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Review

Integrating Falls Assessment into Diabetes Care: A Framework for Fracture-Risk Prediction in Outpatient Settings

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Abstract

Adults with type 2 diabetes experience excess fracture risk through a combination of impaired skeletal quality, falls, treatment-related factors and limitations of conventional risk assessment. This narrative review examines how falls assessment can be incorporated into an outpatient fracture-prevention pathway and proposes a public-health framework for evaluating enhanced risk prediction, including approaches supported by artificial intelligence. Evidence on diabetic bone fragility, falls, fracture-risk tools and implementation science was synthesised to identify the elements that should be measured before a new screening pathway is introduced at scale. The proposed framework begins with explicit definition of the target population and clinical outcome, makes recent falls and functional risk part of routine assessment, and uses bone measurements according to their validated purpose. Prediction models should be compared in the same population and assessed for discrimination, calibration, clinically relevant thresholds and external validity. Programme evaluation should extend beyond model performance to reach, referral completion, waiting time, preventive action, equity, workload, cost and sustainability. This approach reframes fracture-risk prediction as a service intervention rather than a purely technical modelling exercise. For health systems, the value of an enhanced or artificial-intelligence-supported pathway depends not only on predictive accuracy but also on whether it identifies people who can receive timely, equitable and effective preventive care.

Keywords: type 2 diabetes, accidental falls, osteoporotic fractures, primary health care, risk assessment.

1. Introduction

Fracture prevention in people with type 2 diabetes sits at the intersection of chronic-disease management, ageing, injury prevention and primary care. The usual clinical pathway relies on bone mineral density,

conventional fracture-risk factors and established risk calculators. In diabetes, however, the relationship between bone mass and fracture is less straightforward. Older adults with type 2 diabetes may sustain fragility fractures despite bone mineral density values that do not appear severely reduced, and standard risk tools may underestimate risk in some patients [1-4].

Falls add a second pathway to fracture that is particularly relevant to public health. A recent systematic review and meta-analysis of 12 studies involving 40,778 older adults with diabetes reported a 63% higher hazard of falls compared with older adults without diabetes; insulin use was also associated with greater odds of falling [5]. These findings matter because a fracture-prevention strategy that measures skeletal risk but ignores mobility, neuropathy, visual impairment, hypoglycaemia and previous falls may miss a substantial part of the causal chain that leads to injury.

The policy question is therefore broader than whether a new prediction model can produce a higher area under the receiver operating characteristic curve. A screening programme must reach the intended population, work within available staffing and diagnostic capacity, avoid widening inequalities, trigger appropriate follow-up and remain feasible after the research phase. Public-health evaluation frameworks such as RE-AIM and implementation-outcome taxonomies were developed precisely because efficacy in a selected sample does not guarantee population impact [10-12].

Kazakhstan provides a useful setting in which to examine this problem. A country-specific FRAX model is available, and national electronic-health data demonstrate a substantial burden of diabetes [8,9]. At the same time, access to densitometry and specialist osteoporosis services is uneven across regions, making the design of an outpatient triage pathway a health-system issue rather than a purely diagnostic one.

The objective of this review is to propose a practical public-health framework for evaluating an enhanced outpatient pathway that combines established fracture-risk assessment with structured falls assessment and diabetes-specific information. The framework is intended for prospective testing; it does not assume that artificial intelligence, peripheral densitometry or any single risk tool is superior before local validation.

2. Materials and methods

This paper was developed as a focused narrative review and implementation framework. The literature base was assembled from peer-reviewed studies and methodological guidance addressing five domains: diabetes-related skeletal fragility; falls among adults with diabetes; fracture-risk assessment; clinical prediction-model development and validation; and implementation of population or service-level interventions. Priority was given to systematic reviews, cohort studies, national data sources and internationally recognised reporting or implementation frameworks [3-16].

The review did not use an exhaustive database search, duplicate screening or quantitative evidence pooling and therefore is not presented as a systematic review. Evidence was interpreted according to its relevance to a real outpatient pathway: who is eligible, what information can be collected reliably, what happens after a positive screen, whether model performance is transportable and whether the service can sustain the resulting workload.

Two complementary implementation lenses were used. RE-AIM draws attention to reach, effectiveness, adoption, implementation and maintenance, while Proctor and colleagues distinguish implementation outcomes such as acceptability, appropriateness, feasibility, cost, penetration and sustainability [10-12]. For prediction models, the framework incorporates principles from PROBAST and TRIPOD+AI, including attention to bias, sample size, missing data, calibration, external validation and transparent reporting [13,14].

The output of the review is a staged evaluation framework rather than a pooled effect estimate. Quantitative results are reported only when they are directly supported by the cited evidence.

3. Results

Public-health framework for outpatient fracture-risk assessment

3.1 Define the population before defining the algorithm

The denominator determines the meaning of every later result. A programme should distinguish all adults registered with type 2 diabetes from those who attend routine care, those who are invited to screening, those who complete assessment and those who complete follow-up after a positive result. Reporting only the number screened can conceal selective uptake and produce apparently strong performance in a subgroup that is healthier, more mobile or better connected to care. The outcome must also be specified in advance. Osteoporosis defined by central dual-energy X-ray absorptiometry, a low-trauma fracture, a fall during follow-up and a high predicted 10-year fracture probability are not interchangeable outcomes. Each has

a different time horizon and a different consequence for false-positive and false-negative decisions.

3.2 Make falls a core part of the pathway

The association between diabetes and falls is not trivial. In the 2024 meta-analysis cited above, the higher fall risk persisted across large samples of older adults, and insulin treatment was associated with particularly high odds of falling. 5 For service design, this supports collecting a concise but standardised falls history rather than treating falls as an optional add-on. A minimum data set can include falls in the previous 12 months, fall-related injury, use of walking aids, symptoms of hypoglycaemia, documented peripheral neuropathy, visual impairment and functional difficulty. A short timed mobility test may be added where staff are trained and the setting is safe.

3.3 Use bone measurements according to purpose

Central dual-energy X-ray absorptiometry remains the reference method for bone mineral density assessment, while trabecular bone score and other measures can add information about bone quality. Reviews in diabetes consistently show that bone fragility cannot be inferred from bone mineral density alone [3,4,6]. Peripheral quantitative ultrasound may be useful as a triage or research measure where access to central densitometry is constrained, but it should not be presented as interchangeable with central dual-energy X-ray absorptiometry or used outside its validated role. For a public-health programme, the practical question is whether adding a peripheral measure changes appropriate referral, treatment or prevention decisions.

3.4 Compare pathways, not only models

A machine-learning model can outperform a conventional score statistically and still fail as a service intervention. Reviews and emerging studies show growing interest in artificial intelligence for fracture prediction in diabetes, but the literature remains heterogeneous in populations, predictors, outcomes and validation strategies [15,16]. Comparisons should therefore be made in the same target population, with the same outcome definition and follow-up period. Performance should include discrimination with confidence intervals, calibration, sensitivity and specificity at prespecified thresholds, and clinically meaningful measures of reclassification. External validation is essential because repeated cross-validation in a single source population does not establish transportability [13,14].

3.5 Measure the service consequences of a positive screen

A screening pathway creates downstream work. Programmes should record the number of people referred for confirmatory testing, waiting time, completion of referral, treatment or preventive action initiated, and reasons for loss to follow-up. A high-risk label without access to an effective next step has little public-health value and may create anxiety or unnecessary resource use. At population level, useful metrics include the proportion of the eligible population reached, the number of high-risk cases identified per 1,000 people screened, the number needing confirmatory assessment, the fraction completing that assessment and the number receiving an evidence-based action.

3.6 Evaluate equity, adoption and sustainability

Implementation should be assessed across age, sex, place of residence, socioeconomic position where available and relevant clinical subgroups. A digital tool can inadvertently worsen inequity if it depends on data that are missing more often in rural clinics or among patients with limited access to laboratory testing. RE-AIM and implementation-outcome frameworks provide a way to examine whether a pathway is adopted by clinics, delivered as intended and maintained after initial research support ends [10-12]. Costs should be assessed from the service perspective before large-scale roll-out and should include staff time, training, software, equipment, confirmatory testing and specialist referral.

4. Discussion

The evidence reviewed here suggests that fracture-risk prediction in diabetes is most informative when evaluated as part of a care pathway rather than as a stand-alone contest between algorithms. Diabetes combines skeletal vulnerability with a greater likelihood of falling, and the population benefit of screening depends on whether both mechanisms are recognised in routine care. Findings on bone density, conventional risk scores and falls support broader assessment, but they do not justify replacing established tools with an artificial-intelligence model before transportability and service consequences are demonstrated.

For service evaluation, prediction metrics should be reported alongside measures of reach, follow-through and clinical action. External validation is necessary before deployment beyond the development population. Positive screens should be traced through referral, waiting time, confirmatory assessment and preventive intervention, because a risk label has limited value when the next step is unavailable. Analyses should also test whether performance and access differ across demographic, geographic and clinical groups.

This approach is particularly relevant to settings where specialist osteoporosis services and central densitometry are not uniformly available. In such

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contexts, an enhanced primary-care pathway could be useful even if it does not contain a complex algorithm. A standardised falls history, systematic recording of diabetes-specific factors, clear referral rules and reliable follow-up may yield more immediate benefit than an opaque model with marginally better discrimination.

The proposed framework also clarifies what artificial intelligence can and cannot contribute. Machine learning is well suited to non-linear relationships and high-dimensional data, and emerging studies demonstrate its potential in fracture prediction [15,16]. Yet interpretability, fairness and external validity remain central concerns. A technically sophisticated model should not be deployed if it depends on variables that are unavailable in routine practice, performs poorly in a subgroup or creates referral demand that the health system cannot absorb.

This review has limitations. It is narrative rather than systematic and therefore cannot claim exhaustive coverage of the literature. It does not estimate pooled diagnostic performance, cost-effectiveness or fracture reduction. Its purpose is to define the questions and outcomes that a future prospective programme should measure. The framework also requires local adaptation because screening capacity, referral pathways and data completeness differ between health systems.

A logical next step is a prospective, multicentre evaluation in which an enhanced pathway is compared with current practice. The protocol should specify the eligible population, one primary clinical outcome, a prespecified model-comparison plan and implementation outcomes. Such a design would allow model performance and public-health impact to be judged together rather than sequentially.

5. Conclusions

Falls assessment should be considered part of fracture-prevention planning for adults with type 2 diabetes, particularly in older populations. The evidence supports the relevance of falls and diabetes-specific risk factors, but it does not support uncritical deployment of an artificial-intelligence model. A credible outpatient programme should demonstrate population reach, calibrated and externally validated prediction, completed referrals, feasible workload, equitable access and sustainable implementation. Framing the problem in this way moves evaluation from the question of whether an algorithm is accurate to the more consequential question of whether a screening pathway improves care for the population it is intended to serve.

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Түйіндеме

2 типті қант диабетімен ауыратын ересектер қаңқа сапасының нашарлауы, құлау, емдеуге байланысты факторлар және дәстүрлі тәуекелді бағалаудың шектеулері арқылы сыну қаупінің жоғарылауына ұшырайды. Бұл шолуда құлауды бағалауды амбулаториялық сынудың алдын алу жолына қалай енгізуге болатыны қарастырылады және жасанды интеллект қолдайтын тәсілдерді қоса алғанда, тәуекелді болжаудың жақсартылған нұсқасын бағалау үшін қоғамдық денсаулық сақтау негізі ұсынылады. Қант диабетімен ауыратын сүйектердің сынғыштығы, құлау, сыну қаупі құралдары және енгізу ғылымы бойынша дәлелдер жаңа скринингтік жолды ауқымды түрде енгізбес бұрын өлшенуі тиіс элементтерді анықтау үшін синтезделді. Ұсынылған негіз мақсатты популяция мен клиникалық нәтижені нақты анықтаудан басталады, жақында болған құлаулар мен функционалдық қауіпті күнделікті бағалаудың бөлігі етеді және сүйек өлшемдерін олардың тексерілген мақсатына сәйкес пайдаланады. Болжау модельдері сол популяцияда салыстырылып, ажырату, калибрлеу, клиникалық тұрғыдан маңызды шектері және сыртқы жарамдылығы бойынша бағалануы керек. Бағдарламаны бағалау модельдің өнімділігінен тыс, қол жеткізу, жолдамаларды аяқтау, күту уақыты, алдын алу шаралары, әділдік, жұмыс жүктемесі, құны және тұрақтылығына дейін созылуы керек. Бұл тәсіл сыну қаупін болжауды таза техникалық модельдеу жаттығуы емес, қызмет көрсету араласуы ретінде қайта қарастырады. Денсаулық сақтау жүйелері үшін жақсартылған немесе жасанды интеллектпен қолдау көрсетілетін жолдың құндылығы тек болжамдық дәлдікке ғана емес, сонымен қатар уақтылы, әділ және тиімді профилактикалық көмек ала алатын адамдарды анықтайтындығына да байланысты.

Түйін сөздер: 2 типті қант диабеті, кездейсоқ жарақаттар, остеопороздық сынықтар, алғашқы медициналық-санитариялық көмек, тәуекелді бағалау.

Включение оценки риска падений в систему медицинской помощи при сахарном диабете: Концепции для прогнозирования риска переломов в амбулаторных условиях

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Резюме

У взрослых с диабетом 2 типа повышен риск переломов из-за сочетания ухудшения качества скелета, падений, факторов, связанных с лечением, и ограничений традиционной оценки риска. В данном обзорном исследовании рассматривается, как оценка риска падений может быть включена в амбулаторную программу профилактики переломов, и предлагается концепция общественного здравоохранения для оценки улучшенного прогнозирования риска, включая подходы, поддерживаемые искусственным интеллектом. Были обобщены данные о хрупкости костей у диабетиков, падениях, инструментах оценки риска переломов и науке внедрения, чтобы определить элементы, которые следует измерять до внедрения новой программы скрининга в масштабах всего общества. Предложенная концепция начинается с четкого определения целевой популяции и клинического результата, включает недавние падения и функциональный риск в рутинную оценку и

использует измерения костной ткани в соответствии с их подтвержденным назначением. Модели прогнозирования следует сравнивать в одной и той же популяции и оценивать с точки зрения дискриминации, калибровки, клинически значимых пороговых значений и внешней валидности. Оценка программы должна выходить за рамки эффективности модели и охватывать охват, завершение направления, время ожидания, профилактические действия, справедливость, рабочую нагрузку, стоимость и устойчивость. Такой подход переосмысливает прогнозирование риска переломов как вмешательство в оказание услуг, а не как чисто техническое моделирование. Для систем здравоохранения ценность усовершенствованного или поддерживаемого искусственным интеллектом алгоритма оказания помощи зависит не только от точности прогнозирования, но и от того, насколько точно он выявляет людей, которые могут получить своевременную, справедливую и эффективную профилактическую помощь.

Ключевые слова: диабет 2 типа, случайные падения, остеопоротические переломы, первичная медико-санитарная помощь, оценка риска.

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