*FRAX threshold v submission*

Submission to Archives of Osteoporosis, Revision 15 June 2016

REVIEW

**A systematic review of intervention thresholds based on FRAX**

A report prepared for the National Osteoporosis Guideline Group and the International Osteoporosis Foundation

John A Kanis1,2, Nicholas C Harvey3, Cyrus Cooper3, Helena Johansson1, Anders Odén1, Eugene V McCloskey1, the Advisory Board of the National Osteoporosis Guideline Group\*

1 Centre for Metabolic Diseases, University of Sheffield Medical School, Sheffield, United Kingdom

2 Institute of Health and Ageing, Australian Catholic University, Melbourne, Australia

3 MRC Lifecourse Epidemiology Unit, University of Southampton, UK

\*Advisory Board the National Osteoporosis Guideline Group: Cyrus Cooper, Nicholas Harvey, Eugene McCloskey, Ken E Poole (Department of Medicine, University of Cambridge, Cambridge, UK), John A Kanis, Neil Gittoes (Department of Endocrinology, University Hospitals Birmingham and University of Birmingham, Birmingham, UK), Sally Hope (Metabolic Bone Unit/Oxfordshire Osteoporosis Service, Nuffield Orthopaedic Centre, Oxford, UK).

**Address for Correspondence:** John A Kanis, Centre for Metabolic Bone Diseases, University of Sheffield Medical School, Beech Hill Road, Sheffield S10 2RX, UK; Tel: +44 114 285 1109; Fax: +44 114 285 1813; [w.j.pontefract@sheffield.ac.uk](mailto:w.j.pontefract@sheffield.ac.uk)

**Abstract**

In most assessment guidelines, treatment for osteoporosis is recommended in individuals with prior fragility fractures, especially fractures at spine and hip. However, for those without prior fractures, the intervention thresholds can be derived using different methods. The aim of this report was to undertake a systematic review of the available information on the use of FRAX® in assessment guidelines, in particular the setting of thresholds and their validation. We identified 120 guidelines or academic papers that incorporated FRAX of which 38 provided no clear statement on how the fracture probabilities derived are to be used in decision-making in clinical practice. The remainder recommended a fixed intervention threshold (n=58), most commonly as a component of more complex guidance (e.g. bone mineral density (BMD) thresholds) or an age-dependent threshold (n=22). Two guidelines have adopted both age-dependent and fixed thresholds. Fixed probability thresholds have ranged from 4 to 20 % for a major fracture and 1.3-5 % for hip fracture. More than one half (39) of the 58 publications identified utilized a threshold probability of 20 % for a major osteoporotic fracture, many of which also mention a hip fracture probability of 3 % as an alternative intervention threshold. In nearly all instances, no rationale is provided other than that this was the threshold used by the National Osteoporosis Foundation of the US. Where undertaken, fixed probability thresholds have been determined from tests of discrimination (Hong Kong), health economic assessment (US, Switzerland), to match the prevalence of osteoporosis (China) or to align with pre-existing guidelines or reimbursement criteria (Japan, Poland). Age-dependent intervention thresholds, first developed by the National Osteoporosis Guideline Group (NOGG), are based on the rationale that if a woman with a prior fragility fracture is eligible for treatment, then, at any given age, a man or woman with the same fracture probability but in the absence of a previous fracture (i.e. at the ‘fracture threshold’) should also be eligible. Under current NOGG guidelines, based on age-dependent probability thresholds, inequalities in access to therapy arise especially at older ages (≥ 70 years) depending on the presence or absence of a prior fracture. An alternative threshold using a hybrid model reduces this disparity. The use of FRAX (fixed or age-dependent thresholds) as the gateway to assessment identifies individuals at high risk more effectively than the use of BMD. However, the setting of intervention thresholds need to be country-specific.

**Key words**

Assessment guidelines · Calibration · Discrimination · FRAX · Intervention threshold

**Contents**

|  |  |  |
| --- | --- | --- |
| **Executive Summary** |  | 5 |
| **Introduction** |  | 9 |
| **Research questions** |  | 12 |
| **Methods** |  | 12 |
| **Design** |  | 12 |
| **Outcomes** |  | 12 |
| **Inclusion criteria** |  | 12 |
| **Exclusion criteria** |  | 13 |
| **Search strategy for identification of studies** |  | 13 |
| **Screening of abstracts** |  | 13 |
| **Data extraction and quality assessment** |  | 14 |
| **Data synthesis** |  | 14 |
| **Results** |  | 14 |
| **The use of a fixed FRAX intervention threshold** |  | 17 |
| *National Osteoporosis Foundation, US* |  | 21 |
| *The US Preventive Services Task Force* |  | 22 |
| *American College of Rheumatology* |  | 23 |
| *Japanese National Guidelines* |  | 23 |
| *Poland* |  | 24 |
| *Hong Kong* |  | 25 |
| *China* |  | 25 |
| *Switzerland* |  | 25 |
| *Scottish Intercollegiate Guidelines Network (SIGN)* |  | 26 |
| *Taiwan* |  | 28 |
| **Age dependent intervention thresholds using FRAX** |  | 29 |
| *Principles of derivation* |  | 29 |
| *Management algorithm* |  | 30 |
| *National Osteoporosis Guideline Group (NOGG), UK* |  | 31 |
| *Uptake and impact of NOGG* |  | 32 |
| *Age-dependent thresholds in other countries* |  | 34 |
| *Poland* |  | 36 |
| *Australia* |  | 37 |
| *Hong Kong* |  | 37 |
| *Japan* |  | 38 |
| **Hybrid intervention thresholds using FRAX** |  | 38 |
| *Lebanon* |  | 39 |
| *UK* |  | 39 |
| **Health economic approach to intervention thresholds with FRAX** |  | 42 |
| *Cost effectiveness of intervention based on FRAX* |  | 42 |
| **Discrimination of FRAX** |  | 48 |
| *Comparing cohort-specific models with FRAX* |  | 49 |
| **Calibration of FRAX** |  | 50 |
| *England* |  | 50 |
| *Canada* |  | 51 |
| *Denmark* |  | 52 |
| *Kuopio Osteoporosis Risk Factor and Prevention (OSTPRE) study* |  | 52 |
| *Difficulties in calibration of FRAX* |  | 54 |
| *Other determinants of accuracy* |  | 55 |
| *Reclassification* |  | 55 |
| *Comparison of guidelines* |  | 57 |
| *Net reclassification improvement (NRI)* |  | 59 |
| **Discussion** |  | 59 |
| **Use of fixed thresholds** |  | 60 |
| **Setting fixed FRAX thresholds** |  | 63 |
| **Consequences of a 20 % threshold** |  | 64 |
| **Economic thresholds** |  | 66 |
| **Age-dependent intervention thresholds** |  | 67 |
| **Limitations of FRAX** |  | 69 |
| *Well established limitations of FRAX* |  | 69 |
| *Reliance on computer access* |  | 71 |
| *Not all countries have FRAX models* |  | 71 |
| *Efficacy in patients selected without BMD* |  | 72 |
| *Controlled trials* |  | 74 |
| *Age-dependent thresholds are ageist* |  | 74 |
| *Inequity across countries* |  | 74 |
| *Sensitivity of NOGG in subgroups* |  | 75 |
| **Acknowledgements** |  | 76 |
| **Competing interests** |  | 76 |
| **References** |  | 77 |
| **Abbreviations and glossary** |  | 93 |
| **Appendix** Redundant references from systematic search |  | 95 |

**Executive summary**

|  |  |
| --- | --- |
| 1. | According to most current guidelines, treatment for osteoporosis is recommended in individuals with prior fragility fractures, especially fractures at spine and hip. However, for those without prior fractures, the intervention thresholds can be derived using different methods. |
| 2. | FRAX is a tool designed for primary care and developed by the WHO for the calculation of the 10-year probability of hip fracture and a major osteoporotic fracture from readily assessed clinical risk factors. Bone mineral density can be optionally entered to improve its accuracy. |
| 3. | The general aims of this report were to review the available information on the use of FRAX in assessment guidelines, in particular the setting of thresholds and their validation. |
| 4. | A systematic search identified 435 citations from which 307 full publications were read and from which 231 were included in this report. |
| 5. | The widespread uptake and availability of FRAX, during a time of transition since its launch in 2008, has resulted its inclusion in many guidelines. We identified 120 guidelines or academic papers that included FRAX. However, 38 provided no clear statement on how the fracture probabilities derived are to be used in decision-making in clinical practice. |
| 6. | Two broad approaches have been used to develop intervention thresholds with FRAX. The first was to determine a *fixed threshold* probability that could be applied to men and women, irrespective of age. The second approach was to use *age-dependent thresholds* where the fracture probability at which treatment was recommended was age specific. Also, two guidelines have used both fixed and age-dependent thresholds – termed *hybrid thresholds*. |
| 7. | Fixed probability thresholds have ranged from 4 to 20 % for a major fracture and 1.3-5 % for hip fracture. More than one half (39) of the 58 publications identified utilized a threshold probability of 20 % for a major osteoporotic fracture, many of which also mention a hip fracture probability of 3 % as an alternative intervention threshold. In nearly all instances, no rationale is provided other than that this was the threshold used by the National Osteoporosis Foundation of the US. |
| 9. | Where undertaken, fixed probability thresholds have been determined from tests of discrimination (Hong Kong), health economic assessment (US, Switzerland), to match the prevalence of osteoporosis (China) or to align with pre-existing guidelines or reimbursement criteria (Japan, Poland). |
| 10. | Fixed thresholds for a major osteoporotic fracture have been recommended by the US Preventive Services Task Force and the Scottish Intercollegiate Guidelines Network (9.3 % and 10 %, respectively) as a screening tool for osteoporosis (but not fracture risk). Both guidelines perform badly because of poor sensitivity. Several other guidelines in the US have adopted the 9.3 % threshold. |
| 11. | The impact of the use of fixed thresholds has been determined only in the US and Hong Kong for the 20 % major osteoporotic fracture and 3 % hip fracture probability. |
| 12. | The National Osteoporosis Guideline Group (NOGG) in the UK was the architect of the development of age-dependent intervention thresholds. The rationale was that if a woman with a prior fragility fracture is eligible for treatment, then, at any given age, a man or woman with the same fracture probability but in the absence of a previous fracture (i.e. at the ‘fracture threshold’) should also be eligible. The fracture threshold increases with age. Additionally, NOGG devised assessment thresholds to determine the efficient use of bone densitometry. |
| 13. | Linkage of the FRAX web site to the NOGG web site facilitates treatment decisions and is widely used. Similar country-specific linkages are used in Finland, Lebanon and Romania. |
| 14. | The NOGG approach has been compared with previous guidance issued by the Royal College of Physicians, London (RCP). Compared with the RCP strategy, NOGG identified slightly reduced numbers of women without prior fractures above the respective intervention thresholds but these were at higher risk than those identified by the RCP strategy. A major benefit was the reduction in the number of BMD tests required using the NOGG guidance, and this was associated with significant economic dividends. |
| 15. | Proposed and established intervention thresholds using age-specific fracture probabilities were found in 24 guidelines, including European guidance for postmenopausal osteoporosis and for glucocorticoid-induced osteoporosis. |
| 16. | Comparisons of age-dependent thresholds with fixed thresholds (Belgium, Poland, US) showed the former were associated with higher dividends on budget impact (Belgium), cost/fracture identified (UK) and improved sensitivity (US, Poland). |
| 17. | Under current NOGG guidelines, based on age-dependent probability thresholds, inequalities in access to therapy arise especially at older ages (≥ 70 years) depending on the presence or absence of a prior fracture. An alternative threshold using a hybrid model reduces this disparity, increases treatment access and decreases still further the need for bone densitometry. |
| 18. | No randomised studies were identified that examined the cost-effectiveness of strategies that used FRAX for targeting people at high fracture risk, though one is near completion. |
| 19. | There are several appraisals that have determined the fracture probability at which interventions became cost-effective (i.e. an economic threshold). Economic thresholds have been variously used to set intervention thresholds or, more appropriately, to validate the use of clinically driven intervention thresholds. For alendronate in the UK and Switzerland, all treatment scenarios using the NOGG approach were cost-effective. |
| 21. | Consistent discriminative performance of FRAX has been shown worldwide. |
| 22. | All FRAX models are internally calibrated. Comparison with external calibration using samples representative of the national population are few (Canada, Denmark, Finland, and UK) but are concordant. |
| 23. | Calibration within a country does not appear to be affected by concurrent treatment or socioeconomic status (Canada), but is affected by immigrant status (Sweden). |
| 24. | In individuals in whom FRAX is calculated without BMD, subsequent reclassification rates by the inclusion of BMD were low (UK, Canada) and confined to individuals close to an intervention threshold. |
| 25. | Net reclassification improvement was reported comparing a fixed intervention threshold using FRAX and a more parsimonious model (Canadian Association of Radiologists and Osteoporosis Canada; CAROC). |
|  | **Conclusions and recommendations** |
| 26. | The use of a fixed FRAX threshold has some intuitive appeal in that it directs intervention in an equitable manner and is more readily used in clinical practice than more complex approaches inherent in the application of age-dependent thresholds. There is, however only one guideline that directs intervention solely on this basis (Taiwan) but documentation of its impact is wanting. |
| 27. | The use of guidelines that use BMD as the principal gateway and incorporate fixed FRAX thresholds as a component identifies individuals at high risk less effectively than the use of age-dependent thresholds (US National Osteoporosis Foundation). |
| 28. | The use of FRAX as a screening tool for subsequent measurement of BMD for the detection of osteoporosis is not recommended because of low sensitivity of FRAX for the detection of osteoporosis. |
| 29. | We recommend the avoidance of the use of a fixed FRAX intervention threshold as the principal gateway to fracture risk assessment. This view may change with further research. |
| 30. | Fixed intervention thresholds may be used usefully as a component of pre-existing guidelines e.g. confined to individuals with low bone mass in Japan and the US. However, where used, country-specific thresholds need to be determined. |
| 31. | The use of economic thresholds is problematic as analysis of each intervention produces different thresholds; they are sensitive to changes in cost and are not relevant to other countries |
| 32. | We recommend that intervention thresholds be based on clinical imperatives, always provided that the strategy proves to be cost-effective. |
| 33. | The present review has identified several merits of the use of age-specific thresholds. The algorithm can be readily used in all countries where a FRAX model is available. |
| 34. | Concerns that the selection of individuals without measurement of BMD may have normal BMD and not respond to pharmaceutical intervention is misplaced in that the use of FRAX (without BMD) preferentially selects individuals with low BMD. |
| 35. | It is apparent that, following the NOGG guidance, particularly at older ages, those eligible for treatment without a prior fracture have on average higher probabilities than those eligible on the basis of a previous fragility fracture. This appears to be remedied with the hybrid modification. |

**Introduction**

Osteoporosis is a major health problem, particularly in the elderly because of the fractures that arise as a consequence of the decreasing bone mineral density with age. Common sites of fragility fracture are at the hip, spine and wrist. The incidence of these and other fragility fractures rises markedly with age. The most serious fracture in terms of morbidity, mortality and health care costs is hip fracture. As populations expand and life expectancy improves, the number of fractures is set to increase. The demographics of world populations are set to change with more elderly living in developing countries [1]. In Europe in 2010, 22 million women and 5.5 million men were estimated to have osteoporosis; and 3.5 million new fragility fractures were sustained, comprising 610,000 hip fractures, 520,000 vertebral fractures, 560,000 forearm fractures and 1,800,000 other fractures (i.e. fractures of the pelvis, rib, humerus, tibia, fibula, clavicle, scapula, sternum and other femoral fractures). The economic burden of incident and prior fragility fractures was estimated at € 37 billion. Incident fractures represented 66 % of this cost, long-term fracture care 29 % and pharmacological prevention 5 % [2].

A significant advance over the past 15 years has been the development of medical interventions that have been shown to decrease the risk of fragility fractures in high quality randomised controlled trials [2, 3]. Unfortunately, only a minority of men and women receives treatment even after sustaining a fragility fracture [2, 4]. The reason for this large treatment gap (the difference between the number of individuals at high risk and the proportion of the population that receives treatment) is complex and multifactorial. One of the reasons is, however, is limitations in the assessment of fracture risk.

Although the diagnosis of osteoporosis relies on the quantitative assessment of bone mineral density, which is a major determinant of bone strength, the clinical significance of osteoporosis lies in the fractures that arise. The causation of fractures is, however multifactorial. In this respect, there are some analogies with other multifactorial chronic diseases. For example, hypertension is diagnosed on the basis of blood pressure whereas an important clinical consequence of hypertension is stroke.

Assessment of bone mineral density (BMD) provides a crucial determinant of fracture risk and many guidelines have used BMD thresholds to determine whether treatments should be recommended. However, the multifactorial nature of fracture risk means that BMD does not capture non-skeletal determinants of fracture risk such as liability to fall. A number of risk factors for fracture has been identified that contribute significantly to fracture risk over and above that provided by BMD [5]. A good example is age. The same BMD has a different significance at different ages, such that fracture risk is much higher in the elderly than in the young [6, 7]. This is because age contributes to risk independently of BMD. Over the past few years a series of meta-analyses has been undertaken to identify additional clinical risk factors that could be used in case finding strategies, with or without the use of BMD. This gave rise to the development of FRAX®, a tool that integrates the information derived from clinical risk factors and BMD [8].

As well as the FRAX tool, other fracture risk calculators are available online which include the Garvan fracture risk calculator and QFracture® [9, 10]. Both QFracture and FRAX have been approved by the National Institute for Health and Care Excellence (NICE) for use in the UK [11]. Their comparative features are summarised in Table 1. The QFracture tool is based on a UK prospective open cohort study of routinely collected data from 357 General Practices on over 2 million men and women aged 30–85 years (www.qfracture.org). Like the FRAX tool, it takes into account history of smoking, alcohol, glucocorticoid use, parental history (of hip fracture or osteoporosis) and multiple secondary causes of osteoporosis. Unlike FRAX, it also includes a history of falls (yes/no only over an unspecified time frame). It has been internally validated (i.e. from a stratum of the same population) and also externally validated, but only from GP records in the UK [12].

**Table 1**. Comparative features of QFracture and FRAX. Source [13] with kind permission from Springer Science and Business Media.

|  |  |  |
| --- | --- | --- |
|  | QFracture | FRAX |
| Externally validated | Yes (UK only) | Yes, internationally |
| Calibrated | Yes (hip only) | Yes |
| Applicability | UK | 57 countries |
| Falls as an input variable | Yes | No |
| BMD as an input variable | No | Yes |
| Prior fracture as an input variable | Yes | Yes |
| Family history as an input variable | Yes | Yes |
| Outcome | Hip, forearm, spine, shoulder | Hip, forearm, spine, humerus |
| Outcome metric | Incidence | Probability |

FRAX calculates fracture probability in individuals from age, body mass index and dichotomized risk factors comprising prior fragility fracture, parental history of hip fracture, current tobacco smoking, ever use of long-term oral glucocorticoids, rheumatoid arthritis, other causes of secondary osteoporosis and alcohol consumption [8]. Femoral neck BMD can be optionally input to enhance fracture risk prediction. Fracture probability is computed taking both the risk of fracture and the risk of death into account. The use of clinical risk factors in conjunction with BMD and age improves sensitivity of fracture prediction without adverse effects on specificity [14]. Even if the performance of FRAX is enhanced by the use of BMD tests, it should be recognised that FRAX without BMD has a predictive value for fractures that is comparable to the use of BMD alone [15]. The availability and access to densitometry in many countries is low [16], so that a major advantage of FRAX is the ability to assess fracture risk where BMD is unavailable.

Fracture probability varies markedly in different regions of the world [17]. Thus, the FRAX® models need to be calibrated to those countries where the epidemiology of fracture and death is known. Models are currently available for 58 countries across the world: for Argentina, Armenia (surrogate), Austria, Australia, Belgium, Brazil, Canada, Chile, Czech, China (revised 2013), Colombia, Croatia, Denmark, Ecuador, Estonia, France, Finland, Germany, Greece, Hong Kong, Hungary, Iceland, India (surrogate), Indonesia, Ireland, Israel, Italy, Japan, Jordan (updated), S Korea, Kuwait, Lebanon, Lithuania, Malta, Mexico, Morocco, Netherlands, New Zealand, Norway, Palestine (surrogate), Philippines, Poland, Portugal, Romania, Russia, Singapore, Slovakia, Sri Lanka (surrogate), Spain, Sweden, Switzerland, Taiwan, Thailand, Tunisia, Turkey, UK, US, Venezuela. The model is available in 27 languages: Arabic, Bengali, Chinese (traditional and simplified), Czech, Danish, Dutch, English, Finnish, French, German, Greek, Icelandic, Indonesian, Italian Japanese, Korean, Lithuanian, Norwegian, Polish, Portuguese, Romanian, Russian, Slovak, Spanish, Swedish, Thai and Turkish.

FRAX has been widely used for the assessment of fracture risk since the launch of the website in 2008 and currently processes approximately 225,000 calculations per month. Following regulatory review by the US Food and Drug Administration, FRAX was incorporated into DXA scanners to provide FRAX probabilities at the time of DXA scanning. For those without internet access, hand-held calculators and an application for Apple and Android smartphones have been developed by the IOF (<http://itunes.apple.com/us/app/frax/id370146412?mt=8>; https://play.google.com/store/apps/details?id=com.inkrypt.clients.iof.drfrax). A paper-based FRAX pad allows patients to document risk variables prior to medical consultation and is available from the IOF (www.iofbonehealth.org) in several languages.

The limitations of FRAX have been reviewed recently [18, 19]. In order to overcome some of these, relatively simple arithmetic procedures have been proposed which can be applied to conventional FRAX estimates of probabilities of hip fracture and a major fracture to adjust the probability assessment with knowledge of:

High, moderate and low exposure to glucocorticoids [20]  
Concurrent data on lumbar spine BMD [21, 22]  
Information on trabecular bone score (TBS) [23-25]  
Hip axis length [26]  
Falls history [27]

The use of FRAX in clinical practice demands consideration of the fracture probability at which to recommend treatment – termed the intervention threshold. Many different approaches have been used to set intervention thresholds with FRAX. The thresholds used have varied since they depend critically on local factors such as reimbursement issues, health economic assessment, willingness to pay for health care in osteoporosis, and access to DXA. The aim of the present report, supported by a systematic review, was to review the available information on the use of FRAX in assessment guidelines, in particular the setting of thresholds and their rationale. In addition, the performance characteristics of FRAX are reviewed to better inform the future developments of probability-based guidance.

**Research questions**

The National Osteoporosis Guideline Group aims to update its guidance on risk assessment. In so doing, three research questions were posed:

How is the FRAX calculator used in guidelines for fracture risk assessment?

What intervention thresholds are used in such guidelines, and what is the rationale for these thresholds?

How have the performance and implementation of guidelines/thresholds been assessed, and what are the findings?

**Methods**

*Design*

We undertook a systematic review of evidence to address the research questions, following the methods recommended by the Centre for Reviews and Dissemination (CRD), University of York (http://www.york.ac.uk/inst/crd/). Since quantitative synthesis of the data was inappropriate, we undertook a narrative review. The review protocol was registered with the International Prospective Register of systematic Reviews (Prospero; registration number: CRD42015027880)

*Outcomes*

Treatment intervention thresholds using FRAX for major osteoporotic fracture and hip fracture

Incidence of major osteoporotic or hip fracture

Health-economic benefit

*Inclusion criteria*

Studies and guidelines relating to risk assessment in the prevention of osteoporotic fracture using the FRAX calculator

Studies of intervention thresholds using the FRAX calculator including validation of thresholds

All studies which contributed relevant information were included, regardless of the setting. However, the setting was noted as part of data abstraction and was used in narrative synthesis. Studies were not excluded on the basis of publication date. There was no language restriction.

*Exclusion criteria*

Studies were excluded if they did not address human populations. We also excluded paediatric guidelines as the primary aim was to assess adult fracture prevention.

*Search strategy for identification of studies*

The search strategy was informed by initial scoping exercises (NCH, EM). We searched electronic databases including PubMed, Web of Science and Google Scholar, from their inception until 13th October 2015. Additionally, to reduce publication bias and to identify grey literature, we searched the abstracts of conference proceedings of the American Society for Bone and Mineral Research, European Calcified Tissue Society and World Congress of Osteoporosis, and the web sites of the 200+ National Societies affiliated to the International Osteoporosis Foundation (<http://www.iofbonehealth.org/societies-country-index-view/all>). We hand-searched the reference lists of publications and also web pages of national and international scientific societies related to the management of osteoporosis, and agencies that develop guidelines.

Search terms included:

1. FRAX

2. guideline

3. guidance

4. recommendation

5. 1 AND 2

6. 1 AND 3

7. 1 AND 4

We made an additional search to identify assessment guidelines from government agencies and non-governmental organisations where guideline collections were documented:

Obstetrics and gynecology guidelines Geneva Foundation for Medical Education and Research <http://www.gfmer.ch/Guidelines/Osteoporosis/Osteoporosis.htm>

US Department of Health and Human Services. National Guideline Clearing House <http://www.gfmer.ch/Guidelines/Osteoporosis/Osteoporosis.htm>

IOF <http://www.iofbonehealth.org/national-regional-osteoporosis-guidelines>

*Screening of abstracts*

When applying inclusion criteria, all abstracts, guidelines and potentially relevant papers were assessed by JAK, with independent parallel review by NCH, and decisions shown to be reproducible. Disagreements over inclusion were resolved through consensus and, where necessary, following discussion with a third member of the review team (EM).

*Data extraction and quality assessment*

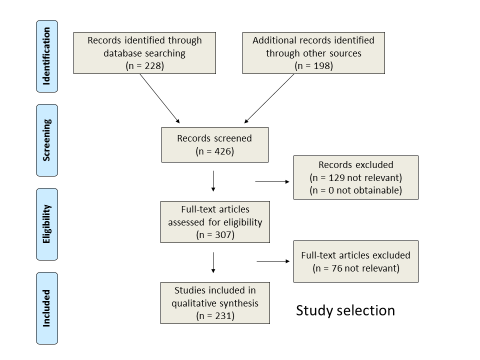
Data extraction was carried out in the same way as the abstract assessment. We undertook the quality assessment of studies using approaches specific to the study type, that is whether it was a guideline, or an assessment of a threshold/ guideline. With regard to the former, the assessment focused on the degree to which a guideline was developed on the basis of a rigorous evidence base versus expert consensus, with recognition that the majority would be a combination of these two approaches. Where several editions of guidelines were available, the most recent was retained unless otherwise specified. Where guidelines were abstracted or reviewed, the original guideline was retained unless further insight was available on the rationale for the setting of intervention thresholds with FRAX. With regard to assessments of thresholds or guidelines, we focused on elements of study design (appropriate adult population, outcome definition, fracture and/or health economic assessment, threshold definition). Given the nature of the studies, it was judged inappropriate to give a formal quality score. However, an appropriate critique was applied to characterise study quality.

*Data synthesis*

Owing to the nature of the review and the included studies, meta-analysis was not appropriate. We therefore undertook a narrative data synthesis in the presentation of the systematic review results.

**Results**

The initial search revealed 228 citations, with a further 198 identified from websites and other sources (Figure 1). After initial assessment for relevance 307 were retained for full appraisal and 231 were included in the narrative synthesis. Redundant or irrelevant articles (77) are provided in the appendix.



**Figure 1.**  Flow diagram demonstrating study identification and selection.

In reviewing FRAX-based intervention thresholds, it is important to recognise that the vast majority of assessment guidelines recommend that men and women with prior fractures are eligible for treatment [28]. In some countries, treatment is recommended in patients with fractures at the spine and hip e.g. Canada [29], the US [30], Japan [31] and Scotland [32]. Thus, with few exceptions, the place for FRAX resides in those patients without prior fractures (or without prior spine or hip fracture). The aim of this review was not to focus on the adequacy of this gateway for patient assessment but, rather, the subsequent triage with FRAX.

FRAX was launched in 2008. It is to be expected that there be a time-delay between the availability of new technologies and in its clinical acceptance, particularly given the long cycle between guideline development and their updates. In addition, the incorporation of FRAX-specific thresholds into guidance is commonly preceded by academic research to provide the rationale. However, the widespread availability of FRAX, during a time of transition, has resulted in the inclusion of FRAX in many with no clear statement on how the fracture probabilities derived are to be used for decision-making in clinical practice. We identified 38 guidelines or academic papers that fell into this category (Table 2).

**Table 2.** Guidelines or academic research papers providing information on FRAX without defining intervention thresholds.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Country/region |  | Sponsor/source | Footnote | Reference |
| Argentina |  | Academia |  | [33] |
| Asia Pacific |  | International Society of Clinical Densitometry |  | [34] |
| Brazil |  | Brazilian Society of Rheumatology and others | a | [35] |
| Bulgaria |  | Ministry of Health; Bulgarian Societies of Endocrinology and Rheumatology |  | [36] |
| Canada |  | Expert group | b | [37] |
| China |  | Chinese Gerontological Society |  | [38] |
| Croatia |  | Croatian Society for Rheumatology |  | [39] |
| Czech Republic |  | International Osteoporosis Foundation |  | [3] |
| Denmark |  | International Osteoporosis Foundation |  | [3] |
| Europe |  | European Society for Medical Oncology | c | [40] |
| Europe |  | European Menopause and Andropause Society |  | [41] |
| Europe |  | European League Against Rheumatism | a | [42] |
| France |  | Expert group | d | [43] |
| Germany |  | Dachverband Osteologie e.V | e | [44] |
| Hong Kong |  | Osteoporosis Society of Hong Kong |  | [45] |
| India |  | Indian Menopause Society | f | [46] |
| International |  | International Society of Clinical Densitometry |  | [47] |
| Ireland |  | Irish Osteoporosis Society |  | [48] |
| Italy |  | Società Italiana dell'Osteoporosi, del Metabolismo Minerale e delle Malattie dello Scheletro |  | [49] |
| Lebanon |  | Ministry of Public Health |  | [50] |
| Latin America |  | Iberoamerican Society of Osteology and Mineral Metabolism |  | [51] |
| Latvia |  | Latvian Osteoporosis and Metabolic Diseases Association |  | [52] |
| Lithuania |  | International Osteoporosis Foundation |  | [3] |
| Luxembourg |  | Conseil Scientifique, Domaine de la Santé |  | [53] |
| Malta |  | International Osteoporosis Foundation |  | [3] |
| Mexico |  | Mexican association for postmenopausal osteoporosis (AMMOM) |  | [54] |
| Netherlands |  | Dutch Institute for Healthcare Improvement (CBO) |  | [55] |
| Romania |  | Ministry of Health |  | [56] |
| Poland |  | Polish Osteoarthrology Society and Polish Foundation of Osteoporosis |  | [57] |
| Saudi Arabia |  | Saudi Osteoporosis Society |  | [58] |
| Slovakia |  | Ministry of Health |  | [59] |
| Spain |  | International Osteoporosis Foundation |  | [3] |
| Singapore |  | Ministry of Health |  | [60] |
| UK |  | National Institute for Health and Care Excellence |  | [61] |
| US |  | American Association of Clinical Endocrinologists |  | [62] |
| US |  | Academy of Orthopaedic Surgeons |  | [63] |
| US |  | American College of Physicians |  | [64] |
| US |  | American College of Preventive Medicine) |  | [65] |

a Guidelines for glucocorticoid induced osteoporosis

b Guideline for coeliac disease

c Guidelines for bone health in cancer

d Guideline for prostate cancer

e Uses an alternative risk assessment tool

f Guidance given in an accompanying editorial [66]

Where guidance on intervention thresholds has been provided, three broad approaches have been adopted. The first was to determine a *fixed threshold* that could be applied to men and women, irrespective of age. This could be applied either alone or as a component of other thresholds (e.g. BMD, parental history of fracture etc.). A second approach was to use *age-dependent thresholds* where the fracture probability at which treatment was recommended was age specific. Finally a study from the UK and a guideline from Lebanon have used both fixed and age-dependent thresholds – termed *hybrid thresholds*. These three approaches are reviewed in turn.

**The use of a fixed FRAX intervention threshold**

Several guidelines that use FRAX have recommended that a fixed probability threshold be used as an intervention threshold. Examples include a 20 % ten-year probability of a major fracture in Canada and the US, and a 15 % probability in Japan and Sweden [29, 31, 67, 68]. Other examples are given in Table 3.

**Table 3.** Intervention thresholds explored or adopted using a fixed FRAX probability for a major osteoporotic fracture (MOF) or hip fracture (HF).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  | Threshold (%) | |
| Country/region |  | Source | Reference | MOF | HF |
| --a |  | Academia | [69] | 20 | 3 |
| Austria |  | Pharmig, Verband der pharmazeutischen Industrie Österreichs | [70] | 20 |  |
| Belgium b |  | Academia | [71] | 20 | 3 |
| Canada |  | Osteoporosis Canada. | [29] | 20 |  |
|  |  |  |  |  |  |
| Canada |  | Ministry of Health, British Columbia | [73] | 20 |  |
| Canada |  | Society of Obstetricians and Gynaecologists of Canada | [74] | 20 |  |
| China |  | Academia | [75] | 4 | 1.3 |
| Czech c |  | Academia | [76] |  | 3 |
| Europe b |  | European Society for Clinical and Economic Aspects of Osteoporosis | [77] | 20 | 3 |
| Finland d |  | National | [78] | 10, 20 |  |
| Greece |  | Greek National Medicine Agency | [79] | 20 | 3 |
| Greece e |  | Academia | [80] | 10  15 | 2.5  5 |
| Hong Kong |  | Academia | [81] | 9.95 |  |
| Hungary |  | Hungarian Society for Osteoporosis and Osteoarthrology | [82] | 20 | 3 |
| Japan |  | Japan Osteoporosis Society; Japanese Society for Bone and Mineral Research; Japan Osteoporosis Foundation | [31] | 15 |  |
| Japan |  | Academia | [83] | 10 | 5 |
| Lebanon f |  | Ministry of Public Health and multiple societies | [84] | 10 |  |
| Malaysia |  | Ministry of Health, Malaysia | [85] | 20 |  |
| Malaysia |  | Malaysian Osteoporosis Society | [86] | 20 | 3 |
| Mexico |  | Colegio Mexicano de Ortopedia y Traumatología | [87] | 20 | 3 |
| Philippines |  | Osteoporosis Society of the Philippines and Philippine Orthopedic Association | [88] | 20 | 3 |
| Poland |  | Academia | [89] | 11.6, 17.4 |  |
| Poland |  | Multiple societies | [90] | 20 |  |
| Poland |  | Academia | [91] | 18 | 9 |
| Poland |  | Multidisciplinary Osteoporotic Forum | [92] | 10 |  |
| Portugal |  | Academia | [93] | 20 | 3 |
| Saudi Arabia |  | Academia | [94] | 20 | 3 |
| Scotland |  | Scottish Intercollegiate Guidelines Network | [32] | 10 j |  |
| Slovakia |  | Academia | [95] | 20 |  |
| Slovenia |  | Endocrine Society | [96] | 20 |  |
| Slovenia |  | Reimbursement agency | [97] | 10-20 |  |
| South Africa |  | National Osteoporosis Foundation of South Africa (NOFSA) | [98] |  | 3-5 |
| South Korea |  | Academia | [99] | 20 or 10 | 3 |
| Spain |  | Spanish Society of Rheumatology | [100] | 20 |  |
| Spain |  | Sociedad Española de Cirugía Ortopédica y Traumatología k | [101] | 20 | 3 |
| Spain |  | Sociedad Española de Endocrinilogia y Nutricion | [102] | 20 | 3 |
| Sri Lanka |  | Ministry of Health | [103] | 11 | 3-5 |
| Sweden g |  | Socialstyrelsen | [68, 104] | 15, 20 |  |
| Switzerland |  | Academia | [105] | 15 |  |
| Taiwan |  | Taiwanese Osteoporosis Association | [106] | 20 | 3 |
| Thailand |  | Royal College of Orthopaedic Surgeons of Thailand and the Thai Osteoporosis Foundation | [107] | 20 | 3 |
| UK |  | National Institute for Health and Care Excellence | [108] | Various k |  |
| UK f |  | Academia | [109] | 20 |  |
| UK h |  | Academia | [110] | 20 | 5 |
| US |  | National Osteoporosis Foundation | [67, 111] | 20 | 3 |
| US |  | US Preventive Services Task Force | [112] | 9.3 j |  |
| US d |  | American College of Rheumatology | [113] | 10 20 |  |
| US |  | Endocrine Society | [114] | 20 | 3 |
| US i |  | Academia | [115] | 20 |  |
| US |  | Michigan Quality Improvement Consortium | 116] | 9.3 j |  |
| US |  | American College of Obstetricians and Gynecologists | [117] | 20 | 3 |
| US |  | North American Menopause Society | [118] | 20 | 3 |
| US |  | Family practice | [119] | 20 | 3 |
| US |  | Academia | [120] | 20 | 3 |
| US |  | National Comprehensive Cancer Network (NCCN) | [121] | 20 | 3 |
| US |  | American Academy of Family Physicians | [122] | 9.3 j |  |
| US |  | Institute for Clinical Systems Improvement | [123] | 9.3 j |  |
| US |  | Institute for Clinical Systems Improvement | [72] | 20 | 3 |

a Guideline for chronic obstructive pulmonary disease

b Guidance for women treated with aromatase inhibitors for breast cancer

c Guidelines for glucocorticoid induced osteoporosis.

d Guidelines for glucocorticoid induced osteoporosis. Thresholds dependent on dose and duration of exposure

e Higher thresholds at age 75 years or more.

f Hybrid model, also uses an age-dependent threshold at some ages (see *Hybrid intervention thresholds using FRAX*)

g 15 % =investigation threshold; 20-30 % = treatment threshold

h Guideline for Parkinson disease

i Endogenous hypercortisolism

j Assessment threshold for subsequent testing with BMD

k Intervention threshold set where treatment becomes cost-effective

More than one half (39) of the 58 publications reviewed utilize a threshold probability of 20 % for a major osteoporotic fracture, many of which also mention a hip fracture probability of 3 % as an alternative intervention threshold. This is understandable in those guidelines arising from the US (see below) but in 25 other countries, in nearly all instances, no rationale is provided other than the fact that this was the threshold used by the National Osteoporosis Foundation of the US.

The minority of papers that provide some logic for the manner by which thresholds were set are those from the US, Japan, Poland, Hong Kong and Switzerland, which are each briefly reviewed. Although the SIGN guidance in Scotland gave no rationale for the chosen threshold [32], this is also included because of its similarity to that of the US Preventive Services Task Force] [112] and because its impact has been assessed [13]. Additionally, the Taiwanese guidelines are reviewed as this is the sole guideline developed that uses FRAX as the exclusive gateway to treatment.

*National Osteoporosis Foundation (NOF), US*

Apart from recommending treatment in individuals with a prior hip or vertebral fracture, the primary gateway for patient assessment under the NOF guidance is the assessment of BMD [111]. Treatment is recommended for those with BMD defined osteoporosis at the femoral neck, total hip, or lumbar spine by DXA. FRAX is reserved for men and women with low bone mass (T-score between −1.0 and −2.5, osteopenia) at the femoral neck, total hip, or lumbar spine. For osteopenic subjects, a fixed intervention threshold is recommended for all ages and for both sexes set at 20 % for a major osteoporotic fractures and 3 % for hip fracture probability [30]. The intervention thresholds were based on an economic analysis [124] (see *Health economic approach to intervention thresholds with FRAX*).

The impact of the introduction of FRAX to the NOF guidelines has been assessed in women from the population-based Framingham study [125]. At all ages, the proportion of women meeting treatment criteria was slightly less when the 2008 guidelines, including FRAX as above, were applied (41.1 %) compared with the 2003 guidelines (47.8 %). However, the impact was age-dependent. The proportion of women under the age 65 years meeting treatment criteria was markedly less when applying 2008 Guidelines (8.3 % vs. 23.1 % in 200 (USPSTF8 and 2003, respectively), whereas the proportion of women at or over age 75 years increased slightly (86.0 % vs. 78.3 %).

An analysis of the National Health and Nutrition Examination Survey III [126] estimated a higher proportion of the women eligible for treatment under the 2003 guidance than in the Framingham study (53% vs. 48%, respectively) but overall the 2008 guidance decreased the percentage of eligible women to 41%. Also, the guideline revision directed intervention more to the elderly at high risk and less to younger women with osteopenia but at low risk. Overall, approximately 20 million men and women in the US would be eligible for treatment [126].

*The US Preventive Services Task Force*

Like the NOF, the US Preventive Services Task Force (USPSTF) recommends BMD testing in all women age 65 years or older. For younger women age 50-65 years, FRAX is recommended as a screening tool for BMD testing. A BMD test is recommended in younger women whose fracture probability is equal to or greater than that of a 65-year-old white woman who has no additional risk factors [112]. With the U.S. FRAX tool, a 65-year-old white woman of average BMI (25 kg/m2) with no other risk factors has a 9.3 % 10-year probability for a major osteoporotic fracture. In women age 50-65 years who exceed this threshold, a BMD test is indicated and treatment recommended in those in whom BMD is in the range for osteoporosis.

The probability threshold of 9.3 % used by the USPSTF appears logical, but is inappropriate in the sense that “The objective of screening is to identify postmenopausal women with T-scores of -2.5 SD or lower” [127]. In such a case it is more appropriate to use tools that detect osteoporosis rather than a tool to assess fracture risk [128]. Appropriate tools include the Osteoporosis Self-Assessment Tool (OST) and Simple Calculated Osteoporosis Risk Estimation Tool (SCORE) [129, 130]. OST is calculated from weight and age, whereas SCORE uses 6 clinical risk factors (race, rheumatoid arthritis, history of non-traumatic fracture, age, prior oestrogen therapy, and weight). As might be expected, Crandall et al [127] showed that the FRAX based (USPSTF) strategy had a somewhat higher specificity but much lower sensitivity than SCORE or OST for the identification of individuals with a femoral neck T-score of ≤-2.5 SD (Table 4). The low sensitivity with the FRAX cut-off means that two thirds of women with a BMD in the range of osteoporosis would be missed. Similar findings have been reported in an independent cohort [131].

**Table 4**. Sensitivity, specificity (%) and area under the receiver operating characteristic curve (AUC) using three assessment tools for the identification of individuals with femoral neck T-score ≤-2.5 SD (extracted from [127]).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Tool | Cut off | Sensitivity | Specificity | AUC |
| FRAX | 9.4 % | 33.3 | 86.4 | 0.60 |
| SCORE | >7 | 74.1 | 70.8 | 0.72 |
| OST | <2 | 79.3 | 70.1 | 0.75 |

Had the intention of screening been to identify women at high fracture risk, then a fracture risk assessment algorithm is the appropriate tool. In this context FRAX outperforms OST or SCORE for fracture prediction [8].

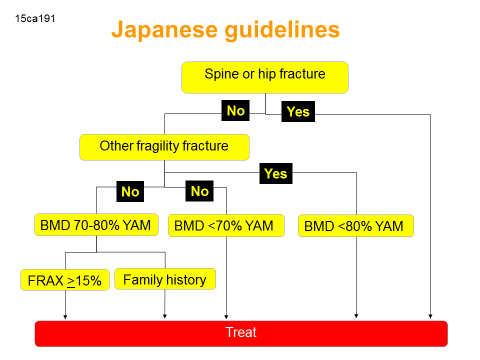
*American College of Rheumatology*

The most recent (2010) recommendations from the American College of Rheumatology (ACR) provide guidance for patients exposed to glucocorticoids [113]. Recommendations are stratified by glucocorticoid dose and fracture risk based on FRAX calculations. They recommend that low- and medium-risk patients (FRAX <10 and 10–20 % probability of a major fracture, respectively) should be treated if their glucocorticoid dose is greater than or equal to 7.5 mg/day. High-risk patients (FRAX >20 %) should be treated if they receive glucocorticoids at any dose for >1 month or if they are on >5 mg/day prednisolone equivalent even for <1 month [113]. The 10 % threshold is lower than the generally accepted 20 % threshold for postmenopausal osteoporosis in use in North America [132]. The rationale for the two thresholds is the established exposure-dependent association of glucocorticoids and fracture risk [133]. The 20 % threshold was chosen to match that of the National Osteoporosis Foundation though there are no details provided on how the 10 % threshold was derived. The same thresholds have been adopted in Finland [78].

*Japanese National Guidelines*

In 2012, the Japan Osteoporosis Society, Japanese Society for Bone and Mineral Research (JSBMR) and Japan Osteoporosis Foundation updated the guidance of the JSBMR issued ten years previously, [31]. As is the case for most assessment guidelines, treatment is offered to individuals with a prior vertebral or hip fracture. In common with the NOF guidelines, testing with BMD provides the gateway thereafter in the assessment algorithm (Figure 2). The BMD thresholds used are unique to Japan; intervention is based on BMD expressed as a % of young adult mean values (YAM). These diagnostic (and intervention) thresholds were derived by maximising sensitivity and specificity for fracture detection with several technologies at several skeletal sites [134]. Intervention thresholds using YAM were set at 70 % and 80 %. For BMD at the femoral neck with DXA, a YAM of 70 % and 80 % are equivalent to a T-score of −2.7 SD and −1.8 SD, respectively, using the NHANES III reference for BMD at the femoral neck in Caucasian women aged 20–29 years (the international T-score referent used in FRAX).

After the FRAX tool became available, probabilities of a major osteoporotic fracture were calculated that were equivalent to the existing intervention thresholds based on YAM [135]. Thresholds of equivalence varied with age, ranging from 5 % at an age of 50 years to more than 20 % at the age of 80 years. Although equivalent probabilities were age-dependent, the guideline revision recommended a fixed intervention threshold of 15 % for major osteoporotic fracture for men and women with no fracture history and a YAM between 80 and 70 % (the Japanese equivalent to osteopenia) [31].



**Figure 2.**  Flow chart for the assessment of osteoporosis in Japan.

*Poland*

A study of a convenience sample of 1,608 women age 40-89 years in the region of Bialystok, Poland recommended an intervention threshold set at 18 % probability of a major osteoporotic fracture or a 9 % probability of a hip fracture [91]. These values approximated the mean fracture probabilities in women with a prior fragility fracture.

A subsequent approach to the development of FRAX-based intervention thresholds in Poland was, as in Japan, to determine the fracture probabilities that were equivalent to intervention thresholds that pre-existed the development of FRAX. At that time, intervention was recommended in individuals with a BMD T-score of < -2.5 SD or a prior fragility fracture. Badurski [89] explored FRAX-based intervention thresholds in 1608 postmeno­pausal women from Białystok, Poland using the UK FRAX model that were equivalent to a T-score of -2.5 SD and a prior fragility fracture. The mean 10‑year probability of a major osteoporotic fracture was 11.6 % with BMD included in the FRAX model in women with a T-score of -2.5 SD or less. In women with a prior fragility fracture, the mean probability was 17.4 %. Note that these thresholds were based on the UK version of FRAX and subsequently, a Polish-specific model became available (June 2011).

The authors concluded that age specific intervention thresholds were more clinically appropriate than a fixed probability threshold for all ages (see *Age-dependent thresholds in other countries* below). Notwithstanding, Polish guidelines subsequently recommended (expert opinion) a fixed intervention threshold of 10 % for a major osteoporotic fracture [92].

*Hong Kong*

Fixed FRAX thresholds were explored in a convenience sample of 2,266 postmenopausal Chinese women from Hong Kong followed for an average of 4.5 years to determine the incidence of new fractures [81]. One hundred and six new major osteoporotic fractures were reported. The sensitivity and specificity of two FRAX-based strategies were explored. The first was to determine the operating characteristics in women where the threshold probability was set to the age-specific fracture probability equal to that of a woman with a prior fracture. The second was to determine the ‘optimal’ fixed FRAX threshold.

Where the threshold probability was set to the age-specific fracture probability equal to that of a woman with a prior fracture (FRAX, with BMD), the sensitivity and specificity was 47 % and 83 %, respectively. Unsurprisingly, the use of a fixed threshold across all ages yielded higher sensitivity. The optimal cut-off point for the 10-year probability of a major fracture as 9.95 % was identified with a sensitivity of 62.3 %, a specificity of 73.5 %) and a positive predictive value of 10.3 %. The current guidance of the Osteoporosis Society of Hong Kong mentions the 20 % fixed threshold of NOF but gives no practical guidance on the use of FRAX in Hong Kong [45].

*China*

In China, intervention thresholds were set at 4 % for the 10-year probability of major osteoporotic fracture and 1.3 % for hip fracture. In a series of postmenopausal women, 37.5 % were found to have osteoporosis calculated with BMD. The FRAX-based thresholds were set at the 62.5 (100-37.5) percentile of the FRAX distribution i.e. to match the prevalence of osteoporosis [75].

*Switzerland*

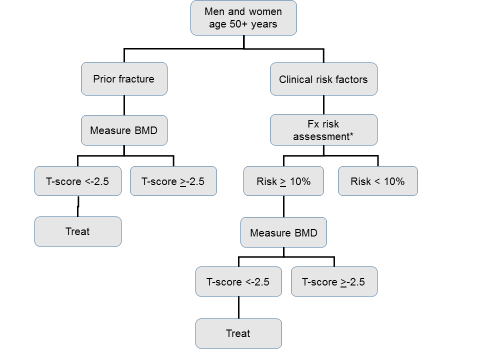
In Switzerland, a FRAX intervention threshold of 15% probability of a major osteoporotic fractures was set, based on a cost-utility analysis. The age-dependent variations around these mean values were judged to be modest [105]. Treatment was recommended in men age 55 years or above and women age 60 years or above with prior fractures. In those without a prior fracture, treatment was recommended where the probability of major osteoporotic fracture was 15% or above. The same paper explored the NOGG approach in order to compare the results with the economic analysis (see *Health economic approach to intervention thresholds with FRAX*).

*Scottish Intercollegiate Guidelines Network (SIGN)*

The Scottish Intercollegiate Guidelines Network (SIGN) issued guidance on the management of osteoporosis and the prevention of fragility fractures [32]. These represent a departure from their earlier guidelines following the endorsement of risk assessment algorithms by National Institute for Health and Care Excellence (NICE) in the UK [11].

The SIGN guidance utilises a 10% fixed intervention threshold but gives no explanation for the choice. However the threshold is similar to that used in the USPTF guidance and is deployed in much the same way [112] (see *The US Preventive Services Task Force* above).

The assessment algorithm is summarised in Figure 3. In brief, there are different pathways for patients with a prior fragility fracture and those with other clinical risk factors for fracture. Patients with a prior fragility fracture are assessed by DXA (at the spine or hip) and treatment considered in patients with a T-score diagnosis of osteoporosis. There is an exception for a prior vertebral fracture (not defined) or prior hip fracture where BMD testing is left to the physician’s discretion. In the case of men and women aged 50 years or more without a prior fracture, individuals are screened using other clinical risk factors. In the presence of clinical risk factors, fracture risk is assessed either with QFracture® or FRAX® (but preferentially the former). Where the cumulative 10-year incidence of major osteoporotic fracture (10-year probability in the case of FRAX) equals or exceeds 10 %, then a BMD test is recommended and treatment considered in patients with a T-score diagnosis of osteoporosis.



**Figure 3.** Summary of assessment algorithm in the SIGN guidance

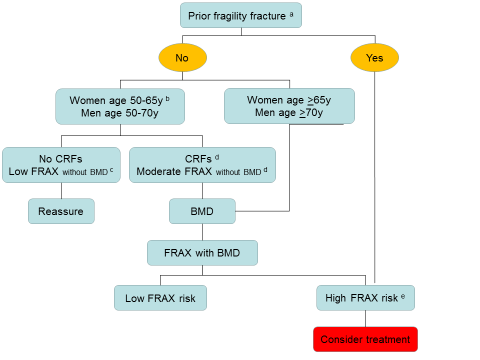
Apart from individuals with a prior fracture where BMD is usually recommended, the FRAX threshold (10 % probability of a major fracture) is used to determine the eligibility of individuals to have a BMD test to detect the presence of absence of osteoporosis. However, the FRAX assessment does not thereafter influence the interpretation of the BMD test. In other words, FRAX (and QFracture) are used as a screening tools for the detection of densitometric osteoporosis. Thus, the SIGN guidance firmly entrenches a T-score threshold of -2.5 SD as an intervention threshold, reminiscent of European and UK guidance nearly 20 years ago [136, 137].

The SIGN guidance does not distinguish the output from FRAX and QFracture. In other words, the 10 % threshold is used irrespective of the assessment tool that is used. Since the units of measurement differ (cumulative incidence for QFracture and probability for FRAX) together with the problems of calibration [13], clinical decisions will also differ.

This makes an assessment of the impact of the guidelines problematic. Indeed, independent research indicated that the number of women eligible for testing in Scotland was 275,600 if FRAX were used as a screening tool but only 26,500 with the use of QFracture (28 % and 3 % of the total population, respectively). The number of women eligible for treatment (i.e. with osteoporosis) was 81,700 with the use of FRAX and 12,300 with QFracture representing 8.2 % and 1.2 % of the total population, respectively [13].

*Taiwan*

The most purist application of the fixed threshold is seen in the guidelines from Taiwan [138]. The Taiwanese guidelines adopt a 20 % threshold for a major osteoporotic fracture and a 3 % threshold for hip fracture probability as in the NOF guidelines but extend its application in that the FRAX thresholds are the sole gateway to treatment (Figure 4). Thus, the Taiwanese guidelines do not differentiate between those with osteoporosis or osteopenia, or on prior fracture status.

****

**Figure 4** Algorithm for the assessment of fracture risk in men and postmenopausal women from Taiwan [138].

CRFs, clinical risk factors. MOF, major osteoporotic fracture.

a Prior fragility from the age of 50 years

b Postmenopausal women age 50-65 years

c Low FRAX risk; probability of MOF or hip fracture <10 % and <1.5 %, respectively

d Moderate FRAX risk; hip fracture probability >1.5 % and <3 % or MOF probability >10 % and <20 %

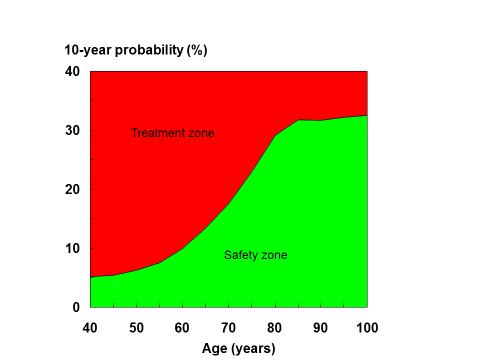
e High FRAX risk; hip fracture probability >3 % or MOF probability >20 %

To our knowledge, this is the only guideline that does not give ‘preferential’ treatment to individuals with a prior fragility fracture. The use of a fixed threshold in this way is likely to outperform the age-dependent algorithms. A small comparative study applied to a Hong Kong cohort compared the Taiwan guidelines to the Hong Kong equivalent of the NOGG guidance [81]. A total of 2266 women (mean age 61 years) were followed for 4.5 years (range 1-14.6). More women were selected under the Taiwan guideline than by NOGG (25.4 % vs 15.5 %, respectively) but the crude incidence in women eligible for treatment was similar (10.9 vs. 10.3 %). This suggests a higher sensitivity in the Taiwanese guidelines. The study suffers from the low number of fractures recorded; during the follow-up period; 106 (4.7 %) women sustained a new fracture at the proximal humerus, hip, clinical spine or forearm. Additionally, the categorisation of women was incorrectly applied to those triaged using the Taiwan guidelines in that individuals with prior fracture were allocated to treatment.

**Age dependent intervention thresholds using FRAX**

*Principles of derivation*

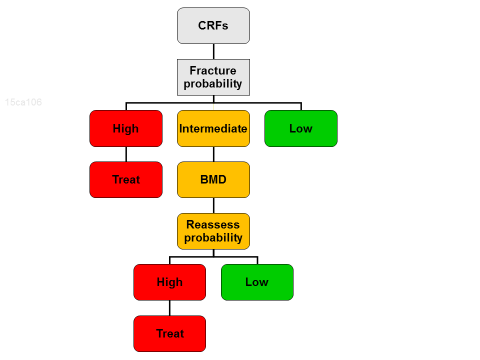
The launch of FRAX in April 2008 was shortly followed by the National Osteoporosis Guideline Group (NOGG) thresholds, with an easy-to-use link via the FRAX UK calculator website [139]. Briefly, the NOGG guidance ‘translated’ the preceding Royal College of Physicians guideline [137] which indicated that women with a prior fragility fracture may be considered for intervention without the necessity for a BMD test for the purpose of making the treatment decision. The translational logic used is that if a woman with a prior fragility fracture is eligible for treatment, then a woman with the same fracture probability but, in the absence of a previous fracture, should also be eligible. For this reason, the intervention threshold in women without a prior fracture at any given age can be set at the age-specific fracture probability equivalent to women with a prior fragility fracture [140] and, therefore, rises with age (Figure 5). In other words, the intervention threshold is set at the age-dependent ‘fracture threshold’.



**Figure 5**. The 10-year probability (%) of a major osteoporotic fracture by age in women with a prior fracture and no other clinical risk factors in the five major EU countries (weighted average of Spain, France, Germany, Italy and UK) as determined with FRAX (version 3.5). Body mass index was set to 24 kg/m2 without BMD. The line dividing the red and green zones represents the age-dependent intervention threshold or ‘fracture threshold’. (Extracted from [28] with kind permission from Springer Science and Business Media.

*Management algorithm*

A general approach to risk assessment is shown in Figure 6 [140]. The process begins with the assessment of fracture probability and the categorization of fracture risk on the basis of age, sex, BMI and the clinical risk factors. On this information alone, some patients at high risk may be considered for treatment without recourse to BMD testing. For example, many guidelines recommend treatment in the absence of information on BMD in women with a previous fragility fracture (a prior vertebral or hip fracture in some countries).

****

**Figure 6** Management algorithm for the assessment of individuals at risk of fracture [140], with kind permission from Springer Science and Business Media.

Conversely low risk individuals would not normally be eligible for further assessment. The intermediate category in Figure 6 will vary in different countries. In countries that encourage screening (the US) or that provide reimbursement for DXA, this will be a large category, whereas in the many countries with limited or no access to densitometry, the size of the intermediate group will necessarily be small. In other countries (e.g. the UK), where provision for BMD testing is sub-optimal [16], the intermediate category will lie between the two extremes.

*National Osteoporosis Guideline Group (NOGG), UK*

NOGG developed age-dependent intervention thresholds for the UK shortly after the first release of FRAX in 2008 [141] with an update in 2013 [139]. The lower assessment threshold was set to exclude a requirement for BMD testing in women with no clinical risk factors, as given in the prevailing RCP and European guidelines [136, 137]. The upper threshold was chosen to minimise the probability that a patient characterised to be at high risk on the basis of clinical risk factors alone would be re-classified to be at low risk with additional information on BMD [142]. The upper assessment threshold was set at 1.2 times the intervention threshold.

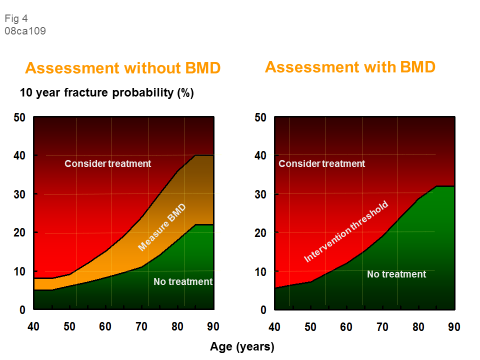
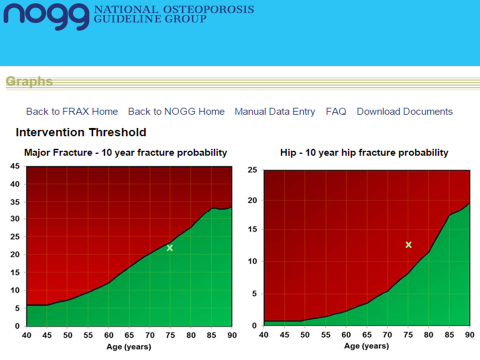


Figure 7. Assessment and treatment thresholds in the absence of a BMD test (left) and with a BMD test to compute fracture probability (right) for men and women. Redrawn from [141]

In keeping the majority of guidelines worldwide, individuals with a prior fragility fracture can be considered for treatment without the need for further risk assessment although BMD measurement may be appropriate to monitor treatment.

In those without prior fragility fracture but other clinical risk factors, the 10-year probability of a major osteoporotic fracture (clinical spine, hip, forearm or humerus) is determined using FRAX. Men and women with probabilities below the lower assessment threshold can be reassured (Figure 7). Those with probabilities above the lower assessment threshold but below the upper assessment threshold can be considered for testing with BMD using DXA and their fracture probability reassessed. NOGG also developed intervention thresholds based on hip fracture probability. Men and women with probabilities above the intervention threshold for major osteoporotic fracture OR for hip fracture are deemed eligible for treatment. Note that the same intervention threshold is applied to men as in women, since the effectiveness Kanis 2011a] and cost-effectiveness of intervention in men are broadly similar to that in women for equivalent risk [105,124, 143].

Without computer access, colour coded charts are available that give average fracture probabilities according to BMI and the number of clinical risk factors. There is, however, a link from the FRAX web site to the NOGG web site ([www.shef.ac.uk/NOGG](http://www.shef.ac.uk/NOGG) ) and the probability of both hip fracture and major osteoporotic fracture can be automatically displayed (Figure 8).

****

**Figure 8**. NOGG web page plotting the results of a FRAX measurement (Female age 75 years with a BMD T-score of -2.0 SD and a parental history of hip fracture). In the example, treatment is recommended since the hip fracture probability exceeds the intervention threshold ([www.shef.ac.uk/NOGG](http://www.shef.ac.uk/NOGG) ).

*Uptake and impact of NOGG*

The linkage of FRAX to the NOGG web site can facilitate treatment decisions and appears to be well used [109]. Between 1st July 2013 and 30th June 2014, there were 348,964 sessions (a user interaction with the website) from UK-based users on the FRAX web site. Over the same time, 253,530 sessions were recorded on the NOGG website and the vast majority (82 %) arose from users in the UK, of which almost all (95.7 %) arose from calculations passing from the FRAX site to NOGG.

The NOGG approach to assessment has been compared with previous guidance issued by the Royal College of Physicians, London (RCP) [144]. Compared with the RCP strategy, NOGG identified slightly reduced numbers of women above the respective intervention threshold (average 34.6 % vs. 35.7 % across all ages). The proportion of women in the UK potentially eligible for treatment using NOGG rises from 20 % to 40 % with age [140]. At older ages (75+ years), NOGG recommended treatment in fewer patients without prior fracture but these were at higher risk than those identified by RCP. For example, at age 80 years the expected incidence was 28.6 % in those identified by RCP but was 40 % in those identified by NOGG. A further difference between the two strategies was that more efficient use was made of BMD measurements in younger women with no loss in sensitivity for hip fracture (Table 5). For example, at the age of 55 years, nine BMD scans were required to identify a single case of future hip fracture in women in the RCP strategy, whereas only two BMD scans were required in the NOGG approach. The lower number of BMD tests means that the acquisition costs for identifying a hip fracture case and the total costs (acquisition and treatment) per hip fracture averted were also lower. The economic dividend is discussed below (see *Health economic approach to intervention thresholds with FRAX; Table 8*). A reduction in the use of BMD tests was also reported in a comparison between NOGG and the NOF guidance applied to a Spanish cohort [145].

**Table 5.** Comparison of the number of patients selected for treatment/1000 and hip fractures identified by the RCP and NOGG strategies in all women, by age. The number selected is the number fulfilling requirements for treatment under the strategies. Hip fracture is the expected numbers of hip fractures in those selected for treatment. NNS is the number needed to scan to identify one hip fracture case. From [144], with kind permission from Springer Science+Business Media B.V.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **RCP** | | |  | **NOGG** | | |
| Age (y) | N selected\* | Hip fractures | NNS |  | N selected\* | Hip fractures | NNS |
| 50 | 218 | 17 | 13.9 |  | 230 | 18 | 3.5 |
| 55 | 254 | 25 | 8.7 |  | 252 | 25 | 1.9 |
| 60 | 295 | 36 | 5.4 |  | 288 | 35 | 1.7 |
| 65 | 328 | 60 | 3.0 |  | 341 | 62 | 2.1 |
| 70 | 371 | 84 | 2.0 |  | 365 | 83 | 1.7 |
| 75 | 422 | 101 | 1.5 |  | 395 | 95 | 0.9 |
| 80 | 468 | 128 | 1.0 |  | 434 | 120 | 0.6 |
| 85 | 503 | 142 | 0.8 |  | 462 | 133 | 0.4 |

\* includes women identified for therapy on the basis of prior fracture alone

*Age-dependent thresholds in other countries*

The age-dependent approach to intervention threshold adopted by NOGG has been explored or adopted in several countries and in European guidance for postmenopausal osteoporosis and glucocorticoid-induced osteoporosis (Table 6). Independent web sites similar to the NOGG site have been developed for Finland, Lebanon and Romania (available via the FRAX website).

**Table 6.** Proposed and established intervention strategies using age-specific fracture probabilities

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Country |  | Source | Reference |  |
| Australia |  | Academia | [146] |  |
| Belgium |  | Academia | [147] |  |
| Brazil |  | Academia | [148] |  |
| Europe |  | European Society for Clinical and Economic Aspects of Osteoporosis and Osteoarthritis; International Osteoporosis Foundation | [28] |  |
| Europe a |  | International Osteoporosis Foundation; European Calcified Tissue Society | [149] |  |
| Finland |  | Finnish Medical Society (Duodecim), Finnish Endocrine Society and Finnish Gynaecological Association | [150] |  |
| France |  | French Society for Rheumatology and Groupe de Recherche et d’Information sur les Ostéoporoses (GRIO), | [151] |  |
| Hong Kong |  | Academia | [81] |  |
| India |  | Indian menopause society | [66] |  |
| Ireland |  | Academia | [152] |  |
| Japan |  | Academia | [135] |  |
| Lebanon b |  | Ministry of Public Health and multiple societies | [84] |  |
| Mexico |  | Ministry of Health | d |  |
| Poland |  | Academia | [89] |  |
| Romania |  | Ministry of Health | [56] |  |
| Romania |  | Academia | [153] |  |
| Russia |  | Academia | [154] |  |
| Russia |  | Russian Association on Osteoporosis | [155] |  |
| Spain |  | Sociedad Española de Cirugía Ortopédica y Traumatologíac | [101] |  |
| Sri Lanka |  | Ministry of Health | [103, 156] |  |
| Switzerland |  | Association Suisse contre l‘Ostéoporose | [105,157] |  |
| UK |  | NOGG | [141] |  |
| UK |  | Nottinghamshire | [158] |  |
| UK b |  | Academia | [109] |  |

a Glucocorticoid-induced osteoporosis

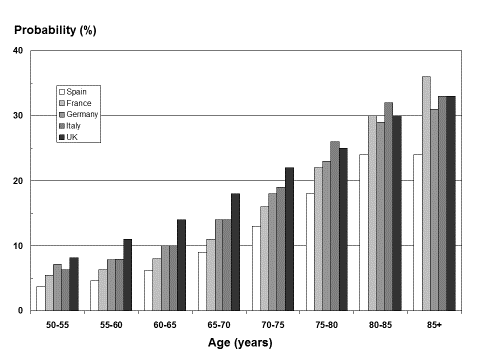
b Hybrid model, also uses a fixed threshold at some ages (see *Hybrid intervention thresholds using FRAX*)

c Also recommend fixed thresholds

d P Clark, personal communication October 2015

The majority of publications adopt an identical approach to NOGG. Two exceptions are hybrid models adopted in Lebanon [84] and being explored in the UK [109]. The impact of guidelines has been explored in Belgium which showed that adoption of the age-dependent guidance, compared with current reimbursement guidelines, would have a marked beneficial effect on the budget impact by the more accurate targeting to high risk patients and the avoidance of intervention in those at low risk [159].

Using the same criteria, the intervention threshold will vary from country to country because the population risks (of fracture and death) vary [17]. The fracture probability in women with a prior fracture in the five major EU countries is shown in Figure 9. Probabilities are highest in the UK and lowest in Spain. The difference between countries is most evident at younger ages and becomes progressively less with advancing age [3]. In Europe, the proportion of men and women age 50 years and older above this threshold varies little from 11-13% [2].



**Figure 9** The 10-year probability of a major osteoporotic fracture by age in women with a prior fracture and no other clinical risk factors in the five major EU countries as determined with FRAX (version 3.5). Body mass index was set to 24 kg/m2 without BMD [3], with kind permission from Springer Science and Business Media.

Several independent research studies have examined age-dependent intervention thresholds with the use of FRAX and these are briefly reviewed.

*Poland*

A comparison of a fixed and age-specific intervention thresholds was explored in 1608 unselected postmeno­pausal women from Białystok, Poland using the UK version of FRAX [89]. Intervention thresholds were set at fracture probability equal to that of women with a BMD T‑score of –2.5 standard deviations irrespective of age (fixed threshold), women with a prior fracture (fixed threshold), the combination (fixed threshold) or an age‑dependent threshold. As expected, all scenarios were more efficient than no threshold (Table 7). Compared to the fixed threshold, the age-dependent threshold identified fewer women but at higher risk thereby increasing the dividends of intervention. The Polish Multidisciplinary Osteoporotic Forum, however, elected to use a fixed probability threshold of 10 % a [92], close to the threshold derived from a fixed BMD T-score of -2.5 SD (11.6 % [89].

**Table 7.** The effect of two different intervention thresholds in postmenopausal women aged 50 years or older. The fixed threshold was the average fracture probability in women with a prior fracture (17.5 % probability of a major fracture). The age-specific threshold was set to be equal to that of a woman of the same age with a prior fragility fracture (4-33 % depending on age). Adapted from [89].

|  |  |  |  |
| --- | --- | --- | --- |
|  | No threshold | Fixed threshold | Age-dependent |
| Eligible women |  | Prior fracture | Prior fracturea |
| % identified | 100 | 38.5 | 15.5 |
| Fracture probability, %c | 12.3 | 18.4 | 23.7 |
| Expected number of fracture patients in 10 years/1000b | 123 | 184 | 237 |
| Fractures saved by treatment c | 36 | 21 | 11 |
| Number needed to treat | 27 | 18 | 14 |

a age‑dependent thresholds

bc in those eligible for treatment

c 30 % efficacy (relative risk = 0.7)

*Australia*

An age-dependent threshold has been explored in Australia using a large cohort of men and women who were randomly selected participants from the database of Australia's universal health insurance provider (Medicare Australia) [146]. A comparison was made of the number of men and women who would be eligible for treatment following the NOGG approach (i.e. age-dependent thresholds using the Australian FRAX model), the NOF thresholds (>3 % or >20 % probability of hip and major fracture, respectively) and the current guidelines. The authors suggested that too few men and women fell above these intervention thresholds and proposed age-dependent thresholds based on hip fracture probability. They were set at ≥3% for men and women age 50–69 years, ≥5 % for 70–79 years and ≥7 % for ≥80 years. No rationale was offered for the choice other than the alternatives “did not work well in the Australian population”.

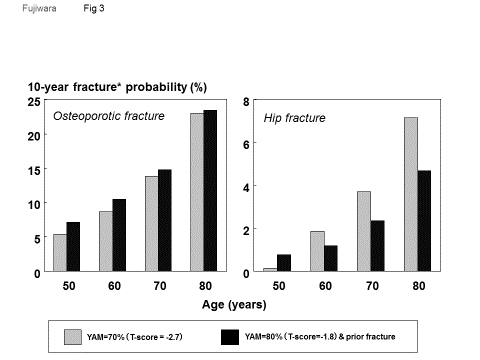
There was a number of limitations in the assessment. The FRAX tool used was a simplified version based on the number of clinical risk factors. A prior history of fracture that was used in the analysis comprised fracture in the previous five years. This would have markedly underestimated the prevalence of a past history of fragility fracture. Thus, a large number of individuals, eligible for treatment under the NOGG or NOF guidelines, would have been missed. The comparison with the NOF guidelines was unfair in that eligibility for treatment on the basis of FRAX was reserved for individuals with osteopenia and not the whole population over the age of 50 years.

*Hong Kong*

In Hong Kong, the NOF, NOGG and Taiwanese guidelines were compared in a cohort of community-dwelling, ambulatory, postmenopausal women age 40 years or more (mean age 62 years) and comprised 2261 women followed on average for 4.5 years [81]. During the follow-up period, only 106 women sustained a new fracture at the proximal humerus, hip, clinical spine or forearm so that the relative performance characteristics were difficult to compare. In addition, FRAX was calculated using locally derived T-scores which would bias the findings differently in each guideline. Overall, the clinical utility index (the product of positive concordance rate and positive predictive value) for the three guidelines was low. In line with the findings from the UK [160], the requirement for BMD testing was lowest for the NOGG approach.

*Japan*

As previously discussed, the revision of the Japanese guidelines by the Japan Osteoporosis Society, Japanese Society for Bone and Mineral Research, and Japan Osteoporosis Foundation opted to use a probability of FRAX for major osteoporotic fracture of 15 % in those subjects without other additional factors, such as low BMD and prior fracture (see Figure2) [31]. However, thresholds of equivalence to BMD- based intervention thresholds also varied with age, ranging from 5 % at the age of 50 years to more than 20 % at the age of 80 years (Figure 10) [135]. Thus, the 15 % fixed threshold was a compromise, possibly driven by the need for simplicity.

**

**Figure 10** Ten-year probability of osteoporotic (hip, clinical spine, humerus or forearm) and hip fracture based on women at the threshold for the diagnosis of osteoporosis using the criteria of the Japanese Bone Mineral Metabolism Association. From [135] with kind permission from Springer Science and Business Media.

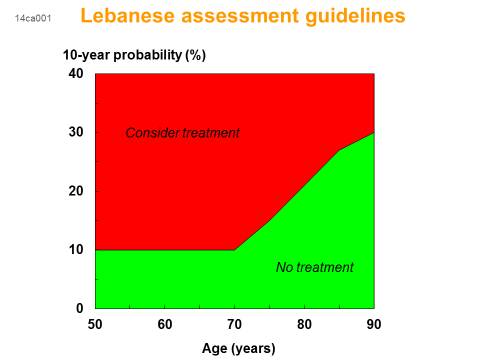
**Hybrid intervention thresholds using FRAX**

The hybrid model for intervention adopts both fixed and age-dependent thresholds. To date, two such models have been explored that differ substantially in their approach. The one from Lebanon uses a fixed threshold up to the age of 70 years and an age-dependent threshold over the age of 70 years [84]. The other from the UK uses an age- dependent threshold up to the age of 70 years and fixed threshold over this age [109].

*Lebanon*

For the determination of an intervention threshold, both a fixed (20% ten-year probability of a major fracture) and an age-dependent (NOGG-like) intervention threshold model were considered, and a hybrid model finally adopted [84]. It was considered that application of the NOGG model at the fracture threshold for Lebanon would result in over-treating a large proportion of women at low risk for fractures (below 10 %) up to the age of 70 years. It also would be too taxing financially at the public health level, as it would treat 25-30 % of postmenopausal women, a treatment that is also not without its risks when started at such a young age. The authors did not define overtreatment.

Treatment is recommended with a history of fragility fracture at the spine or hip or the presence of two or more fragility fractures at other sites. For subjects who have not experienced any fragility fracture, the intervention threshold is set at ≥ 10 % for the 10-year probability of a major fracture for individuals up to age 70 years. For individuals above age 70 years, the threshold increases with age: 15% at 75 years, 21% at 80 years, 27% at 85 years, and 30% at 90 years (Figure 11).



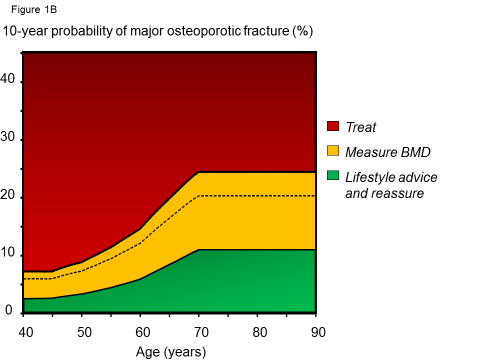
**Figure 11.** Intervention thresholds in Lebanon that use a fixed threshold up to the age of 70 years and thereafter an age-dependent threshold.

Of note is that a BMD T-score ≤ -2.5 SD, in the absence of additional risk factors, is no longer an indication for treatment in itself due to the very low estimated 10-year probability of fracture in such clinical scenarios (the 10-year overall risk of fractures is less than 10 %, both in women up to age 70 years, and men up to age 90 years).

*UK*

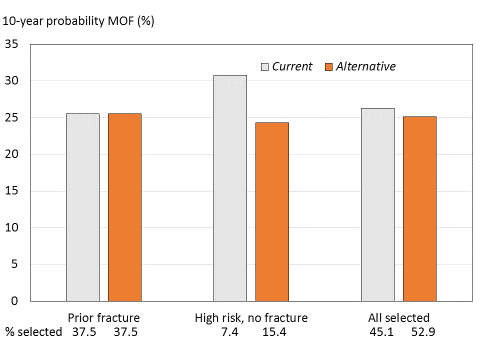
Although NOGG has become well accepted, some anomalies arise from the starting premise that individuals with a prior fragility fracture should be eligible for treatment without the requirement for a BMD test. Although not a prerequisite for the eligibility for treatment, many primary care practitioners undertake a BMD test – sometimes as a baseline to monitor treatment. When fracture probability is reassessed this may lie below the treatment threshold in some patients (for example in women with a higher than average age-specific BMD). This may be a source of confusion. The obverse is also true; namely that those eligible for treatment without a prior fracture have on average higher probabilities than those eligible on the basis of a previous fragility fracture. This inequity, results in a lower sensitivity of the algorithm for individuals without a prior fracture, as previously noted [160]. The inequity is most apparent in the elderly. As a mechanism of compensation, it was proposed that a fixed intervention threshold be used at the age of 70 years or more [109].

The analysis was based on a simulated population of 50,633 women aged 50-90 years in the UK, with a distribution of risk factors similar to that in the European FRAX derivation cohorts and a UK-matched age distribution. The 5th percentile of major osteoporotic fracture probability in UK women aged 75 years or older with prior fracture was 19.2%. This value approximated the mean value of major osteoporotic fracture probability at the age of 70 years (20.3%) so that for ease of translation, a fixed threshold at 20% was chosen from the age of 70 years. The assessment thresholds for BMD testing were also fixed from the age of 70 years (Figure 12). The corresponding threshold for intervention based on hip fracture probability was 5.4% at 70 years and was applied to women age 70 years or above.

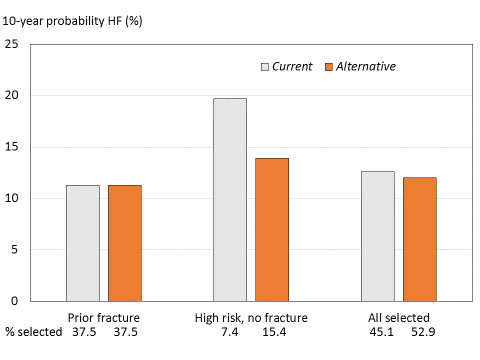
****

**Figure 12.** Graph of intervention and assessment thresholds showing the alternative thresholds in the hybrid model. The dotted line represents the intervention threshold and the assessment thresholds enclose the amber area. From [109] with kind permission from Springer Science and Business Media.

In the case of major osteoporotic fracture probability, women in the UK at the age of 70 years or more with a prior fracture had an average 10-year probability of 25.5% using the NOGG algorithm. This was lower than the probability in women selected without prior fracture (30.8%). For hip fracture probability, the inequity was more marked (average probability 11.3% and 19.7%). With the use of a fixed intervention threshold set at a 20% probability for a major osteoporotic fracture, the differences in average probability all but disappeared (Figure 13). The same phenomenon was seen for hip fracture probabilities (Figure 14). Another feature of the hybrid model was that the need for BMD testing in the elderly was reduced, particularly at older ages (>80 years). The number of BMD tests would be decreased by approximately half.



**Figure 13.** Mean probability of major osteoporotic fracture (MOF, %) in patients age 70 years or more identified for consideration of treatment under the current thresholds (light bars) and the alternative thresholds (shaded bars). Data extracted from [109].



**Figure 14**. Mean probability of hip fracture (HF, %) in patients age 70 years or more identified for consideration of treatment under the current thresholds (light bars) and the alternative thresholds (shaded bars). Data extracted from [109].

Figures 13 and 14 also show the proportions of women eligible for treatment. Amongst women age 70 years or more the use of the alternate hybrid model would increase the proportion of women assessed over the age of 70 years without a prior fracture from 7.4 % to 15.4 %.

**Health economic approach to intervention thresholds with FRAX**

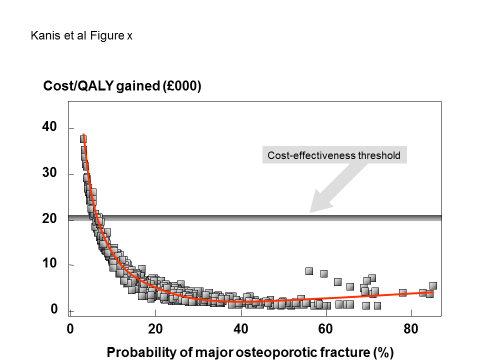
The National Clinical Guideline Centre (UK) did not identify economic studies that examined the cost-effectiveness of measures that used FRAX for targeting people at high fracture risk [161]. The deficit is being addressed in the SCOOP (screening of older women for prevention of fracture study) [162]. SCOOP is a randomised controlled trial designed to test screening for risk of fracture for women aged 70 to 85 years with the use of FRAX. Women in this age group recruited to the study will either be screened or managed as usual. Those screened and considered at high risk will be offered treatment by their GPs. The study will have a follow-up of 5 years and it is hoped that screening will reduce the number of fractures by around 25 %. The study has a health-economics component and is due to report its findings later this year.

*Cost effectiveness of intervention based on FRAX*

There are several appraisals that have assessed the cost-utility of interventions that used the probability of fracture. Indeed, models have been developed that incorporate the FRAX algorithms [163, 164]. The approach has generally been to determine the fracture probability at which interventions became cost-effective (i.e. an economic threshold). Economic thresholds have been variously used to set intervention thresholds or to validate the use of clinically driven intervention thresholds

National Osteoporosis Guideline Group

The NOGG age-dependent thresholds were driven by clinical considerations. At the same time NOGG wished to determine whether the strategy was cost-effective. The relationship between fracture probability and cost-utility were derived from all of the possible combinations of CRFs and BMD and age. This approach has been explored for the use of alendronate [105-165], risedronate [166], denosumab [164, 167], raloxifene, [168], strontium [169] and bazedoxifene [163, 170]. The major intervention in the UK and many other countries is alendronate [2]. In the case of generic alendronate treatment compared to no treatment was found to be cost-effective at a 10-year probability of a major fracture of 5.6 % (95% credibility interval; 4.8-6.8 %) in women from the UK at the age of 50 years (Figure 15) [14]. The economic threshold varied little by age and the mean threshold was 6.9 % with the range of 95 % credibility intervals between 4.2 and 9.6 %. In this analysis, the cost of alendronate was set at £95 per year, which is now a conservative figure since the current price has subsequently fallen to £12. Given that NOGG-based intervention thresholds range from 7.5 % at the age of 50 years to 30 % in the elderly [140], NOGG concluded that treatment with alendronate under the NOGG strategy was cost-effective.



**Figure 15.** Correlation between the probability of a major osteoporotic fracture and cost-effectiveness of generic alendronate at the age of 50 years in women from the UK (BMI set to 26 kg/m2). The line indicates the willingness to pay set at £20,000/QALY gained. Each point represents a particular combination of BMD and clinical risk factors. Taken from [140] with kind permission from Springer Science and Business Media.

The threshold probability at which treatment became cost-effective was higher with treatments other than alendronate, related in large part to the higher cost of intervention. For example, with willingness to pay set at £20,000 per QALY, treatment in the UK with risedronate was cost-effective at a probability threshold of 17% at the age of 50 years [166]compared with a threshold of 7% with generic alendronate. Other studies have examined strontium ranelate, bazedoxifene and denosumab in this way [167, 169, 170]. However, the cost-effectiveness of different interventions will vary between countries due to differences in drug costs, fracture risk, costs of treating fractures, utility estimates and willingness to pay.

The cost of the NOGG strategy has also been determined and compared with the RCP guidelines [160]. The identification costs and costs per averted hip fracture for the RCP and NOGG strategies are shown in Table 8. The NOGG strategy resulted in a lower cost per identified or averted fracture across all ages. As a consequence of the larger number of scans required, the costs of identification of incident hip fractures were somewhat higher, particularly at younger ages, using the RCP strategy. For example, at the age of 60 years, the cost per hip fracture identified was almost 1.5-fold higher for the RCP approach (£407 vs. £278). The differences in costs between the two strategies were less marked at older ages (Table 8).

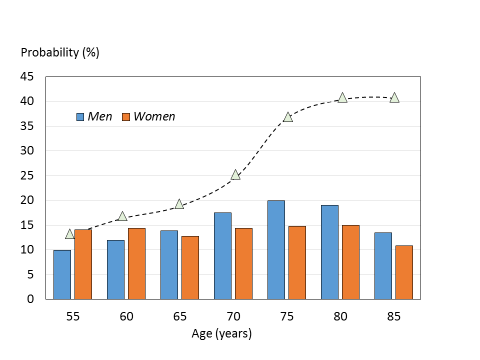
**Table 8.**  Comparison of the identification and total costs (identification and treatment) per hip fracture averted for the RCP and NOGG strategies. From [160] with kind permission from Springer Science and Business Media.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Age (years) | Cost per hip fracture identified (£) | |  | Total cost per hip fracture averted (£)\* | |
|  | RCP | NOGG |  | RCP | NOGG |
| 50 | 891 | 506 |  | 6,211 | 4,797 |
| 55 | 597 | 352 |  | 4,607 | 3,678 |
| 60 | 407 | 278 |  | 3,505 | 3,020 |
| 65 | 243 | 216 |  | 2,256 | 2,144 |
| 70 | 176 | 171 |  | 1,765 | 1,716 |
| 75 | 145 | 132 |  | 1,609 | 1,537 |
| 80 | 114 | 102 |  | 1,371 | 1,306 |
| 85 | 103 | 89 |  | 1,306 | 1,231 |

\* The cost of treatment was set at £100 equivalent to 5 years of therapy with generic alendronate (approximately £19 per annum [p.a.]) on the assumption that 5 years of treatment would confer a 10-year fracture benefit with a relative risk reduction of 35 %,

Switzerland*.*

In Switzerland, FRAX intervention thresholds of 13.8 % (for major osteoporotic fractures) or above (range, 10.8 to 15.0 %) and 15.1 % (range, 9.9 to 19.9 %) for women and men, respectively, were reported to be cost-effective using branded alendronate as the intervention [105]. The willingness to pay was set at 2 X GDP/capita. In addition to women age 60 years or above and men age 55 years or above with prior fractures, treatment was recommended for rest of the population at risk who had FRAX (for major osteoporotic fracture) probabilities of 15 % or above. If a NOGG approach to intervention thresholds were applied to the Swiss population, the vast majority of intervention scenarios would be cost-effective (Figure 16). Subsequent Swiss guidelines abandoned this approach in favour of age-dependent thresholds [157].

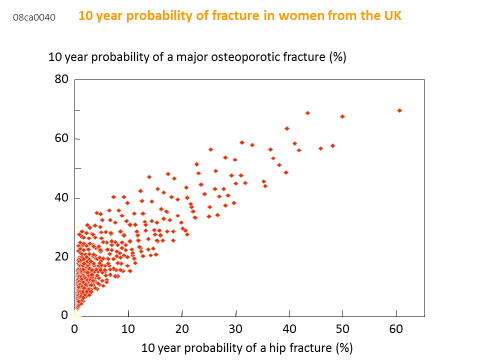


**Figure 16.**  Fracture probabilities at which treatment with alendronate becomes cost-effective in men and women from Switzerland. The dotted line denotes the fracture probability at the fracture threshold (i.e. the probability equivalent to a woman with a prior fracture by age). Adapted from [105].

National Osteoporosis Foundation

The NOF set a 3% probability of hip fracture and a 20% 10-year probability of a major fracture as intervention thresholds in women with osteopenia in their clinical practice guidelines of 2008 [132]. The basis of this was a health economic analysis that examined the cost-effectiveness of pharmaceutical intervention [124]. A Markov cohort model of annual US age-specific incidence of hip, wrist, clinical spine and other fractures, costs (2005 US dollars), and quality-adjusted life-years (QALYs) was used to assess the cost-effectiveness of osteoporosis treatment ($600/year drug cost for 5 years with 35 % fracture reduction). A 5-year course of treatment with a bisphosphonate-like therapy was modelled. In white men and women, treatment became cost-effective at a hip fracture probability of 3.4 % and 3.8 %, respectively. The corresponding probabilities in blacks were 3.3 % and 3.4 %. On this basis, the NOF chose (optimistically) a 10-year hip fracture probability of 3 % as an intervention threshold. A 20 % probability of a major osteoporotic fracture was chosen as being equivalent to a hip fracture probability of 3 %.

The adoption of the 20 % fixed intervention threshold has had an enormous impact on the setting of thresholds in many countries worldwide for no better reason than this was the threshold adopted by the US (see Table 3). It is relevant then to draw attention to some limitations in the interpretation of the findings. The first relates to the threshold for hip fracture probability that was chosen by the NOF since the analyses consistently showed that at this threshold, intervention was cost-ineffective as noted above. Secondly, the relationship between hip fracture probability and that for major fracture is not straightforward. Whereas there is a correlation between the probability of hip fracture and the probability of a major fracture, this is of poor predictive value (Figure 17) [140]. Indeed, the predicted probability of a major osteoporotic fracture derived from the probability of hip fracture could lie anywhere between 5 and 25%. Thirdly, the economic analysis was undertaken 8 years ago and many of the underlying assumptions will have changed in the interval.



**Figure 17**. Relation between the 10-year probability of a major osteoporotic fracture and the 10-year probability of a hip fracture in women aged 50 years from the UK. Each point represents a particular combination of BMD and clinical risk factors. From [140] with kind permission from Springer Science and Business Media.

A fixed threshold was also evaluated in a Spanish population and compared with the use of BMD as a gateway to treatment [171]. The use of a 7.5% threshold for a major osteoporotic fracture decreased markedly the requirements for BMD testing and the cost/fracture averted.

National Institute for Health and Care Excellence (NICE)

Although the FRAX algorithm was used in early appraisals by NICE, the output was to determine the cost-effectiveness of individual agents according to clinical characteristics (T-score at -2.5 SD, prior fracture etc. [172-174]. The resulting guidance was complex and not without some controversy [175]. More recently a draft appraisal from NICE has been released for consultation [108] that incorporates fracture probability as an output variable. For the bisphosphonates alendronate and risedronate, the incremental net benefit with a willingness to pay of £20,000/QALY gained was positive over the range of fracture probabilities that were studied.

Hybrid thresholds (UK)

There has been no formal health economic assessment of the UK hybrid variant where an age-dependent intervention threshold is used up to the age of 70 years and, thereafter, a fixed threshold is employed. Up to the age of 70 years, the threshold is identical to that used by NOGG. In the economic analysis from NOGG, intervention with generic alendronate was cost-effective at fracture probabilities for a major osteoporotic fracture that exceeded 7-8 % [140], significantly far removed from the 20 % threshold provided in the hybrid model. A similar analysis with risedronate, which cost £264 at the time, showed cost-effectiveness at a probability threshold of 18 % [166], close to the alternative intervention threshold studied in this paper. The 8-fold reduction in the cost of alendronic acid since then and the more recent availability of cheap generic forms of other osteoporosis agents including risedronate, ibandronic acid and zoledronic acid support the notion that the fixed intervention threshold comfortably represent cost-effective scenarios.

Greece

In a health economic assessment from Greece [80] proposed a biphasic intervention threshold based on cost-utility derived from on a previously developed state transition Markov cohort model developed for the International Osteoporosis Foundation [176]. The model was used to determine fracture probabilities at which intervention became cost-effective. The model was used in the Greek healthcare setting and economic thresholds determined employing the FRAX tool, recently calibrated for Greece. A bisphosphonate-like intervention for 5 years was modelled using the weighted average cost of treatments offered in Greece. From the results (Table 9) a “biphasic” economic probability threshold was proposed using 10-year probabilities for hip and major osteoporotic fractures of 2.5 and 10 %, respectively, under the age of 75 years, and 5 and 15 %, respectively from the age of 75 years. The authors indicate that the proposed thresholds are consistent with the present guidelines for Greece which recommend treatment based on BMD defined osteoporosis or a prior fragility fracture [79].

**Table 9.** Probability thresholds at which treatment in men and women from Greece became cost effective determined for the 10-year probability of hip fracture or a major osteoporotic fracture (MOF). Data extracted from [80].

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Women | |  | Men | |
| Age (years) | Threshold | Range |  | Threshold | Range |
| *MOF* |  |  |  |  |  |
| 50-54 | 13 | 8.9-20 |  | 20 | 11-34 |
| 55-64 | 8.5 | 7.8-9.1 |  | 9.5 | 9.3-9.6 |
| 65-74 | 8.9 | 8.5-9.2 |  | 9.5 | 8.9-10 |
| >75 | 15 | 13-16 |  | 11 | 10-11 |
|  |  |  |  |  |  |
| *Hip fracture* |  |  |  |  |  |
| 50-54 | 1.2 | 0.9-1. |  | 1.4 | 1.0-1.8 |
| 55-64 | 1.2 | 1.0-1.5 |  | 1.2 | 1.2-1.5 |
| 65-74 | 2.2 | 1.8-2.6 |  | 2.3 | 2.3-2.4 |
| >75 | 6.5 | 4.7-7.8 |  | 5.7 | 4.5-6.6 |

**Discrimination of FRAX**

Discrimination is the ability to distinguish people at high risk from people at low risk. The performance characteristics of FRAX were validated prior to its launch by comparing the increase in fracture risk per SD of change in the risk score (termed the gradient of risk) [14]. The gradients of risk in the nine cohorts used to construct FRAX were compared with those determined in 11 validation cohorts comprising 230,486 men and women studied for 1,208,528 person years. During follow-up, there were 18,543 osteoporotic fractures, 3360 of which were hip fractures. Gradients of risk did not differ from the original cohorts used for model building (Table 10). Whereas both BMD and the clinical risk factors alone provide significant gradients of risk for fracture, the highest gradients of risk are seen when BMD is co-entered into the FRAX model. These data give some credence to the view that the original algorithms may be widely applicable, though further validation is required in men and in ethnic groups not covered in these analyses. An important observation was that gradients of risk were markedly age-dependent making cross-comparison not possible with studies that do not adjust for age.

**Table 10.** Gradients of risk (RR per SD change in with 95 % confidence intervals) in men and women with the use of BMD at the femoral neck, clinical risk factors or the combination. Source [14] with kind permission from Springer Science+Business Media B.V]

|  |  |  |  |
| --- | --- | --- | --- |
|  | Gradient of risk | | |
| Age (years) | BMD only | Clinical risk  factors alone | Clinical risk  factors + BMD |
| *(a) Hip fracture* |  |  |  |
| 50 | 3.68 (2.61–5.19) | 2.05 (1.58–2.65) | 4.23 (3.12–5.73) |
| 60 | 3.07 (2.42–3.89) | 1.95 (1.63–2.33) | 3.51 (2.85–4.33) |
| 70 | 2.78 (2.39–3.23) | 1.84 (1.65–2.05) | 2.91 (2.56–3.31) |
| 80 | 2.28 (2.09–2.50) | 1.75 (1.62–1.90) | 2.42 (2.18–2.69) |
| 90 | 1.70 (1.50–1.93) | 1.66 (1.47–1.87) | 2.02 (1.71–2.38) |
| *(b) Other osteoporotic fractures* | |  |  |
| 50 | 1.19 (1.05–1.34) | 1.41 (1.28–1.56) | 1.44 (1.30–1.59) |
| 60 | 1.28 (1.18–1.39) | 1.48 (1.39–1.58) | 1.52 (1.42–1.62) |
| 70 | 1.39 (1.30–1.48) | 1.55 (1.48–1.62) | 1.61 (1.54–1.68) |
| 80 | 1.54 (1.44–1.65) | 1.63 (1.54–1.72) | 1.71 (1.62–1.80) |
| 90 | 1.56 (1.40–1.75) | 1.72 (1.58–1.88) | 1.81 (1.67–1.97) |

In this context, there was a rash of so-called validation studies between 2009 and 2012, that reported the performance characteristics of FRAX using ROC curves [177-188] to give but a few. Other examples are given elsewhere [189]. Some of these were summarised and reported by the National Clinical Guideline Centre [161] though, for unknown reasons, the validation studies in Table 10 were omitted. The same paper reported sensitivities and specificities at a fixed but inappropriate threshold. For a variety of reasons, it is inappropriate to compare performance characteristics using ROC curves across studies [190]. Reasons include the variable follow up of different cohorts and the need to standardise by age [14]. Fewer such analyses have been reported recently although those listed above regrettably still appear in systematic reviews [161, 191, 192]. For the reasons given above, we prefer the use of gradients of risk as given in Table 10.

*Comparing cohort-specific models with FRAX*

Omission of CRFs from fracture prediction models has been suggested in a number of publications, since alternative and simpler models discriminate as well as or better than FRAX [178- 184]. The attraction for the deletion of CRFs is either to convert a complex model into a simpler tool that is easier to use in routine clinical practice, or to have a more accurate tool for a local population. The argument runs that the application of an independent ‘home grown’ model to an index cohort with fewer risk factors gives the same or better discrimination of cases and controls than does the more complex FRAX model. Irrespective of the reasoning, the logic is faulty as are the methodological approaches [193]. An internal model will almost invariably provide higher gradients of risk (or fracture discrimination) than models that are derived externally. This arises because the internal model is constructed to best fit the data within the index cohort, whereas an external model is necessarily derived from other sources. It follows that any assessment of predictive value within a single cohort will not necessarily be identical to the predictive value for the future. In the context of fracture risk prediction, the internal model is un-validated and only of retrospective value to the population studied.

The fallacy of comparing internal with external models is shown in a report by Bolland and colleagues [180] who studied a cohort of healthy women from New Zealand enrolled in a 5-year trial of calcium supplements, and followed on average for 8.8 years. The area under the curve (AUC) for receiver operating characteristic curves (ROC) curve for hip fracture was 0.69-0.70 with FRAX. The AUC was similar in the cohort –specific model that only used age.

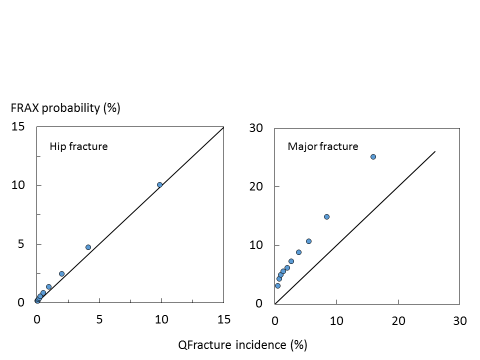
**Calibration of FRAX**

Several sources have reported that there are limited studies of the calibration available for FRAX [161, 192]. However, the view is somewhat misplaced in that each FRAX model goes through an *internal* calibration step [8]. Thus, if the whole population of a country were to be FRAXed with the country-specific model, the number of deaths and hip fractures would match those predicted by FRAX. The calibration is, however, dependent on the accuracy of the fracture hazard and death hazard for each country or ethnicity. For this reason, where possible, FRAX models are built on national data.

Additionally any validation exercise will be critically dependent on the representativeness of the population tested for the index country. There are several studies that have studied populations that represent national populations.

*England*

The first was based on a UK prospective open cohort study of routinely collected data from 357 general practices on over 2 million men and women aged 30-85 years. The area under the ROC curve for the FRAX algorithm in hip fracture prediction was 0.85 for women and 0.82 for men. Given the small differences in the incidence of hip fracture assumed by FRAX and that observed in the cohort, FRAX appears well calibrated for hip fracture in the UK. The calibration of major osteoporotic fractures differs markedly when compared with Q fracture [9] (Figure 18), which has been attributed to a greater accuracy of QFracture compared with FRAX [11, 32]. However, the available evidence indicates that the converse is more likely, and that QFracture is poorly calibrated for this fracture outcome, probably because of the low quality of computerised general practitioner records [13].



**Figure 18.** Comparison of the distribution of FRAX and QFracture (QF) model output by decile of risk in women for hip fracture (left panel) and major fracture (right panel). The diagonal line shows the line of identity. From [13] with kind permission from Springer Science and Business Media.

*Canada*

The second study was from Canada [194]. Observed ten-year fracture incidence from men and women in the CaMos study (n = 1,919 and 4,778, respectively) was compared with fracture probabilities based on the Canadian FRAX tool (both without and with BMD). FRAX-estimated 10-year probabilities for a major osteoporotic fracture were similar to the incidence rates in men (5.4 % vs. 6.4 %, respectively) and in women (10.8% vs. 12.0%). Similar findings were reported for hip fracture risk. Comparable findings were also reported in a large Canadian BMD referral population from Manitoba [195] (Figure 19). Note however, that incidence is compared with probability so that, as expected, incidence values are higher than probability values. In a subsequent analysis in untreated women, FRAX estimates of fracture probability were very closely matched with those observed when adjusted for competing mortality; for hip fracture, the mean predicted probability was 1.9% and that observed was 1.9%. For major fractures, the respective values were 10.9% and 10.0% (95% CI, 8.8-11.2) [197]. Thus, FRAX appears well calibrated for Canada. A strength of these studies is that fracture incidence was collected over 10 years and only the first major fracture taken into account.



**Figure 19.** 10-year fracture probability for a major fracture derived from the Canadian FRAX tool with and without BMD versus observed 10 year fracture rates (95 % confidence interval) by risk category (low, less than 10 %; moderate, 10-20 %; high, greater than 20 %) with BMD (solid line) and without BMD (dashed line). The dashed line depicts the line of identity. Redrawn from [195].

*Denmark*

A registry linkage study (Danish National Register of social security numbers) was undertaken to determine FRAX-based probabilities using baseline questionnaire data derived from a structured questionnaire [197]. From a random sample of 5000 women, complete information was available for 3,636 women. FRAX hip fracture probabilities were calculated without BMD using the Swedish tool. Predicted and observed risks estimates incorporated adjustment for 10-year survival rates. The predicted 10-year hip fracture risk was 7.6 % overall with observed risk also 7.6 %, ranging from 0.3 % at the age of 41–50 years (observed risk 0.4 %) to 25.0 % at the age of 81–90 years (observed risk 24.0 %). There were no significant differences overall or by decade of age. For the closely related Scandinavian countries of Sweden and Denmark, a single FRAX tool may be sufficient.

*Kuopio Osteoporosis Risk Factor and Prevention (OSTPRE) study*

The most thoughtful and revealing calibration study was undertaken in Finland using information from the Kuopio Osteoporosis Risk Factor and Prevention (OSTPRE) study cohort of postmenopausal women from the Kuopio Region of Finland. OSTPRE was one of the 12 cohorts used in the risk factor evaluation of osteoporotic fractures during the development of FRAX. The population included 13,917 women who were still alive after a 10-year follow-up, and excluded women who had sustained a previous hip fracture. Observed hip fracture outcomes were compared with hip fractures expected using the Finnish FRAX model [198]. The Finnish FRAX model (version 3.6) was based on the national incidence of the first hip fracture for 2002 to 2006 [199] and national mortality data supplied by the WHO. FRAX without BMD was calculated in 11,182 women and femoral neck BMD information was available in a subset of 2,755 women for the calculation of hip fracture probability with BMD.

The relationship between the FRAX probability of a hip fracture and the 10-year period prevalence of a hip fracture was examined by quintiles of hip fracture probability. The average predicted probability of a hip fracture during a 10-year period was 0.80 % (95 % CI: 0.78–0.81) when calculated without BMD and the same for the subset of women with BMD measurement. The similarity of predictions with and without BMD indicates that the subgroup studied was not preferentially enriched by women with low (or high) BMD for age. The 10-year period prevalence was lower than predicted (0.71 %), was even lower in women in whom FRAX without BMD had been calculated (0.66 %) and lowest in those in whom FRAX with BMD had been calculated (0.61 %).

The relatively moderate calibration might lead one to the view that the use of the Finnish FRAX model results in misleading information as a result of errors in accuracy. Errors of accuracy in the FRAX model may, in principle, reside in the fracture hazards or the death hazards, both of which contribute to fracture probability but the model used national data and there is no reason to question the validity of these hazards, especially because it is known that regional variation in hip fracture incidence is small in Finland [200].

However, these findings also showed that the 10-year period prevalence of the hip fracture (and thereby hip fracture incidence) varied according to observation status. Thus the likely reason for poor calibration is the selection bias between those who did and did not respond. Women who had reported enough information for the calculation of a FRAX probability had a tendency for a lower risk of hip fracture than women who did not respond; that is, many women with a high risk for a hip fracture may have been missing from the calibration calculations. This occurred in spite of the relatively high response rate of 84–88 % in each of the OSTPRE enquiries used. Thus, such bias is likely to be present in most of the corresponding study cohorts: not only do they not represent the whole population, but the people with the highest risks are missing.

As an aside, self-reports missed 38 % of all hip fractures in the national register in women who responded and missed about 45 % of hip fractures in women who had a FRAX estimate.

*Difficulties in calibration of FRAX*

The considerations above highlight intrinsic difficulties with sampling bias and incomplete fracture acquisition. There are several additional problems to be faced with the external calibration of FRAX models.

Difficulties arise when FRAX probabilities are compared with observed incidences [177, 179-182, 184-186, 188, 201, 202]. Other examples are listed in Leslie and Lix [189]. In the case of FRAX, the algorithm computes a fracture probability (i.e. a metric that incorporates the death hazard), which is not synonymous with simple fracture incidence. As a result, the comparison is largely invalid, particularly at older ages, and it is wrong to conclude that a FRAX tool or comparator tool is ill-calibrated.

One of the ways of checking bias is to compare calibration with and without the inclusion of BMD. Because of the internal calibration of FRAX, fracture probabilities (particularly for hip fracture) will be the same in a sample representative of the national population. The several studies that report differences in fracture probabilities with and without BMD [182], [181, 182, 184, 202-206] should be treated with suspicion with regard to calibration.

Cohorts used for validation should be representative of the population because fracture and death rates may vary within countries. For fracture risk, this may vary more than two-fold [18] so that the interpretation of non-representative cohorts is difficult.

In addition to geographic variation reported in the incidence of hip fracture within countries, the age-and sex-specific incidence of fracture is changing in several countries. This has been well characterised for hip fracture, but also noted at other sites of fracture [207, 208]. Estimates of incidence trends have varied widely and variously reported as an increase, plateau, and decrease, in age-adjusted incidence rates for hip fracture among both men and women. In contrast, the mortality hazard has continued to decrease in most regions of the world. FRAX is based on cohorts studied years prior to the launch of FRAX in 2008, so that there may 10+ years between the FRAX model and the cohort testing the calibration. As noted above, the calibration of the FRAX algorithms is only as good as the epidemiology with which the tools are populated. Indeed the FRAX models have been updated where more recent or higher quality data have become available (e.g. Turkey and the US).

Regardless of the difficulties to be faced with calibration, it should be noted that any systematic errors have little impact on the rank order of fracture probabilities produced by the FRAX tool. For example, the FRAX tool for the United States was revised to take into account changes in hip fracture and mortality risks [209]. Importantly, the revisions have little impact on the stratification of fracture probabilities because the revisions do not change the rank order of fracture probability in any population. In the US revision, the correlation coefficients between versions 2.0 and 3.0 probabilities exceeded 0.99, so that the one can be accurately predicted from the other. In other words, an individual at the 90th percentile of risk would still be at the 90th percentile of risk using the revised FRAX tool, though the probability of a major fracture that was 53 % in the original version was 44 % in the revision. Thus, the consequences of improving accuracy reside in the absolute number generated and not in the rank order of risk so that the consequences of inaccurate epidemiological data are of minor consequence to daily clinical practice. An exception arises when fracture probabilities are used in health-economic analysis to inform practice guidelines where accuracy becomes a matter of importance.

*Other determinants of accuracy*

A number of studies have investigated potential errors of accuracy within populations. The accuracy of FRAX does not appear to be affected by socioeconomic status – at least in Canada [210]. A much smaller study from Australia suggested no association of FRAX with socioeconomic status in women with a history of prior fracture but surprisingly, a significant effect in women without a prior fracture [197].

It has been suggested that FRAX should not be used in patients taking medication for osteoporosis. In a large study that addressed the question [211], the impact of compliance to bisphosphonates on calibration was very modest and non-significant. The study reported good concordance between observed and predicted major osteoporotic fractures in patients with high compliance, suggesting that FRAX is not invalid in patients exposed to treatment (observed/predicted ratio 0.92, 95 % CI 0.78-1.06). Only in the highest risk tertile of women highly adherent to at least 5 years of bisphosphonate treatment was the observed hip fracture risk significantly less than predicted.

A factor that appears to affect calibration is immigrant status. The incidence of hip fracture in Sweden was reported to be substantially lower in immigrants than in the population native to Sweden [212]. Although there was a small rise in age- and sex-specific incidence after immigration, the incidence remained markedly lower than that observed in Swedish-born individuals even after 20 or more years. Thus, the use of a FRAX model for Sweden will overestimate the risk of fracture for foreign-born individuals living in Sweden. Sweden has one of the highest hip fracture rates worldwide and, if the findings in Sweden are replicated in other countries (with a lower indigenous fracture risk), the quantum of effect may be more modest.

*Reclassification*

The guidelines developed by NOGG and adopted in several other countries has the characteristic that individuals may be eligible or otherwise without a BMD test. Rather, the use of BMD is restricted to individuals that lie close to the age-dependent intervention threshold. In turn decision rules are required to determine a threshold probability below which neither treatment nor a BMD test should be considered (lower assessment threshold) and a threshold probability above which treatment may be recommended irrespective of BMD (upper assessment threshold). The attraction of the approach is that efficient use is made of BMD testing. The justification of these assessment thresholds depends on reclassification rates when FRAX is calculated with and without BMD.

An example of such an approach is shown in Table 11, which shows the distribution of fracture probability in a random sample of women aged 75 years or more drawn from the general population of Sheffield [142]. With an arbitrary treatment threshold set at a probability of any fracture of 35 % (note, all fractures and not just a major fracture- this was a forerunner of FRAX), approximately 17 % of the 2113 women were classified at high risk when assessed in the absence of BMD. When all women were reassessed with the inclusion of BMD, a total of 319 women (15 %) were reclassified from high risk to low risk and vice versa. However reclassification was most frequent at probabilities close to the intervention threshold. Indeed 96 % (305 of 319) of women reclassified had probabilities without BMD within 10 % of the treatment threshold (see Table 11). In other words, if BMD testing was confined to those with a probability between 25 and 45 % then almost no cases would be missed that would otherwise (using probabilities with BMD) have been detected. Importantly, a BMD test would only be required in about 50 % of the population. In practice, the NOGG upper assessment threshold is 20 % higher than the intervention threshold, so that almost all relevant cases are appropriately stratified.

**Table 11.** Distribution of 10-year probabilities of a major fracture in 2113 elderly women assessed with and without BMD measurements. From [142], with kind permission from Springer Science and Business Media.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Number of women categorised | | |  |  |
| Fracture probability  (%) | Without BMD |  | With BMD | Number reclassified | % reclassifieda |
| 5-10 | 0 |  | 9 | 0 | 0 |
| 10-15 | 15 |  | 76 | 0 | 0 |
| 15-20 | 302 |  | 349 | 1 | 0.05 |
| 20-25 | 621 |  | 502 | 9 | 0.43 |
| 25-30 | 312 |  | 399 | 36 | 1.70 |
| 30-35 | 509 |  | 323 | 164 | 7.69 |
|  |  |  |  |  |  |
| 35-40 | 245 |  | 218 | 99 | 4.64 |
| 40-45 | 55 |  | 126 | 8 | 0.38 |
| 45-50 | 45 |  | 59 | 2 | 0.09 |
| 50-55 | 9 |  | 35 | 0 | 0 |
| 55-60 | 0 |  | 10 | 0 | 0 |
| 60-65 | 0 |  | 6 | 0 | 0 |
| 70-75 | 0 |  | 1 | 0 | 0 |
| Totals | | | | 319 | 14.98 |
| a % of all women | | | |  |  |

Broadly similar conclusions have recently been reported in a large Canadian referral population [213] and in the UK, an analysis, using the finalised FRAX algorithm, to examine hip fracture outcomes [214]. These various studies examined reclassification rates within a single assessment algorithm; several publications have compared concordance or discordance following different guidelines.

*Comparison of guidelines*

It is axiomatic that different intervention thresholds will identify different patients at different risk. However, empirical data examining the degree of concordance between high risk and low risk classification based upon FRAX probability estimates and thresholds based on BMD suggest that discordance rates are low [195, 215]. Indeed, a large majority (85 %) of individuals designated by FRAX as high risk, when BMD was not used in the calculation, had a T-score in the osteoporotic range at one or more BMD measurement sites (Table 12). Conversely, there were extremely few individuals (<1 %) who were at high risk of major osteoporotic or hip fracture with normal T-scores at any BMD measurement sites. Similar patterns were seen for hip fracture probability, when data were stratified by sex and age.

**Table 12.** Number (percentage) of men and women predicted to have a low, intermediate and high risk of major osteoporotic fracture assessed by FRAX without the use of BMD (Canadian model, version 3.1) according to diagnostic category based on the T-score. From [195] with kind permission from Springer Science+Business Media B.V.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Lowest T-score | N | Low | Moderate | High |
|  |  | FRAX risk calculated with BMD | | |
| Normal | 8,248 | 7721 (33.4) | 517 (4.2) | 10 (0.1) |
| Low bone mass | 19,465 | 12651 (54.7) | 6177 (50.4) | 637 (15.1) |
| Osteoporosis | 11,890 | 2765 (12.0) | 5552 (45.3) | 3573 (84.7) |
| Totals | 39,603 | 23137 (100) | 12246 (100) | 4220 (100) |
|  |  | FRAX risk calculated without BMD | | |
| Normal | 8,248 | 6665 (29.5) | 1358 (11.7) | 225 (4.2) |
| Low bone mass | 19,465 | 12019 (53.2) | 5617 (48.3) | 1829 (34.0) |
| Osteoporosis | 11,890 | 3915 (17.3) | 4655 (40.0) | 3320 (61.8) |
| Totals | 39,603 | 22599 (100) | 11630 (100) | 5374 (100) |

Further examples of different strategies are given in Table 13 based on the National Health and Nutrition Examination Survey (NHANES) 2005–2008 [215]. The application of FRAX used the US model for Caucasian men and women. Not surprisingly all examples select individuals at high risk. It is of interest that the guideline of the US National Osteoporosis Foundation (scenario F in Table 13) selects the greatest number of patients eligible for treatment and that the application of an age-specific FRAX threshold with (D) or without prior fracture (C) identifies a smaller proportion of the population but at higher risk. Also of relevance is that a fixed FRAX threshold set according to the NOF guidelines (but applied to the whole cohort) (scenario B) identifies men and women at lower fracture risk than the use of an age-dependent intervention threshold (C).

**Table 13.** Number selected as being above the intervention threshold and the proportion who will fracture over 10 years (mean 10-year fracture probability of major osteoporotic fracture (MOF) and hip fracture) in men and women aged 50 years or more from the NHANES cohort according to different intervention thresholds. From [216] with permission from John Wiley and Sons.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | men |  |  |  | women |  |
|  |  | % who fracture | |  |  | % who fracture | |
| Selection | N | MOF | Hip |  | N | MOF | Hip |
| A None | 1959 | 6.0 | 1.5 |  | 1649 | 10.2 | 2.4 |
| B FRAX fixed thresholdsa | 266 | 13.5 | 6.3 |  | 387 | 21.2 | 7.9 |
| C FRAX at fracture thresholdb | 54 | 16.3 | 4.0 |  | 144 | 26.0 | 9.7 |
| D FRAX fixed thresholds + prior fracturec | 326 | 12.3 | 5.3 |  | 414 | 20.5 | 7.5 |
| E FRAX at fracture threshold + prior fracturec | 121 | 11.9 | 2.9 |  | 179 | 23.4 | 8.2 |
| F NOFd | 330 | 11.7 | 4.9 |  | 511 | 17.7 | 6.2 |
| G Prior fracturec | 71 | 8.9 | 2.1 |  | 57 | 19.0 | 6.1 |
| H T-score <-2.5e | 79 | 11.2 | 5.4 |  | 298 | 17.3 | 6.7 |
| I Prior fracture & T-score <-2.5e | 148 | 9.9 | 3.6 |  | 335 | 17 | 6.4 |

a FRAX with 20 % and 3 % probability thresholds for major fracture and hip fracture, respectively

b FRAX with age-specific thresholds plus prior fracture

c Prior hip or spine fracture

d National Osteoporosis Foundation Guidelines

e T-score at proximal femur or lumbar spine

*Net Reclassification Improvement (NRI)*

As reviewed above, there has been some debate regarding the value of complex fracture risk assessment tools over simpler more intuitive tools. Indeed, the Canadian clinical practice guidelines go so far as to endorse both complex (WHO FRAX) and simple (Canadian Association of Radiologists and Osteoporosis Canada (CAROC) tools [29]. CAROC uses age, sex, femoral neck BMD and two clinical risk factors (prior fracture and prolonged glucocorticoid use) to assign semi-quantitative 10-year probabilities (low: 10 %, moderate: 10-20 %, high: >20 %). The net incremental benefit of using the complete FRAX tool vs CAROC tool was explored using Net Reclassification Improvement (NRI) to quantify the differences between FRAX vs CAROC [217].

The study population included 54,493 women and men with a mean age of 67 years, of whom 4,508 (8.3 %) had sustained an incident major osteoporotic fracture during a mean follow up of 6 years. FRAX and CAROC both provided good risk stratification and calibration with identical risk categorisation in 82.3 % (FRAX higher 6.7 %, CAROC higher 11. 0 %). NRI for FRAX vs CAROC was no different in those who experienced an incident major osteoporotic fracture (-0.7 %, p=0.23) but it was significantly greater for those who did not (+4.6 %, p<0.001) as well as for the entire cohort (+3.9 %, p<0.001). The NNF (‘‘Number Needed to FRAX’’) to improve fracture prediction was 26 overall and 7 in those with a prior fracture. Thus, both FRAX and CAROC provide good risk stratification and are well calibrated to the Canadian population, but FRAX provides a more accurate quantitative assessment of risk, particularly in those with prior fracture, compared with more parsimonious semi-quantitative systems.

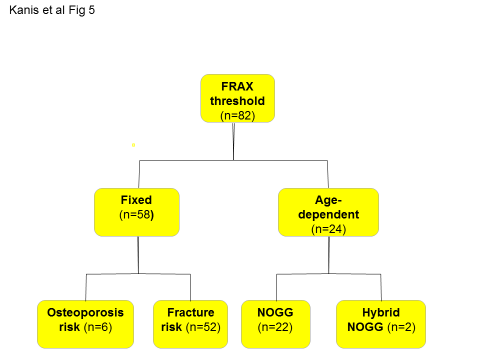
**Discussion**

The use of FRAX in assessment guidelines has grown progressively since its launch in 2008. At the time of writing, FRAX had been incorporated variously into 120 guidelines developed by government agencies or learned societies. Of these 82 provide intervention thresholds. As might be expected for a new technology, its uptake and application is heterogeneous. The present review identifies two broad approaches to the implementation of FRAX in assessment guidelines (Figure 20):

The use of a fixed FRAX intervention threshold either alone or as a component of other thresholds (e.g. BMD, parental history of fracture etc.). Fixed thresholds have been variously used to screen for osteoporosis (BMD testing threshold) or as an intervention threshold.

Age-dependent intervention thresholds using FRAX as a principal gateway to assessment.

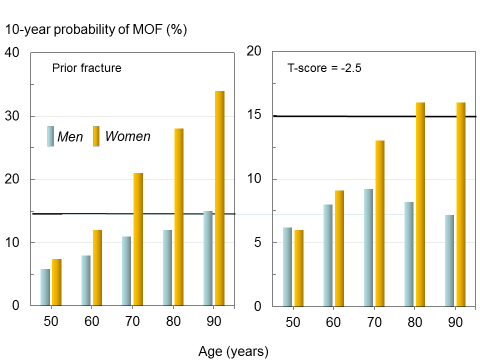
In some instances, economic thresholds based on cost-effectiveness of intervention have been used to set either approach.



**Figure 20.** The various ways in which FRAX has been used to set thresholds.

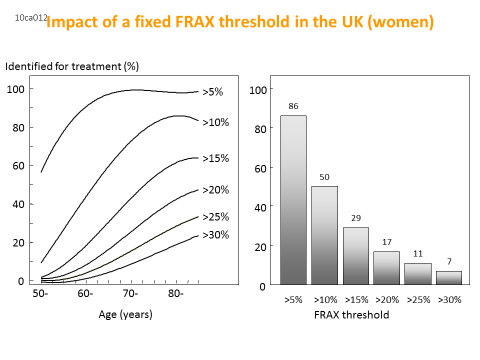
**Use of fixed thresholds**

The use of a fixed FRAX threshold has some intuitive appeal in that it directs intervention in an equitable manner and is more readily used in clinical practice than more complex approaches inherent in the application of age-dependent thresholds. There is, however only one poorly validated guideline that directs intervention solely on this basis (Taiwan). An important precedent is that the vast majority of guidelines worldwide recommend that individuals with a prior fragility fracture should be offered treatment. Irrespective of the merits of this approach, this sets up an immediate problem of consistency in that the fracture probability in men and women with a prior fracture is age dependent (Figure 21). Thus, the setting of a fixed threshold, say at 15 %, would mean that few individuals with a prior fracture would be eligible for treatment below the age of 65 years.

****

**Figure 21**. The probability of a major osteoporotic fracture (MOF) in men and women from the UK by age. The horizontal line depicts an arbitrary intervention threshold set at 15 %. The left panel gives probabilities in the presence of a prior fracture and the right panel, probabilities with a T-score of -2.5 SD (BMI set to 23 kg/m2, no other clinical risk factors). [<http://www.shef.ac.uk/FRAX>]

A further problem with the use of fixed thresholds alone arises in the proportion of the population eligible for treatment. The impact of using different intervention thresholds is shown in Figure 22 for postmenopausal women in the UK [3]. Very similar findings are reported from Japan [218]. At high thresholds e.g. >20 % fracture probability, 20.5 % of postmenopausal women would be eligible for treatment. A problem that arises is that very few women under the age of 60 years would ever attain this threshold (less than 1 %). On the other hand, if a less stringent threshold were chosen, say 10 %, then approximately 5 % of women at the age of 50 years would exceed this threshold, and a majority of women over the age of 65 years would be eligible and the treatment threshold would be exceeded in 50 % of all postmenopausal women. Both scenarios are counterintuitive to clinical practice [81, 218].

****

**Figure 22.** The impact of a fixed treatment threshold in postmenopausal women in the UK according to threshold values for the probability of a major osteoporotic fracture. The left hand panel shows the proportion of the postmenopausal population exceeding the threshold shown at each age. The right hand panel shows the proportion of the total postmenopausal population that exceed a given threshold. From [3] with kind permission from Springer Science and Business Media.

The problem of consistency with the use of a fixed FRAX threshold is not unique to FRAX. The same problem arises with fixed BMD thresholds in that the fracture probability in men and women with a fixed T-score is also age dependent (see Figure 21).

These considerations support the avoidance of the use of a fixed FRAX intervention threshold as the principal gateway to fracture risk assessment. This is one of the reasons why fixed thresholds form but one component of more complex assessment models. The prime examples are in the US and Japan where the use of FRAX is confined to individuals with osteopenia [30, 31]. A second reason is that, where there have been established guidelines for many years, there has been a reluctance to disturb historical precedent with potential consequences for regulatory approval or reimbursement. Rather, FRAX has been fitted into the historical guidelines.

Although fixed thresholds are not used as the principal gateway to treatment, FRAX (without the inclusion of BMD) is recommended as a screening tool to direct the use of subsequent BMD testing by the ACR and SIGN [32, 113], as well as in an academic paper from Japan [83]. Since the detection of osteoporosis is the goal, then it is inappropriate to use FRAX, which is designed for the prediction of fracture but not osteoporosis [13]. Indeed there are more appropriate tools available for the detection of osteoporosis [8,192]. In one study, for example, the sensitivity of FRAX (i.e. the detection rate for osteoporosis) at a similar probability threshold as used by SIGN and the US Preventive Services Task Force (10 and 9.3 %, respectively) was 33.3 % whereas the Osteoporosis Self-Assessment Tool (OST) [130] had, in the same population, a sensitivity of 79.3 % [127, 128]. Sensitivities in the order of 90 % or more are reported in other populations [8]. Moreover these instruments are easier to administer than FRAX; OST is calculated only from weight and age. If the intention of screening had been to identify women at a high risk, then a fracture risk assessment algorithm would the appropriate tool. In this context, it is worth noting that FRAX outperforms OST for fracture prediction [8].

**Setting fixed FRAX thresholds**

A variety of approaches has been used to set intervention thresholds. Relatively few publications provide an explanation of the manner in which they have been derived. Those noted in this review are summarised in Table 14. Apart from the US Preventive Services Task Force thresholds that are used for screening, there are nine relevant publications which provide a rationale for the intervention threshold. Notably, only two of these have been incorporated in official guidelines (Lebanon and NOF).

**Table 14.** Intervention thresholds explored or adopted using a fixed FRAX probability for a major osteoporotic fracture (MOF) or hip fracture (HF).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  | Threshold (%) | | |
| Country |  | Source | Reference | MOF | HF | Adoption | |
| Greece a |  | Academia | [80] | 10, 15 | 2.5, 5 | No | |
| China |  | Academia | [75] | 4 | 1.3 | No | |
| Hong Kong |  | Academia | [81] | 9.95 |  | No e | |
| Lebanon b |  | Ministry of Public Health | [84] | 10 |  | Yes | |
| Poland |  | Academia | [89] | 11.6, 17.4 |  | No e | |
| Switzerland |  | Academia | [105] | 15 |  | No e | |
| UK |  | National Institute for Health and Care Excellence | [108] | Various c |  | No d | |
| UK b |  | Academia | [109] | 20 |  | No d | |
| US |  | National Osteoporosis Foundation | [124] | 20 | 3 | Yes | |
| US |  | Preventive Services Task Force | [112] | 9.3 |  | Yes | |

a Higher thresholds at age 75 years or more.

b Hybrid model, also uses an age-dependent threshold at some ages (see *Hybrid intervention thresholds using FRAX*)

c Intervention threshold set where treatment becomes cost-effective

d Appraisal in the consultation process

e Guidance recommends age-dependent thresholds

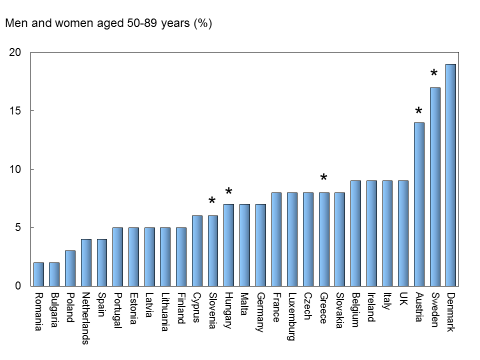
The most influential thresholds are those derived from the National Osteoporosis Foundation in the US. Treatment is recommended when the 10-year probability of a major fracture is 20 % or above, or where the probability of a hip fracture exceeds 3 %. It should be noted that these fixed thresholds are not used in isolation and are reserved for patients with low bone mass (osteopenia). As reviewed in this report, the basis on which these are derived may no longer be appropriate. Reasons include that the thresholds are derived from cost-effectiveness in 2008 and the cost of intervention has changed since then; the threshold was derived from hip fracture probabilities and their transformation to MOF equivalents is not straightforward. Thus, the thresholds may have to be revisited.

This apart, the thresholds are relevant only to the US and are inappropriate for use elsewhere because of differences in the importance of osteoporosis, the heath care budget allocated, current practice guidelines, reimbursement and health economic considerations. Although this states the obvious, the majority of guidelines that use a fixed threshold have chosen a 20 % fracture probability without any justification other than its use in North America.

Additionally, within Europe, the proportion of the population aged 50 years or more with a FRAX probability of a major fracture >20 % varies from 2 % (Romania) to 19 % (Denmark) [28] (Figure 23). This variation in risk needs to be balanced against the health care spend (4.5 % of gross domestic product in Romania and 10.8 % in Denmark, equivalent to €309 and €4759/per capita per year, respectively [2]. In Europe, the 20 % threshold has been recommended in Austria, Greece, Hungary, Slovenia and Sweden (see Table 3), which in turn will have a marked effect on the population eligible for treatment. Given also that the cost of intervention varies little between countries, no one fixed FRAX threshold is applicable to all countries, and if fixed thresholds are to be used, they need to be country-specific [219].

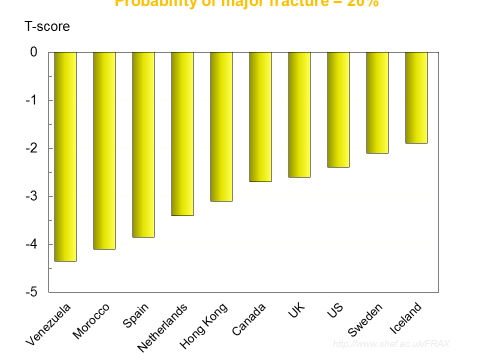
**Consequences of a 20% threshold**

The use of the 20% threshold without economic justification has important implications for clinical practice. The proportion of the population at risk varies according to the distribution of fracture probabilities. Since there are marked international differences in the death and fracture hazards, so too are there differences in the proportion of the population who would be deemed at high risk. Figure 23 shows the proportion of the population (aged 50-85 years) above the 20% threshold value in countries of the European Union [3] with a 10-fold variation. Of these countries, the 20% threshold has been recommended in Austria, Greece, Hungary, Slovenia and Sweden (see Table 3), which in turn will have a marked effect on the population eligible for treatment.

****

**Figure 23.**  Proportion of men and women (%) aged 50–89 years with a 10-year probability of a major fracture that is more than 20 % in different countries of the European Union. Those marked with an asterisk utilise a 20 % intervention threshold for a major osteoporotic fracture. Adapted from [3].

Another way of looking at this is to determine the T-score that is equivalent to a probability threshold of 20 %. Given that fracture rates vary widely from country to country – much more so than can be explained by variations in BMD for any given fracture risk [220], the T-score threshold will vary from country to country. For example, when an intervention threshold is set at a 10-year probability of a major fracture of 20 %, the femoral neck T-score ranges widely in different countries. Figure 24 illustrates this for women aged 65 years, prior fracture and a BMI of 24 kg/m2 using the FRAX tool. For this clinical scenario, a 10-year fracture probability of 20 % is equivalent to a T-score of -4.6 SD in Venezuela whereas the equivalent T-score in women from Iceland is -2.0 SD. In the absence of a prior fracture the T-score ranges from -3 to -5 SD.

****

**Figure 24.**  T-scores in selected countries that are equivalent to a 20% 10-year probability of a major fracture (women aged 65 years, prior fracture and a BMI of 24kg/m2) From [216] with permission from John Wiley and Sons.

This argues strongly that intervention thresholds need to be determined on a country-by-country basis.

**Economic thresholds**

Health economic assessment in the context of intervention thresholds and guideline development has used two approaches with FRAX. The first has been to set a FRAX intervention threshold at the point at which intervention becomes cost-effective. This is the approach that historically has been used by the National Institute for Health and Care Excellence in the UK [173, 174]. Other examples, reviewed in this report, include the development of the 20 % thresholds used in the NOF guidelines of the United States [124]. The fracture probabilities at which intervention becomes cost-effective have been explored for the use of alendronate [105, 165], risedronate [166], denosumab [167], , raloxifene [168], strontium [169] and bazedoxifene [163, 170]. As would be expected, analysis of each intervention produces different thresholds. Moreover, a threshold determined for one country cannot inform a threshold in another. This poses problems in the application of the guidance to primary care if intervention thresholds are drug-specific. This has led to analyses being based on a basket of interventions, an approach that has been resisted by NICE [108]. This in turn raises additional problems of management. Imagine, for example, Mrs x aged 56 years with a prior vertebral fracture whose probability of a major osteoporotic fracture is 10 %, well above the threshold where treatment with alendronate is reimbursed. She is given alendronate, which is poorly tolerated, but she cannot be offered an alternative treatment (e.g. risedronate) until her fracture probability has increased to 18 %, because the agent-specific threshold had not been reached. In this example a wait of 11 years is required, all other things being equal. Such guidance is cumbersome and cannot be readily used in the primary care setting. Moreover, thresholds produced in this way are very sensitive in that even a modest change in the cost of intervention will invalidate the threshold.

The second and alternative approach, adopted by NOGG was to devise intervention thresholds based on clinical imperatives, always provided that the strategy proves to be cost-effective [139]. In the former scenario, health technology assessment sets intervention thresholds and in the latter, intervention thresholds are validated by economic analysis. The major intervention in the UK and many other countries is alendronate [2]. In the case of generic alendronate treatment compared to no treatment was found to be cost-effective at a 10-year probability of a major fracture of approximately 7 % indicating that the use of NOGG thresholds were cost-effective [165].

**Age-dependent intervention thresholds**

Prior to the advent of FRAX, many guidelines in Europe, North America and elsewhere recommended treatment in women with a previous fragility fracture (a prior vertebral or hip fracture in some countries) in the absence of information on BMD. This gave rise to the view that intervention thresholds in women without a prior fracture could be set at the age-specific fracture probability equivalent to women with a prior fragility fracture and therefore rises with age. In other words, the intervention threshold is set at the ‘fracture threshold’. This approach to intervention thresholds, first adopted by the National Osteoporosis Guideline Group (NOGG) for the UK [140, 141] is now used in two European guidelines (one for postmenopausal osteoporosis [3] and the other for glucocorticoid-induced osteoporosis [149], 12 practice guidelines and explored in 10 another research papers (see Table 6). The same intervention threshold is applied to men, since the effectiveness and cost-effectiveness of intervention in men are broadly similar to that in women for equivalent risk.

The present review has identified several merits of the use of FRAX and, in particular, age-specific thresholds that are summarised in Table 15. They include the wide availability of well-calibrated models which can be applied to a large segment of the world population. Indeed the 62 FRAX models in 57 countries that are available to date, cover approximately 80 % of the world population [221]. With regard to the strategy itself, there are several features which indicate that the performance characteristics are significantly better than the UK or European guidance that it replaces. Of strategic importance, the use of age-dependent thresholds has been demonstrated to be more effective than fixed thresholds in identifying populations at high risk. In the UK, there appears to be high concordance between clinician-determined treatment interventions to reduce fracture risk compared with FRAX-NOGG output data. The predominant reason for differences in opinion was the use of lumbar spine BMD to help assess fracture risk by clinicians [222].

**Table 15.** Strengths of FRAX and the age-dependent NOGG approach

|  |  |  |
| --- | --- | --- |
|  | Country | Reference |
| ***FRAX*** |  |  |
| Models internally calibrated | All models | [8] |
| Well calibrated externally | UK Canada Finland Denmark | [13] [194] [198] [197] |
| Extensively validated | Worldwide | [8] |
| Readily administered in primary care | UK | [223] |
| Attuned to clinical practice | UK | [222] |
| Can be applied to all countries with a FRAX model or a surrogate | 80 % of world | [221] |
| Multimedia availability including densitometers | Worldwide |  |
| More accurate than simpler models | Canada | [217] |
| ***Age-dependent thresholds*** |  |  |
| Strategy is cost-effective | UK  Switzerland | [140]  [105] |
| Lower costs per fracture case identified than RCP guidelines | UK | [144] |
| More economic use of BMD tests than RCP or NOF guidelines | UK | [144] [145] |
| Treatment decisions not wholly based on BMD |  | [140] |
| Fewer but higher risk patients identified than RCP guidelines | UK | [144] |
| Fewer but higher risk patients identified than NOF guidelines | US | [216] |
| More effective than fixed thresholds | US Poland | [216] [89] |

**Limitations of FRAX**

No risk assessment engine is perfect. The introduction of FRAX, particularly with BMD has increased the sensitivity of fracture risk prediction. In the case of FRAX without BMD included the gradient of risk for a major osteoporotic fracture is approximately equal to that of BMD alone [14]. Despite the step change in prognostic value, sensitivity remains low. Thus FRAX should not be viewed through rose tinted spectacles but considered as a reference platform to aid but not replace decision-making. The rapid and widespread uptake of FRAX has made it the subject of great scrutiny and the limitations have been widely articulated. In some instances concerns have been raised over FRAX in general or its use in assessment guidelines (Table 16), which are reviewed briefly.

**Table 16**. Limitations of FRAX – real and perceived

FRAX in general

Reliance on computer access

Not all countries have FRAX models

Efficacy in patients selected without BMD

FRAX in guideline development

No controlled trials

Age-dependent thresholds are ageist

Inequity across countries

Sensitivity of NOGG in subgroups

*Well established limitations of FRAX*

The limitations of FRAX have been extensively reviewed [8, 18] and are only briefly mentioned. The risk factors included in FRAX were chosen carefully to limit the number and complexity, for ease of input, and to include only well-recognised, independent contributors to fracture risk. In addition, it was important that the factors used identified a risk that was amenable to an intervention [8, 15]. The FRAX tool has been appreciated for its simplicity for use in primary care but criticised for the same reason because it does not take account of exposure response. For example, the risk of fracture increases with exposure to glucocorticoids, but FRAX only accommodates a yes/no response to the relevant question. Other well-researched examples of ‘dose–response’ include the number of prior fractures and the consumption of alcohol. Other concerns are the lack of provision for lumbar spine BMD which is commonly recommended in treatment guidelines, and the absence of measurements of the material or structural properties of bone. A concern that treatment might invalidate the interpretation of FRAX is misplaced [196].

If FRAX is to be made more accurate by the inclusion of different degrees of exposure, then information is required not only on the risk of fracture associated with these exposures but also on their dependence on the other risk variables in FRAX and their independent effect on the death hazard. This demands the collection of new population cohorts that include such information as well as the other FRAX variables in sufficient numbers and with wide geographical representation.

In order to overcome some of these demands, relatively simple arithmetic procedures have been formulated which can be applied to conventional FRAX estimates of probabilities of hip fracture and a major fracture to adjust the probability assessment with knowledge of:

High, moderate and low exposure to glucocorticoids [20]

Concurrent data on lumbar spine BMD [21, 22]

Information on trabecular bone score (TBS) 23-25]

Hip axis length [26]

Falls history [27]

Such analyses can inform the clinician how to temper clinical judgement on the existing output of the FRAX models.

The most frequent concern, however, is the omission of falls as a risk variable in the FRAX model, particularly as this is included in other risk assessment tools. Indeed, a Task Force of the ISCD recommended that falls should be incorporated into FRAX [27]. Whereas this view is a sound academic conclusion from the literature on falls risk, the incorporation into FRAX is problematic for several reasons. First, at the time of the release of FRAX, existing falls data were not of adequate quality, including the heterogeneous construct of questions on falls. Second, falls risk is inherently taken into account in the algorithm, though not as an input variable. Thus, the fracture probability given for any combination of risk factors assumes that the falls risk is that observed (but not documented) in the cohorts used to construct FRAX. Third, the interrelationship of falls risk with the other FRAX variables has been inadequately explored on an international basis. Fourth, the relationship between the risk variable and mortality needs to be accounted for, but there are no data available.

These technical problems aside, FRAX is intended to identify a risk that is amenable to a therapeutic intervention. In a single study, a post hoc analysis of a community-based intervention study with clodronate in elderly women [224] showed that fracture reduction was similar in women with or without recent multiple falls or in those with impaired ability in rising from a chair. This finding suggests that falls or falls risk may identify a risk amenable to intervention. In contrast, in the phase III trial of risedronate, where hip fracture was the primary end point, hip fracture risk was not significantly decreased in women over the age of 80 years, the majority of whom were purportedly selected on the basis of falls risk [225]. Thus, falls as a risk variable does not consistently pass the test of reversibility of risk, a necessary feature of any risk variable used in FRAX [8, 15]. More recently, both FRAX and past falls were shown to be associated with falls on follow-up in elderly men. Whereas past falls were a significant predictor of incident falls, even after adjustment for FRAX, the hazard ratio decreased markedly with increasing follow-up time [226] and an analysis in the same cohort, only available as a meeting abstract, indicated the predictive value of falls for fracture also waned significantly with time [227]. If the phenomenon is replicated more generally, then this would call into question the utility of falls history in the long term (e.g. 10-year) assessment of fracture risk. Thus a useful role of falls history in fracture risk assessment remains *sub judice*.

*Reliance on computer access*

The vast majority of FRAX calculations are undertaken through the FRAX website so that there is a reliance on access to computers. In this context a link from the FRAX website to a site that plots the result on a country specific chart allows easy interpretation of result according to the relevant guideline. Such links are available for the models of Finland, Lebanon, Romania and the UK. A recent audit from the UK indicated a high uptake of this facility [223] and the approach could usefully be adopted in all countries for which a FRAX model and a guideline are available.

In countries with limited electronic access in primary care, downloadable country-specific charts are available through the FRAX website. These provide a simplified assessment, relying on the number of clinical risk factors rather than on their independent weights. They are used in Belgium, Japan, Mexico, Poland and Russia The web site is not the sole portal for the calculation of fracture probabilities. FRAX is also available in most BMD equipment that measures the femoral neck. Versions for use on smartphones, tablets and computer driven versions that do not rely on internet connection are available through the International Osteoporosis Foundation.

*Not all countries have FRAX models*

The creation of a FRAX model requires high quality (preferably national) data on fracture risk and mortality. At present, there are upwards of 60 models available but this number will increase at a rate that depends on the generation of new data. Thus, the options are to use a surrogate model from another country where the fracture risk is judged to be similar to the index country. Indeed the UK model was used for several years in Poland before a Polish model became available. At present, approximately 15-20 % of FRAX visits to the UK web site arise from outside the UK. In this regard, it may be recalled that the categorisation of risk will be very similar irrespective of the model used [209]. A more satisfactory solution is to adopt a surrogate country but to incorporate the death hazard of the index country, as recommended by the International Society for Clinical Densitometry [228]. This type of surrogate model is available for Armenia, India, Sri Lanka and Palestine.

*Efficacy in patients selected without BMD*

A concern that is raised with the NOGG guidelines is that treatment is offered to patients in whom BMD is unknown, since BMD is tested in a minority of patients [32, 173, 174, 229]. For example, the SIGN guidance states “that the beneficial effects (of treatment) on fracture risk is restricted to patients with osteoporosis as defined by the presence of pre-existing vertebral fractures and or those with BMD values that lie within or close to the osteoporotic range.” The concern is misplaced in that the use of FRAX (without BMD) preferentially selects individuals with low BMD [15, 142, 216, 230].

For example, in a population sample of approximately 2000 older women (aged 75 years or more), those characterized at higher fracture probability (by a precursor of FRAX but not FRAX) without the inclusion of BMD had progressively lower mean femoral neck BMD values (Figure 25). In women above an arbitrary risk threshold (e.g. 30 % 10-year fracture probability), mean femoral neck BMD was approximately 1 SD lower than in women below the threshold [142].



**Figure 25.**  Mean BMD at the femoral neck (with 95 % confidence intervals) in randomly selected women aged 75 years or more according to their 10-year probability of a major fracture calculated without BMD. Figure derived from data in [142].

Similar findings were reported in a large referral population from Manitoba, Canada [231]. In this study, the minimum T-score (of measurements at the femoral neck, total hip, trochanter or lumbar spine) decreased progressively with increasing FRAX probability measured without BMD. Thus, in patients categorised at low risk using FRAX without BMD (<10 % probability of a major fracture), the mean minimum T-score was -1.5 SD. In those at intermediate risk (10-20% probability), the T-score was -2.2 SD, and in those at high risk (> 20% probability) was -2.8 SD.

Low BMD values are also noted when the NOGG strategy is applied to a simulated UK population (Table 17).

**Table 17.**  NOGG strategy applied to women from without prior fracture, by age (/1000) [144] with kind permission from Springer Science+Business Media B.V.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Age (years) | Number scanned | Number selected | Expected hip fractures | Expected MOF | Mean FN  T-score |
| 50 | 63 | 22 | 2 | 52 | -1.78 |
| 55 | 48 | 16 | 2 | 27 | -2.28 |
| 60 | 59 | 14 | 2 | 17 | -2.67 |
| 65 | 131 | 38 | 7 | 48 | -2.58 |
| 70 | 140 | 29 | 8 | 38 | -2.91 |
| 75 | 89 | 18 | 6 | 23 | -3.35 |
| 80 | 69 | 15 | 6 | 16 | -3.60 |
| 85 | 50 | 15 | 7 | 20 | -3.66 |
|  |  |  | 40 | 241 |  |

*FN femoral neck*

*MOF major osteoporotic fracture (hip, clinical spine, forearm, proximal humerus)*

These data indicate that FRAX without BMD identifies individuals with low BMD. The reason is that several of the FRAX input variables are weakly correlated with BMD (though of statistical significance) such as age, prior fracture and glucocorticoid exposure. The conclusion is also supported by NICE [161] which made two recommendations of relevance in this regard.

*Recommendation 6*. Do not routinely measure BMD to assess fracture risk without prior assessment using FRAX (without a BMD value) or QFracture.

*Recommendation 7*. Following risk assessment with FRAX (without a BMD value) or QFracture, consider measuring BMD with DXA in people whose fracture risk is in the region of an intervention threshold for a proposed treatment, and recalculate absolute risk using FRAX with the BMD value.

Both recommendations support the parsimonious use of BMD and the strategy intrinsic to NOGG.

*Controlled trials*

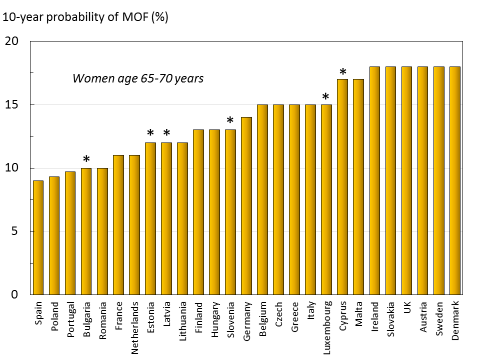
There is no conclusive evidence that providing treatment on the basis of risk assessment will result in better clinical and cost-effective care. However, the NOGG strategy is less costly than the RCP strategy that it replaces [144], and intervention with alendronate is cost-effective over all intervention scenarios [140]. It is relevant to note that no trials have been undertaken with guidelines that are currently used to identify high risk patients. There is an ongoing trial in which the efficacy of treatment in individuals identified by FRAX as being at high risk of fracture is being investigated (the SCOOP study) which will include a health economic appraisal [162].

*Age-dependent thresholds are ageist*

It has been said that the NOGG approach discriminates by age and is one of the reasons cited for avoiding this method of threshold-setting [44]. This is somewhat ironic given that under the DVO guidelines in Germany, eligibility for testing is age and sex dependent. For example, a woman with a parental history of hip fracture is not eligible for assessment between the ages of 50 and 60 years, but becomes eligible for assessment from the age of 60 years. The corresponding age-dependent thresholds for men are 60–70 years and >70 years, respectively. Notwithstanding, the intervention threshold used In NOGG is overtly age-dependent but so too is the use of the T-score (see Figure 21) or probability fixed thresholds (see Figure 22), both of which ‘discriminate’ by age, though somewhat more covertly.

*Inequity across countries*

The merit of the NOGG approach (age-dependent thresholds) is that it can be readily applied to all countries and is more allied to a fracture threshold. Given the heterogeneity of mortality and fracture risk in different countries, the intervention threshold (i.e. the fracture threshold) will also differ. An example is shown in Figure 26 in women age 65-70 years for countries of the European Union [2]. This means that fracture thresholds need to be tailored individually on a country-by-country basis. This is a straightforward process but leaves the unsatisfactory position that a woman aged 72 years with a fracture probability of, say 15 %, would be eligible for treatment in Slovakia but not in Slovenia (see Figure 26). In Europe, the proportion of men and women above the age-dependent threshold varies little from 11-13 % across countries [2]. Although age-dependent thresholds seem to offer several advantages over fixed thresholds, problems of equality remain in that that the probability at which treatment is recommended is country-specific, though varies little in the western world.



**Figure 26**. FRAX 10-year probability (%) of a major osteoporotic fracture (MOF) in women between the ages of 65 and 70 years from the European Union with a previous fracture (no other clinical risk factors, BMI of 24 kg/m2 and without BMD) representing the age-specific intervention threshold under the NOGG approach. Note that FRAX models were not available for Bulgaria, Cyprus, Estonia, Latvia, Luxembourg and Slovenia (labelled above with an asterisk). For these countries surrogate FRAX models were used. Extracted from [2].

A limitation of country-specific thresholds that are set at the fracture threshold is that, assuming a constant efficacy, there will be a much larger number of patients treated to prevent one fracture in countries with lower FRAX probabilities (e.g. China) compared to those counties with higher FRAX scores (e.g. Sweden). There is of course no obligation to use the fracture threshold as the route to age dependency. In countries with a more conservative approach or low fracture probabilities, the threshold can be uplifted, say by 10 or 20 %. Conversely, an intervention threshold can be downward-adjusted where a more liberal approach is desired.

*Sensitivity of NOGG in subgroups*

The concept that women without fracture merit treatment if their risk of fracture is similar to or exceeds that of an average woman with a prior fracture is a concept that attempts to embrace fairness and equity of access to treatment.

Within a country, it would seem desirable that at any given age, the selection criteria for intervention results in equitable access to therapy for patients with the same age-specific absolute probability of fracture.

It is apparent that, following the NOGG guidance, this goal is not realised, particularly at older ages in that that those eligible for treatment without a prior fracture have on average higher probabilities than those eligible on the basis of a previous fragility fracture. This inequity results in a lower sensitivity of the algorithm for individuals without a prior fracture [109, 144].

This appears to be resolved with the UK hybrid model [109]. This uses an age-dependent intervention up to the age of 70 years, and thereafter a fixed threshold of 20 % probability of a major osteoporotic fracture. It must be emphasised, however, that the identification of a threshold for major osteoporotic fracture at or around 20 % is not a validation of this threshold on a global scale, but rather represents a chance occurrence. Fortuitously, this is the probability at the age of 70 years in a woman with a prior fracture in the UK, but will differ if the same approach is taken to determine fracture thresholds in other populations.

**Acknowledgements**

We are grateful to the University of Southampton and the International Osteoporosis Foundation for their help with the literature searches. The manuscript was appraised by the members of the Committee of Scientific Advisors of the International Osteoporosis Foundation and the National Osteoporosis Guideline Group (UK) and we appreciate their constructive reviews. We are grateful to the International Osteoporosis Foundation and the National Osteoporosis Guideline Group for their endorsement of this paper.

**Competing interests**

Professor Kanis led the team that developed FRAX as director of the WHO Collaborating Centre for Metabolic Bone Diseases; he has no financial interest in FRAX. Professors McCloskey, Oden, Harvey and Dr Johansson are members of the FRAX team. Professors Cooper, Kanis, Harvey and McCloskey are members of the Advisory Board of the National Osteoporosis Guideline Group. Ken E Poole, Neil Gittoes and Sally Hope declare no competing interests with respect to this paper.

**Funding source**

None

**References**

|  |  |
| --- | --- |
| 1. | Johnell O, Kanis JA (2006) An estimate of the worldwide prevalence and disability associated with osteoporotic fractures. Osteoporos Int 17:1726–1733 |
| 2. | Hernlund E, Svedbom A, Ivergård M et al (2013) Osteoporosis in the European Union: Medical Management, Epidemiology and Economic Burden. A report prepared in collaboration with the International Osteoporosis Foundation (IOF) and the European Federation of Pharmaceutical Industry Associations (EFPIA). Arch Osteoporos 8: 136. |
| 3. | Kanis JA, Borgström F, Compston J et al (2013) SCOPE: a scorecard for osteoporosis in Europe. Arch Osteoporos 8:144. |
| 4. | Elliot-Gibson V, Bogoch ER, Jamal SA, Beaton DE (2004) Practice patterns in the diagnosis and treatment of osteoporosis after a fragility fracture: a systematic review. Osteoporos Int 15:767-778 |
| 5. | Kanis JA (2002) Diagnosis of osteoporosis and assessment of fracture risk. Lancet 359: 1929-36. |
| 6. | Hui SL, Slemenda CW, Johnston CC, Jr (1988) Age and bone mass as predictors of fracture in a prospective study. J Clin Invest 81: 1804-9. |
| 7. | Kanis JA, Johnell O, Oden A, Dawson A, De Laet C, Jonsson B (2001) Ten year probabilities of osteoporotic fractures according to BMD and diagnostic thresholds. Osteoporosis International 12; 989-995. |
| 8. | Kanis JA, on behalf of the World Health Organization Scientific Group (2007) Assessment of osteoporosis at the primary health-care level. Technical Report. World Health Organization Collaborating Centre for Metabolic Bone Diseases, University of Sheffield. Accessed <https://www.shef.ac.uk/FRAX/reference.aspx> 14 July 2015 |
| 9. | Hippisley-Cox J, Coupland C (2012) Derivation and validation of updated QFracture algorithm to predict risk of osteoporotic fracture in primary care in the United Kingdom: prospective open cohort study. BMJ 344:e3427. doi: 10.1136/bmj.e3427 |
| 10. | Nguyen ND, Frost SA, Center JR, Eisman JA, Nguyen TV (2008) Development of prognostic nomograms for individualizing 5-year and 10-year fracture risks. Osteoporos Int 19:1431–1444 |
| 11. | National Institute for Health and Care Excellence (2014) NICE Clinical Guideline 146. Osteoporosis: assessing the risk of fragility fracture. London, UK. https://www.nice.org.uk/guidance/cg146, Accessed18 May 2015 |
| 12. | Collins GS, Mallett S, Altman DG (2011) Predicting risk of osteoporotic and hip fracture in the United Kingdom: Prospective independent and external validation of QFractureScores. BMJ 342:d3651 |
| 13. | Kanis JA, Compston J, Cooper C et al (2016) SIGN guidelines for Scotland. BMD vs. FRAX vs. QFracture. Calcif Tissue Int 98: 417-25 |
| 14. | Kanis JA, Oden A, Johnell O, Johansson H, De Laet C, Brown J, et al (2007) The use of clinical risk factors enhances the performance of BMD in the prediction of hip and osteoporotic fractures in men and women. Osteoporos Int 18: 1033-46. |
| 15. | Kanis JA, McCloskey E, Johansson H, Oden A, Leslie WD (2012) FRAX with and without BMD. Calcif Tissue Int 90:1–13. |
| 16. | Kanis JA, Johnell O (2005) Requirements for DXA for the management of osteoporosis in Europe. Osteoporos Int 16:229–238 |
| 17. | Kanis JA, Odén A, McCloskey EV, Johansson H, Wahl D, Cyrus Cooper C on behalf of the IOF Working Group on Epidemiology and Quality of Life (2012) A systematic review of hip fracture incidence and probability of fracture worldwide. Osteoporos Int. 23: 2239-2256. |
| 18. | Kanis JA, Hans D, Cooper C et al (2011) Interpretation and use of FRAX in clinical practice. Osteoporos Int 22:2395–2411 |
| 19. | Middleton RG, Shabani F, Uzoigwe CE, Shoaib A, Moqsith M, Venkatesan M (2012) FRAX and the assessment of the risk of developing a fragility fracture. J Bone Joint Surg 94B: 1313-20. |
| 20. | Kanis JA, Johansson H, Oden A, McCloskey EV (2011) Guidance for the adjustment of FRAX according to the dose of glucocorticoids. Osteoporos Int 22: 809-16. |
| 21. | Leslie WD, Lix, LM Johansson H, Oden A, McLoskey, EV, Kanis JA for the Manitoba Bone Density Program (2011) Spine-hip discordance and fracture risk assessment: A physician-friendly FRAX enhancement. Osteoporos Int 22 : 839-47. |
| 22. | Johansson H, Kanis JA, Odén A et al (2014) Impact of femoral neck and lumbar spine BMD discordances on FRAX probabilities in women: a meta-analysis of international cohorts. Calc Tiss Int 95: 428-35. |
| 23. | Leslie WD , Johansson H, Kanis JA, Lamy O, Oden A, McCloskey EV, Hans D (2014) Lumbar spine texture enhances ten-year fracture probability assessment. Osteoporos Int 25: 2271-7. |
| 24. | McCloskey EV, Odén A, Harvey NC et al (2015) Adjusting fracture probability by trabecular bone score. Calcif Tiss Int 96: 500-9. |
| 25. | McCloskey EV, Odén A, Harvey NC et al (2016) A meta-analysis of trabecular bone score in fracture risk prediction and its dependence on FRAX. J Bone Miner Res 31: 940-8. |
| 26. | Leslie WD, Lix LM, Morin SN et al (2015) Adjusting Hip Fracture Probability in Men and Women Using Hip Axis Length: the Manitoba Bone Density Database. J Clin Densitom. Aug 6. pii:S1094-6950(15)00145-6. doi: 10.1016/j.jocd.2015.07.004. [Epub ahead of print] |
| 27. | Masud T, Binkley N, Boonen S, Hannan MT; FRAX® Position Development Conference Members (2011) Official Positions for FRAX® clinical regarding falls and frailty: can falls and frailty be used in FRAX®? From Joint Official Positions Development Conference of the International Society for Clinical Densitometry and International Osteoporosis Foundation on FRAX®. J Clinl Densitom 14: 194-204. |
| 28. | Kanis JA McCloskey EV, Johansson H, Cooper C, Rizzoli R, Reginster J-Y on behalf of the Scientific Advisory Board of the European Society for Clinical and Economic Aspects of Osteoporosis and Osteoarthritis (ESCEO) and the Committee of Scientific Advisors of the International Osteoporosis Foundation ( IOF) (2013) European guidance for the diagnosis and management of osteoporosis in postmenopausal women. Osteoporos Int. 24: 23-57. |
| 29. | Papaioannou A, Morin S, Cheung AM et al (2010) Clinical practice guidelines for the diagnosis and management of osteoporosis in Canada: summary. CMAJ. 2010; 182: 1864-73 |
| 30. | Dawson-Hughes B, National Osteoporosis Foundation Guide Committee (2008) A revised clinician’s guide to the prevention and treatment of osteoporosis. J Clin Endocrinol Metab 93:2463–2465 |
| 31. | Orimo H, Nakamura T, Hosoi T et al. Japanese 2011 guidelines for prevention and treatment of osteoporosis--executive summary. Arch Osteoporos. 2012; 7: 3-20. |
| 32. | Scottish Intercollegiate Guidelines Network (SIGN) (2015) Management of osteoporosis and the prevention of fragility fractures. Edinburgh: SIGN; 2015. (SIGN publication no. 142). [March 2015]. Available from URL: <http://www.sign.ac.uk> accessed May 11th, 2015 |
| 33. | Schurman L, Bagur A, Claus-Hemberg H, Messina OD, et al (2013) Guias 2012 para el diagnostico, la prevencion y el tratamiento de la osteoporosis. Medcina (Buenos Aires) 73: 55-74 |
| 34. | Wu CH, McCloskey EV, Lee JK et al (2014) Consensus of official position of IOF/ISCD FRAX initiatives in Asia-Pacific region. J Clin Densitom 17:150-5 |
| 35. | Pereira RM, Carvalho JF, Paula AP et al (2012) Guidelines for the prevention and treatment of glucocorticoid-induced osteoporosis. Rev Bras Reumatol 52:580-93. English, Portuguese |
| 36. | Borissova A-M, Zacharieva S, Boyanov M et al (2013) Recommendations for good clinical practice in osteoporosis. <http://www.iofbonehealth.org/guideline-references#ref_42> Accessed 22 October 2015 |
| 37. | Fouda MA, Khan AA, Sultan MS, Rios LP, McAssey K, Armstrong D (2012) Evaluation and management of skeletal health in celiac disease: position statement. Can J Gastroenterol 26: 819-29. |
| 38. | Zhang Z, Gao B, Liu Z (2012) Fracture risk assessment tool (FRAX) for osteoporosis diagnosis and treatment. Chin J Osteoporos 18: 589-595. |
| 39. | Curković B, Grazio S, Babić-Naglić D, Anić B, Vlak T, Hanih M (2008) [Recommendations of the Croatian Society for Rheumatology for prevention, diagnostics and treatment of post-menopausal osteoporosis]. Reumatizam. 55: 26-30. Croatian. PubMed PMID: 19024267. |
| 40. | Coleman R, Body JJ, Aapro M, Hadji P Herrstedt J on behalf of the ESMO Guidelines Working Group (2014) Bone health in cancer patients: ESMO Clinical Practice Guidelines. Ann Oncol 25 (suppl 3): 124-137. |
| 41. | Brincat M, Calleja-Agius J, Erel CT et al (2011) EMAS position statement: Bone densitometry screening for osteoporosis. Maturitas 68: 98-101. |
| 42. | Duru N, van der Goes MC, Jacobs JW et al (2013) EULAR evidence-based and consensus-based recommendations on the management of medium to high-dose glucocorticoid therapy in rheumatic diseases. Ann Rheum Dis. 72: 1905-13 |
| 43. | Cortet B, Lartigau E, Caty A, et al (2012) Androgen deprivation therapy for prostate cancer and osteoporotic risk. Progres En Urologie 22: S31-S8. |
| 44. | Dachverband Osteologie e.V (2011) DVO guideline 2009 for prevention, diagnosis and therapy of osteoporosis in adults. Osteologie 20: 55–74. <http://www.schattauer.de/en/magazine/subject-areas/journals-a-z/osteology/contents/archive/issue/special> (Accessed 19 May 2012) |
| 45. | Osteoporosis Society of Hong Kong (2013) OSHK Guideline for clinical management of postmenopausal osteoporosis in Hong Kong. Hong Kong Med J 19 (suppl 2): 3-40 |
| 46. | Meeta, Harinarayan CV, Marwah R, Sahay R, Kalra S, Babhulkar S (2013) Clinical practice guidelines on postmenopausal osteoporosis: An executive summary and recommendations. J Midlife Health. 4: 107-26. doi: 10.4103/0976-7800.115293. |
| 47. | Lewiecki EM, Compston JE, Miller PD et al (2011) Official Positions for FRAX® bone mineral density and FRAX® simplification. From Joint Official Positions Development Conference of the International Society for Clinical Densitometry and International Osteoporosis Foundation on FRAX®. J Clin Densitom 14: 226-236. |
| 48. | Irish Osteoporosis Society (2011) Osteoporosis guidelines for health professionals. Pp1-78. Accessed 14 Oct 2015 [www.irishosteoporosis.ie](http://www.irishosteoporosis.ie) |
| 49. | Adami S, Bertoldo F, Brandi ML (2009) Linee guida per la diagnosi, prevenzione e terapia dell’osteoporosi [Guidelines for the diagnosis, prevention and treatment of osteoporosis] Reumatismo, 61: 260-284 |
| 50. | Maalouf G, Bachour F, Issa M et al (2012) Guidelines for fragility fracture in Lebanon. J Med Liban 60: 153-8 |
| 51. | Sociedad Iberoamericana de Osteología y Metabolismo Mineral [Iberoamerican Society of Osteology and Mineral Metabolism] (2009) Osteoporosis: Prevention, Diagnosis, and Treatment. [http://www.iofbonehealth.org/sites/default/files/PDFs/National%20Guidelines/SIBOMMConsensus-2009-english.pdf](http://www.iofbonehealth.org/sites/default/files/PDFs/National%20Guidelines/SIBOMMConsensus-2009-english.pdf%20Accessed3)  Accessed 3 November 2015 |
| 52. | Latvian Osteoporosis and Metabolic Diseases Association (2012) Osteporosis Clinical Guidelines [Osteoporozes klīniskās vadlīnijas]. Nacionālais veselības dienests. Accessed Jan 2013 <http://www.vmnvd.gov.lv/lv/420-kliniskas-vadlinijas/klinisko-vadliniju-datu-baze/registretas-2012gada> |
| 53. | Conseil Scientifique , Domaine de la Santé, Analyses de laboratoire (2010) Ostéoporose. Accessed 22 October 2015 <http://www.conseil-scientifique.lu/index.php?id=84> |
| 54. | Peña-Ríos DH, Cisneros-Dreinhofer FA, del Pilar De la Peña-Rodríguez M et al (2015) Consenso de diagnóstico y tratamiento de la osteoporosis en la mujer posmenopáusica mexicana [Consensus for diagnosis and treatment in Mexican women with postmenopausal osteoporosis. Med Int Méx 31:596-610. |
| 55. | Dutch Institute for Healthcare Improvement (CBO) (2011) Richtlijn Osteoporose en fractuurpreventie, derde herziening. Utrecht: CBO. |
| 56. | Romanian Ministry of Health (2010) Guidelines for the diagnosis and treatment of postmenopausal osteoporosis. Order number 1322/2010. ([www.ms.ro](http://www.ms.ro)). Accessed 13 March 2015. |
| 57. | Czerwiński E, Badurski J, Lorenc R, Osieleniec J (2010) Guidelines on the diagnosis of osteoporosis and assessment of fracture risk in Poland. Ortop Traumatol Rehabil. 2010 Mar-Apr;12(2):194-200. English, [Polish]. |
| 58. | Al-Saleh Y, Sulimani R, Sabico S, et al (2015) Guidelines for Osteoporosis in Saudi Arabia: Recommendations from the Saudi Osteoporosis Society Ann Saudi Med 35: 1-12 |
| 59. | International Osteoporosis Foundation guideline references, Slovakia <http://www.iofbonehealth.org/guideline-references#ref_27> Accessed 22 October 2015 |
| 60. | Ministry of Health (2010) Osteoporosis: Ministry of Health Practice Guidelines. Ministry of Health, Singapore |
| 61. | Rabar S, Lau R, O’Flynn N, Li L, Barry P on behalf of the Guideline Development Group (2012) Risk assessment of fragility fractures: summary of NICE guidance. BMJ 20012;345:e3698 |
| 62. | American Association of Clinical Endocrinologists (2010) Medial guidelines for clinical practice for the diagnosis and treatment of postmenopausal osteoporosis. Endocrine practice 16 (suppl 3): 1-37 |
| 63. | Tosi LL, Dell RM (2012) AAOS. Challenging orthopaedics to reduce osteoporotic hip fractures, 2012. <http://www.aaos.org/news/aaosnow/may09/research5.asp> (accessed 6 November 2015). |
| 64. | Qaseem A, Snow V, Shekelle P, Hopkins R Jr, Forciea MA, Owens DK (2008) Clinical Efficacy Assessment Subcommittee of the American College of Physicians. Pharmacologic treatment of low bone density or osteoporosis to prevent fractures: a clinical practice guideline from the American College of Physicians. Ann Intern Med 149: 404-15. |
| 65. | Lim LS, Hoeksma LJ, Sherin K (2009) Screening for osteoporosis in the adult US population: ACPM position statement on preventive practice. Am J Prev Med 36: 366–375 |
| 66. | Kanis JA (2013) Commentary on guidelines on postmenopausal osteoporosis – Indian Menopause Society. Journal of Midlife Health 4: 129-31. Available from: <http://www.jmidlifehealth.org/text.asp?2013/4/2/129/> |
| 67. | National Osteoporosis Foundation (2015) Clinician’s guide to prevention and treatment of osteoporosis. <http://nof.org/hcp/resources/913> Accessed 9 Feb 2015 |
| 68. | Socialstyrelsen (2010) Nationella riktlinjer för rörelseorganens sjukdomar 2010 – stöd för styrning och ledning. Preliminär version. Artikelnr 2010-11-15. Published at [www.socialstyrelsen.se](http://www.socialstyrelsen.se) Accessed 3 November 2015 |
| 69. | Mazokopakis EE, Starakis IK (2011) Recommendations for Diagnosis and Management of Osteoporosis in COPD Men. ISRN Rheumatol. 2011:901416. doi: 10.5402/2011/901416. Epub 2011 Aug 10. |
| 70. | Arznei & Vernunft (2010) Osteoporose. Knochenbruch- Krankheit. Pharmig, Verband der pharmazeutischen Industrie Österreichs |
| 71. | Body J-J (2012) Aromatase inhibitors-induced bone loss in early breast cancer. BoneKEy reports 1: 201. doi:10.1038/bonekey.2012.201 |
| 72. | Florence R, Allen S, Benedict L et al (2013) Diagnosis and treatment of osteoporosis. Bloomington (MN): Institute for Clinical Systems Improvement (ICSI); <https://www.icsi.org/guidelines__more/catalog_guidelines_and_more/catalog_guidelines/catalog_musculoskeletal_guidelines/osteoporosis/> Accessed 1 November 2015 |
| 73. | British Columbia Medical Association (2012) Osteoporosis: Diagnosis, Treatment and Fracture Prevention. British Columbia Medical Association and British Columbia Ministry of health. |
| 74. | Khan A, Fortier M (2014) Osteoporosis in menopause. J Obstet Gynaecol Can 36 (9 eSuppl C):S1-S15 |
| 75. | Zhang Z, Ou Y, Sheng Z, Liao E (2014) How to decide intervention thresholds based on FRAX in central south Chinese postmenopausal women. Endocrine 45: 195-7 |
| 76. | Stepan J (2009) Algorithm of treatment of glucocorticoid induced osteoporosis--search for criteria. Vnitrni lekarstvi 55: 448-54. |
| 77. | Rizzoli R, Body JJ, DeCensi A, Reginster JY, Piscitelli P, Brandi ML (2012) Guidance for the prevention of bone loss and fractures in postmenopausal women treated with aromatase inhibitors for breast cancer: an ESCEO position paper. Osteoporos Int 23: 2567-76. and erratum Osteoporos Int 23: 2577 |
| 78. | Koski AM (2013) Glukokortikoidin aiheuttaman osteoporoosin hoitokaavio. <http://www.kaypahoito.fi/web/kh/suositukset/suositus?id=ima02292> Accessed 4 November 2015 |
| 79. | Makras P, Paiopoulos G, Lyritis GP (2012) 2011 Guidelines for the Diagnosis and Treatment of Osteoporosis in Greece. J Musculoskelet Neuronal Interact 12 : 38-42 |
| 80. | Makras P, Athanasakis K, Boubouchairopoulou N et al (2015) Cost-effective osteoporosis treatment thresholds in Greece. Osteoporos Int 26: 1949-57. |
| 81. | Cheung E, Kung AWC, Tan KCB (2014) Outcomes of applying the NOF, NOGG and Taiwanese guidelines to a cohort of Chinese early postmenopausal women. Clinl Endocrinol 80: 200-7. |
| 82. | Lakatos P, Szekeres L, Takács I, et al (2011) [Diagnostic and therapeutic guidelines for the age‑related and glucocorticoid‑induced osteoporosis –2011, Hungary]. Magyar Reumatológia 1: 28-33. Hungarian. |
| 83. | Nakatoah S, Takemaru Y (2013) Application of the fracture risk assessment tool (FRAX®) and determination of suitable cut-off values during primary screening I specific health check-ups in Japan. J Bone Miner Metab 31: 674-680 |
| 84. | Chakhtoura M, Baddoura R , El-Hajj Fuleihan G (2013) Lebanese FRAX-Based Osteoporosis Guidelines. <http://www.osteos.org.lb/admin/uploads/Full%20document.pdf> accessed 19 October 2015 |
| 85. | Malaysian Osteoporosis Society (2012) Clinical guidance on management of osteoporosis. <http://www.iofbonehealth.org/sites/default/files/PDFs/National%20Guidelines/Malaysia_CG_Mgmt_Osteoporosis_2012-0912-final.pdf> Accessed October 14 2015 |
| 86. | Yeap SS, Hew FL, Lee JK, et al (2013) The Malaysian clinical guidance on the management of postmenopausal osteoporosis, 2012: A Summary. International Journal of Rheumatic Diseases 16: 30-40. |
| 87. | Cymet-Ramírez J, Cisneros-Dreinhofer FA, Alvarez-Martínez MM et al (2011). [Diagnosis and treatment of osteoporosis. Position of the Mexican College of Orthopedics and Traumatology]. Acta Ortop Mex. 25: 303-12. Spanish. PubMed PMID: 22509637. |
| 88. | Li-Yu J, Perez EC, Cañete A, Bonifacio L et al (2011) Clinical Practice Guidelines Task Force Committee on Osteoporosis. Consensus statements on osteoporosis diagnosis, prevention, and management in the Philippines. Int J Rheum Dis 14: 223-38 |
| 89. | Badurski JE, Kanis JA, Johansson H, et al (2011) The application of FRAX (R) to determine intervention thresholds in osteoporosis treatment in Poland. Polskie Archiwum Medycyny Wewnetrznej-Polish Archives of Internal Medicine 121: 148-54. |
| 90. | Lorenc R, Głuszko P, Karczmarewicz E et al (2011) Polish recommendations on the diagnosis and treatment of osteoporosis. Medycyna Praktyczna(Reumatologia) Special Edition 1/2011 [Polish] |
| 91. | Badurski J, Jeziernicka E, Dobrenko A, et al (2011) The characteristics of osteoporotic fractures in the region of Bialystok (BOS-2). The application of the WHO algorithm, FRAX (R) BMI and FRAX (R) BMD assessment tools to determine patients for intervention. Endokrynologia Polska 62: 290-8. |
| 92. | Gluszko P, Lorenc RS, Karczmarewicz E, Misiorowski W, Jaworski M (2014) Polish guidelines for the diagnosis and management of osteoporosis: a review of 2013 update. Polskie Archiwum Medycyny Wewnetrznej-Polish Archives of Internal Medicine 124: 255-63. |
| 93. | Goncalves MJ, Rodrigues AM, Canhao H, Fonseca JE (2013) Osteoporosis: From bone biology to individual treatment decision. Acta Med Port 26: 445-455 |
| 94. | Amin TT, Al Owaifeer A, Al-Hashim H, et al (2013) Osteoporosis among older Saudis: risk of fractures and unmet needs. Arch Osteoporos 8: 118. |
| 95. | Niemethova E, Killinger Z, Payer J (2013) Fracture risk prediction with FRAX in Slovak postmenopausal women. Cent Eur J Med 8: 571-586 |
| 96. | Kocjan T, Prezelj J, Pfeifer M, Sever MJ, Cokolic M, Zavratnik A (2013) Guidelines for the detection and treatment of osteoporosis. Zdravniski Vestnik-Slovenian Medical Journal 82: 207-17. |
| 97. | International Osteoporosis Foundation guideline references, Slovenia <http://www.iofbonehealth.org/guideline-references#ref_38> Accessed 22 October 2015 |
| 98. | Hough S, Ascott-Evans B-H, Brown SL et al for the National Osteoporosis Foundation of South Africa (NOFSA) (2010) NOFSA Guideline for the Diagnosis and Management of Osteoporosis. Available online at: www.jemdsa.co.za and [www.osteoporosis.org.za](http://www.osteoporosis.org.za) Accessed 22 October 2015 |
| 99. | Kim JW, Jeon YJ, Baek DH, Kim TN, Chang JS (2014) Percentage of the population at high risk of osteoporotic fracture in South Korea: analysis of the 2010 Fifth Korean National Health and Nutrition Examination survey data. Osteoporos Int 25: 1313-9. |
| 100. | Pérez Edo L, Alonso Ruiz A, Roig Vilaseca D et al; Spanish Society of Rheumatology (2011) [2011 Up-date of the consensus statement of the Spanish Society of Rheumatology on osteoporosis]. Reumatol Clin 7: 357-79. Spanish. |
| 101. | Etxebarria-Foronda I, Caeiro-Rey JR,Larrainzar-Garijo R et al (2015) Guía SECOT-GEIOS en osteoporosis y fractura por fragilidad. Actualización. Rev Esp Cir Ortop Traumatol 59:373-393. |
| 102. | García R, Jódar Gimeno E, García Martín A et al (2012) [Clinical practice guidelines for evaluation and treatment of osteoporosis associated to endocrine and nutritional conditions. Bone Metabolism Working Group of the Spanish Society of Endocrinology]. Endocrinol Nutr 59: 174-96. Erratum in: Endocrinol Nutr. 2012 59: 469. |
| 103. | Lekamwasam S (2013) Sri Lankan FRAX model and country-specific intervention thresholds. Arch Osteoporos 8: 148. |
| 104. | Johansson H, Kanis JA, Ljunggren O, Strom O, Svensson O, Mellstrom D ( 2011) FRAX--model for 10-year fracture risk assessment. Support in the treatment of osteoporosis, according to preliminary Swedish guidelines. Lakartidningen 108: 336-9. |
| 105. | Lippuner K, Johansson H, Borgström F et al (2012) Cost-effective intervention thresholds against osteoporotic fractures based on FRAX® in Switzerland. Osteoporos Int 23: 2579–2589 |
| 106. | TAO Taiwanese Osteoporosis Association (2012) Taiwanese Guidelines for the Prevention and Treatment of Osteoporosis <http://www.iofbonehealth.org/sites/default/files/PDFs/National%20Guidelines/Taiwanese_guidelines_prevention_treatment_osteoporosis.pdf> Accessed 22 October 2015 |
| 107. | Pongchaiyakul C, Leerapun T, Wongsiri S, Songpattanasilp T, Taechakraichana N (2012) Value and Validation of RCOST and TOPF Clinical Practice Guideline for Osteoporosis Treatment. J Med Assoc Thailand 95: 1528-35. |
| 108. | Davis S, Martyn-St James M, Sanderson J, et al (2015) Bisphosphonates for preventing osteoporotic fragility fractures (including a partial update of NICE technology appraisal guidance 160 and 161).Technology Assessment Report commissioned by the NIHR HTA Programme on behalf of the National Institute for Health and Care Excellence. Produced by ScHARR, The University of Sheffield |
| 109. | McCloskey E, Kanis JA, Johansson H et al (2015) FRAX-based assessment and intervention thresholds – an exploration of thresholds in women aged 50 years and older in the UK. Osteoporosis Int 26:2091-9 |
| 110. | Lyell V, Henderson E, Devine M, Gregson C (2015) Assessment and management of fracture risk in patients with Parkinson’s disease. Age Ageing 44: 34–41 |
| 111. | Cosman F, de Beur SJ, LeBoff MS et al (2014) Clinician’s guide to prevention and treatment of osteoporosis. Osteoporos Int 25: 2359-81. |
| 112. | Nelson HD, Haney EM, Chou R, Dana T, Fu R, Bougatsos C (2010) Screening for osteoporosis: systematic review to update the 2002 US Preventive Services Task Force Recommendation. Evidence Syntheses No. 77. AHRQ Publication No. 10-05145-EF-1. |
| 113. | Grossman JM, Gordon R, Ranganath VK et al (2010) American College of Rheumatology 2010 recommendations for the prevention and treatment of glucocorticoid-induced osteoporosis. Arthritis Care Res (Hoboken) 62: 1515–1526 |
| 114. | Watts NB, Adler RA, Bilezikian JP et al (2012) Osteoporosis in men: an Endocrine Society clinical practice guideline. J Clin Endocrinol Metab 97: 1802-22. |
| 115. | Scillitani A, Mazziotti G, Di Somma C, et al (2014) Treatment of skeletal impairment in patients with endogenous hypercortisolism: when and how? Osteoporos Int 25: 441-6. |
| 116. | Michigan Quality Improvement Consortium Guideline (2014) Management and Prevention of Osteoporosis [Michigan Quality Improvement Consortium](http://www.mqic.org/) Accessed 25 October 2015 |
| 117. | American College of Obstetricians and Gynecologists (ACOG). Osteoporosis. Washington (DC): American College of Obstetricians and Gynecologists (AC OG); 2012 Sep. 17. p. (ACOG practice bulletin; no. 129). |
| 118. | North American Menopause Society (NAMS) (2010) Management of osteoporosis in postmenopausal women: 2010 position statement of The North American Menopause Society. Menopause 17: 25-54 |
| 119. | Sweet MG, Sweet JM, Jeremiah MP, Galaska SS (2008) Diagnosis and Treatment of Osteoporosis. American Family Physician 79: 193-200 |
| 120. | Adler RA, Hastings FW, Petkov VI (2010) Treatment thresholds for osteoporosis in men on androgen deprivation therapy: T-score versus FRAX. Osteoporos Int. 21:647-53 |
| 121. | Gralow JR, Biermann JS, Farooki A, et al (2009) NCCN Task Force Report: Bone Health in Cancer Care. Journal of the National Comprehensive Cancer Network 7: S1-S32. |
| 122. | Jeremiah MP, Unwin BK, Greenawald MH, Casiano VE (2015) Diagnosis and management of osteoporosis. Am Fam Physician 92: 261-8 |
| 123. | Institute for Clinical Systems Improvement (2013) Diagnosis and treatment of osteoporosis. <http://www.isci.org/guidelines_more> Accessed Jan 29, 2016 |
| 124. | Tosteson AN, Melton LJ 3rd, Dawson-Hughes B et al. Cost-effective osteoporosis treatment thresholds: the United States perspective. Osteoporos Int. 2008; 19:437–447 |
| 125. | Berry SD, Kiel DP, Donaldson MG, et al (2010) Application of the National Osteoporosis Foundation Guidelines to postmenopausal women and men: the Framingham Osteoporosis Study. Osteoporos Int 21: 53-60 |
| 126. | Dawson-Hughes B, Looker AC, Tosteson AN, Johansson H, Kanis JA, Melton LJ 3rd (2010) The potential impact of new National Osteoporosis Foundation guidance on treatment patterns. Osteoporos Int 21: 41-52 |
| 127. | Crandall CJ, Larson J, Gourlay M et al (2014) Osteoporosis screening in postmenopausal women 50-64 years-old: Comparison of U.S. Preventive Services Task Force strategy and two traditional strategies in the Women’s Health Initiative. J Bone Miner Res. 29: 1661-6 |
| 128. | Kanis JA, Harvey N, McCloskey EV (2014) Pre-screening young postmenopausal women for BMD testing. BoneKEy Reports 3, Article number: 544 doi:10.1038/bonekey.39, Published online 11 June 2014. |
| 129. | Lydick E, Cook K, Turpin J, Melton M, Stine R, Byrnes C (1998) Development and validation of a simple questionnaire to facilitate identification of women likely to have low bone density. Am J Manag Care 4: 37-48. |
| 130. | Koh LK, Sedrine WB, Torralba TP et al (2001) A simple tool to identify Asian women at increased risk of osteoporosis. Osteoporos Int 12: 699–705. |
| 131. | Bansal S, Pecina JL, Merry SP, et al (2015) US Preventative Services Task Force FRAX threshold has a low sensitivity to detect osteoporosis in women ages 50-64 years. Osteoporos Int 26: 1429-33. |
| 132. | National Osteoporosis Foundation (NOF) (2008) Clinician’s Guide to prevention and treatment of osteoporosis. Washington: DC National Osteoporosis Foundation. |
| 133. | van Staa TP, Leufkens HG, Abenhaim L, Zhang B, Cooper C (2000) Oral corticosteroids and fracture risk: relationship to daily and cumulative doses. Rheumatol (Oxford) 39: 1383-9. |
| 134. | Orimo H, Hayashi Y, Fukunaga M et al (2001) Diagnostic criteria for primary osteoporosis: year 2000 revision. Jap J Bone Miner Metab 19: 331–337 |
| 135. | Fujiwara S, Nakamura T, Orimo H (2008) Development and application of a Japanese model of the WHO fracture risk assessment tool (FRAX). Osteoporos Int 19: 429–435 |
| 136. | Kanis JA, Delmas P, Burckhardt P, Cooper C, Torgerson D (1997) Guidelines for diagnosis and management of osteoporosis. Osteoporos Int 7:390–406 |
| 137. | Royal College of Physicians (1999) Osteoporosis: clinical guidelines for the prevention and treatment. RCP, London |
| 138. | Hwang J, Chan D, Chen J, Cheng T, Wu C, Soong Y, et al (2013) Clinical practice guidelines for the prevention and treatment of osteoporosis in Taiwan: Summary. J Bone Miner Metab. 31:1-7. |
| 139. | Compston J, Bowring C, Cooper A, et al (2013) Diagnosis and management of osteoporosis in postmenopausal women and oldermen in the UK: National Osteoporosis Guideline Group (NOGG) update 2013 Maturitas 75:392-396. |
| 140. | Kanis JA, McCloskey EV, Johansson H, Strom O, Borgstrom F, Oden A and the National Osteoporosis Guideline Group (2008) Case finding for the management of osteoporosis with FRAX® - Assessment and intervention thresholds for the UK Osteoporosis International 19; 1395-1408. PMID: 18751937. Erratum in Osteoporos Int 2009;20:499–502 |
| 141. | Compston J, Cooper A, Cooper C et al (2009) Guidelines for the diagnosis and management of osteoporosis in postmenopausal women and men from the age of 50 years in the UK. Maturitas 62:105–108. |
| 142. | Johansson H, Oden A, Johnell O et al (2004) Optimization of BMD measurements to identify high risk groups for treatment – a test analysis. J Bone Miner Res 19: 906-913. |
| 143. | Kanis JA, Stevenson M, McCloskey EV, Davis S, Lloyd-Jones M (2007) Glucocorticoid-induced osteoporosis: a systematic review and cost-utility analysis. Health Technol Assess. 2007; 11:1–256. |
| 144. | Johansson H, Kanis JA, Oden A, Compston J, McCloskey E (2012) A comparison of case-finding strategies in the UK for the management of hip fractures. Osteoporos Int 23:907–915 |
| 145. | Kyriakos G, Vidal-Casariego A, Fernandez-Martinez MN et al (2015) Impact of the NOGG and NOF Guidelines on the Indication of Bone Mineral Density in Routine Clinical Practice. J Clin Densitom 18: 533-538 |
| 146. | Chen JS, Simpson JM, Blyth FM, March LM (2014) Managing osteoporosis with FRAX (R) in Australia: Proposed new treatment thresholds from the 45 &Up Study cohort. Bone 69: 148-53. |
| 147. | Johansson H, Kanis JA, McCloskey EV, et al (2011) A FRAX (R) model for the assessment of fracture probability in Belgium. Osteoporos Int 22: 453-61. |
| 148. | Zerbini CAF, Szejnfeld VL, Abergaria BH, McCloskey EV, Johansson H, Kanis JA (2015) Incidence of hip fracture in Brazil and the development of a FRAX model. Arch Osteoporos 10(: 224. |
| 149. | Lekamwasam S, Adachi JD, Agnusdei D, et al (2012) A framework for the development of guidelines for the management of glucocorticoid-induced osteoporosis. Osteoporos Int 23: 2257-76. |
| 150. | Niskanen L, Kettunen J, Koski A-M et al for the Finnish Medical Society Duodecim, Finnish Endocrine Society and Finnish Gynaecological Association (National) (2014) Osteoporosis. Current care guidelines. Suomalaisen Lääkäriseuran Duodecimin, Suomen Endokrinologiyhdistyksen ja Suomen Gynekologiyhdistyksen asettama työryhmä (2014) Osteoporoosi. <http://www.terveysportti.fi/xmedia/hoi/hoi24065.pdf> accessed 26 October 2015 |
| 151. | Briot K, Cortet B, Thomas T et al (2012) 2010 update of French guidelines for the pharmacological treatment of postmenopausal osteoporosis. Joint Bone Spine 79:304–313. |
| 152. | McGowan B, Kanis JA, Johansson H, Silke C, Whelan B (2013) Development and use of FRAX in the management of osteoporosis in Ireland. Arch Osteoporos 8:146. Doi: 10.1007/s11657-013-0146-z. |
| 153. | Grigorie D, Sucaliuc A, Johansson H, Kanis JA, McCloskey E (2013) FRAX-based intervention and assessment thresholds for osteoporosis in Romania. Arch Osteoporos 8: 164. |
| 154. | Lesnyak O, Ershova O, Belova K et al (2012) Epidemiology of fracture in the Russian Federation and the development of a FRAX model. Arch Osteoporos 7: 67-73. doi: 10.1007/s11657-012-0082-3. |
| 155. | Russian Association on Osteoporosis (2013) http://www.osteoporoz.ru/content/view/891/113/ Accessed 22 October 2015 |
| 156. | International Osteoporosis Foundation (2012) Ministry of Health official officially launches FRAX model in Sri Lanka <http://www.iofbonehealth.org/ministry-health-official-officially-launches-frax-model-sri-lanka> Accessed 21 October 2015 |
| 157. | Association Suisse Contre l‘Ostéoporose (2015) [www.svgo.ch](http://www.svgo.ch) accessed 18th October 2015 |
| 158. | Nottinghamshire Osteoporosis Guidelines 2014 <http://www.nottsapc.nhs.uk/attachments/article/3/osteoporosis%20guideline.pdf> Accessed 1November 2015 |
| 159. | Bruyere O Fossi M, Zegels D, Leonori L, Hiligsmann M, Neuprez A, Reginster JY (2013) Comparison of the proportion of patients potentially treated with an anti-osteoporotic drug using the current criteria of the Belgian national social security and the new suggested FRAX criteria. Rheumatol Int 33 :973-8. |
| 160. | Johansson H, Kanis JA, Oden A, Compston J, McCloskey E (2012) A comparison of case-finding strategies in the UK for the management of hip fractures. Osteoporos Int 23: 907-15. |
| 161. | National Clinical Guideline Centre (2012) Osteoporosis: fragility fracture risk. Osteoporosis: assessing the risk of fragility fracture. Short clinical guideline - CG146 Evidence and recommendations August 2012. Published by the National Clinical Guideline Centre by the Royal College of Physicians, London |
| 162. | Shepstone L, Lenaghan E, Cooper et al (2012) A pragmatic randomised controlled trial of the effectiveness and cost effectiveness of screening older women for the prevention of fractures: rationale, design and methods for the ‘SCOOP’ Study. Osteoporosis Int 23: 2507-2515. |
| 163. | Strom O, Borgstrom F, Kleman M et al (2010) FRAX and its applications in health economics—cost-effectiveness and intervention thresholds using bazedoxifene in a Swedish setting as an example. Bone 47:430–437 |
| 164. | Strom O, Jonsson B, Kanis JA (2013) Intervention thresholds for denosumab in the UK using a FRAX(R)-based cost-effectiveness analysis. Osteoporos Int 24:1491–1502 |
| 165. | Kanis JA, Adams J, Borgstrom F et al (2008) The cost-effectiveness of alendronate in the management of osteoporosis. Bone 42:4–15. |
| 166. | Borgström F, Ström O, Coelho J, Johansson H, Oden A, McCloskey EV, Kanis JA. (2010) The cost-effectiveness of risedronate in the UK for the management of osteoporosis using the FRAX. Osteoporosis International 21: 495-505. |
| 167. | Jonsson B, Strom O, Eisman JA et al (2011) Cost-effectiveness of denosumab for the treatment of postmenopausal osteoporosis. Osteoporos Int 22: 967–82 |
| 168. | Ivergard M, Strom O, Borgstrom F, Burge RT, Tosteson AN, Kanis J (2010) Identifying cost-effective treatment with raloxifene in postmenopausal women using risk algorithms for fractures and invasive breast cancer. Bone 47:966–974 |
| 169. | Borgstrom F, Strom O, Coelho J et al (2010) The cost-effectiveness of strontium ranelate in the UK for the management of osteoporosis. Osteoporos Int 21:339–349 |
| 170. | Borgstrom F, Strom O, Kleman M et al (2010) Cost-effectiveness of bazedoxifene incorporating the FRAX(R) algorithm in a European perspective. Osteoporos Int 22: 955–65 |
| 171. | Azagra R, Roca G, Martin-Sanchez et al (2015) FRAX thresholds to identify people with high or low risk of osteoporotic fracture in Spanish female population. Med Clin (Barc) 144: 1-8. |
| 172. | National Institute for Health and Clinical Excellence (2010) Denosumab for the prevention of osteoporotic fractures in postmenopausal women. Technology appraisal 204 http://guidance.nice.org.uk/TA204 Accessed 24 May 2011 |
| 173. | National Institute for Health and Clinical Excellence (2011a) Alendronate, etidronate, risedronate, raloxifene and strontium ranelate for the primary prevention of osteoporotic fragility fractures in postmenopausal women. Technology appraisal TA160. http://guidance.nice.org.uk/TA160 Accessed 24 May 2011 |
| 174. | National Institute for Health and Clinical Excellence (2011b) Alendronate, etidronate, risedronate, raloxifene, strontium ranelate and teriparatide for the secondary prevention of osteoporotic fragility fractures in postmenopausal women. Technology appraisal TA161.http://egap.evidence.nhs.uk/TA161 Accessed 24 May 2011 |
| 175. | Kanis JA, McCloskey E, Jönsson B, Cooper A, Ström O Borgström F (2010) An evaluation of the NICE guidance for the prevention of osteoporotic fragility fractures in postmenopausal women. Arch Osteoporos 5: 19-48 |
| 176. | Zethraeus N, Borgstrom F, Strom O, Kanis JA, Jonsson B (2007) Cost-effectiveness of the treatment and prevention of osteoporosis—a review of the literature and a reference model. Osteoporos Int 18:9–23 |
| 177. | Hippisley-Cox J, Coupland C (2009) Predicting risk of osteoporotic fracture in men and women in England and Wales: prospective derivation and validation of QFractures Scores. Br Med J 339: b4229 |
| 178. | Chen P, Krege JH, Adachi JD, et al (2009) Vertebral fracture status and the World Health Organization risk factors for predicting osteoporotic fracture risk. J Bone Miner 24:495–502. |
| 179. | Sornay-Rendu E, Munoz F, Delmas PD, Chapurlat RD (2010) The FRAX® tool in French women : how well does it describe the real incidence of fracture in the OFELY cohort. J Bone Miner Res 25: 2101–2107 |
| 180. | Bolland MJ, Siu AT, Mason BH et al (2011) Evaluation of the FRAX and Garvan fracture risk calculators in older women. J Bone Miner Res 26: 420-427 |
| 181. | Ensrud KE, Lui LY, Taylor BC et al (2009) A comparison of prediction models for fractures in older women: is more better? Arch Intern Med 169:2087-94. |
| 182. | Tremollieres FA, Pouilles JM, Drewniak N, Laparra J, Ribot CA, Dargent-Molina P (2010) Fracture risk prediction using BMD and clinical risk factors in early postmenopausal women: sensitivity of the WHO FRAX tool. J Bone Miner Res 25: 1002-9. |
| 183. | Donaldson MG, Palermo L, Schousboe JT, Ensrud KE , Hochberg MC, Cummings SR (2009) FRAX and risk of vertebral fractures: The Fracture Intervention Trial. J Bone Miner Res 24:1793–1799 |
| 184. | Hillier TA, Cauley JA, Rizzo JH (2011) The WHO absolute fracture risk models (FRAX): Do clinical risk factors improve fracture prediction in older women without osteoporosis? J Bone Miner Res. 26: 1774-82. |
| 185. | Pluskiewicz W, Adamczyk P, Franek E et al (2010) Ten-year probability of osteoporotic fracture in 2012 Polish women assessed by FRAX and nomogram by Nguyen et al.- Conformity between methods and their clinical utility. Bone 46:1661-1667 |
| 186. | Tamaki J, Iki M, Kadowaki E, Sato Yet al (2011) The clinical utility of FRAX to discriminate fracture status in men and women with chronic kidney disease. Osteoporos Int 25: 71-6. |
| 187. | Azagra R, Roca G, Encabo G et al (2012) FRAX® tool, the WHO algorithm to predict osteoporotic fractures: the first analysis of its discriminative and predictive ability in the Spanish FRIDEX cohort. BMC Musculoskelet Disord. 13:204. doi: 10.1186/1471-2474-13-204. |
| 188. | Sandhu SK, Nguyen ND, Center JR, Pocock NA, Eisman JA, Nguyen TV (2010) Prognosis of fracture: evaluation of predictive accuracy of the FRAX™ algorithm and Garvan nomogram. Osteoporos Int 21:863–871 |
| 189. | Leslie WD, Lix LM (2014) Comparison between various fracture risk assessment tools. Osteoporos Int. 25: 1-21 |
| 190. | Kanis JA, Oden A, Johansson H, McCloskey E (2012) Pitfalls in the external validation of FRAX. Osteoporos Int 23: 423-31 |
| 191. | Marques,A, Ferreira RJO, Santos E, Loza E, Carmona L, Pereira da Silva JA (2015) The accuracy of osteoporotic fracture risk prediction tools: a systematic review and meta-analysis. Ann Rheum Dis. Downloaded from http://ard.bmj.com/ on August 7, 2015 |
| 192. | Nayak S, Edwards DL, Saleh AA, Greenspan SL (2015) Systematic review and meta-analysis of the performance of clinical risk assessment instruments for screening for osteoporosis or low bone density. Osteoporos Int 26:1543-54. |
| 193. | Kanis JA, Odén A, Johansson H, McCloskey EV (2013) Pitfalls in the external validation of FRAX: response to Bolland et al. Osteoporos Int. 24: 391-2 |
| 194. | Fraser LA, Langsetmo L, Berger C, et al (2011) Fracture prediction and calibration of a Canadian FRAX tool: a population-based report from CaMos. Osteoporos Int22: 829-837 |
| 195. | Leslie WD, Lix LM, Johansson H et al (2010) Independent clinical validation of a Canadian FRAX tool: fracture prediction and model calibration. J Bone Miner Res 25: 2350-2358 |
| 196. | Brennan SL, Leslie WD, Lix LM et al (2014). FRAX provides robust fracture prediction regardless of socioeconomic status Osteoporos Int 25: 61-69. |
| 197. | Rubin KH, Abrahamsen B, Hermann AP et al (2011) Fracture risk assessed by fracture risk assessment tool (FRAX) compared with fracture risk derived from population fracture rates. Scand J Public Health 39:312–318 |
| 198. | Sund R, Honkanen R, Johansson H, Oden A, McCloskey EV, Kanis JA, Kröger H (2014) Evaluation of the FRAX model for the prediction of hip fractures in Kuopio, Finland. Calcif Tiss Int 95: 39-45. |
| 199. | Sund R (2007) Utilization of routinely collected administrative data in monitoring of aging-dependent hip fracture incidence. Epidemiol Perspect Innov 4:2 |
| 200. | Sund R (2006) Hip fracture incidence in Finland, 1998–2002. Duodecim 122(9):1085–1091 |
| 201. | Abrahamsen B, Vestergaard P, Rud B et al (2006) Ten-Year Absolute Risk of Osteoporotic Fractures According to BMD T Score at Menopause: The Danish Osteoporosis Prevention Study. J Bone Miner Res 21: 796–800 |
| 202. | Azagra R, Roca G, Zwart M, Encabo G (2011) Differences in the predictive values of the FRAX (TM) tool between the Spanish and United Kingdom population and considerations about the intervention threshold. Med Clin (Barc) 2011; 137(15): 713-4. |
| 203. | Ettinger B, Ensrud KE, Blackwell T et al (2013) Performance of FRAX in a cohort of community-dwelling, ambulatory older men: the Osteoporotic Fractures in Men (MrOS) study. Osteoporos Int 24:1185-93. |
| 204. | Schwartz AV, Vittinghoff E, Bauer DC et al (2011) Association of BMD and FRAX score with risk of fracture in older adults with type 2 diabetes. JAMA 305: 2184–2192 |
| 205. | Pressman AR, Lo JC, Chandra M, Ettinger B (2011) Methods for assessing fracture risk prediction models: experience with FRAX in a large integrated healthcare delivery system. J Clin Densitom 14:407–415 |
| 206. | Donaldson MG, Cawthon PM, Schousboe JT et al (2011) Novel methods to evaluate fracture risk models. J Bone Miner Res 26: 1767–1773 |
| 207. | Gullberg B, Johnell O, Kanis JA (1997) World-wide projections for hip fractures. Osteoporos Int 7: 407–413 |
| 208. | Cooper C, Cole ZA, Holroyd CR, Earl SC, Harvey NC, Dennison EM, and the IOF CSA Working Group on Fracture Epidemiology (2011) Secular trends in the incidence of hip and other osteoporotic fractures. Osteoporos Int 22: 1277-88 |
| 209. | Kanis JA, Johansson H, Odén A, Dawson-Hughes B, Melton LJ 3rd, McCloskey EV (2010) The effects of a FRAX® revision for the USA. Osteoporos Int 21:35–40 |
| 210. | Brennan SL, Quirk SE, Hosking SM et al (2015) Is there an interaction between socioeconomic status and FRAX 10-year fracture probability determined with and without bone density measures? Data from the Geelong Osteoporosis Study of Female Cohort. Calcif Tissue Int 96:138–144 |
| 211. | Leslie WD, Lix LM, Johansson H, Oden A, McCloskey E, Kanis J (2012) Does osteoporosis therapy invalidate FRAX for fracture prediction? J Bone Miner Res 27: 1243-1251. |
| 212. | Johansson H, Odén A, Lorentzon M et al (2015) Is the Swedish FRAX model appropriate for immigrants to Sweden? Osteoporos Int 26: 2617-22. |
| 213. | Leslie WD, Berger C, Langsetmo L et al (2011) Construction and validation of a simplified fracture risk assessment tool for Canadian women and men: results from the CaMos and Manitoba cohorts. Osteoporos Int 22: 1873-1883 |
| 214. | Johansson H, Kanis JA, Oden A, Johnell O, McCloskey E (2009) BMD, clinical risk factors and their combination for hip fracture prevention. Osteoporos Int 20: 1675-1682. |
| 215. | Yoon J, Kwon S-R, Lim M-J, et al (2010) A Comparison of Three Different Guidelines for Osteoporosis Treatment in Patients with Rheumatoid Arthritis in Korea. Korean Journal of Internal Medicine 25: 436-46. |
| 216. | Kanis JA, McCloskey EV, Harvey NC, Johansson H, Leslie WD (2015) Intervention thresholds and the diagnosis of osteoporosis. J Bone Miner Res 30: 1747-1753 |
| 217. | Leslie W, Morin S, Majumdar S et al (2016) Net reclassification Improvement with FRAX versus a simpler risk assessment system: More is more. J Bone Miner Res 30: S103 (Paper accepted OI, Feb 2016) |
| 218. | Kanis JA, Johansson H, Odén A, McCloskey EV (2012) The distribution of FRAX® based probabilities in women from Japan. J Bone Miner Metab 30: 700-5. |
| 219. | Borgstrom F, Johnell O, Kanis JA, et al (2006) At what hip fracture risk is it cost-effective to treat? International Intervention thresholds for the treatment of osteoporosis. Osteoporos Int 17:1459–71. |
| 220. | Oden A, McCloskey EV, Johansson H, Kanis JA (2013) Assessing the Impact of osteoporosis on the burden of hip Fractures. Calcif Tissue Int 92:42–49. |
| 221. | Kanis JA, Johansson H, Oden A, Cooper C, McCloskey EV and the Epidemiology and Quality of Life Working Group of IOF (2013) Worldwide uptake of FRAX Arch Osteoporosis 8:166. DOI 10.1007/s11657-013-0166-8 |
| 222. | Crabtree NJ, Bebbington NA, Chapman DM, et al (2010) Impact of UK National Guidelines based on FRAX(R)--comparison with current clinical practice. Clin Endocrinol 73: 452-6. |
| 223. | McCloskey EV, Johansson H, Harvey NC, Compston J, Kanis JA (2015) Online linkage of FRAX fracture risk assessment to management guidance is used by clinical practitioners. An analysis of access to National Osteoporosis Guideline Group Guidance in the UK (July 2013-June2014). Journal of Bone and Mineral Research 30: S290-291 Submitted OI under review |
| 224. | Kayan K, Johansson H, Oden A et al (2009) Can fall risk be incorporated into fracture risk assessment algorithms: a pilot study of responsiveness to clodronate. Osteoporos Int 20:2055–2061 |
| 225. | McClung MR, Geusens, P, Miller, PD et al (2001) Effect of risedronate on the risk of hip fracture in elderly women. Hip Intervention Program Study Group. N Engl J Med 344:333-340 |
| 226. | Harvey NC, Johansson H, Odén A et al (2016) FRAX predicts incident falls in elderly men. Findings from MrOs Sweden. Osteoporos Int 27: 267-274. |
| 227. | Johansson J, Harvey N, Odén’ A et al (2015) The predictive value of falls history for incident fracture decreases with time: MrOs Sweden. Jf Bone Miner Res 30: S424 |
| 228. | Cauley JA, El-Hajj Fuleihan G, Luckey MM; FRAX® Position Development Conference Members (2011). Official positions for FRAX clinical regarding international differences. FRAX® International Task Force of the 2010 Joint International Society for Clinical Densitometry & International Osteoporosis Foundation Position Development Conference. J Clin Densitom 14: 237-9. |
| 229. | van den Bergh JP, van Geel TA, Lems WF, Geusens PP (2010) Assessment of individual fracture risk: FRAX and beyond. Curr Osteoporos Rep. 2010 Sep;8(3):131-7. |
| 230. | Leslie WD, Majumdar SR, Lix LM et al (2012). High fracture probability with FRAX usually indicates densitometric osteoporosis: implications for clinical practice. Osteoporos Int. 23: 391–397 |
| 231. | Leslie WD, Morin S, Lix LM et al (2012) Fracture risk assessment without bone density measurement in routine clinical practice. Osteoporos Int 23:75–85. |

**Abbreviations**

|  |  |  |
| --- | --- | --- |
| AACE |  | American Association of Clinical Endocrinologists |
| ACR |  | American College of Rheumatology |
| AUC |  | Area Under the receiver operating characteristic (ROC) Curve |
| BMD |  | Bone mineral density |
| BMI |  | Body mass index |
| CAROC |  | Canadian Association of Radiologists and Osteoporosis Canada |
| CI |  | Confidence interval |
| CRF |  | Clinical risk factor |
| DXA |  | Dual-energy X-ray absorptiometry |
| ECTS |  | European Calcified Tissue Society |
| EFPIA |  | European Federation of Pharmaceutical Industry Associations |
| ESCEO |  | European Society for Clinical and Economic Aspects of Osteoporosis |
| FRAX |  | WHO fracture risk assessment tool. |
| HF |  | Hip fracture |
| HSOO |  | Hungarian Society for Osteoporosis and Osteoarthrology |
| IOF |  | International Osteoporosis Foundation |
| ISCD |  | International Society of Clinical Densitometry |
| JSBMR |  | Japanese Society for Bone and Mineral Research |
| MOF |  | Major osteoporotic fracture |
| NCGC |  | National Clinical Guideline Centre |
| NCGC |  | National Clinical Guideline Centre |
| NICE |  | National Institute for health and Clinical Excellence |
| NNF |  | Number Needed to FRAX |
| NNS |  | Number needed to scan |
| NOF |  | National Osteoporosis Foundation, US |
| NOFSA |  | National Osteoporosis Foundation of South Africa |
| NOGG |  | National Osteoporosis Guideline Group, UK |
| NRI |  | Net reclassification improvement (I) |
| OST |  | Osteoporosis Self-Assessment Tool |
| OSTPRE |  | Kuopio Osteoporosis Risk Factor and Prevention - study |
| PSTF |  | US Preventive Services Task Force |
| QALY |  | Quality-adjusted life year |
| QALY |  | Quality-adjusted life year |
| QFracture |  | A fracture risk assessment tool |
| RCP |  | Royal College of Physicians, London |
| ROC |  | Receiver operating characteristics |
| SCOOP |  | Screening of older women for prevention of fracture - study |
| SCORE |  | Simple Calculated Osteoporosis Risk Estimation Tool |
| SD |  | Standard deviation |
| SIGN |  | Scottish Intercollegiate Guidelines Network |
| SIOMMMS |  | Società Italiana dell'Osteoporosi, del Metabolismo Minerale e delle Malattie dello Scheletro |
| TBS |  | Trabecular bone score |
| THIN |  | The Health Improvement Network |
| T-score |  | The number of SD units that BMD differs from the young healthy reference population |
| WHO |  | World Health Organization |
| YAM |  | Young adult mean values for BMD |

**Glossary**

|  |  |  |
| --- | --- | --- |
| Age-dependent threshold |  | Intervention or assessment threshold of fracture probability that varies with age |
| Assessment threshold |  | The fracture probability at which further assessment id recommended (usually BMD) |
| Fixed threshold |  | Intervention or assessment threshold of fracture probability that is fixed over all ages |
| Fracture threshold |  | The average probability of fracture for a specific age |
| Hybrid threshold |  | Intervention or assessment threshold of fracture probability that partly varies with age and is partly fixed |
| Intervention threshold |  | For this report, the fracture probability at which treatment is recommended |
| Major osteoporotic fracture |  | Fracture of hip, spine (clinical), distal forearm or humerus. |
| NOGG strategy |  | The strategy that describes intervention or assessment threshold of fracture probability that varies with age |
| Osteopenia |  | In this report, BMD defined : a T-score of between -1 and -2.5 |
| Osteoporosis |  | In this report, BMD defined : a T-score of < -2.5 |

**Appendix** Redundant references from systematic search.

Adami S, Bertoldo F, Gatti D, et al (2013) Treatment thresholds for osteoporosis and reimbursability criteria: Perspectives associated with fracture risk-assessment tools. Calcif Tissue Int 93: 195-200.

Aker MB, Abu Taha AS, Zyoud SH, Sawalha AF, Al-Jabi SW, Sweileh WM (2013) Estimation of 10-year probability bone fracture in a selected sample of Palestinian people using fracture risk assessment tool. Bmc Musculoskeletal Disorders 2013; 14.

Atik OS (2013) How valid FRAX is in different countries? Eklem Hastaliklari Ve Cerrahisi-Joint Diseases and Related Surgery 24: 63.

Aubry-Rozier B, Stoll D, Krieg M-A, Lamy O, Hans D (2013) What was your fracture risk evaluated by FRAX® the day before your osteoporotic fracture? Clin Rheumatol 32: 219-23.

Becorpi A, Sisti G, Sorbi F, Malosso ERM, Guaschino S (2014) Management options of breast cancer related osteoporosis. Clinical cases in mineral and bone metabolism: the official journal of the Italian Society of Osteoporosis, Mineral Metabolism, and Skeletal Diseases 11: 110-3.

Blake GM, Fogelman I (2010) An Update on Dual-Energy X-Ray Absorptiometry. Seminars in Nuclear Medicine 40: 62-73.

Bolland MJ, Jackson R, Gamble GD, Grey A (2013) Discrepancies in predicted fracture risk in elderly people. BMJ 346:e8669.

Brennan SL, Leslie WD, Lix LM (2014) Is lower income associated with an increased likelihood of qualification for treatment for osteoporosis in Canadian women? Osteoporos Int 25: 273-9.

Brewer L, Mellon L, Duggan J 92013) Ability of fracture risk assessment tool and National Osteoporosis Guideline Group Guidance to stratify people appropriately before fracture. J Am Geriatr Soc 61: 1633-4.

Bridges M, Ruddick S (2012) Modifying FRAX/NOGG guidelines in rheumatology patients receiving corticosteroids: does it make any difference? Rheumatol 51: 106-7.

Bridges MJ, Ruddick S (2010) Ability of FRAX/NOGG guidelines to identify patients sustaining low trauma fractures. Rheumatol 49: 391-2.

Bridges MJ, Ruddick SA (2012) Do FRAX/NOGG guidelines predict fractures in post - menopausal women with type 2 diabetes? Diabetic Med 2012; 29: 555-6.

Bruyère O, Nicolet D, Compère S et al (2013) Perception, knowledge, and use by general practitioners of Belgium of a new WHO tool (FRAX) to assess the 10-year probability of fracture. Rheumatol Int 33: 979-83.

Canavan JB, Trivedi PJ, Bailey AN, et al (209) Fracture risk assessment using DXA and FRAX in patients with celiac disease. Gastroenterol 136: A474-A.

Carlos F, Clark P, Galindo-Suarez RM, Chico-Barba LG (2013) Health care costs of osteopenia, osteoporosis, and fragility fractures in Mexico. Arch Osteoporos 8: 125.

Chakhtoura M, Cheung AM, Kanis JA, et al (2014) FRAX based guidelines : is a universal model appropriate ? Osteoporos Int 25: S121-S2.

Chapurlat R (2012) [Osteoporosis without fracture: when do we treat?]. La Revue du Praticien 62: 199-201.

Chinese Medical Association of osteoporosis and bone mineral disease branch (2011) Primary osteoporosis treatment guidelines. Chinese J Osteoporos Bone Miner Res 4 : 2-18.

Cianferotti L, Brandi ML (2012) Guidance for the diagnosis, prevention and therapy of osteoporosis in Italy. Clin Cases Miner Bone Metab 9: 170-8.

Committee of Japanese Guidelines for the Prevention and Treatment of Osteoporosis (2012) The Japanese guidelines for the prevention and treatment of osteoporosis (2011 edition). Life Science Publishing, Tokyo. [ Japanese].

Compston J (2009) Guidelines for prevention and treatment of glucocorticoid-induced osteoporosis. Bone 45: S128-S9.

Czerwiński E, Kanis JA, Osieleniec J et al (2011) Evaluation of FRAX to characterize fracture risk in Poland. Osteoporos Int 22 : 2507-2512

Czerwinski E, Kanis JA, Trybulec B, Johansson H, Borowy P Osieleniec J (2009) The incidence and risk of hip fracture in Poland. Osteoporos Int 20; 1363-1368

Dawson-Hughes B, Tosteson AN, Melton LJ, III et al. (2008) Implications of absolute fracture risk assessment for osteoporosis practice guidelines in the USA. Osteoporos Int. 19: 449-458.

Dimic A, Sonja SJovan N et al (2011) Potential role of FRAX analysis in postmenopausal women with osteopenia. Cent Eur J Med 6: 185-189

Douglas F, Petrie KJ, Cundy T, Horne A, Gamble G, Grey A (2012) Differing perceptions of intervention thresholds for fracture risk: a survey of patients and doctors. Osteoporos Int 23: 2135-40.

Edwards FD, Grover ML, Cook CB, Chang Y-HH (2014) Use of FRAX as a determinant for risk-based osteoporosis screening may decrease unnecessary testing while improving the odds of identifying treatment candidates. Womens Health Issues 24: 629-34.

El-Hajj Fuleihan G (2012) 4th Annual meeting of the Lebanese Society of Osteoporosis and Metabolic Bone Disorders, December 2012

El-Hajj Fuleihan G, Chakhtoura, M, Baddoura R (2013) Executive Summary-FRAX–Lebanese FRAX based guidelines 2013.

Elvey MH, Pugh H, Schaller G, Dhotar G, Patel B, Oddy MJ (2014) Failure in the application of fragility fracture prevention guidelines. Ann Roy Coll f Surg Engl 96: 381-5.

Gadam RK, Schlauch K, Izuora KE (2013) FRAX prediction without BMD for assessment of osteoporosis fracture risk. Endocrine Practice 19: 780-4

Gobierno Federal (2013) Diagnostico y tratamiento de osteoporosis en mujeres postmenopauicas. Guideline IMSS-673-13. Secretary of Health. Accessed 17 October 2015. [www.cenetec.salud.gob.mx/interior/gpc.html](http://www.cenetec.salud.gob.mx/interior/gpc.html).

González-Macías J, Del Pino-Montes J, Olmos JM, Nogués X; en nombre de la Comisión de Redacción de las Guías de Osteoporosis de la SEIOMM (2015) Clinical practice guidelines for postmenopausal, glucocorticoid-induced and male osteoporosis. Spanish Society for Research on Bone and Mineral Metabolism (3rd updated version 2014). Rev Clin Esp 215: 515-526

Greenspan SL, Bilezikian JP, Watts NB, et al (2013) A clinician performance initiative to improve quality of care for patients with osteoporosis. Jo Women’s Health 22: 853-61.

Halldorsson BV, Bjornsson AH, Gudmundsson HT, Birgisson EO, Ludviksson BR, Gudbjornsson B (2015) A clinical decision support system for the diagnosis, fracture risks and treatment of osteoporosis. Comput Math Methods Med 189769. doi: 10.1155/2015/189769

Hosoi T (2012) Clinical application of FRAX in Japan. Clin Calcium 2012; 22: 857-63.

Hosoi T (2015) [2015 Guidelines for Prevention and Treatment of Osteoporosis. Diagnostic criteria of primary osteoporosis and the criteria for pharmacological treatment]. Clin Calcium 25: 1279-83.

Hungarian Society for Osteoporosis and Osteoarthrology (HSOO) (2006) National Guidelines. Calcium Bone 8: 116-155

Hwang J-S, Chan D-C, Chen J-F, et al (2014) Clinical practice guidelines for the prevention and treatment of osteoporosis in Taiwan: summary. J Bone Miner Metab 32: 10-6.

Ip TP, Cheung SK, Cheung TC et al (2013) OSHK Guideline for clinical management of postmenopausal osteoporosis in Hong Kong. Hong Kong Med J. 19 Suppl 2:1-40. <http://www.hkmj.org/supplements/article_pdfs/hkm1304sp2p6.pdf> Accessed 24 October 2015

Juozaitytė E, Aleknavičius E, Jančiauskienė R et al (2014) Guidelines for diagnostics and treatment of aromatase inhibitor-induced bone loss in women with breast cancer: a consensus of Lithuanian medical oncologists, radiation oncologists, endocrinologists, and family medicine physicians. Medicina (Kaunas 50: 197-203.

Kanis JA, Burlet N, Cooper C et al on behalf of the European Society for Clinical and Economic Aspects of Osteoporosis and Osteoarthritis (ESCEO) (2008e) European guidance for the diagnosis and management of osteoporosis in postmenopausal women. Osteoporos Int 19: 399-428.

Kanis JA, Johansson H, Oden A, McCloskey EV (2009) Bazedoxifene reduces vertebral and clinical fractures in postmenopausal women at high risk assessed with FRAX (R). Bone 44: 1049-54.

Kanis JA, McCloskey EV, Johansson H, Strom O, Borgstrom F, Oden A (2009) How to decide who to treat. Best Practice & Research in Clinical Rheumatology 23: 711-26.

Kanis JA, Odén A, McCloskey EV, Johansson H, Wahl D, Cyrus Cooper C on behalf of the IOF Working Group on Epidemiology and Quality of Life (2012e) A systematic review of hip fracture incidence and probability of fracture worldwide. Osteoporos Int 23: 2239-2256.

Khan SN, Craig L, Wild R (2013) Osteoporosis: therapeutic guidelines. Guidelines for practice management of osteoporosis. Clin Obstet Gynecol 56: 694-702.

Kraenzlin ME (2013) Swiss guidance for the diagnosis and management of osteoporosis. Rev Medicale Suisse 9: 1274-8.

Lakatos P, Balogh A, Czerwinski E, et al (2011) New considerations on the management of osteoporosis in Central and Eastern Europe (CEE): summary of the "3rd Summit on Osteoporosis-CEE", November 2009, Budapest, Hungary. Arch Osteoporos 6: 1-12.

Lakatos P, Takács I, Szekeres L, et al (2010] Reumatológiai és Fizioterápiás Szakmai Kollégium: A korral járó és a kortikoszteroidok indukálta osteoporosis diagnosztikus és terápiás protokollja – 2011. Háziorvosi Útmutató Klinikai Irányelvek Kézikönyve, Medition Kiadó, Budapest, 3: 215-224 Hungarian].

Leslie WD, Schousboe JT (2011) A review of osteoporosis diagnosis and treatment options in new and recently updated guidelines on case finding around the world. Curr Osteoporos Rep 9:129–140

Lewiecki EM, Watts NB (2009) New guidelines for the prevention and treatment of osteoporosis. Southern Med J 102: 175-9.

Lin X, Xiong D, Peng Y-Q et al (2015) Epidemiology and management of osteoporosis in the People’s Republic of China: current perspectives. Clin Interv Aging 10: 1017–1033.

Lippuner K (2012b) Osteoporosis—whom to treat? The importance of FRAX® in Switzerland. Ther Umsch 69:207–213

Lippuner K, Johansson H, Kanis JA, Rizzoli R (2010) FRAX® assessment of osteoporotic fracture probability in Switzerland. Osteoporos Int 21: 381-390

Mendoza N, Sánchez-Borrego R, Villero J et al (2013) Up-date of the consensus statement of the Spanish Menopause Society on postmenopausal osteoporosis. Maturitas 76: 99-107.

Muncie HL Jr (2014) Guidelines for osteoporosis care for fragility fractures. J Am Geriatr Soc 62: 997-8.

Naranjo A, Ojeda-Bruno S, Francisco-Hernandez F, Erausquin C, Rua-Figueroa I, Rodriguez-Lozano C (2011) Application of guidelines for secondary prevention of fracture and the FRAX index in patients with fragility fracture. Medicina Clinica 136: 290-2.

New Zealand Guidelines Group (NZGG) (2003) Prevention of hip fracture amongst people aged 65 years and over. New Zealand Guidelines Group (NZGG), Wellington,NZ. <http://www.moh.govt.nz/NoteBook/nbbooks.nsf/0/9A1DDBCD2ABB9D31CC256DCE006F7073/$file/Hip_Fracture_Prevention_Fulltext.pdf> Accessed 14 November 2015

Orimo H (2011) [Bone and calcium update; diagnosis and therapy of metabolic bone disease update. Guideline for prevention and treatment of osteoporosis update]. Clin Calcium 21: 123-43

\*Ortega MM, Cárdenas VMM, Alanis AV et al (2016) Guia de practica clinica sobre el diagnostico y tratamiento de la osteoporosis en la mujer postmenopausica Mexicana. Asociacion Mexicana del Metabolismo y Mineral (AMMOM) [https://www.ammom.mx](https://www.ammom.mx/)

Orthopedic Society of Chinese Medical Association (2008) Guidelines for osteoporosis fracture management, Chinese Medical Association. Chin J Orthop 28: 875-878

Overman RA, Toliver JC, Yeh J-Y, Gourlay ML, Deal CL (2013) Proportion of US older adults meeting Inclusion criteria for 2010 ACR recommendations on glucocorticoid-induced osteoporosis. Arthritis Rheum 65: S41.

Pavon JM, Sanders LL, Sloane R, Colón-Emeric C (2014) Sensitivity of osteoporosis screening guidelines for eventual hip fracture in older male veterans. Bonekey Rep 7: 530.

Rizzoli R, Adachi JD, Cooper C, et al (2012) Management of glucocorticoid-Induced osteoporosis. Calcif Tiss Int 91: 225-43.

Royal Australian College o0f General Practitioners (2010) Clinical guideline for the prevention and treatment of osteoporosis in postmenopausal women and older men The Royal Australian College of General Practitioners, 1 Palmerston Crescent, South Melbourne, Vic 3205 Australia ACN 000 223 807, ABN 34 000 223 807, February 2010

Sanfelix-Genoves J, Catala-Lopez F, Sanfelix-Gimeno G, Hurtado I, Baixauli C, Peiro S (2014) Variability in the recommendations for the clinical management of osteoporosis. Medicina Clinica 142: 15-22.

Schweizerische Vereinigung gegen die Osteoporose Switzerland SVGO (2015) Osteoporosis guidelines 2012 <http://www.svgo.ch/content/documents/2015/SVGO%20Empfehlungen%202015.pdf> Accessed 2 December 2015

Shah TT, Stone M, Kynaston H (2013) Assessing the applicability of the WHO FRAX osteoporotic fracture risk scoring system and national osteoporosis group guidance (NOGG) in patients with prostate cancer on androgen deprivation therapy (ADT). Bju Int 111: 44.

Siris ES, Adler R, Bilezikian J et al (2014) The clinical diagnosis of osteoporosis: a position statement from the National Bone Health Alliance Working Group. Osteoporos Int 25: 1439-43

Società Italiana dell'Osteoporosi, del Metabolismo Minerale e delle Malattie dello Scheletro (2013) [Guidelines for the diagnosis, prevention and treatment of osteoporosis. Italian Osteoporosis, Mineral Metabolism, and Skeletal Diseases Society]. Minerva Endocrinol 38(1 Suppl 1):1-30. Italian.

Torre I, Perez C, Estopinan L, et al (2013) Utility of the treatment thresholds in FRAX proposed by the NOF and the NOGG in patients with breast cancer in adjuvant treatment with aromatase inhibitors. Ann Rheum Dis 72: 295.

Triantafyllopoulos IK, Lambropoulou-Adamidou K, Nacopoulos CC et al (2014) European Menopause and Andropause Society. EMAS position statement: The management of postmenopausal women with vertebral osteoporotic fracture. Maturitas 78: 131-7.

Tsang SWY, Kung AWC, Kanis JA, Johansson H, Oden A (2009) Ten-year fracture probability in Hong Kong Southern Chinese according to age and BMD femoral neck T-scores. Osteoporos Int 20:1939–1945

Tuzun S, Eskiyurt N, Akarirmak U, et al (2012) The impact of a FRAX-based intervention threshold in Turkey: the FRAX-TURK study. Arch Osteoporos 7: 229-35.

Vondracek SF, Linnebur SA (2009) Diagnosis and management of osteoporosis in the older senior. Clin Interv Aging 4 121–136

Warriner AH, Outman RG, Saag KG et al (2009) The management of osteoporosis among home health and long term care patients with a prior fracture. South Med J 102: 397–404

Watts NB (2011) Fracture Risk Assessment Tool (FRAX®): Applications in clinical practice. J Womens Health 20: 525-31.

World Health Organization (2015) WHO World Report on Ageing and Health (draft Sept 2015). <http://who.int/ageing/ageing-global-strategy-draft1-en.pdf> Accessed 21 February 2016

\*Published after the cut-off date. Recommends an intervention threshold of 20% and 3% probability of major and hip fracture, respectively.