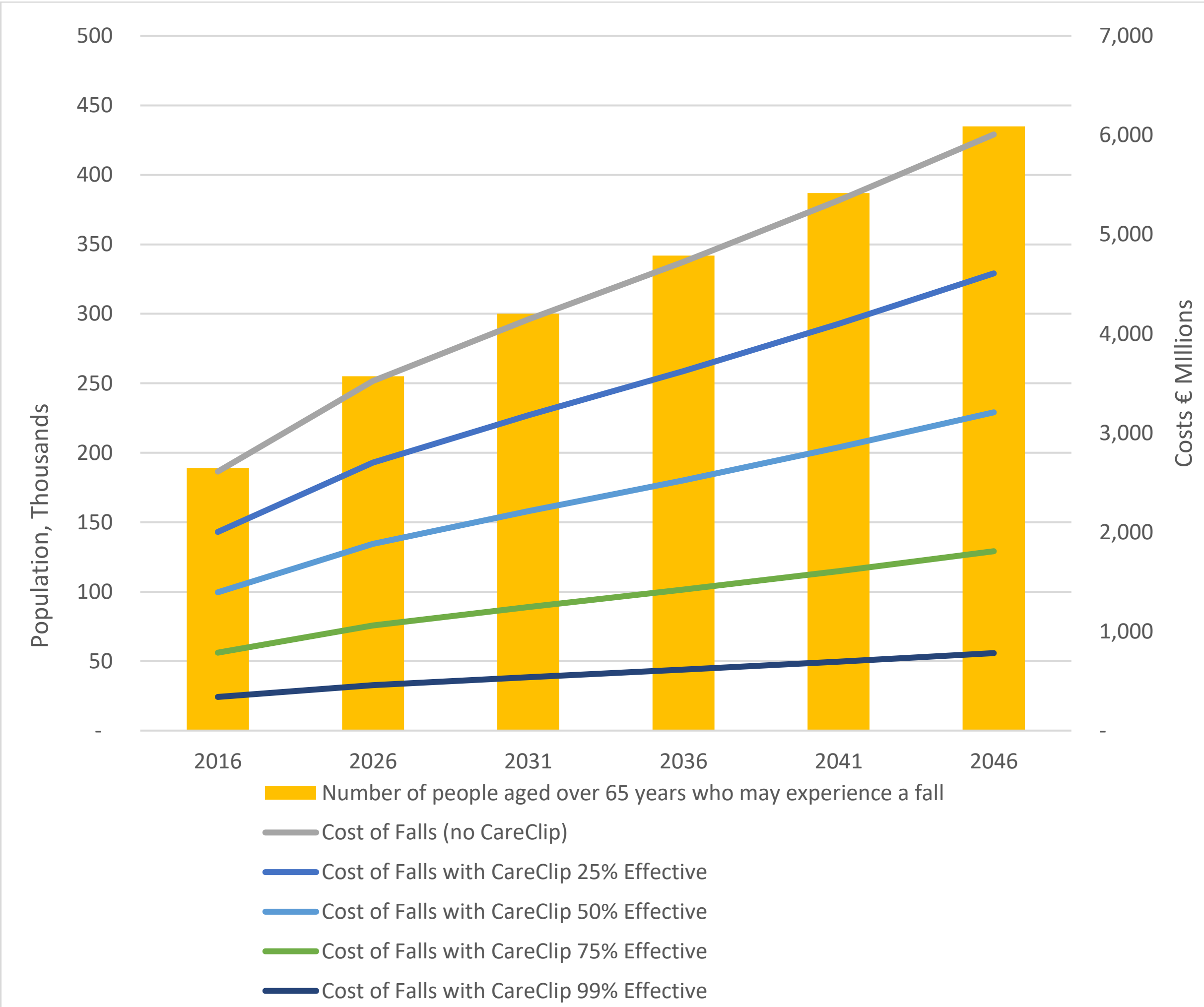
CentralStatisticsOffice.http://www.cso.ie/en/csolatestnews/pressreleases/2013pressreleases/pressreleasepopulationandlabourforceprojections2016-2046/. As accessed on 7th March 2018.

Figure 3.3. Cost of Falls.



However, if a body worn fall detection device such as CareClip was introduced to the appropriate cohort a corresponding decrease in the cost of falls can be anticipated. Figure 3.4 presents the anticipated cost of falls if CareClip is disseminated to all aged 65 at varying levels of effectiveness of CareClip (99%, 75%, 50% or 25%). Considering the population estimates for 2016, if CareClip was 99% effective in reducing long lies, the cost of falls could decrease from €2.6 billion to less than €0.33 billion. Even if CareClip was only 25% effective the cost of falls could reduce from €2.6 billion to €2 billion. This cost of falls can be extrapolated over time by applying the cost estimates (Figures 3.2(b-f)) to the predicted population estimates (Table 14 and Figure 3.3). Figure 3.4 presents this analysis.

Figure 3.4. Cost of Falls with CareClip being 25%, 50%, 75% and 99% effective (100% Roll Out**).**



Considering the health service perspective then, they may ask, is there a net benefit for CareClip to be provided to every person aged over 65 years of age in Ireland so that falls can be detected quickly and thus prevent the consequences of long lies. Table 15 demonstrates that there may be a net benefit to health care providers to do so. If the example of the year 2016 is taken, the expected population of people over 65 years of age was 0.63m of which 30% of these may have expected to experience a fall. By these estimates this means 0.19m elderly experienced a fall in 2016. The estimated cost of falls to the health care provider may be €2.6b as described previously. The cost of CareClip if provided to every person aged over 65 years of age in 2016 for a year would be €393m. This would result in a net cost of CareClip ranging from €2.3b if 25% effective at detecting falls and therefore reducing long lies in this cohort to €732m if CareClip was 99% effective at detecting falls in the over 65s in 2016. The net benefit to the health service of providing CareClip (versus not providing CareClip) to all over 65s in 2016 could then range from a net benefit of €214m if 25% effective to €1.87b if CareClip was assumed to be 99% effective. The net benefits for future years are demonstrated in Table 15 based on CSO population estimates.

Greater net benefit could be derived if CareClip was only applied to those at risk of falling. Looking from the perspective of the health service, if a person was identified through a falls risk assessment as at risk of falling, then CareClip could be provided to that person and not the elderly population at large. Table 16 displays the net benefit of providing CareClip if 50% of the elderly population were to be provided with CareClip assuming they were identified as being at risk of falling following a falls risk assessment. The net benefit to a health care system provider on that basis would increase from €411m to €2.07b depending on CareClip effectiveness.

Table 15. Cost of falls. Net cost of CareClip 100% take up and retention. Net benefit of CareClip. 2016-2046.

	Irl Pop	Pop Over 65	Cost of Falls[1]	Cost of Care Clip (100% take up and retention)[2]	Net cost CareClip[3]				Net Benefit CareClip[4]			
Year	Over 65 years (Millions)	Fall			25% Effective	50% Effective	75% Effective	99% Effective	25% Effective	50% Effective	75% Effective	99% Effective
2016	0.63	0.19	2,609.97	393.28	2,395.02	1,786.78	1,178.55	732.52	214.95	823.18	1,431.41	1,877.45
2026	0.85	0.26	3,521.39	351.85	3,052.61	2,231.98	1,411.35	809.56	468.78	1,289.41	2,110.04	2,711.83
2031	1.00	0.30	4,142.81	383.06	3,560.42	2,594.98	1,629.53	921.54	582.38	1,547.83	2,513.27	3,221.27
2036	1.14	0.34	4,722.80	427.90	4,050.09	2,949.48	1,848.87	1,041.76	672.71	1,773.32	2,873.93	3,681.04
2041	1.29	0.39	5,344.22	481.81	4,580.60	3,335.18	2,089.75	1,176.44	763.62	2,009.04	3,254.47	4,167.78
2046	1.45	0.44	6,007.07	539.13	5,146.30	3,746.40	2,346.51	1,319.92	860.77	2,260.67	3,660.56	4,687.15

[1]With no CareClip: Model 1. [2] 100% take up and retention**.** [3] Cost of falls & device cost: Models 2A-2D**.** [4] Compared with no CareClip. CareClip have a 5-year lifespan after which they need replacing. Replacement costs are considered here.

Table 16. Cost of falls. Net cost of CareClip 50% take up and retention. Net benefit of CareClip. 2016-2046.

	Irl Pop	Pop Over 65	Cost of Falls[1]	Cost of Care Clip (50% take up and retention)[2]	Net cost CareClip[3]				Net Benefit CareClip[4]			
Year	Over 65 years (Millions)	Fall			25% Effective	50% Effective	75% Effective	99% Effective	25% Effective	50% Effective	75% Effective	99% Effective
2016	0.63	0.19	2,609.97	196.64	2,198.38	1,590.15	981.91	535.88	411.59	1,019.82	1,628.05	2,074.09
2026	0.85	0.26	3,521.39	265.31	2,966.06	2,145.43	1,324.81	723.01	555.32	1,375.95	2,196.58	2,798.37
2031	1.00	0.30	4,142.81	312.13	3,489.49	2,524.04	1,558.60	850.60	653.32	1,618.77	2,584.21	3,292.20
2036	1.14	0.34	4,722.80	355.82	3,978.01	2,877.41	1,776.80	969.69	744.79	1,845.39	2,946.00	3,753.11
2041	1.29	0.39	5,344.22	402.64	4,501.44	3,256.01	2,010.59	1,097.28	842.78	2,088.21	3,333.63	4,246.94
2046	1.45	0.44	6,007.07	452.58	5,059.75	3,659.86	2,259.96	1,233.37	947.31	2,347.21	3,747.11	4,773.70

[1]With no CareClip: Model 1. [2] 50% take up and retention**.** [3] Cost of falls & device cost: Models 2A-2D**.** [4] Compared with no CareClip. CareClip have a 5-year lifespan after which they need replacing. Replacement costs are considered here.

3.4. Summary Of Economic Analysis Of CareClip

In this section various economic analyses were conducted and examined from the perspective of the health service. Employing data from the literature review and assumptions, models were developed to estimate the cost of falls in the elderly. This data was extrapolated out to consider future years demonstrating that the health service can expect this economic cost to increase in future years as the population ages. Using 2016 as an example, these estimates show that €2.6b may have been spent from the national health care budget on the clinical impact of falls in the elderly if no action is taken. This may increase to €6b in 2046 due to the aging population. This section of the analysis examined if CareClip, by detecting a fall early and reducing long lies, may be able to lessen the economic burden on the already stretched health service. A cost benefit analysis demonstrated that there was a net benefit to providing CareClip. This was the case even if the CareClip was effective in bringing quick assistance to only 25% of the elderly fallers. The net benefit increased if CareClip was more effective at bringing quick assistance and reducing the length of time a person lies on the floor after a fall, thus reducing further clinical complications.

A further analysis using 2016 figures demonstrated that the cost of falls in the elderly in 2016 may have cost the State €2.6b. If CareClip was provided to every elderly person in the country that would have cost the State €393m but the resultant net benefit to the health service when the cost of falls are considered could range from €214m to €1.8b depending on how effective CareClip was. Finally, a further exercise in coordinating CareClip provision with an existing falls risk assessment programme could see further net benefits to the State. Using the same 2016 figures and assuming the population that CareClip is provided to 50% of the elderly population (those identified as at risk of falling) the cost of providing CareClip would decrease to €196m and the net benefit to the health service may increase to €411m and €2.07b, when cost of falls are considered. This may result in savings in time and money to the health care system to free up these resources for utilisation elsewhere.

4. Recommendations For Future Research

In response to aging populations a broad range of fall detection interventions are emerging. Several types of technology-based interventions have been developed. While evidence on their clinical effectiveness is beginning to emerge their cost effectiveness is yet to be demonstrated in the literature. While cost effectiveness analyses have been performed for other fall detection strategies (See Appendix ii), as the literature review concludes in Section 1 there is a dearth of evidence on the cost effectiveness of technology-based interventions to detect falls.

Using secondary estimates from the literature efforts were made in Section 3 to estimate the potential cost effectiveness and budget impact of detecting falls earlier to examine the cost effectiveness of CareClip an economic evaluation is warranted.

However, these analyses are subject to a number of limitations.

- No primary data on the effectiveness of CareClip was available so several assumptions had to be made.
- In the absence of primary data on resource utilisation estimates from the literature had to be relied upon.
- There are multiple potential benefits of CareClip, in the absence of primary data one benefit was chosen to measure effectiveness in this analysis – the prevention of long lies.
- Health care resources were valued using historical estimates sourced from the literature. These may not reflect current costs but are best available at this time.
- The choice of comparator (no detection device) may not be an accurate reflection of usual care. We acknowledge for example the "Senior Alert Scheme" is currently available but no effectiveness data were available on this to incorporate into the evaluation.
- The perspective adopted for the analysis was that of the health service provider. However, only direct health care costs were included. We acknowledge there are wider cost implications of falls too which should be incorporated. And often schemes lie this are funded from other public funds eg local government.
- Single estimates from the Central Statistics Office and the literature were employed.

- One-way sensitivity analyses are included to examine the impact of the assumptions surrounding CareClip's effectiveness. A probabilistic sensitivity analysis was not concluded. This could facilitate an examination of joint parameter and decision uncertainty.
- Cost Benefit Analyses are a useful and valid time of economic evaluation. However, they measure health benefits in monetary terms, not in terms of quality of life as advocated in national and international guidelines.

It is recommended that a full economic evaluation is conducted that incorporates:

- primary data on effectiveness of CareClip;
- all relevant resources used, valued using recent prices;
- accurate comparator for example, the Senior Alerts Scheme;
- a broader perspective that goes beyond direct health care costs;
- measures health in terms of quality of life such as Quality Adjusted Life Years, as recommended by HIQA
- appropriate consideration of uncertainty through a probabilistic sensitivity analysis.

To conduct such a study, data on health resource utilisation, events (such as falls and injuries from falls) and quality of life (to measure health benefit, including decrements for adverse events) is required from a baseline time point and beyond for a suitable sample of participants. Furthermore, follow-up data would be required on these variables for a meaningful timeframe that is conducive to detecting events. Using decision analytical modelling techniques and epidemiological data, this follow-up data could be extrapolated to end of life/admission to long-term care etc. The data required for this analysis could be collected in a variety of ways including, randomized control trial, observational study, registries etc. Previous registries are in existence and have been described in the literature for example the FARSEEING real world depository [25].

Once the costs of the intervention and comparator and health benefits of each are available a full cost effectiveness analysis can be performed. The incremental costs could then be compared to the incremental benefits and Incremental Cost Effectiveness Ratio (ICER) could be estimated, as per national and international guidelines, which would be compared to a cost effectiveness threshold to determine if the intervention is cost effective, i.e. if it offers value for money. Furthermore, based on previous arrangements it is likely that some type of cost sharing scheme would be utilised, so costs are shared between public payer and person with the device. This could also be incorporated into future economic evaluations.

5. Conclusions

CareClip is a body worn fall detection device that may assist in preventing the health consequences of lying on the floor for a long period of time prior to getting assistance. The clinical benefit of using these types of devices are beginning to emerge in the literature. However, there is little evidence regarding cost effectiveness of these type of devices. Results of a literature review informed of the cost of these health consequences, and alongside population estimates they were used in the cost benefit analysis and budget impact analysis. These calculations were used to estimate the numbers of people and cost of the different health consequences that can result from remaining on the ground for a long time after a fall. There are limitations with this analysis however, as no probabilistic sensitivity analysis was conducted. There was limited meta-analysis used point estimates and secondary data and no primary data were employed.

Despite the dearth of economic analysis evidence and employing the estimates from the literature review, a preliminary cost benefit analysis and sensitivity analysis was conducted. The results demonstrated that there was a net incremental benefit to the health care systems if CareClip were to be used in this cohort of the population. Taking 2016 as a base year, if all people aged over 65 was provided with CareClip it may result in a net benefit, (ranging from €214m if 25% effective to €1.87b if 99% effective) in comparison to not providing CareClip to this cohort of the population. Net benefit was demonstrated also in the same scenario but where CareClip would be given to 50% and not 100% of the over 65 population (assuming they had been identified as at risk of falling). In this instance the net benefit to the health care system could range from €411m to €2.074b.

Results suggest a fall detection device such as CareClip could bring savings to the health care system and prevent a worsening of falls for the individual holder. By automatically notifying a nominated carer that the holder has fallen and allowing them to come to their assistance quickly, this may prevent the holder from lying on the floor for a long time after the fall. The effect of which may prevent the holder from experiencing further health consequences of their fall. From a health care systems perspective, the economic benefit of not having that pressure in the system could be worth the investment in the device, particularly if it was managed in tandem with existing fall prevention measure so those most at risk of falling will be identified and provided with the device.

Appendices

Appendix A1

Data Extraction Table. Cost of falls in the elderly.

Appendix A1. Full Text Read Extraction Table - Study Details, and Outcome.

Study	Intervention	Setting/ Country	Condition(s) or population targeted	The type of study	Outcome
Iglesias,C.P. et al (2009). [3]	primary data collected to estimate falls and fractures cost	United Kingdom	Participants of the Calcium and vitamin D study who had consented to being contacted for future research. Women 70 or over with one or more risk factors for hip fracture.	Returned Questionnaire from population was assessed for costings provided by NHS reference costs and the Chartered Institute of Public Finance and Accountancy database and from the Personal and Social Services Research Unit at the university of Canterbury. Two other studies the Hip protector study and the Epidemiological risk factor study were assessed to estimate fractures and QoL results.	Cost of fall was £1088 or €1493

Davis JC (2010). [4]	To determine the economic burden of falls in different countries	9 studies from US, 2 Austrailia, 4 Europe, 2 UK	Elderly living in the community	Systematic literature review. Constrained by variation of terms and data. All information was converted to USDollars	Ranged from US$3476 per faller to $10749 per injurious fall and US$26483 per fall requiring hospitalisation
Tian, Y et al (2013) [5]	Exploration of system wide costs of falls in older people	Torbay UK	421 Elderly patients aged 65 and over from Torbays linked health and social care data set called the Mede system. Who were admitted as an emergency admission with falls. Between July and December 2010.	Using the mede system which is linking both health and social care data the patients were followed for costs in each service 12-month s prior to fall and 12 months post fall. They were further categorised into survivors and non-survivors.	For the 421 patients £5million was spent on both the care associated with the fall itself and in the year following the fall. This is 1% of torbays over 65 population but accounted for 4% of the whole annual inpatient spending and 4% of the whole local adult social care budget.
Sartini et al (2009) [6]	Epidemiological study to assess cost of injurious falls	Italy	In one trimester period, 227 subjects >75 years of age were admitted to the emergency room (ER) because of a domestic injury from June through October 2006. Seventy-four (32.6%) of the 227 subjects were hospitalized and their data were examined.	The statistical analysis was done using non-parametric chi-square test to evaluate the difference between the two groups by the Kaplan Meier method for the survival analysis and by COX proportional hazard model to assess the role of possible confounders	Analysis of DRG of the hospital discharge schedules showed an average cost of E5479.09 for fall-related hospitalization

Hartholt et al (2012) [7]	An incidence-based cost model was used to assess cost per case spent on fall related injuries in patients 65 years or older	The Netherlands	Patients 65 years of age or older presenting to an emergency dept. of a participating (Dutch injury surveillance system) due to an unintended fall between Jan12007 and Dec 312009.	Using a previously developed Dutch Burden of injury Model which used the patient numbers described previously and health care consumption and cost related to incident were calculated.	The total health care expenses including medical treatment hospitalisation and long-term care cost of fall per inhabitant aged 65 years or older was estimated €281. The burden increased with age and gender.
Hekoten, L (2009) [8]	A cost effectiveness of implementing a fall prevention programme	Norway	Females greater or equal to 80 years of age.	The study aimed to assess the established cost of falling and compared the cost effectiveness of implementing a fall prevention programme. Existing cost of falls were established thorough a literature search to quantify cost and describe the content and delivery of effective programmes. Various assumptions were made. Unit cost were obtained from the Norwegian labour and welfare administration statistics Norway and the Norwegian medical association.	Average health care cost per fall was Nok 11254.

Cotter, P.E. (2006) [9]	Quantified the yearly cost of fall related admissions and readmissions to an acute hospital and its affiliated rehabilitation services.	Acute orthopaedic ad geriatric services in a university teaching hospital. Ireland	A review of hospital case notes of inpatients and the inpatient enquiry system (HIPE) and admission through emergency departments of all patients over 65 with a discharge code of fall or trauma were screened with non-falls being excluded.	The number of inpatient bed days were calculated most admissions had sustained a fracture, so the average bed day cost used was that of an orthopaedic speciality bed, including hotel costs and average medical nursing and therapist time (hospital finance department). Similarly, for the geriatric and orthopaedic hospitals were determined. Any readmissions within one year following discharge due to a fall or complication were cost analysed. Also, a detailed cost analysis of a typical hip fracture was performed.	810 fall related admission. mean age 79 years females 79% 80% had a fracture of which 49% were femoral neck. Total no. of acute hospital bed days was 8771 of which 26 were intensive care beds. Mean length of stay was 10.8days rising to 15.3 days mean for hip fracture. Cost of acute hospital bed €7.46 million (850per acute bed day). 6220 rehabilitation bed days were used at a cost of €2.9m Readmission was 10% at one year. 60% of these were directly attributed to the fall. 480 acute and 170 rehab beds occupied €400k and €80k cost the total of one year of fall related admissions to an acute hospital was €10.8m Hip fracture admission averaged from €14339 from five random cases therefore the total cost for older patients with hip fracture would expect to be €4.65m

Gannon, B (2008) [10]	Quantify all resource costs for falls and fractures in older people in Ireland. Beyond hospitalisation and both direct and indirect costs.	Cost analysis from a variety of sources to analyse both direct and indirect costs of falls and fractures in Ireland.	Older people in Ireland admitted to hospitals for fracture or injuries attributed to falls	Using a variety of sources for data such as European statistics [22] of number who fall. Hipe data for admissions [23] Number of A&E visits from an Australian study [24] Hipe data for discharge Hospital costs from HSE and Casemix data Pharmaceutical costs from the centre of Pharmacoeconomic UK data for non-fractures falls [25] Care costs from O'Shea and O'Reilly [26]	6813 people admitted to hospital for al fractures in 2004 85% resulting from falls. Colles fracture stayed 4.1 days hip fracture stayed 17.1 days other injuries due to falls 8.3 days 1472 over 65 were admitted with other injuries. Direct and indirect costs to fractures were €225m total inpatient cost€58m hip fractures being two thirds of cost. Total cost of long stay with fractures €88m the total cost of informal care with fractures €16m Quality of life with fractures cost €54m. total cost for fractures €225m Total falls is €19m Mortality costs €135m. Annual drug costs of €25m. Combination of all costs of falls and fractures is €404m = 4.2%of public health expenditure in 2004.

Carey, D. (2005) [11]	To quantify the main reasons for hospitalisations due to falls in older people and to describe the outcomes of the injury and to estimate the hospital costs of both hip fracture and intracranial injury.	Acute hospital in Eastern Region of Ireland	Older people aged 65 years upwards. That were admitted as emergency inpatient for injuries sustained after a fall. Patients were residents of the Eastern region of Ireland who were treated in acute public HIPE reporting hospitals in Ireland	Hospital discharges during 2002 of patients described previously. Variables examined were gender, age, area of residence, type of admissions, source of admission, all recorded diagnoses, principal procedure, length of stay, destination on discharge. Chi square test were applied to categorical data and t test to continuous data. Linear regression was used for time trend analysis. All were two tailed and a p value less than 0.05was statistical significance level.	14521 hospitalisations due to injury and 2309 (15.9%) were over 65 years. Unintentional injury due to a fall was 1760(76%). The proportion of hospitalisations due to injury in older people ranged from 15.2% in 1994 to 16.6% in 2000. And the proportion of injuries caused by a fall ranged from 73.7% in 2000 to 80.8% in 1998. Of the 1769 hospitalisations, 1364 (78%) were female and 1189 (68%)were aged 75 years or older .184 =65-69,366=85 upwards. This pattern not seen in males. Fractures wre the main diagnosis in 1448 (82) 87% of females had a fracture compared to 67% of males. Limb fractures related to hip more females (41%) than males (31%)Head injuries 23% male ad 9% female. Nursing home residents =6.5% of hospitalisations and 11% of hip

					fractures. The costliest hip fracture was €8659 and head injury were €3750.
Schuffham, P. et al (2003) [12]	Background on epidemiology resource use and cost implications of falls in the older UK population. Estimates costs of different types of falls and by age group.	A&E deps or admittance to hospital in the United Kingdom using Home accident surveillance system (HASS)and Leisure accident surveillance system(LASS) and Hospital episode statistics (HES). 199.	Patients aged 60 years or older in groups 60-64,65-69, 70-74, and >75.	Analysis of the databases to determine the following HASS/LASS: estimates in proportions of patients who incurred additional resources. Patients admitted to hospital after an unintentional home or leisure injury and outcomes data. A&E admissions scaled up to reflect UK population HES for number of admissions to hospital for fall related injuries in England and wales Demographic and admission data. All data were grouped into the appropriate age grouping. And age group specific rate of falls per 10000 population were also calculated.	647721 A&E attendances 204424 admissions to hospital for fall related injuries in people aged 60 and over. For the age groups A&E attendance per 10000 population were 273.5, 287.3,367.9 and 945.3. Hospital admission rates per 10000 population were 34.5, 52.0, 91.9 368.6 for the different age groups. £300000 was the cost per 10000 in the 60-64 group and £1500000 in the 75plus group. Falls cost £981m 59.2% incurred by NHS. mainly to falls in over 75as they were admitted in 49.4% of the cases also long-term care cost accounted for 41% in this age group.

Appendix A2

Appendix A2. Full Text Read Extraction Table – Study Details, Analysis, Outcomes and impact.

Study	Intervention	Setting/Country	Condition or population targeted	The type of study	Outcome	Impact of long lie
Bloch (2012) [14]	A systematic review and meta-analysis of early mortality related to inability to rise after a fall was conducted in elderly adults.	global	Meta-analysis	A computer search strategy on MEDLINE using the Medical Subject Headings accidental falls and aged 80 and over identified 3,401 articles published from 1981 to 2011; 3,333 were excluded, leaving 68 articles concerning prospective studies about consequences and prognosis after falls in elderly adults, to which two references from a manual search were added to obtain	The current study shows that lying on the floor for a long period after a fall nearly doubles the risk of death. Even a seemingly minor fall can be fatal if the person stays lying on the ground for a long time because of pressure ulcers, dehydration, hypothermia,	Lying of floor for a long period of time nearly doubles the risk of death. A minor fall can be fatal if on floor for a long time due to pressure ulcers dehydration hypothermia rhabdomyolysis or renal failure.

				70 studies. Selecting studies with numerical data on mortality in groups lying or not lying on the ground for extended periods of time, four studies were included.3,6–8 A meta-analysis was performed, and the odds ratios (ORs) and 95% CIs to assess mortality related to inability to rise after a fall were estimated for each study and overall. The Mantel– Haenszel fixed-effects method was used.9 Heterogeneity was assessed using the I^2 statistic.10	rhabdomyolysis, or renal failure, all these disorders being likely to compromise survival This meta-analysis can help to define the association between early mortality and inability to rise after a fall, but multivariate analyses could have helped to estimate the real degree of connection.	
Fleming, J (2008) [15]	A prospective study of falls. Quantifying lying on floor for a long time and extent of alarm use	United Kingdom	Over 90-year olds who had enrolled in Cambridge City over-75s Cohort (CC75C)	90 women and 20 men were followed up in a prospective study of falls for one year or until death if sooner. Details of each fall were gathered. Data included whether the individual who fell had been able to get up without help,	Fifteen per cent (n=40) of all reported falls in different settings resulted in the person lying on the floor for an hour or more. The length of time on the floor was	15% resulted in lying of floor for an hour or more 6% unknown length of time. Length of time on floor depended on help at hand and ability to get up.

				how long they were on the floor, any injuries, and whether they called for assistance.	unknown for a further 6%. those who were on the floor for at least an hour (n=20) on at least one occasion during the follow-up year, and the prevalence of injury, admission to hospital, and admission to long term care. Injuries can be both a cause and a result of lying on the floor for a long time. 141 falls, 38 resulted in lying on the floor for over an hour, despite an installed alarm system, and in 97% of these "long lies" (37/38) the person who fell alone did not	More falls led to longer times on floor. Severe cognitive impairment was highly significantly associated with lying on floor for a long time. Living alone quadrupled the odds of lying on floor for a long time 60% had a fall related hospital admission during the follow up year. 36% moved into long term care within a year of interview and 53 % by study end. A threefold increase of admission to care home. Use of call alarm: 70% had use 80% did not use call alarm

					use their alarm to summon help. Barriers to using alarms arose at several crucial stages: not seeing any advantage in having such a system, not developing the habit of wearing the pendant even if the system was installed, and, in the event of a fall, not activating the alarm— either as a conscious decision or as a failed attempt.	97% of long lies did not use alarm
Gurley, R.J., (1996) [16]	To determine how often elderly people are found helpless or dead in their homes and to assess the demographic characteristics of such patients	United States	People who were found helpless or dead over a 12-week period in US.	a population-based study of patients who were found in their homes either helpless or dead. Over 12 weeks, paramedics employed by the city of San Francisco identified 387 such events involving 367 persons.	The median age of the persons found helpless or dead was 73 years; The highest rate was among men 85 years and older who were living alone. In 23	Longer time spent helpless was associated with being found dead or being transported to hospital being admitted and being discharged to other care rather than independent living.

	and the outcomes of those found alive but incapacitated.			We obtained information on these patients from the emergency-medical-services department or the hospitals to which they were taken and determined their outcomes.	percent of the cases, the person was found dead; an additional 5 percent died in the hospital. Thus, total mortality was 28 percent. Of the patients found alive, 62 percent were admitted to the hospital. The average hospital stay was eight days, and 52 percent of those admitted required intensive care. Of the survivors, 62 percent were unable to return to living independently.	Males were significantly associated with being helpless for 12 hours or more but race age or ethnic group or insurance status were not significantly associated with length of time spent incapacitated. Number f deaths for those immobilised for more than 72 hours = 62% dead, 5% died in hospital = 67%. Those found lying for less than one hour =12%.
Ryananen (2012) [13]	Zeitschrift fur Gerontologie [01 Jul 1992, 25(4):278-282]				Twelve percent of men and 19% of women aged 65 years and over who sought	Consequence of fall followed by long lie related independently to high body temperature, low

					medical attention after a fall, lie where they fell for 15 min or more after falling. The occurrence of a fall with a long period of lying helpless was associated in bivariate analyses with severe injury, an intrinsic or unknown mechanism of falling, falling indoors, poor functional capacity, use of walking aids, body temperature 37.5 degrees C or over, and serum potassium concentration under 3.5 mmol/l. A log-linear model showed that a	serum potassium concentration, and severe injury.

					fall with a lie of this kind was related independently to high body temperature, low serum potassium concentration, and severe injury. The occurrence of such a fall due to an extrinsic mechanism was related to poor functional capacity, but no similar relationship could be found when the fall was due to an intrinsic or unknown mechanism.	
Tinetti M (1993) [17]	To identify the predictors and prognosis associated with inability to get up after falling.	United States	1103 New Haven, Conn, residents aged 72 years and older who were able to follow simple	self-reported inability to get up without help after falls not resulting in serious injury; activity restriction and hospitalization after a fall; death; and	Inability to get up without help was reported after 220 of 596 noninjurious falls. Of 313 noninjured	

			commands and walk unassisted.	placement in a nursing home.	fallers, 148 (47%) reported inability get up after at least one fall. Compared with nonfallers, the risk factors independently associated with inability to get up included the following: an age of at least 80 years (adjusted relative risk [RR], 1.6; 95% confidence interval [Cl], 1.2 to 2.1); depression (RR, 1.5; Cl, 1.1 to 2.0); and poor balance and gait (RR, 2.0; Cl, 1.5 to 2.7).	

Appendix A3

Appendix A3. Full Text Read Extraction Table - Study Details, Analysis and Outcome

Study	Intervention	Design (number of studies)	Condition or population targeted	Type of study	Outcome Measurement and results	Outcome
Mohler,M.J. (2016) [18]	Using wearables to assess if there measures (gait, balance and physical activity) could be a predictor of falls.	The Arizona frailty cohort study. An observational descriptive study of individuals 65 years or older in Tucson Arizona. Primary secondary and teritary health care settings community providers assisted living facilities retirement homes and aging service organisations.	Adults over 65 years in community dwelling. Stratified by frailty status (without cognitive deficit, severe movement disorders or recent stroke). Frailty was assessed using five components specified in the Fried Frailty phenotype criteria. Prospective falls incidence was recorded Sensor derived balance gait and pa parameters using a validated wearable	Frailty Criteria – in-home and sensor-based gait, balance and spontaneous daily physical activity, were measured using wearable devices for over 6months, for falls.	Participant characteristics frailty assessment, prospective falls ascertainment, sensor derived balance gait and physical activity parameters and statistical analysis. 128 participants with 9 drop outs. Age increased across frailty categories but was not significantly different by faller status. Fallers in the pre-frail group were significantly more likely to have reported a fall in the previous 6 months compared to non- fallers but this was	Sensor derived parameters such as balance (balance deficit) and physical activity (longer typical walking episodes and shorter typical standing episodes) may be useful fall risk predictors in populations with indicators of frailty. Performance based tests are insensitive predictors of future falls in particular in frail

			technology of five small inertial sensors (tri-axial acccelerometers and gyroscope) attached to shins above ankles thighs and lower back. Balance test were carried out including sway of hips ankle and center of mass. PA included posture durations postural transitions and locomotion outcomes using sensor.		not significant. they were significantly more likely to use an assistive device compared to non-fallers but not significant in the non-frail or frail groups difference may be seen with using a walker or cane. The TUG test did not discriminate between fallers and non-fallers.	and pre-frail older adults. Among frail and pre-frail older adults balance and pa parameters are predictive of fall risk but gait parameters are not. Sensor based measures such as com sway mean waling bout duration and mean standing bout duration could enhance the accuracy of a fall risk assessment in frail elders.
Nyan M.N. (2008) [19]	By determining if a fall can be predicted a wearable was used which would deploy an airbag to soften the fall.	A sensor wearable was used in healthy volunteers to ascertain if a fall could be detected prior to falling and how soon it could be detected.	21 Healthy young volunteers.		Measurement of activities of daily living and of falling by using senor wearables.	The use of this sensor device could detect a fall with a lead time of 700 ms before the impact occurred with no false

						alarms. in this time an airbag could be deployed to break the fall and reduce injuries of the wearer.
Ejupi, A. (2017) [20]	A wavelet-based algorithm to detect and assess sit to stand movement using a pendant style inertial monitoring device.	Two studies: 1.Freeliving study – 30 min daily activities while wearing pendant in home environment 2. laboratory study follow a standardised protocol while wearing the pendant.	119 community dwelling older people living in Sydney Australia		Detection of sit to stand candidates Accuracy of sit to stand detection algorithm Sit to stand performance measurements Statistical analysis	The wavelet-based algorithm accurately detected sit to stand movements during activities of daily living in older people and discriminated significantly between fallers and non-fallers. This algorithm and wearable pendant may be used to capture sit to stand movement in home settings to assess fall risk and to monitor the

						success of exercise-based fall prevention interventions.
Lee, C. (2016) [21]	Comparing data collected from wearable sensor technology with a collection of clinical tests to assess whether data from wearables can be used as an effective metric to categorize falling behaviour	Patients were assessed for clinical fall prevention tests and allowed to wear sensor devices.	Elderly community in Taiwan	Prospective study	Clinical test assessments and wearable accelerometers	Wearables can be an effective metric of falling behaviour in community dwelling elderly and are a low cost and ordinary method of prevention.

Appendix A4.
Data Extraction Table. Cost effectiveness of fall detection/prevention systems.

Appendix A4i. Full Text Read Extraction Table - Study Details, Analysis and Results

Author Year	Intervention	Design (number of studies)	Condition(s) or population targeted	The type of economic evaluation	Outcome Measurement
Rantz [26]	A nonwearable sensor system which detect changes in health or functional status and sends signals to health care providers	A prospective randomized intervention study.	Elderly in assisted living community. N =171 Randomly assigned to intervention (n-86) or control group (n=85).	- Effectiveness analysis. -Cost comparison.	Functional status of older people – respiration pulse restlessness in sleep. Gait sensor. Detect potential changes in health or functional status Falls

Analysis Details

Study	(1) Setting-country or jurisdiction (2) Perspective (3) Time Horizon	(4) Included costs (cost type, cost categories) and resource items	(5) Data source costs and resource use	(6) Data source outcomes and benefits	(7) Methods of measuring or valuing outcomes and benefits	(8) Discounting (rate and reference year)	(9) Currency and currency conversions	(10) Analysis of sensitivity and uncertainty

Rantz [26]	1.United States 2.Health Care Provider 3.2.5years	Falls Fractures ER visits Hospitalizations Rehabilitation days Mental health facility days Number not returning to AL community Hospitalization And average length of stay in emergency room.	Primary data from sites valued using Kaiser State Health Facts (medicare files were not sourced)	12-item short form Health Survey Geriatric depression scale Mini Mental State Examination Activities of Daily living Gait speed Gaitrite Step length left and right Stride length left and right Hand grips. Tracking of falls, ER visits, hospitalizations nursing home stays and physician visits.	General linear models tested fixed effects. The independent.	Not considered	$US	Not considered.

Result Details

Study	Costs and resource use	Outcomes and benefits	ICER
Rantz [26]	No significant differences in costs of health care utilisation were measured for any carriable reported (cost of intervention was not considered, nor were absolute costs reported).	Walking speed in seconds: control walking speed increased by 0.8 sec intervention group by 0.04 sec indicating a more rapid decline for the control group than the intervention group. Velocity decline was statistically significant for both groups. Stride length right and left for both groups declined over time with the control group being more pronounced. Other outcomes no significant differences of group comparisons were measured. There were more falls in the control arm that the intervention, but difference was not statistically significant.	Not calculated. Study concludes intervention is cost effective but no formal cost effectiveness analysis/economic evaluation performed.

Appendix A4ii Full Text Read Extraction Table - Study Details, Analysis and Results

Author Year	Intervention	Design (number of studies)	Condition(s) or population targeted	The type of economic evaluation	Outcome Measurement
Farag [27]	A public health falls prevention programme. A range of intervention strategies including individual prescription of exercises, group base community exercise programme (Tai-Chi or Otago) and multi factorial interventions which incorporate a process of assessment and referral to appropriate intervention	A Markov model was designed of five health states	Individuals aged 65 with no prior history of falls and living independently in the community	Cost effectiveness of implementation of a fall preventative programme compared to the programme not been implemented.	A fall, A fall requiring treatment, hospital admission, emergency department consultation, non-hospital treatment transfer to a high care residential aged care facility.

	strategies.				
Smith [28]	Falls prevention programme for the elderly – primary prevention	A decision analytic model (Markov Model)	Elderly people aged over 75 living independently in the community	Cost effectiveness analysis	Fall rate injury rate after a fall type of injury and the treatment for injured elderly

Analysis Details

Study	(1) Setting-country or jurisdiction (2) Perspective (3) Time Horizon	(4) Included costs (cost type, cost categories) and resource items	(5) Data source costs and resource use	(6) Data source outcomes and benefits	(7) Methods of measuring or valuing outcomes and benefits	(8) Discounting (rate and reference year)	(9) Currency and currency conversions	(10) Analysis of sensitivity and uncertainty
Farag [27]	(1) Australia (2) Health funder (3)	Health service use Hospital admission Emergency department consultation Allied health treatment	Watson et al 2010. [6] Church et al 2012. [7]	Literature NWS health report Australian Bureau of statistics	Base case scenario was $as28932 per QALY. Gains driven by avoidance of decrements of quality of life. Estimates of programme effectiveness	None stated	Australian Dollars	A 1 way and 2 Way sensitivity analysis for programme effectiveness and cost indicated that by increasing cost of programme a lower risk ratio is required.

		Annual cost of residential care admission. Age specific costs Fall prevention programme costs			were used to adjust the probability of falling where a programmes is offered compared to no programme condition.			
Smith [28]	1.Australia data where possible 3.One-year time horizon	Assessment cost costs related to the precision of aids nursing home cost rehabilitation costs home help costs and costs of the ambulance service	Based on primary studies Englander ,F 1996 [8] Smith, R (1998) and expert opinion.	Previously published studies and estimates based on expert opinion	Increment all saving per fall prevented was $AS1720.8 and $17208 per injury prevented	Discounting for the ten-year analysis was at 5%. Reference year 1996	$AS	Discounting at 0 and 10% in sensitivity analysis

Results section.

Study	Costs and resource use	Outcomes and benefits	ICER
Farag [27]	Health service use Hospital admission Emergency department consultation Allied health treatment Annual cost of residential care admission	Number of falls prevented. Estimated benefits not explicitly given. Falls prevention programme was more expensive however it was also more effective than not participating in the programme.	ICER cost effective at $AS 50000 per QALY gained A threshold of $As50k per qaly gained there is a 57% probability that the programme will be cost effective.
Smith [28]	Cost of assessment and of providing aids $As 70 and $As120 Nursing home $As 70.71/day Rehab costs $As7454 Home help $As69.96 Ambulance service $As 247/service	Number of falls prevented, and number of injuries prevented. Cost per fall prevented =$As1720.8 Incremental cost per injury prevented $As17,208. A ten-year time horizon the incremental saving per fall $A915.71 and injury $As9157.09. substantially less over one year.	

Appendix A5. Economic models per cohort of 1000 elderly.

Table 17. Economic Model 1 – No CareClip (Cohort 1000 people)

	Falls	No Long Lie	Long Lie	No Medical Attention Req	Hospitalisations	Death	Total Cost
Cohort	300	255	45	238	36	27	
Costs					€12,731,780	€1,077,576	€13,809,356

Table 18. Economic Model 2A –CareClip (Cohort 1000 fallers) 99% Effective Detecting Fallers

	Falls	No Long Lie	Long Lie	No Medical Attention Req	Hospitalisations	Death	Total Cost
Cohort	300	297	3	277	21	2	
Costs					€ 1,161,840.02	€633,083	€1,794,923

Table 19. Economic Model 2B –CareClip (Cohort 1000 fallers) 75% Effective Detecting Fallers

	Falls	No Long Lie	Long Lie	No Medical Attention Req	Hospitalisations	Death	Total Cost
Cohort	300	289	11	269	24	7	
Costs					€ 3,434,507	€720,394	€4,154,901

Table 20. Economic Model 2C –CareClip (Cohort 1000 fallers) 50% Effective Detecting Fallers

	Falls	No Long Lie	Long Lie	No Medical Attention Req	Hospitalisations	Death	Total Cost
Cohort	300	278	23	259	28	14	
Costs					€6,533,598	€839,455	€7,373,052

Table 21. Economic Model 2D –CareClip (Cohort 1000 fallers) 25% Effective Detecting Fallers

	Falls	No Long Lie	Long Lie	No Medical Attention Req	Hospitalisations	Death	Total Cost
Cohort	300	266	34	248	32	20	
Costs					€9,632,689	€ 958,515	€10,591,204

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