

RESEARCH PAPER

A modelling-based economic evaluation of primary-care-based fall-risk screening followed by fall-prevention intervention: a cohort-based Markov model stratified by older age groups

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Abstract

Background: fall-risk assessment with fall-prevention intervention referral for at-risk groups to avoid falls could be cost-effective from a care-payer perspective.

Aims: to model the cost-effectiveness of a fall-risk assessment (QTUG compared to TUG) with referral to one of four fall-prevention interventions (Otago, FaME, Tai Chi, home safety assessment and modification) compared to no care pathway, when the decision to screen is based on older age in a primary care setting for community-dwelling people.

Methods: a cohort-based, decision analytic Markov model was stratified by five age groupings (65–70, 70–75, 65–89, 70–89 and 75–89) to estimate cost per quality-adjusted life years (QALYs). Costs included fall-risk assessment, fall-prevention intervention and downstream resource use (e.g. inpatient and care home admission). Uncertainty was explored using univariate, bivariate and probabilistic sensitivity analyses.

Results: screening with QTUG dominates (>QALYs; <costs) screening with TUG irrespective of subsequent fall-prevention intervention. The QTUG-based care pathways relative to no care pathway have a high probability of cost-effectiveness in those aged 75–89 (>85%), relative to those aged 70–74 (~10 < 30%) or 65–69 (<10%). In the older age group, only a 10% referral uptake is required for the QTUG with FaME or Otago modelled care pathways to remain cost-effective.

Conclusion: the highest probability of cost-effectiveness observed was a care pathway incorporating QTUG with FaME in those aged 75–89. Although the model does not fully represent current NICE Falls guidance, decision makers should still give careful consideration to implementing the aforementioned care pathway due to the modelled high probability of cost-effectiveness.

Keywords: cost-effectiveness, falls, economic model, fall-risk screening, fall-prevention intervention, older people

Key points

- A care pathway including fall-risk assessment followed by fall-prevention intervention appears to have a high probability of cost-effectiveness in those aged 75–89 in this modelling analysis.
- The potential for cost-effectiveness is dependent on type of fall-risk assessment and fall-prevention intervention used, as well as the age-based cohort used for analysis.
- An injurious fall is estimated to occur 3 to 4 times more often in those aged 75–89 than those aged 65–74, which in part drives the modeling results.

- Basing screening on frailty rather than age may be a better initial predictor of an injurious fall relative to a generalised fall in older people, but data for modelling purposes are currently lacking.
- Obtaining informative results from an economic model while appropriately controlling for the uncertainty around the decision problem can be more cost-effective than implementing a complex, multi-arm RCTs accounting for each care pathway.

Introduction

The National Institute for Health and Care Excellence (NICE) in 2013 estimated that falls in older adults cost the UK's National Health Service (NHS) around £2.3 billion per year [1]. Up to 30% of adults aged 65+ years (i.e. older people) are estimated to fall each year, rising to 50% of those aged 80+ years [2]. Not all falls result in injury, but the probability of a fall requiring medical attention increases with age [3] and may result in declined levels of physical functioning and social activities [4]. Technologies and methods have been developed to screen for fall risk and reduce risk and rate of falls, particularly in older people. NICE Falls guidance states: individuals at risk of falling should be given a multifactorial risk assessment followed by a multifactorial intervention, which addresses risk factors identified by the initial assessment [1].

For assessing fall risk, the timed up and go (TUG) test is quick, simple and frequently used in clinical practice worldwide to assess an individual's balance and gait [1, 5]. A systematic review of TUG test efficacy suggested it should not be used on its own to predict fall risk, due to the high number of false positives for people being at high fall risk [6]. An adapted version of the TUG test, the Quantitative Timed Up and Go (QTUGTM), uses a statistical assessment of fall risk and has already been shown to have improved sensitivity and specificity compared to the TUG test [7, 8], for which there is an NICE Medtech innovation briefing report [9].

For fall prevention, a wide variety of community-based interventions have been summarised and included in a 2012 Cochrane review (159 trials; 79,193 participants) focussed on their efficacy in relation to reducing risk and rate of falls [2]. These interventions can be broadly classified as inclusive of exercise as a single intervention (59 trials) and multifactorial programmes (40 trials), and included specific examples such as multiple-component group or home-based exercise, Tai Chi, multifactorial interventions including individual risk assessment and home-safety assessment and modification interventions, among other interventions [2]. Cochrane produced updated reviews of fall-prevention interventions for community-dwelling people in 2018 (multifactorial and multiple component interventions) [10] and 2019 (exercise) [11], albeit with a different perspective/grouping of the interventions compared to Gillespie, Robertson [2].

The aim of this study is to evaluate the cost-effectiveness of a fall-risk assessment (QTUG compared to TUG) plus a fall-prevention intervention as a 'fall-related care pathway' compared to each other care pathway and no care pathway using a health economic decision model. Modelling has been chosen as the most appropriate method to evaluate the care pathways due to the various fall-risk assessment and

fall-prevention interventions, which need to be included. This would not be feasible within a randomised controlled trial (RCT) due to the large number of arms or complex methodology such a trial would need. Instead, modelling offers a timely and cost-effective method for providing information to decision makers about the probability of a specific care pathway being cost-effective relative to an alternative [12] and is recommended by the UK Medical Research Council Complex Intervention Guidance (2006; to be updated by 2019) [13], albeit the current model is a necessary simplification of the complexities around falls and does not fully represent current NICE Falls guidance [1].

Methods

A decision analytic model was developed focussed on fall-related care pathways; when fall-risk screening is conducted in primary care, screening is offered to community-dwelling older people based on age and the suitability of the fall-prevention interventions being provided in that age group (i.e. aged 65–89 years; whereby the upper age limit is applied for modelling purposes only). A Markov structure with a one-year cycle period and five event states represent outcomes associated with falling. The model was used to estimate the impact of a fall-related care pathway on number of fallers and falls, health service use (e.g. hospitalisation), residential care admission and death. To explore the impact of care-pathway effectiveness, age-related characteristics, cost and uptake on cost-effectiveness, eight fall-based care pathways and no care pathway were modelled stratified by five age groups with univariate and bivariate sensitivity analyses conducted using a range of values for the modelled intervention referral uptake, fall-risk screening efficacy and utility decrements.

Choice of modelled care pathways

The model was developed as part of the Perfect Patient Pathway (PPP) Test Bed [14]. The QTUG device was used to screen for fall risk within older people (e.g. aged 65+) within primary care practices in the Sheffield city region, with subsequent referral to a fall-prevention intervention if identified at high fall risk (i.e. statistical risk of falling >70%). Further details on the QTUG and PPP can be found elsewhere [14].

In the model, QTUG is compared to TUG as a commonly used fall-risk assessment test; however, it should be noted that QTUG sensitivity and specificity data were based on those at medium risk (i.e. statistical risk of falling >50% [8]) and for TUG high risk (i.e. TUG score ≥ 13.5 seconds [6]) of falling, which is described as a limitation and

assessed in the univariate and probabilistic sensitivity analyses (PSA). Modelled fall-prevention interventions included: Otago home-based exercise, Falls Management group Exercise programme (FaME) Tai Chi and home safety assessment and modification (HAM); which were all included in a recent fall-based return-on-investment tool commissioned by Public Health England [15]. All care pathways were assessed against 'no care pathway' (i.e. no fall-risk assessment nor fall-prevention intervention). [Appendix S1](#) provides a brief description of these assessments and interventions.

Model structure and assumptions

A two-part model structure included: (i) an initial decision tree models the accuracy of the fall-risk assessment to inform fall-prevention intervention referral and (ii) longer-term fall-related events are captured using a state transition, cohort-based Markov model with five event states, building on the fall-related model by Poole, Smith [16] (see [Appendix S2](#)). The five event states are as follows: (1) 'well/insignificant fall'—a person can be well or suffers an insignificant fall, which has no effect on quality of life and requires no additional care; (2) 'minor fall: emergency department (ED)'—minor fall requiring an ED visit; (3) 'major fall: hospitalisation'—same as minor fall with subsequent inpatient admission; (4) 'long-term care'—care home admission; (5) 'dead'—due to a fall, 1-year care-home-related or age-related mortality. Transition probabilities were assigned to the likelihood of movement between event states. A decision tree and Markov state-transition schematic model are depicted in [Appendix S3](#). Model cycle period and time horizon is 1 and 2 years, respectively, due to limited trial evidence to suggest any longer term intervention benefit [2, 15].

This model is a necessary simplification of the complexities around falls and does not fully represent current NICE Falls guidance [1] (NICE checked these guidelines in May 2019 and are currently being updated), instead focussing on specified screening with prevention interventions independently based on available empirical evidence. A full list of model assumptions is provided in [Appendix S4](#). A key assumption is that a person can only be referred to a fall-prevention intervention if deemed at risk of fall by a fall-risk assessment. Being referred to a fall-prevention intervention in any other way or outside of a primary-care setting is not modelled (e.g. an acute setting).

Model input parameter estimates

Transition probabilities, utilities and costs were sourced from the empirical literature or other data sources (e.g. office for national statistics), as presented and referenced in [Table 1](#).

Transition probabilities

Transition probabilities represent the probability of moving between the five states in the model per 1-year cycle period as presented in the model schematic ([Appendix S3](#)). The model accounts for the prevention interventions' efficacy for

reducing risk of being a faller (dependent on age) and rate of falls (see [Table 1](#)), which affects transition through the model. The majority of transition probabilities are based on observational data stratified by age groups (65–69, 70–74 and 75–89); parameterised using R (number of occurrences) and N (sample size) [12].

Utilities

Health state utilities are used to represent a preference value placed on a health state, where a value of 1 is considered equivalent to 'perfect health' and 0 equivalent to 'dead'. A utility decrement reflects negative events (i.e. how an event such as falling can negatively impact on a person's preference-based health state). These are used to calculate quality-adjusted life years (QALY) whereby the 'quality adjustment' is the utility value, and this is calculated over 'life years', which is the amount of time spent in a health state. A base-case utility value was used for the 'well' state based on community dwelling older people aged 65 (i.e. youngest age in the model) [17] to which age-related multipliers were applied [18]. To conserve monotonicity in the PSA, state-based utility decrements were applied, which included the utility decrement of the less severe state(s) (see [Table 1](#)); e.g. a major fall can never have a utility decrement lower than a minor fall.

Costs

Care pathway costs were based on the PPP study implementation costs or sourced from Public Health England [15]. For the PSA, gamma distributions were fitted at the unit cost level (see [Appendix S5](#)). Care home costs are treated as social care costs (as the costing perspective for care homes is complex; e.g. if self, local authority or NHS funded) and so modelled separately to healthcare (HC) costs.

Other model characteristics

As the model focuses on GP practice-based screening, it is necessary to estimate the eligible practice population. The number of patients per practice in England is estimated at 7,685 people [19]. Assuming the age split in practices is similar to the general population, of the total practice population on average this equates to: 425 people (5.53%) aged 65–69, 333 (4.34%) aged 70–74 and 557 (7.25%) aged 75–89 [19]. 'Base rate of falls for fallers' ([Table 1](#)) is estimated from Gillespie, Robertson [2] using control group data for the parameters: 'falls per person year', 'number in analysis' and 'number of fallers'.

Base-case economic evaluation: cost per QALY

QALYs based on health-state utility values and costs, the latter for a HC and health and social care (HSC) costing perspective, are estimated for the whole cohort rather than for an individual. Head-to-head analyses are run whereby one care pathway is compared to another care pathway (or no care pathway) and incremental cost-effectiveness ratios (ICERs)

Table 1. Summary of decision tree and Markov model parameters

Variable	Description or transition	Age group	Mean/[N]	SE/[95% CI]/(R, N)	Distribution	Reference/comment
Base-case model characteristics						
Eligible people for risk assessment	Average fall-risk assessment eligible population per surgery (number of people)	65–69 70–74 75–89	[425] [333] [557]	N/A N/A N/A	N/A N/A N/A	Estimated: [19, 23]
Falls ^a	Base rate of falls for fallers	65–89	2.83	1.41	Gamma	Estimated: [2]
Transition probabilities—decision tree						
Percentage who fall ^{b,c}	% who fall aged 65–69 % who fall aged 70–74 % who fall aged 75–89	65–69 70–74 75–89	0.144 0.184 0.473	0.01 0.02 0.05	Lognormal Lognormal Lognormal	Estimated: [2, 3]
QTUG ^c	Sensitivity Specificity	65–89 65–89	0.670 0.810	[0.53, 0.79] [0.63, 0.94]	Beta Beta	[8]
TUG	Sensitivity Specificity	65–89 65–89	0.310 0.740	[0.13, 0.57] [0.52, 0.88]	Beta Beta	[6]
Otago ^d	Reduced falling risk, RR	65–89	0.78	[0.64, 0.94]	Beta	[2]
FaME ^e	Reduced falls rate, RaR	65–89	0.68	[0.58, 0.80]	Beta	
	Reduced falling risk, RR	65–89	0.85	[0.76, 0.96]	Beta	[2]
	Reduced falls rate, RaR	65–89	0.71	[0.63, 0.82]	Beta	
Tai Chi ^f	Reduced falling risk, RR	65–89	0.80	[0.70, 0.91]	Beta	[11]
	Reduced falls rate, RaR	65–89	0.81	[0.67, 0.99]	Beta	
HAM ^g	Reduced falling risk, RR	65–89	0.88	[0.80, 0.96]	Beta	[2]
	Reduced falls rate, RaR	65–89	0.81	[0.68, 0.97]	Beta	
Transition probabilities—Markov model						
Well	Well from following states: well, minor fall, major fall	65–89	Remainder	N/A	N/A	Remaining well is dependent on any other event <i>not</i> occurring
Minor fall	Minor fall from following states: well, minor fall, major fall	65–69 70–74 75–89	0.024 0.028 0.058	(235.3, 10,000) (276, 10,000) (576.7, 10,000)	Beta Beta Beta	[3]
Major fall	Major fall from following states: well, minor fall, major fall	65–69 70–74 75–89	0.005 0.009 0.037	(52, 10,000) (91.9, 10,000) (368.6, 10,000)	Beta Beta Beta	[3]
Long-term care	Major fall from following states: major fall	65–69 70–74 75–89	0.000 0.086 0.274	(0, 0) (7.9, 91.9) (101.0, 368.6)	Beta Beta Beta	[3]
Leave long-term care	Well (leave long-term care) from: long-term care	65–89	0.038	(106, 2544)	Beta	[24]
Fall-related death	Dead (fall-related death) from: major fall	65–69 70–74 75–89	0.040 0.070 0.100	(2.1, 52) (6.4, 91.9) (36.9, 368.6)	Beta Beta Beta	[3]
One-year mortality, long-term care	Dead (one-year mortality) from: long-term care (first year only)	65–69 70–74 75–89	0.160 0.215 0.289	(144.8, 905) (669.7, 3115) (1350.5, 4673)	Beta Beta Beta	[24, 25]
Age-related death	Dead (age-related death) from: all states	Age-related (yearly)	Not presented	Not presented	Beta	[26]
Utilities—Markov states						
Well	Base-case well (aged 65 in base case); 65 base-case age-adjusted (not presented)		0.780	0.110	Beta	Base case: [27] Age-adjustment: [18]
Minor fall ^{c,h}	Utility decrement from well	65–89	0.025	0.003	Beta	[28]
Major fall ^{c,i}	Utility decrement from minor fall	65–89	0.073	0.007	Beta	[28]
Long-term care ^c	Utility decrement from major fall	65–89	0.096	0.010	Beta	[16]
Dead	Set utility value	65–89	0.000	N/A	Beta	N/A
Costs per person (£)—decision tree						
QTUG ^c	QTUG device and staff (time and training)	65–89	10.50	1.05	Gamma	Set up cost: £2806 per practice See Appendix S5.1
TUG ^c	TUG test and staff (time and training)	65–89	7.50	0.75	Gamma	Set up cost: £24 per practice See Appendix S5.2
Otago ^c	Staff (time, training, travel), equipment and evaluation costs	65–89	441.33	44.13	Gamma	[15] See Appendix S5.3
FaME ^c	Staff (time, training, travel), equipment, location, and evaluation costs	65–89	220.96	22.10	Gamma	[15] See Appendix S5.3

(Continued)

Table 1. Continued

Variable	Description or transition	Age group	Mean/[N]	SE/[95% CI]/(R, N)	Distribution	Reference/comment
Tai Chi ^c	Staff (time, training, travel), equipment, location, and evaluation costs	65–89	374.99	37.50	Gamma	[15] See Appendix S5.3
HAM ^c	Initial assessment, modification, and evaluation	65–89	247.41	24.74	Gamma	[15] See Appendix S5.3
Cost per person (£)—Markov states						
Well	No event results in no resource-use	65–89	0	N/A	N/A	Assumed
Minor fall (cost per fall)	Includes A&E attendance, ambulance, 999 call (proportion also have GP or outpatient visit)	65–69 70–74 75–89	421.74 432.17 427.84	See Appendix S5.4 See Appendix S5.4 See Appendix S5.4	Gamma Gamma Gamma	[29, 30] Distribution applied to unit costs (see Appendices S5.4 & S5.5)
Major fall (cost per fall)	Includes A&E attendance, ambulance, 999 call, hospital inpatient (proportion also have GP or outpatient visit)	65–69 70–74 75–89	4047.77 4023.05 4014.52	See Appendix S5.4 See Appendix S5.4 See Appendix S5.4	Gamma Gamma Gamma	
Long-term care ^c	Care home fee (per week = £480)	65–89	24,960.00	2496	Gamma	
Dead	Ambulance cost for conveying dead	65–89	236.44	33.62	Gamma	[29] See Appendix S5.6

Acronyms. FaME = Falls Management group Exercise programme; HAM = Home safety assessment and modification; Otago = Otago home-based exercise; QTUG = Quantitative Timed Up and Go device; TUG = Timed Up and Go test; RR = Risk Ratio; RaR = Rate Ratio.

Footnote. If the 'Reference/comment' is preceded by the word 'Estimated' then the figure presented is not a value obtained directly from the reference; rather, it was used in a further calculation, for which more information about how the value was estimated is described in the manuscript (e.g. 'Eligible people for risk assessment' and 'Falls') or as an additional table footnote (e.g. 'Percentage who fall' and 'Falls').

^aCalculated across all studies with raw control group data available within Appendix 8 of Gillespie, Robertson [2] for the following parameters: 'falls per person year', 'number in analysis', 'number of fallers'.

^bMean percentage of older people who fall per year estimated based on the assumption that one in five older people have an injurious falls per year as described by Gillespie, Robertson [2]; these figures are five times the percentage of people who have an injurious fall by the specified age group based on those estimates presented by Scuffham, Chaplin [3].

^cStandard errors were not provided in the original paper or with the unit cost. In order to make this parameter probabilistic, the standard error around the point estimate was assumed to be 10% of the mean.

^dBased on those studies included as having an intervention described as 'Multiple-component home-based exercise' within Gillespie, Robertson [2].

^eBased on those studies included as having an intervention described as 'Multiple-component group exercise' within Gillespie, Robertson [2].

^fBased on those studies included as having an intervention described as 'Tai Chi' within Sherrington, Fairhall [11]. Only Tai Chi as an exercise-based intervention could be updated to use the 2019 Cochrane review focussed on the use of exercise due to the fact that 'Multiple-component home-based exercise' and 'Multiple-component group exercise' are not distinguished in the 2019 review.

^gBased on those studies included as having an intervention described as 'Home safety assessment and modification intervention' within Gillespie, Robertson [2].

^hThis is the utility decrement estimated by Thiem, Klaaßen-Mielke [28] associated with 'two or more falls' (0.025).

ⁱThis is the utility decrement estimated by Thiem, Klaaßen-Mielke [28] associated with a 'Fear of falling' (0.073) brought on by the major relative to minor fall during the fall cycle; note, the 'minor fall' utility decrement is also applied in the modelling analysis such that the cumulative utility decrement for a major fall is 0.98 (i.e. 0.025 + 0.073).

estimated. An ICER is the difference in costs divided by the difference in benefits (e.g. QALYs) between two alternatives. Cost-effectiveness is then evaluated in terms of the additional cost per one additional unit of benefit (i.e. QALYs). This is then compared to a decision threshold such as NICE's willingness to pay (WTP) per additional QALY threshold of £20,000 to £30,000 [20]; e.g. an ICER less than £30,000 (i.e. ICER < £30,000) would be considered cost-effective and an ICER above this would not be considered cost-effective. Also, a £0 WTP threshold is used whereby cost savings are preferred to QALY gains.

The base-case assumes that everyone aged between 65 and 89 that is registered with a GP practice is eligible for fall-risk screening and subsequent fall-prevention intervention. If a person is identified at risk of falling, they will take the advice of their GP and attend one of the modelled interventions independently.

Probabilistic sensitivity analysis (PSA)

The uncertainty around cost and effects was modelled by fitting appropriate distributions to estimates obtained from the literature (Table 1) and were used in a Monte Carlo simulation with 5,000 repetitions to model joint parameter uncertainty as part of the PSA. A PSA is a random resampling of the model parameters followed by a recalculation of the ICER. The input parameter is not necessarily the point estimate value (e.g. mean value), but rather it is a random value from a pre-specified fitted distribution to reflect the range of possible values the parameter can take. This is then done 5,000 times to try to capture the impact the uncertainty of each parameter has on the probability that an intervention is cost-effective. Key results are presented as cost-effectiveness acceptability curves (CEACs) that plot the likelihood an intervention is cost-effective over a range of a WTP per QALY thresholds (e.g. £20,000 to £30,000).

Univariate and bivariate sensitivity analyses

In the univariate (i.e. changing one-point estimate input parameter independently) and bivariate (i.e. changing two-point estimate input parameters jointly) sensitivity analyses: (i) uptake on fall-prevention intervention post-risk-screening was varied from 100 (base case i.e. all people accept their referral) to 75, 50, 25, 10 and 1%; noting that at 0% no one receives intervention and no benefits are observed; (ii) QTUG sensitivity and specificity were independently or jointly varied from 0.05 to 0.95 in 0.05 increments; noting that 0 and 1 were not tested as these imply no or perfect sensitivity and specificity, which was deemed improbable and (iii) utility decrements were varied by 0.01 increments from ≈ 50 up to $\approx 200\%$ the base-case value.

Results

Base-case analysis and PSA

As the QTUG-based care pathways dominate ($>QALYs$; $<cost$) the TUG-based care pathways across all age-based cohorts, only QTUG versus no-care-pathway results have been presented here (see Appendices S6 and S7 for more details). The cost-effectiveness of the QTUG-based care pathways relative to no care pathway is dependent on the age of the cohort (see Table 2). If the QTUG-based care pathway is provided to patients aged 75–89, it has a high probability of being cost-effective across all interventions compared to no care pathway (a CEAC showing these results are presented in Figure 1). Using the NICE upper threshold (i.e. $ICER < £30,000$) for cost-effectiveness, the QTUG-based care pathways are not cost-effective compared to no care pathway for patients under the age of 75. If patients aged 65–74 are combined with those aged 75–89, a QTUG-based care pathway can be cost-effective dependent on subsequent fall-prevention intervention, but at lower probabilities, than for 75–89 alone.

An additional nine-way analysis comparing all care pathways simultaneously was conducted based on net monetary benefit (NMB), a description and associated results that are presented in Appendix S8.

Univariate and bivariate sensitivity analyses

The ICERs (cost-effectiveness, $ICER < £30,000$) at 10% uptake of intervention post-QTUG-based referral compared to no care pathway in those aged 75–89 were (see also Appendix S9): FaME, dominates ($>QALYs$; $<cost$), Otago, £24,035 (cost-effective), HAM, £42,025 (not cost-effective) and Tai Chi, £43,900 (not cost-effective).

Appendix S10 shows the matrix trade-off between relative changes in QTUG sensitivity to specificity and subsequent effect on cost-effectiveness compared to TUG or no care pathway (focussing specifically on those aged 75–89 with FaME). If QTUG and TUG sensitivity are equivalent (i.e. both 0.31), QTUG compared to TUG produces lower costs (equivalent QALYs) due to its higher specificity (0.81 versus 0.74), thus better ability to avoid additional cost of providing

fall-preventions intervention to non-fallers albeit with no QALY gain; if QTUG and TUG specificity are equivalent (i.e. both 0.74), QTUG still dominates TUG at a sensitivity rate ≈ 0.35 (QTUG base-case sensitivity = 0.67). At a sensitivity rate ≈ 0.45 , QTUG dominates no care pathway irrespective of specificity rate.

Appendix S11 shows the matrix trade-off between falls and long-term-care-related utility decrements. If the base-case utility decrements were increased to 200%, the QTUG-based care pathways in those aged 65–74 would still not be considered cost-effective (i.e. $ICER > £30,000$).

Discussion

QTUG-based fall-risk screening and providing a fall-prevention intervention to those identified as at fall risk is cost-effective compared to TUG-based screening. The cost-effectiveness of QTUG-based care pathways compared to no care pathway is dependent on the age of the cohort screened for fall-risk, with the most cost-effective option to screen only people aged 75–89 with referral to a fall-prevention intervention for those identified at risk of falling.

The probability of a care pathway being cost-effective compared to no care pathway increases as the age of the cohort increases because the modelled probability of an injurious fall increases with age. This is an important factor for consideration because if screening is based on age, the suggestion is that you screen all people in this age group (e.g. everyone aged 65–89) until you identify those at risk of an adverse outcome (e.g. falling) followed by intervention referral to avoid the adverse outcome; however, as four out of five people who fall do not suffer an injury which requires medical care (modelled as no utility decrement nor resources used), many of these avoided falls have no QALY benefit or potential cost saving, as it is only one in five who have a fall for whom a QALY gain and cost saving could be achieved. Fall-related adverse events (e.g. injurious falls) do not seem to occur enough in those aged 65–74 to warrant care-pathway investment to avoid these events in the modelled analysis, whereas these adverse events occur more often (around 3–4 times more often) in people aged 75–89 where the care pathways have a high probability of being cost-effective. However, it should also be noted that there can be non-injurious aspects of falls, for example fear of falling and the accompanying negative aspects of social isolation and inactivity. These are not fully accounted for in the model, as described below in section ‘Limitations’.

Chronological age though is potentially a poor differentiating factor to use to identify those who would benefit from screening. Instead, frailty has been shown to be a better predictor of mortality and variations in outcomes in older age [21], with falls often considered as a deficit associated with frailty [22]. Although the QTUG can assess frailty [9], primary-care-based frailty screening can be conducted using the electronic Frailty Index (eFI) based on care record data [22] (i.e. without the person present; noting this has its limitations e.g. aspects such as current physical functioning

Table 2. Incremental deterministic and probabilistic cost-effectiveness results: QTUG-based care pathway versus no care pathway, by age group per practice

Intervention (QTUG-based care pathway versus no care pathway) & age group	Incremental results			ICERs		Prob. Cost-effective < λ (HC)			Prob. Cost-effective < λ (HSC)		
	HC costs	HSC costs	QALYs	HC costs	HSC costs	$\lambda = £0$	$\lambda = £20 \text{ k}$	$\lambda = £30 \text{ k}$	$\lambda = £0$	$\lambda = £20 \text{ k}$	$\lambda = £30 \text{ k}$
QTUG Otago											
65–69	£38,873	£38,873	0.11	£364,277	£364,277	1%	2%	2%	1%	2%	2%
70–74	£25,769	£23,819	0.14	£186,160	£172,076	6%	8%	10%	7%	10%	11%
75–89	–£15,059	–£54,778	0.96	Dominates	Dominates	49%	61%	66%	74%	84%	89%
65–89	£43,971	£2,302	1.21	£36,396	£1,906	29%	37%	41%	43%	53%	58%
70–89	£7,904	–£33,765	1.10	£7,176	Dominates	38%	47%	53%	58%	70%	75%
QTUG FaME											
65–69	£17,321	£17,321	0.07	£238,055	£238,055	6%	8%	8%	6%	8%	8%
70–74	£8,649	£6,699	0.10	£87,368	£67,674	19%	24%	26%	23%	29%	32%
75–89	–£46,492	–£86,211	0.75	Dominates	Dominates	74%	84%	88%	97%	99%	99%
65–89	–£26,134	–£67,803	0.92	Dominates	Dominates	57%	66%	71%	80%	88%	91%
70–89	–£40,649	–£82,318	0.84	Dominates	Dominates	66%	76%	81%	91%	95%	97%
QTUG Tai Chi											
65–69	£35,924	£35,924	0.10	£370,309	£370,309	1%	1%	1%	1%	1%	1%
70–74	£25,004	£23,054	0.13	£196,640	£181,307	4%	6%	7%	5%	7%	8%
75–89	£1,346	–£38,373	0.90	£1,494	Dominates	40%	53%	60%	70%	82%	87%
65–89	£56,662	£14,994	1.13	£50,363	£13,327	21%	29%	34%	37%	48%	54%
70–89	£23,544	–£18,125	1.03	£22,901	Dominates	30%	40%	46%	52%	65%	71%
QTUG HAM											
65–69	£24,279	£24,279	0.06	£417,121	£417,121	1%	2%	2%	1%	2%	2%
70–74	£16,125	£14,175	0.08	£196,427	£172,678	7%	9%	11%	9%	12%	14%
75–89	–£10,775	–£50,494	0.65	Dominates	Dominates	49%	61%	67%	87%	93%	95%
65–89	£24,017	–£17,651	0.79	£30,287	Dominates	30%	38%	43%	53%	64%	69%
70–89	£2,544	–£39,125	0.73	£3,462	Dominates	39%	49%	55%	71%	81%	85%

Footnote. All results are presented at the cohort-level based on number of eligible people in an average primary care practice, rather than at the person-level.

Acronyms. FaME = Falls Management group Exercise programme; HAM = Home safety assessment and modification; HC = Healthcare; HSC = Health & social care; ICER = Incremental cost-effectiveness ratio; Otago = Otago home-based exercise; QTUG = Quantitative Timed Up and Go device; TUG = Timed Up and Go test; RR = Risk Ratio of falling; RaR = Rate Ratio of falls.

Definitions. Dominates = QTUG with intervention relative to no care pathway produces >QALYs and < costs (i.e. cost-effective).

Symbols. λ = willingness to pay (WTP; £) per quality adjusted life year (QALY) thresholds; £20 & £30 k = £20,000 & £30,000.

cannot be assessed using the eFI, which can be using the QTUG frailty assessment [9]); the eFI was considered within the PPP, but no data were obtained for modelling purposes. Basing screening on frailty rather than age may be a better initial predictor of an injurious fall relative to a generalised fall in older people, but data for modelling purposes are currently lacking. There are also other characteristics, which could be considered as part of screening for fall-risk outlined within NICE guidance, in particular a history of falls [1], which could be included within a model. However, we did not include these in our model due to: (i) the PPP basing initial screening on age rather than history of falls for practical reasons; (ii) known difficulties with identifying a history of falls, as older people often do not report falls unless they result in an injury requiring care and hence history of falls can be imperfect; and (iii) identifying people at fall risk based on a history of falls means that the first fall cannot be prevented as it has already occurred, and hence a key benefit of not basing fall risk on history of falls is the possibility of preventing a first fall. Despite the limitations of basing initial screening on age followed by a fall-risk screening tool such as QTUG, age tends to be more readily, reliably known relative

to history of falls and allows for the potential to avoid the first fall, which could lead to further falls. History of falls could be combined with these other factors and modelled when this evidence is available.

Limitations

Those wishing to use these modelling results as part of evidence-based decision making should consider the key model assumptions outlined in Appendix S4, also noting that the model does not fully represent NICE Falls guidance [1]. One key thing to note is that not all parameters control for age-related characteristics. Specifically, fall-prevention intervention effectiveness was not stratified by age cohorts within which efficacy may differ for various age-related factors (e.g. muscle deterioration and ability to benefit from intervention; falls rate relative to injurious falls and subsequent effects on quality of life and care resources consumed), which subsequently effect cost-effectiveness. As such, this modelling analysis may under- or over-estimate care-pathway cost-effectiveness if intervention efficacy is age dependent, which is not transparent based on the 2012

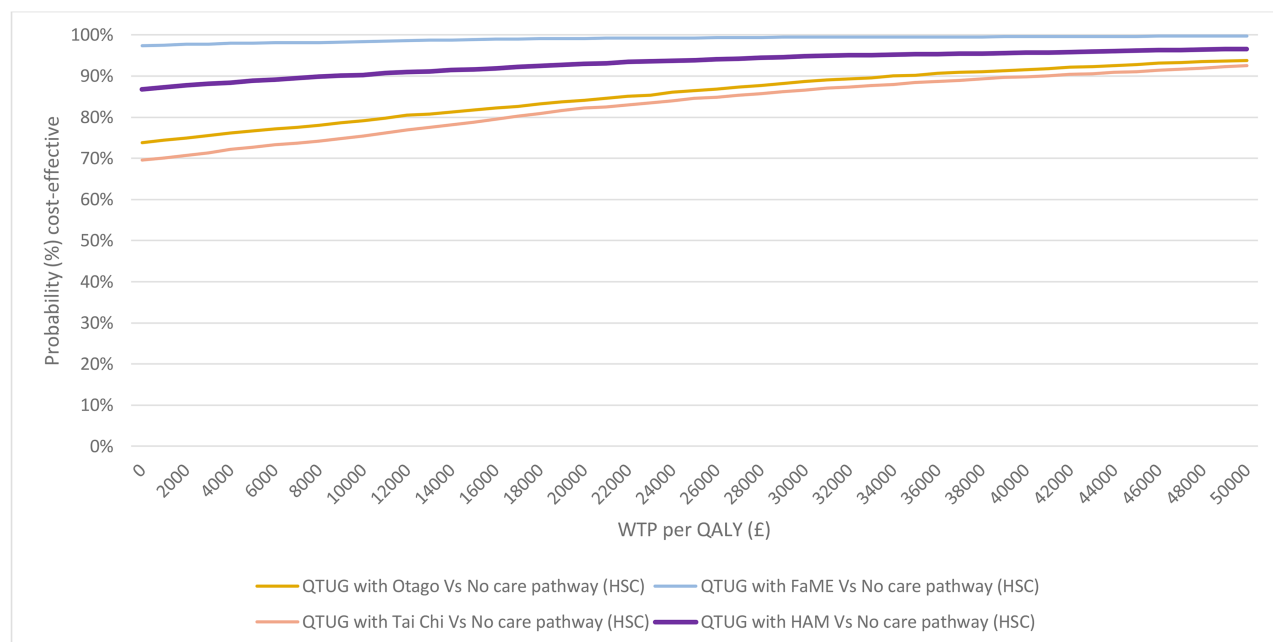


Figure 1. CEAC based on health and social care (HSC) costs for QTUG-based care pathway versus no care pathway (age-based cohort: 75–89).

Cochrane review evidence [2]. However, the recent 2019 Cochrane review of exercise interventions [11] does present some age-related sub-group analyses, but could not be used for this analysis as it does not differentiate between group and home exercise (but does include Tai Chi), which is needed to differentiate between Otago and FaME as commonly used, but different (e.g. setting, efficacy and cost) exercise interventions; this is also the reason why Tai Chi efficacy evidence in the model is sourced from the 2019 review [11] compared to Otago and FaME efficacy sourced from the 2012 review [2]. Also noting, it is assumed that four in five falls has no effect on quality of life or care resource use; however, non-injurious effects related to even insignificant falls (e.g. fear of falling) has quality of life implications, which are not captured in this model other than for major falls (which captures fear of falling as a utility decrement, applied as an assumption), as there is no evidence to suggest what proportion of fallers suffer from ‘fear of falling’. Therefore, the model may underestimate QALY gains from insignificant and minor falls; although utility decrement values were assessed in the univariate and bivariate analyses, which suggested that the modelled utility decrements would have to greatly increase (>200% base-case) to affect potential for a care pathway to move from being considered not cost-effective to cost-effective. It is also assumed that the efficacy of the fall-risk assessment and fall-prevention intervention are independent of each other, which may not be true.

The QTUG sensitivity and specificity data source has two key limitations: (1) it is based on one main study of QTUG sensitivity and specificity conducted by the manufacturer (i.e. Kinesis Health Technologies Ltd) [8] and as a result may be biased [9]; (2) the study was based on medium risk

of falling (i.e. statistical risk of falling >50%; note, high risk >70%) and for the TUG, this was based on high risk (i.e. TUG score ≥ 13.5 s). To account for these limitations, we specified efficacy uncertainty associated with QTUG in the PSA and assessed a change in QTUG sensitivity and specificity estimates on subsequent cost-effectiveness results in the univariate analysis (see [Appendix S10](#)); in both cases, QTUG efficacy would need to decrease closer to TUG efficacy to be considered comparatively not cost-effective due to the small difference in per-person screening and sunk cost.

Conclusion

The QTUG fall-risk assessment with FaME fall-prevention intervention had the highest probability of cost-effectiveness when primary-care-based screening was conducted in community-dwelling people aged 75–89. Despite limitations and the fact the model does not fully represent current NICE Falls guidance, decision makers should give careful consideration to implementing the aforementioned care pathway due to the high probability of cost-effectiveness identified from the modelling analyses.

Supplementary data: [Supplementary data](#) mentioned in the text are available to subscribers in *Age and Ageing* online.

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Declaration of Conflicts of interest: Kinesis Health Technologies Ltd (aka. 'Kinesis') who developed the QTUG technology was a part of the Perfect Patient Pathway Test Bed, for which the model was developed and representatives of Kinesis provided their thoughts on the initial design of the model; however, they did not inform the overall development and analysis of the model and subsequent results in this manuscript. M.F. and R.H. have no other conflicts of interest to report.

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References

1. NICE. Falls in Older People: Assessing Risk And Prevention (NICE Clinical Guideline 161). National Institute for Health and Care Excellence (NICE) in 2013. <https://www.nice.org.uk/guidance/cg161/evidence/full-guideline-pdf-190033741> (Manchester, 14th May 2019).
2. Gillespie LD, Robertson M, Gillespie WJ, Sherrington C, Gates S, Clemson LM, Lamb SE. Interventions for preventing falls in older people living in the community. *Cochrane Database Syst Rev* 2012; 1–420, CD007146. doi: [10.1002/14651858.CD007146.pub3](https://doi.org/10.1002/14651858.CD007146.pub3)
3. Scuffham P, Chaplin S, Legood R. Incidence and costs of unintentional falls in older people in the United Kingdom. *J Epidemiol & Comm Health* 2003; 57: 740–4.
4. Stel VS, Smit JH, Pluijm SM, Lips P. Consequences of falling in older men and women and risk factors for health service use and functional decline. *Age Ageing* 2004; 33: 58–65. (24th Jan 2019, date last accessed).
5. NHS Digital. Updated Guidance on Supporting Routine Frailty Identification and Frailty Care Through the GP contract 2017/2018 in 2017. <https://www.england.nhs.uk/wp-content/uploads/2017/04/supporting-guidance-on-frailty-update-sept-2017.pdf> (10 December 2017, date last accessed).
6. Barry E, Galvin R, Keogh C, Horgan F, Fahey T. Is the timed up and go test a useful predictor of risk of falls in community dwelling older adults: A systematic review and meta-analysis. *BMC Geriatr* 2014; 14: 14.
7. Greene BR, O'Donovan A, Romero-Ortuno R, Cogan L, Scanail CN, Kenny RA. Quantitative falls risk assessment using the timed up and go test. *IEEE Trans Biomed Eng* 2010; 57: 2918–26.
8. Greene BR, Redmond SJ, Caulfield B. Fall risk assessment through automatic combination of clinical fall risk factors and body-worn sensor data. *IEEE J Biomed Health Inform* 2017; 21: 725–31.
9. NICE. QTUG for assessing falls risk and frailty (Medtech innovation briefing [MIB73]). National Institute for Health and Care Excellence (NICE) in 2016. <https://www.nice.org.uk/advice/mib73> (20 January 2019, date last accessed).
10. Hopewell S, Adedire O, Copsey BJ, Boniface GJ, Sherrington C, Clemson L, Close JCT, Lamb SE. Multifactorial and multiple component interventions for preventing falls in older people living in the community. *Cochrane Database Syst Rev* 2018; CD012221. doi: [10.1002/14651858.CD012221.pub2](https://doi.org/10.1002/14651858.CD012221.pub2).
11. Sherrington C, Fairhall NJ, Wallbank GK, Tiedemann A, Michaleff ZA, Howard K, Clemson L, Hopewell S, Lamb SE. Exercise for preventing falls in older people living in the community. *Cochrane Database of Systematic Reviews* 2019; 1–446, CD012424. doi: [10.1002/14651858.CD012424.pub2](https://doi.org/10.1002/14651858.CD012424.pub2)
12. Briggs A, Sculpher M, Claxton K. *Decision Modelling for Health Economic Evaluation*. Oxford: OUP, 2006.
13. Medical Research Council. *Developing and Evaluating Complex Interventions*. UK: MRC, 2006.
14. Sheffield Teaching Hospitals NHS Foundation Trust. Perfect Patient Pathway Test Bed Overview Report in 2016. <http://ppptestbed.nhs.uk/wp-content/uploads/2018/12/Test-Bed-Overview-Report-DIGITAL-VERSION.pdf> (20 February 2019, date last accessed).
15. Public Health England. *A Return on Investment Tool for the Assessment of Falls Prevention Programmes for Older People Living in the Community*. London, UK: Public Health England, 2018; 1–59.
16. Poole C, Smith J, Davies J. Cost-effectiveness and budget impact of empirical vitamin D therapy on unintentional falls in older adults in the UK. *BMJ Open* 2015; 5: e007910.
17. Kind P, Hardman G, Macran S. UK population norms for EQ-5D, 1999. York: Centre for Health Economics, 1999. <https://www.york.ac.uk/che/pdf/DP172.pdf> (08 October 2019, date last accessed).
18. Ara R, Brazier JE. Populating an economic model with health state utility values: Moving toward better practice. *Value Health* 2010; 13: 509–18.
19. ONS. Population Estimates Analysis Tool, Mid 2016. Office for National Statistics (ONS) in 2017. <https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/populationestimatesanalysistool> (18 October 2017, date last accessed).
20. NICE. Guide to the Methods of Technology Appraisal 2013. National Institute for Health and Care Excellence (NICE) in 2013. <https://www.nice.org.uk/process/pmg9/chapter/foreword> (24 January 2019, last date accessed).
21. Song X, Mitnitski A, Rockwood K. Prevalence and 10-year outcomes of frailty in older adults in relation to deficit accumulation. *J Am Geriatr Soc* 2010; 58: 681–7.

22. Clegg A, Bates C, Young J *et al.* Development and validation of an electronic frailty index using routine primary care electronic health record data. *Age Ageing* 2016; 45: 353–60.
23. NHS Digital. General practice trends in the UK to 2016 2017 in 2017. http://content.digital.nhs.uk/media/25201/General-Practice-Trends-in-the-UK-to-2016/pdf/General_Practice_Trends_in_the_UK_to_2016.pdf (18 October 2017, date last accessed).
24. Bebbington A, Brown P, Darton R, Miles K, Netten A. Longitudinal study of elderly people admitted to residential and nursing homes: 42 months on. *Nursing* 1999; 21: 2.
25. Shah SM, Carey IM, Harris T, DeWilde S, Cook DG. Mortality in older care home residents in England and Wales. *Age Ageing* 2013; 42: 209–15.
26. ONS. National Life Tables: England 2014–2016. Office for National Statistics (ONS) in 2017. <https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/lifeexpectancies/datasets/nationallifetablesenglandreferencetables> (20 November 2017, date last accessed).
27. Kind P, Hardman G, Macran S. UK Population Norms for EQ-5D. York, UK: University of York, 1999.
28. Thiem U, Klaaßen-Mielke R, Trampisch U, Moschny A, Pientka L, Hinrichs T. Falls and EQ-5D rated quality of life in community-dwelling seniors with concurrent chronic diseases: A cross-sectional study. *Health Qual Life Outcomes* 2014; 12: 2.
29. NHS Improvement. NHS Reference Costs 2016 to 2017. NHS Improvement in 2017. <https://improvement.nhs.uk/resources/reference-costs/> (22 November 2017, date last accessed).
30. Curtis LA, Burns A. Unit Costs of Health and Social Care 2017. Canterbury UK: Personal Social Services Research Unit (PSSRU), University of Kent, 2017.

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