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Mechanism-equivalent age quantifies how many years of ageing equal a road traffic injury after limb fracture in 547,024 patients

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Abstract

Purpose.

We expressed the in-hospital mortality of a road traffic injury, against a fall, in years of ageing (mechanism-equivalent age, MEA) and asked whether it depends on age and bone.

Methods.

Retrospective cohort of adults with hip, femoral shaft, tibial or forearm shaft fracture after a fall or road traffic injury in Brazilian, Mexican and US hospital databases. MEA at age x was the number of years a fall related patient had to be older to match the standardized mortality of a traffic patient aged x. Added value of mechanism over age and fracture site was validated in later years and held-out hospitals.

Results.

Among 547,024 patients and 10,253 deaths, a traffic injury at 40 in Brazil was worth 17.6 years of ageing after femoral shaft fracture (95% CI 10.9 to 21.9) and 17.2 after tibial fracture (12.6 to 20.8), but 3.1 (minus 7.7 to 11.4) after hip fracture. By 80 it was 2.9 years (minus 2.0 to 6.7) for femoral shaft, 8.5 (5.3 to 15.0) for tibia and nil for hip. Ten years of ageing outweighed mechanism from age 31 for hip and the early sixties for tibia and femoral shaft. Mechanism raised the area under the curve by 0.001 with unchanged calibration; Mexico agreed.

Conclusion.

A road traffic injury equals about 17 years of ageing in middle age after femoral shaft and tibial fracture, a few years in old age, and nothing after hip fracture. Mechanism loses weight as host vulnerability rises; a fall does not mean low risk.

Introduction

Trauma care sorts injuries by the energy of their mechanism. A fall from standing height is called low energy and a road traffic collision high energy [1, 2]. The distinction helps to predict which injuries to look for, and field triage criteria give weight to mechanism when physiology and anatomy look unremarkable [3]. It also carries an unspoken message about risk. A low energy fracture sounds like a low risk fracture.

In older adults this message may be wrong. Hip fracture after a fall is followed by in-hospital death in 2 to 6% of patients and by death within a year in a fifth or more, and ground level falls in the elderly can carry mortality close to that of high energy trauma in the young [4 to 7]. Fracture site is associated with one year mortality in older patients after adjustment for age and sex [8], and predictors of five year

mortality after major upper extremity fractures have been described in older adults [9]. What is less clear is whether mechanism tells us anything about risk once age and fracture site are known. A fall in an 80 year old and a collision in a 40 year old differ in both age and mechanism, so a higher mortality after the fall cannot be credited to the mechanism.

Clinicians have no unit for the prognostic weight of mechanism. An odds ratio of 2 for traffic injury says nothing about what that means for a given patient, and the same relative risk means very different absolute risks at 40 and at 80. Years of age are a unit everyone understands, and biological age clocks already use it, converting a person's mortality risk profile into the chronological age that carries the same risk in a reference population [17, 18]. We applied that idea to injury mechanism. The mechanism-equivalent age (MEA) at a given age is the number of years a fall related patient would have to be older to carry the same in-hospital mortality as a traffic related patient of that age, within the same fracture. We asked three questions in three hospital databases. How many years of ageing is a traffic injury worth after each of four limb fractures? Does this equivalence shrink as patients age? And, as the test that bounds its clinical weight, does mechanism improve the prediction of death beyond age and fracture site in later years and in hospitals not used to build the model?

Methods

Design and data sources

Retrospective cohort study reported according to STROBE, RECORD and, for the prediction analysis, TRIPOD [16]. Brazil's Sistema de Informacoes Hospitalares do SUS (SIH/SUS) holds every admission paid by the public health system, with a principal diagnosis, up to nine secondary diagnoses including external cause, a hospital identifier (CNES) and discharge status. We used admissions from January 2023 to the latest 2026 extract. Mexico's Sistema Automatizado de Egresos Hospitalarios (SAEH) covers public hospitals of the Secretaria de Salud with a similar structure and a hospital identifier (CLUES); we used 2022 and 2023. MIMIC-IV version 3.1 holds admissions to Beth Israel Deaconess Medical Center, Boston, from 2008 to 2022 with ICD-9-CM and ICD-10-CM codes. The registries are open government data and MIMIC-IV was used under its data use agreement. The study was exempt from ethical review. We did not use eICU-CRD because it records no mechanism and holds only intensive care patients.

Population

Adults aged 18 years or over with hip fracture (ICD-10 S72.0 to S72.2), femoral shaft fracture (S72.3), tibial fracture (S82.1 to S82.3) or forearm shaft fracture (S52.2 to S52.4) as the principal diagnosis (Brazil, Mexico) or within the first three diagnoses (MIMIC-IV, with ICD-9-CM equivalents). These four fractures make up the primary cohort in every database. Proximal humeral, vertebral and pelvic fractures were secondary strata and are in the supplementary file. In MIMIC-IV we kept the first qualifying admission of each patient.

Exposure, outcome and covariates

Exposure, outcome and covariates
Mechanism came from the external cause code in any diagnosis field. Fall related was W00 to W19 (ICD-9-CM E880 to E888) and traffic related V01 to V89 (E810 to E829). Admissions with another recorded cause or no cause were left out of the contrast. We call the exposure fall related and traffic related and avoid the words low and high energy, because the code does not record the energy of the event. Falls from height (W10 to W17) were separated in a sensitivity analysis. The outcome was in-hospital death. Covariates were age, sex and, in the standardized models, calendar year. Concomitant intracranial, thoracic, abdominal and pelvic injury were coded from secondary diagnoses as in our previous work [10] and used only in a sensitivity analysis.

Statistical analysis

Primary analysis, mechanism-equivalent age. Within each fracture we fitted a logistic model for death on mechanism, a cubic spline of age with one interior knot, their product, sex and calendar year, on grouped counts of identical covariate cells, which reproduces the individual level estimates exactly. Standardized mortality at each year of age from 18 to 100 for each mechanism was obtained by g computation over the sex and year distribution of the cohort, giving a fall related curve and a traffic related curve. MEA at age x was found by linear interpolation as the number of years by which x must be increased on the fall related curve to reach the traffic related mortality at x. It is reported at ages 30, 40, 50, 65 and 80 and as a curve from 25 to 85. Where the fall related curve was not yet rising, or the traffic related mortality exceeded the fall related mortality at age 100, MEA was censored and the proportion of censored bootstrap samples is given. Uncertainty came from 1,000 hospital clustered bootstrap samples with percentile intervals. MEA was computed in Brazil and attempted in Mexico with the same code; MIMIC-IV was not used because several groups had no deaths. Two hypotheses were written into the plan before MEA was computed. First, MEA for hip fracture would be under 5 years at every age. Second, MEA for tibial fracture would decrease with age, expressed as MEA at 40 minus MEA at 80 with its interval. The crossover age was the youngest age at which ten years of ageing on the fall related curve added at least as much mortality as the change from fall to traffic at that age.

Secondary analysis, incremental value of mechanism (Brazil). Model 0 contained a cubic spline of age with one interior knot, specific to each fracture, sex and fracture site. Model 1 added mechanism, mechanism by fracture and mechanism by age spline. Models were fitted on admissions from 2023 and 2024 and tested on admissions from 2025 and 2026. In a second validation, we fitted models in a random half of hospitals and tested them in the other half. We report the area under the receiver operating curve, the Brier score, the calibration slope and intercept [15], and the difference in area under the curve with a percentile interval from 1,000 patient level bootstrap samples of the test set. A likelihood ratio test of the mechanism terms was done in the training data. We did this for hip, femoral shaft and tibial fractures and for the four fractures together; forearm fracture had 32 deaths in total and

was left out. Mexico and MIMIC-IV were not used for validation because their numbers of deaths cannot estimate a difference in area under the curve of this size.

Descriptive analysis. From the same curves we report standardized mortality at ages 40, 65 and 80, the difference between traffic related and fall related mortality at the same age, and the difference between fall related mortality at 80 and traffic related mortality at 40. Whether the mechanism difference changes with age was tested by a joint Wald test of the product terms with hospital clustered errors, and a three way product with fracture type was tested in Brazil. Sensitivity analyses excluded falls from height and conditioned on recorded concomitant intracranial, thoracic, abdominal and pelvic injury; the latter is an association conditioned on injury burden and is not read as a direct effect. Strata with fewer than 15 deaths were not modelled. In MIMIC-IV, standardized models were unstable because some groups had no deaths, so only crude rates are given.

Pre specification. The analysis plan was hash stamped before any cohort was built. Its original question, whether mortality after a fall related fracture at 80 reached that of a traffic related fracture at 40, mixes age with mechanism, as external reviewers pointed out. Two dated amendments followed. The first, written after the original results were known, added the incremental value analysis. The second defined MEA, its censoring rules, the two hypotheses and the crossover age, and was hash stamped before any MEA value was computed. Plan, amendments and hashes are in the supplementary file. Analyses used Python 3.12 with statsmodels.

Results

Cohorts

Among 769,917 Brazilian admissions with one of the four fractures as principal diagnosis, 98.9% carried an external cause code and 65.5% a fall or traffic code. The analysis included 504,260 admissions with 9,780 deaths from 1,737 hospitals (median age 67 years, interquartile range 45 to 80, for fall related; 35, 25 to 48, for traffic related; 42% women). Mexico contributed 37,608 admissions with 358 deaths (67.8% of 55,434 admissions with these fractures) and MIMIC-IV 5,156 with 115 deaths (92.4% of 5,579). The three databases together gave 547,024 patients and 10,253 deaths (Table 1). Hip fracture dominated the fall related group and tibial fracture the traffic related group. Median length of stay in Brazil was similar between mechanisms within each fracture, for example 6 days (interquartile range 3 to 10) for fall related and 5 (3 to 9) for traffic related hip fracture (Supplementary S8).

Table 1
Admissions with one of four limb fractures and a fall or traffic related external cause, by database (n; deaths, % in hospital mortality).

Fracture, mechanism	Brazil	Mexico	MIMIC-IV
Hip, fall	189,393; 7,956 (4.2)	11,720; 281 (2.4)	2,862; 92 (3.2)
Hip, traffic	16,599; 327 (2.0)	1,086; 11 (1.0)	172; 2 (1.2)
Femoral shaft, fall	25,056; 541 (2.2)	1,053; 19 (1.8)	323; 9 (2.8)
Femoral shaft, traffic	30,481; 340 (1.1)	987; 5 (0.5)	165; 2 (1.2)
Tibia, fall	92,751; 213 (0.2)	8,362; 14 (0.2)	846; 3 (0.4)
Tibia, traffic	104,399; 371 (0.4)	8,960; 23 (0.3)	578; 6 (1.0)
Forearm shaft, fall	27,953; 22 (0.1)	3,798; 3 (0.1)	103; 0
Forearm shaft, traffic	17,628; 10 (0.1)	1,642; 2 (0.1)	107; 1 (0.9)
Fall, all four fractures	**335,153; 8,732 (2.6)**	**24,933; 317 (1.3)**	**4,134; 104 (2.5)**
Traffic, all four fractures	**169,107; 1,048 (0.6)**	**12,675; 41 (0.3)**	**1,022; 11 (1.1)**
Total	**504,260; 9,780 (1.9)**	**37,608; 358 (1.0)**	**5,156; 115 (2.2)**
Admissions with these fractures, any cause	769,917	55,434	5,579
Fall or traffic code, % of these	65.5	67.8	92.4
Any external cause code, %	98.9	99.99	99.7
Hospitals	1,737	604 (all fracture strata)	1

Pooled total across the three databases 547,024 patients and 10,253 deaths. The fall related group is older in every fracture; Brazil median age 67 years (interquartile range 45 to 80) for fall related and 35 (25 to 48) for traffic related.

Mechanism-equivalent age

Figure 2A and Table 2 give the number of years of ageing that carried the same in-hospital mortality as the change from a fall to a road traffic injury. For femoral shaft fracture, a traffic injury at age 40 was worth 17.6 years (95% CI 10.9 to 21.9); a 40 year old hit by a vehicle carried the mortality of a 58 year old who had fallen. The gap was 15.1 years at 50, 9.9 at 65 and 2.9 at 80 (minus 2.0 to 6.7), a fall of 14.7 years between 40 and 80 (6.4 to 21.6). For tibial fracture it was 17.2 years at 40 (12.6 to 20.8), 13.1 at 50, 9.5 at 65 and 8.5 at 80 (5.3 to 15.0), a fall of 8.7 years (1.0 to 14.1). For hip fracture it was 3.1 years at 40

(minus 7.7 to 11.4), minus 1.7 at 50, minus 3.0 at 65 and minus 0.9 at 80 (minus 4.7 to 1.8). Both pre specified hypotheses held, that MEA for hip fracture would be below 5 years at every age from 40 and that MEA for tibial fracture would decrease with age. For forearm fracture, with 32 deaths, MEA could not be estimated with any precision (Supplementary S5). Fewer than 1% of bootstrap samples were censored for hip, femoral shaft and tibial fracture. In Mexico, with 292 hip and 37 tibial deaths, MEA intervals spanned more than 50 years and 16 to 69% of bootstrap samples were censored, so Mexico does not inform MEA (Supplementary S5); its contribution is the direction of the standardized mortality differences below.

Table 2
Mechanism-equivalent age, Brazil. Years of ageing on the fall related mortality curve that equal the change from fall to road traffic injury at the stated age (primary analysis).

Fracture (n; deaths)	**Age 30**	**Age 40**	**Age 50**	**Age 65**	**Age 80**	**MEA 40 minus MEA 80, years**	**Crossover age, years**
Hip (205,992; 8,283)	+ 10.8 (0.0 to + 18.4)	+ 3.1 (-7.7 to + 11.4)	-1.7 (-10.7 to + 5.1)	-3.0 (-8.6 to + 1.1)	-0.9 (-4.7 to + 1.8)	+ 3.9 (-6.7 to + 12.6)	31 (18 to 42)
Femoral shaft (55,537; 881)	+ 18.7 (-4.2 to + 25.2)	+ 17.6 (+ 10.9 to + 21.9)	+ 15.1 (+ 10.7 to + 18.6)	+ 9.9 (+ 6.5 to + 13.4)	+ 2.9 (-2.0 to + 6.7)	+ 14.7 (+ 6.4 to + 21.6)	65 (18 to 73)
Tibia (197,150; 584)	+ 22.7 (+ 14.7 to + 27.8)	+ 17.2 (+ 12.6 to + 20.8)	+ 13.1 (+ 9.6 to + 16.3)	+ 9.5 (+ 6.8 to + 12.9)	+ 8.5 (+ 5.3 to + 15.0)	+ 8.7 (+ 1.0 to + 14.1)	63 (18 to 81)
Forearm shaft (45,581; 32)	not estimable	not estimable	not estimable	not estimable	not estimable		exploratory

Positive values mean a traffic related patient of the stated age has the mortality of an older fall related patient. 95% confidence intervals from 1,000 hospital clustered bootstrap samples; fewer than 1% of samples were censored for hip, femoral shaft and tibia. Crossover age is the youngest age at which ten years of ageing on the fall related curve adds at least as much mortality as the change from fall to traffic. Forearm shaft fracture intervals spanned more than 50 years (Supplementary S5). Mexican MEA could not be estimated (Supplementary S5).

Ten years of ageing on the fall related curve added at least as much mortality as the change of mechanism from age 31 onward for hip fracture (bootstrap interval 18 to 42), from 65 for femoral shaft (18 to 73) and from 63 for tibial fracture (18 to 81) (Fig. 2B). The lower bounds reach the youngest age because in some samples the two curves cross early.

Does mechanism add to age and fracture site

In the later years test set of 235,290 patients with 4,600 deaths, a model with age, sex and fracture site had an area under the curve of 0.835 (Table 3, Fig. 2C). Adding mechanism raised it to 0.836, a difference of 0.0011 (95% CI 0.0004 to 0.0018). The Brier score changed from 18.412 to 18.408 per thousand, the calibration slope was 1.02 in both models, and the calibration curves overlapped (Fig. 2D). Testing in held-out hospitals (257,624 patients, 4,893 deaths) gave 0.828 and 0.829, a difference of 0.0008 (0.0001 to 0.0015).

Table 3

Added value of injury mechanism over age, sex and fracture site for in-hospital death, Brazil.

Group (test n; deaths)	AUC, age and fracture	AUC, plus mechanism	Change in AUC (95% CI)	Brier score x1000	Calibration slope	LR test P
Later years (trained 2023 to 2024, tested 2025 to 2026)						
Hip (95,470; 3,884)	0.708	0.708	-0.0003 (-0.0008 to + 0.0003)	38.089 to 38.090	1.03 to 1.02	0.016
Femoral shaft (26,095; 431)	0.750	0.755	+ 0.0051 (-0.0057 to + 0.0151)	15.853 to 15.845	1.03 to 1.02	< 0.001
Tibia (92,868; 270)	0.722	0.741	+ 0.0189 (+ 0.0001 to + 0.0379)	2.876 to 2.872	1.03 to 1.01	< 0.001
All four (235,290; 4,600)	0.835	0.836	+ 0.0011 (+ 0.0004 to + 0.0018)	18.412 to 18.408	1.02 to 1.02	< 0.001
Held-out hospitals (random half of hospitals for training)						
Hip (108,540; 4,169)	0.700	0.700	-0.0001 (-0.0006 to + 0.0003)	36.176 to 36.177	0.94 to 0.94	0.098
Femoral shaft (28,703; 435)	0.756	0.764	+ 0.0078 (0.0000 to + 0.0151)	14.542 to 14.537	1.10 to 1.09	< 0.001
Tibia (97,702; 273)	0.721	0.734	+ 0.0128 (-0.0073 to + 0.0330)	2.775 to 2.773	0.93 to 0.92	< 0.001
All four (257,624; 4,893)	0.828	0.829	+ 0.0008 (+ 0.0001 to + 0.0015)	17.976 to 17.974	0.98 to 0.98	< 0.001

Model with age (fracture specific spline), sex and fracture site, against the same model plus mechanism, mechanism by fracture and mechanism by age. The pooled model uses fracture specific age splines. AUC, area under the receiver operating curve; confidence intervals from 1,000 bootstrap samples of the test set; LR test, likelihood ratio test of the mechanism terms in training data. Forearm shaft fracture (32 deaths) was not modelled.

The gain differed by fracture. For hip fracture it was nil in both validations (difference minus 0.0003, 95% CI minus 0.0008 to 0.0003, in later years; minus 0.0001 in held-out hospitals) on 3,884 and 4,169 deaths.

For femoral shaft fracture it was 0.005 (minus 0.006 to 0.015) and 0.008 (0.000 to 0.015). For tibial fracture it was 0.019 (0.0001 to 0.038) and 0.013 (minus 0.007 to 0.033), on 270 and 273 deaths. Likelihood ratio tests in the training data were small for femoral, tibial and pooled models (P below 0.001), as expected with hundreds of thousands of patients, and not for hip fracture (P 0.016 and 0.098).

Standardized mortality by age and mechanism

Standardized in-hospital mortality rose steeply with age in every fracture (Table 4, Fig. 1), which is why a constant mechanism difference on the relative scale is worth fewer years of age as patients grow older. At age 80 a fall related fracture carried a mortality of 4.1% for hip, 5.2% for femoral shaft and 1.7% for tibial fracture. This was higher than the mortality of a traffic related fracture at 40 by 3.5 points for hip (95% CI 3.1 to 3.9), 4.0 for femoral shaft (3.3 to 4.9) and 1.4 for tibial fracture (1.0 to 1.8), and by 0.6 points for forearm fracture (0.2 to 1.3, on 32 deaths). Mexico gave the same direction for hip (1.9 points, minus 0.3 to 2.8) and tibial fracture (1.1, 0.0 to 2.2). The Mexican femoral shaft estimate rests on 24 deaths and is shown in the supplementary file only. In MIMIC-IV, crude mortality at age 80 and over after hip fracture was 3.9% for fall related and 3.5% for traffic related admissions (2,862 and 172 hip fractures in all), and no deaths occurred among traffic related hip fractures under 65 (Supplementary S4).

Table 4
Standardized in-hospital mortality (%) by mechanism at ages 40, 65 and 80, and mechanism differences. Descriptive.

Fracture, database (n; deaths)	Fall 40	Traffic 40	Fall 65	Traffic 65	Fall 80	Traffic 80	Traffic minus fall at 80, points	Fall 80 minus traffic 40, points	Interaction P
Hip, Brazil (205,992; 8,283)	0.54	0.62	1.69	1.46	4.13	3.90	-0.23 (-1.09 to + 0.53)	+ 3.51 (+ 3.13 to + 3.87)	0.06
Hip, Mexico (12,806; 292)	0.38	0.71	1.23	0.75	2.63	2.85	+ 0.22 (-2.62 to + 6.78)	+ 1.92 (-0.29 to + 2.84)	0.71
Femoral shaft, Brazil (55,537; 881)	0.58	1.14	1.80	3.57	5.19	6.42	+ 1.23 (-0.74 to + 3.13)	+ 4.04 (+ 3.31 to + 4.88)	0.019
Tibia, Brazil (197,150; 584)	0.10	0.24	0.42	0.97	1.65	4.07	+ 2.42 (+ 1.45 to + 3.61)	+ 1.41 (+ 1.01 to + 1.84)	0.90
Tibia, Mexico (17,322; 37)	0.09	0.11	0.30	1.13	1.17	3.60	+ 2.43 (-0.75 to + 5.75)	+ 1.06 (-0.04 to + 2.19)	0.48
Forearm shaft, Brazil (45,581; 32)	0.03	0.05	0.10	0.34	0.64	0.10	-0.55 (-1.25 to + 0.39)	+ 0.59 (+ 0.19 to + 1.28)	0.008

Percent standardized to each cohort's sex and year distribution by g computation. Confidence intervals from 1,000 hospital clustered bootstrap samples in both databases. Interaction P, joint Wald test of mechanism by age terms. Three way interaction of mechanism, age and fracture in Brazil, P 0.09. Mexican femoral shaft fracture (24 deaths) is in the supplementary file. MIMIC-IV was not standardized because of groups without deaths (crude rates in Supplementary S4). Forearm shaft fracture had 32 deaths and is exploratory.

At the same age, the difference between traffic related and fall related mortality depended on the fracture. For hip fracture there was none (0.08, minus 0.23 and minus 0.23 points at 40, 65 and 80 in Brazil, with intervals spanning zero; Mexico 0.3, minus 0.5 and 0.2; interaction P 0.06 and 0.71). For tibial fracture traffic related mortality was about 2.4 times fall related mortality at each age (interaction P 0.90 in Brazil), so the absolute difference grew from 0.14 points at 40 to 0.55 at 65 and 2.4 (1.5 to 3.6) at 80; Mexico showed the same pattern. For femoral shaft fracture the excess was 0.57, 1.78 and 1.23 points (minus 0.74 to 3.13 at 80; interaction P 0.019). For forearm fracture the sign changed at 80 (minus 0.55

points, minus 1.25 to 0.39; interaction P 0.008, 32 deaths). The three way interaction of mechanism, age and fracture was not significant (P 0.09), so these fracture specific patterns are descriptive.

Sensitivity analyses

Excluding falls from height changed the fall at 80 against traffic at 40 differences by 0.15 points or less (hip 3.5, femoral shaft 3.9, tibia 1.5, forearm 0.4). Conditioning on concomitant injuries gave 3.5, 4.1, 1.4 and 0.6 points (Supplementary S6). Secondary strata are in Supplementary S5.

Discussion

We expressed the prognostic weight of injury mechanism in a unit that needs no explanation. After femoral shaft or tibial fracture, a road traffic injury at age 40 carried the same in-hospital mortality as a fall related fracture in a patient about 17 years older. By age 80 the equivalent had fallen to three years for femoral shaft and eight for tibial fracture. After hip fracture the equivalent was zero at every age. The Mexican and US databases had too few deaths to estimate the equivalent in years, but their standardized mortality showed the same direction, and adding mechanism to age and fracture site improved the prediction of death by a negligible amount overall and by nothing for hip fracture.

Mechanism loses prognostic weight as host vulnerability rises. In a 40 year old with a tibial fracture, the question of how the bone broke tells the clinician something, because the patient has reserve and the energy of the event is a proxy for injuries elsewhere; in our data traffic related fractures were accompanied by intracranial, thoracic and abdominal injuries far more often. In an 80 year old, the host has little reserve and the fracture itself, with its immobilisation, blood loss and surgery, is what kills [4, 5, 11, 12]. Hip fracture is the extreme case [13]. A hip fracture in an older adult marks a frail patient whatever the cause, and an older adult who is hurt in traffic is also frail or becomes so, so the mechanism tells nothing at any age. This is consistent with the Swiss cohort of 1,739 patients aged 65 years and over in which fracture location was associated with one year mortality after adjustment for age and sex and was read as a marker of frailty and not a cause [8]. The crossover ages make the same point in another way. From the early sixties onward, for femoral shaft and tibial fracture, ten years of ageing matter more than the mechanism; for hip fracture this is already true at 31.

The comparison that first drew us to these data, that a fall related fracture at 80 carries three to seven times the mortality of a traffic related fracture at 40, is true but is mostly the effect of age, and we report it as descriptive. MEA is the comparison that holds the fracture fixed and puts age and mechanism on one scale. A constant odds ratio of about 2.4 for traffic in tibial fracture translates into a shrinking number of years as baseline risk rises, because the fall related curve is steep in old age. This is not a new mechanism effect in the old, it is the arithmetic of a relative effect on a rising baseline, and MEA makes that arithmetic visible to a clinician without a logistic model.

The clinical message has two parts. For a middle aged patient with a femoral shaft or tibial fracture, a traffic mechanism should raise concern in the same way that an extra 15 to 20 years of age would, which

argues for looking harder for other injuries and physiological derangement. For an older patient, and for any patient with a hip fracture, the mechanism should not reassure; a fall is not a low risk event in the old, and the risk should be read from age and fracture site. We did not study whether mechanism helps to find other injuries, which is what field triage criteria and injury scoring are built for [3, 14], and our data do not argue against them. Conditioning on recorded concomitant injuries did not change our estimates, which suggests that the years of age a traffic injury is worth are not explained by the injuries that administrative data record.

Strengths are a single new estimand defined and hash stamped before it was computed, with two hypotheses written in advance, the size of the Brazilian data, validation of the incremental value analysis in later years and in held-out hospitals, the replication of direction in Mexico, and open reporting of two dated amendments to the plan. Expressing a risk profile as an equivalent chronological age is established in the biology of ageing [17, 18]; to our knowledge it has not been applied to injury mechanism or to fracture anatomy.

Limitations

In-hospital death is the only outcome shared by the registries, and most deaths after hip fracture in older adults happen after discharge [4]. Hospital stay depends on transfer and discharge policy, and transfers cannot be linked in these data; median stay was similar between mechanisms. Only 65.5% of Brazilian, 67.8% of Mexican and 92.4% of Boston admissions carried a fall or traffic code. The rest had another cause, such as being struck by an object or an assault, or none, and are not covered by our findings. The external cause code gives mechanism and not energy or height. Comorbidity and injury severity are not recorded in the national registries, so we could not test whether mechanism adds to them. The incremental value analysis and MEA rest on Brazil; Mexico and MIMIC-IV could only confirm direction, and MEA needs several hundred deaths per fracture, which few registries outside Brazil will have. Small event counts limit forearm and Mexican femoral shaft estimates, and MIMIC-IV could not be standardized. The Brazilian data cover the public system and the Mexican data the Secretaria de Salud hospitals, and the Brazilian extract was built for limb injuries. The incremental value analysis was added after the results of the original analysis were known, and MEA was defined after that analysis, although before any MEA value was seen. MEA depends on the shape of the fall related curve; where that curve is flat, as in young adults, small differences in mortality translate into many years, which is why the intervals at age 30 are wide. MEA expresses equivalence of in-hospital mortality only and says nothing about function or long term survival.

Conclusion

A road traffic injury is worth about 17 years of ageing in middle age after femoral shaft or tibial fracture, a few years in old age, and nothing after hip fracture. Mechanism loses prognostic weight as host vulnerability rises, age and fracture site carry almost all the information about in-hospital death, and a fall related label should not be read as low risk.

Declarations

Author Contribution

M.U. (Mete Ucdal) performed all statistical analyses. A.D. (Ahmet Demir) and O.K. (Olcay Korkmaz) contributed to study conception, cohort definition and interpretation of the results. O.D.A. (Omer Dogan Alatas) and A.A. (Ahmet Aksakal) contributed to the clinical interpretation and critical revision of the manuscript. M.U. and A.D. drafted the manuscript. O.D.A. supervised the project and is the corresponding author. All authors reviewed the manuscript, approved the final version and agree to be accountable for all aspects of the work.

Data Availability

The datasets analysed during this study are available from the following sources. The Brazilian Sistema de Informações Hospitalares do SUS (SIH/SUS) microdata for 2023 to 2026 and the Mexican Sistema Automatizado de Egresos Hospitalarios (SAEH) microdata for 2022 and 2023 are open government data, available from the DATASUS portal (https://datasus.saude.gov.br) and the Mexican Secretaría de Salud open data portal, respectively. The MIMIC-IV version 3.1 database is available on PhysioNet (https://physionet.org/content/mimiciv/3.1/) to credentialed researchers who complete the required training and sign the data use agreement. The analysis code, the hash-stamped analysis plan and its two dated amendments are provided as a supplementary file, and the code will be deposited in a public repository upon acceptance.

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Figures

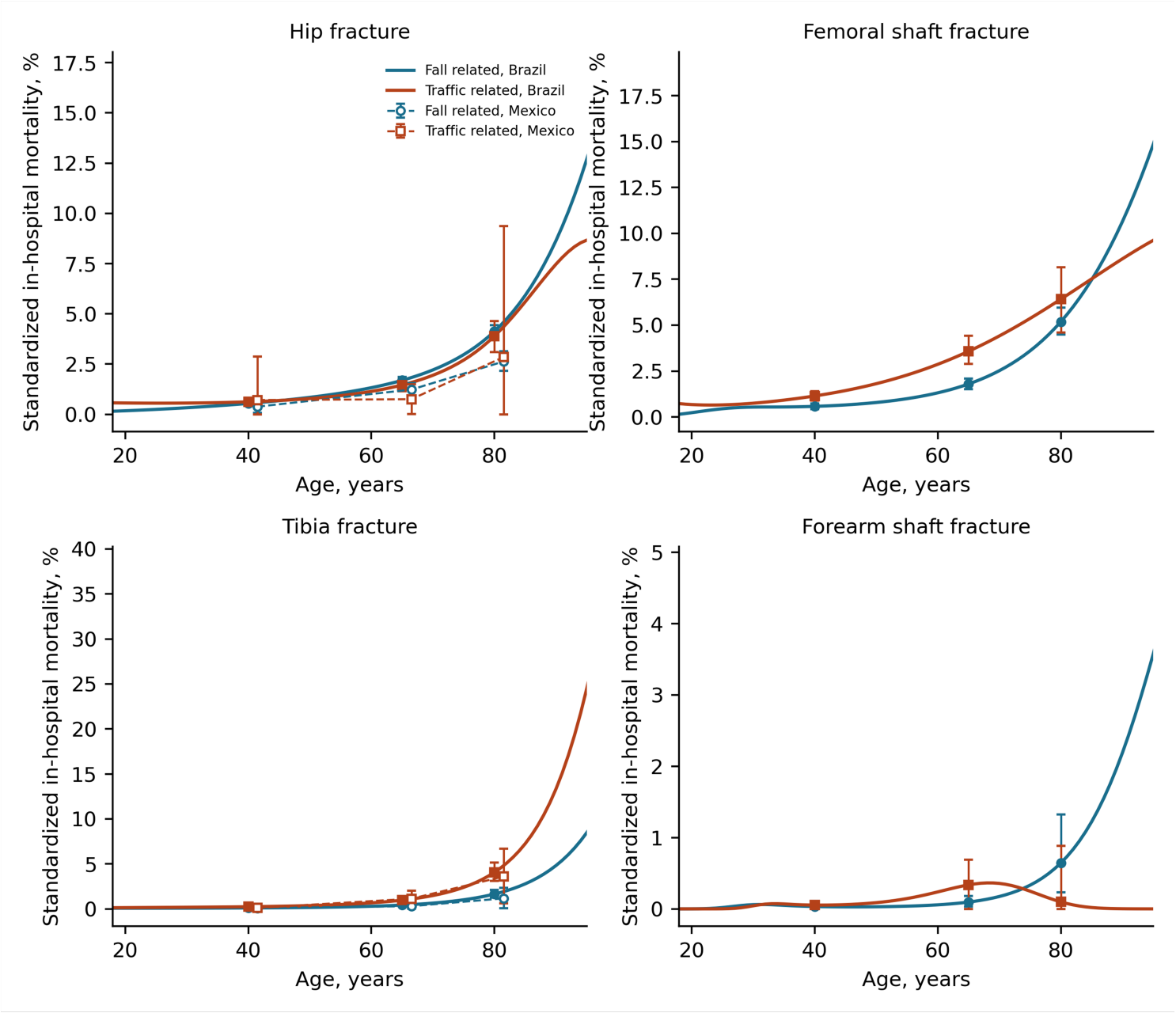


Figure 1

Standardized in-hospital mortality by age and mechanism for the four fractures. Lines are the Brazilian fall related (blue) and traffic related (red) curves from which mechanism-equivalent age is read; filled markers with bars are Brazilian estimates at 40, 65 and 80 with 95% hospital clustered bootstrap intervals; open markers are Mexican estimates (hip and tibia).

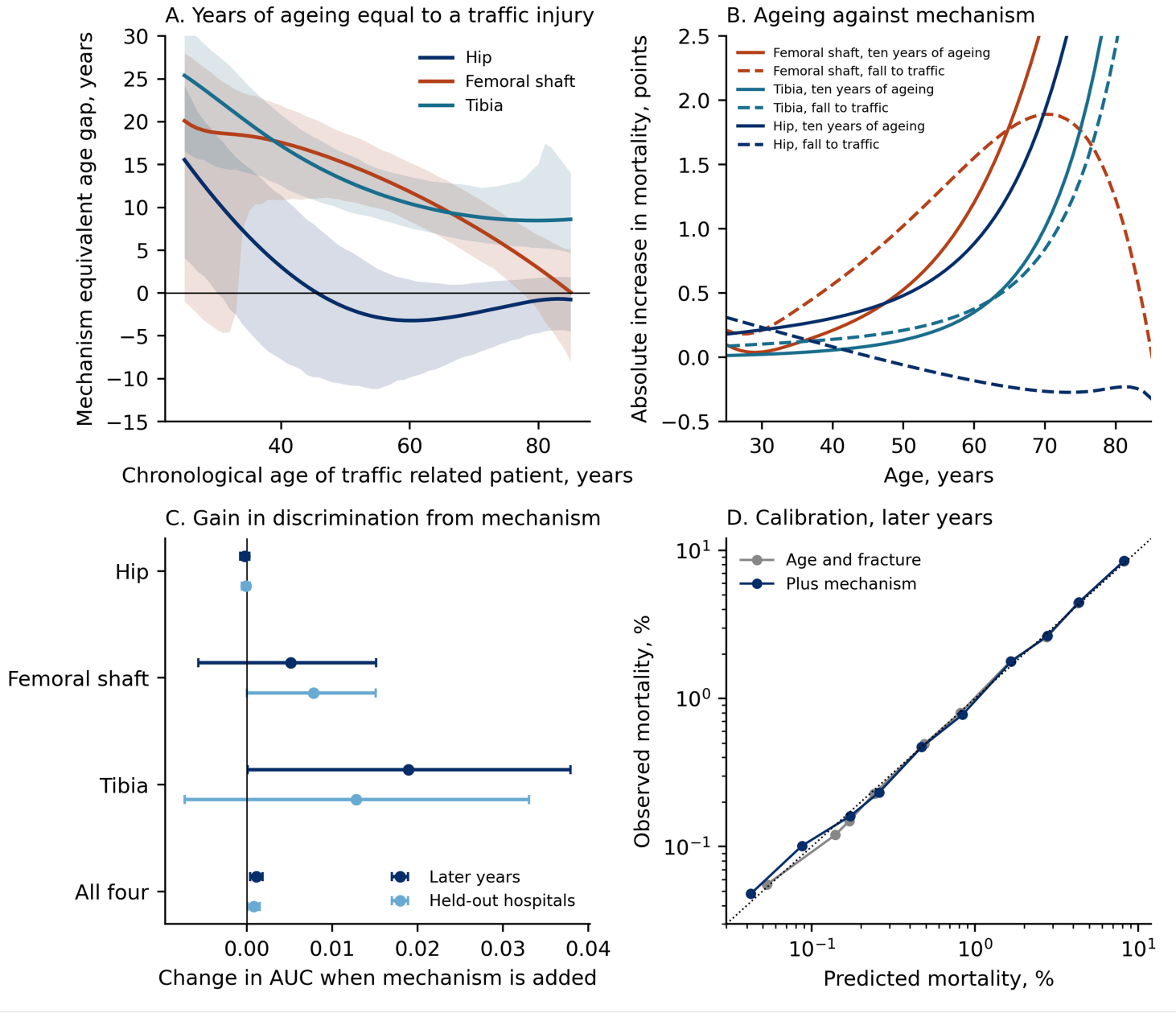


Figure 2

Brazil. A, mechanism-equivalent age by chronological age of the traffic related patient for hip, femoral shaft and tibial fracture, with 95% bootstrap bands; a value of 17 at age 40 means that a traffic related patient aged 40 has the in-hospital mortality of a fall related patient aged 57. B, absolute increase in mortality from ten years of ageing on the fall related curve (solid) and from the change of mechanism at the same age (dashed); the crossing is the crossover age. C, change in area under the curve when mechanism is added to age, sex and fracture site, in later years and in held-out hospitals. D, calibration of both models in later years by tenths of predicted risk.

Supplementary Files

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- 03SupplementaryFile.docx
- 04CodeandAnalysisPlan.zip