Past, present and future of injury prevalence in high-income countries: insights and projections up to 2030 from the Global Burden of Disease Study

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ABSTRACT

Background Injury prevalence is a metric which can be used to understand healthcare utilisation and prioritise injuries based on the magnitude of the injury rate. Given the ageing population in high-income countries and subsequently ageing of the injured population, the probability of long-term or permanent consequences of injuries is also likely to increase. By understanding past trends and exploiting patterns of prevalence injury rates (PIRs), future PIRs can be predicted.

Design Data on PIRs from the Global Burden of Disease Study 2019 (GBD2019) were collected. To understand past trends of GBD2019, joinpoint regression analysis was used to find trends expressed as annual per cent changes (APCs), averaged APCs and to compare trends across injuries. To project future PIRs up to 2030, autoregressive integrated moving average time series analysis was used on the GBD2019 data.

Results All injuries showed negative averaged APCs during 1990–2019, However, an increased PIR is found for the last APC period of the same time interval, the greatest being in amputations with 2.3 (2.1–2.4). All PIR trends were statistically neither parallel nor identical across the injuries. Forecasts showed an absolute and relative increase in PIR projection.

Conclusion The PIRs positively declined in the past. However, the latest past trends up to 2019 increased, as well as the forecasts to 2030. Reflection and advocating for strategies to mitigate the possible outcome of increased PIRs are given. This proactive approach will form the foundation for future resource allocation and planning. Additionally, there may be a need to adjust current treatment strategies and standards to address the expected increase in demand.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Prevalence injury rates (PIRs) and patterns vary across countries based on the gross domestic product (GDP) but also vary between countries classified with a high GDP, that is, high-income countries (HICs). The healthcare system is organised differently in HICs, and with the ageing population and increased probability of long-term injuries, the PIR is likely to increase as well.

WHAT THIS STUDY ADDS

⇒ This study presented the trends in PIRs of different injuries in HICs across a three-decade interval and provided projections for the next decade (2030). It establishes a scientific foundation by analysing past trends and providing projections. Past injury trends were unique across injuries and future projection shows a spike in PIRs for all injuries. Injuries follow specific patterns that can be predicted, and past patterns can be analysed.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This study highlighted the net raw results of injury management of the past and the high projection with great effects in HICs. It illuminates possible forthcoming challenges and underscores the necessity of focused injury prevention, to ensure that the healthcare system in HICs can plan for the required personnel, facilities and goods to meet rising rates. Furthermore, healthcare utilisation in HICs regarding this high projection should include preventative programmes, transfer processes, stepped and specialised hospital treatments and posthospital care to mitigate the burden of the possible PIRs of the future.

INTRODUCTION

Injuries are a public health concern that impacts individuals and communities worldwide. Injuries can be intentional or unintentional, stemming from various causes such as road traffic crashes, interpersonal violence, drowning, fires, war, poisonings and falls, as defined by the WHO.[1]

A comprehensive assessment by the Global Burden of Disease Study (GBD) includes publicly available estimates of a range of injuries with different epidemiological metrics at different geographical and economic regional levels from 1990 to 2019.[2] One of these metrics is injury prevalence, which can be used to understand healthcare utilisation and prioritise injuries based on the magnitude of the injury rate. Prevalence rates per year are the proportion of a population who have a specific injury for a given year, regardless of when they first sustained the injury. Some injuries have higher probability of permanent consequences or are by definition permanent (eg, amputation, third-degree burns and lower extremity fractures).[3] Also, with the ageing of

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the population, and subsequent ageing of the injured population, the probability of long-term or permanent consequences of injuries also increases.[4 5] Thus, when evaluating the burden of injury, prevalence is a relevant outcome measurement.[6]

However, the burden of injury is not evenly distributed across the globe.[7] While injuries pose a significant global health challenge, their prevalence is higher in lower-income and middle-income countries than in high-income countries (HICs). However, the epidemiology of injuries in HICs presents distinct characteristics that warrant focused analysis.[7 8] First, HICs have the financial resources to implement preventive measures, invest in innovative health technology and improve healthcare.[9 10] Research shows that the prevalence injury rates (PIRs) and patterns vary across countries based on gross domestic product (GDP), and variations are also observed among countries classified as HICs.[11] A high GDP allows for different levels of healthcare utilisation as compared with lower-income and middle-income countries. HICs can invest more in healthcare and prevention due to their greater resources, especially if sustained over longer periods.[12 13] Consequently, the healthcare system in HICs is organised differently. For example, many HICs have advanced emergency healthcare systems and highly specialised medical facilities.[14 15] Lastly, with the ageing population in HICs and increased probability of long-term injuries, the PIR is likely to increase as well, especially in HICs. Understanding past and future PIR can put emphasis on burden of injury, priority setting and resource allocation with health reform initiatives, policy responses and prevention measures.[16 17]

The term 'accidental injury' implies randomness, but frequently intentional injuries follow specific patterns that can be predicted and explained when major policy changes occur over time as opposed to unintentional injuries like natural disasters or war.[6 18] Exploiting the specific patterns PIRs have, past trends can be analysed, and forecasting methods can predict future injury rates. Therefore, we sought to provide temporal analysis of past trends and projections of PIRs to 2030. The following research questions were addressed:

- What PIR trends in HICs can be identified and descriptively analysed for the period between 1990 and 2019?
- Do these trends statistically differ from one another?
- What are the projected PIRs for HICs from 2020 to 2030, based on a time series analysis?

METHODS

Study design and data

This was a modelling study in which we used the GBD 2019 data.[7] Briefly, the GBD 2019 study organises injuries into a levelled hierarchy and classifies injuries based on a standard diagnostic tool, the International Classification of Diseases (ICD). Because injury disability is derived from to nature of injury and not based on the cause of injury, we focused only on main categories of injury, namely amputations, burns, fractures, head injuries and spinal injuries. The ICD codes for nature of injury are given (online supplemental appendix S1). We extracted the HIC age-standardised prevalence rates per 100 000 from 1990 to 2019 from the GBD Results tool (https://www.healthdata.org/data-visualization/gbd-results). An HIC is defined by the World Bank as a country with a high-income economy and corresponding gross national income per capita for a given year. Countries belonging to HICs are listed in online supplemental appendix S2. This study adhered to the Guidelines for Accurate and Transparent Health Estimates Reporting (online supplemental appendix S3). No patients were involved in this study.

Statistical analyses

To understand past trends, we employed joinpoint regression analysis to assess temporal changes as described previously.[19] This method involved fitting least-squares regression lines on the log-transformed PIRs to identify joinpoints, representing significant shifts in trends and calculating annual per cent changes (APCs) within multiple time intervals per nature of injury. The optimal number and length of intervals were determined through a grid search approach, allowing for a maximum of nine joinpoints. We ensured a minimum of two observations between each joinpoint and from the joinpoint to either end of the data. Model selection was conducted using the data-driven weighted Bayesian information criteria technique (online supplemental appendix S4A).[20] To describe the trends descriptively, we used average APCs (AAPCs), computed to summarise trends per injury. 95% CIs for AAPCs were estimated using the empirical quantile method with a 10 000 samples.[21] To compare trends statistically between injuries, we employed the parallelism test to assess similarity and the coincidence test to evaluate equality of PIRs over time (online supplemental appendix S4B), respectively.[19] These analyses were conducted using the Joinpoint Regression Programme.[22] The p values of parallelism and coincidence tests are estimated from the distribution of 10 000 randomly permutations of the test statistic generated by Monte Carlo sampling. All statistical tests were performed at a two-sided significance level of 0.05. Joinpoint model selection and calculations details are provided in online supplemental appendix S4A.

To forecast future PIRs, we used the same GBD data covering the period from 1990 to 2019 to determine the correct time series model to be used. Our approach involved employing a projection model that relies on existing (past) years, in other words, projection can be modelled based on lagged values, that is, forecasting new PIRS per year on previous years (GBD 1990 to 2019 data).[23] Different types of models exist to forecast time series. We selected, however, one type of time series model (from five in total; from classical, new time series methods and machine learning) to ensure to ensure comparability of the different injury projections based on the statistical assumptions of one type of time series model (online supplemental appendix S5A).[24] We have used small-sample corrected Akaike information criteria (AIC) as our chosen information criterion, given its efficacy as a proxy for one-step forecast out-of-sample mean squared error (MSE). MSE quantifies the average squared deviation between predicted and actual values within a specified time frame. The autoregressive integrated moving average (ARIMA) model was ultimately chosen to calculate projections for this study, as it had the lowest error metrics compared with the other time-series model types.[25] ARIMA, a popular time series forecasting method, is defined by the three hyperparameters: ARIMA (p, d, q). The autoregressive term captures current and past values' relationships (p), while moving average term grasps the link between the present value and past errors (q). The integrated (I) term ensures stationarity (ie, that the statistical properties are constant over time, meaning the values of the time series do fluctuate around a constant mean or with a constant variance) by differencing with past values (d), if needed. The purpose of each of these hyperparameters is to make the best model fit to the data. Transformations to find the best model were considered, and if applied, back-transformations with appropriate bias-adjustment were performed. Modelling procedure was done as described previously (online supplemental appendix S5B).[26] The Ljung-Box test was used to test whether autocorrelations in the time series were different from zero. If autocorrelation was detected, time series

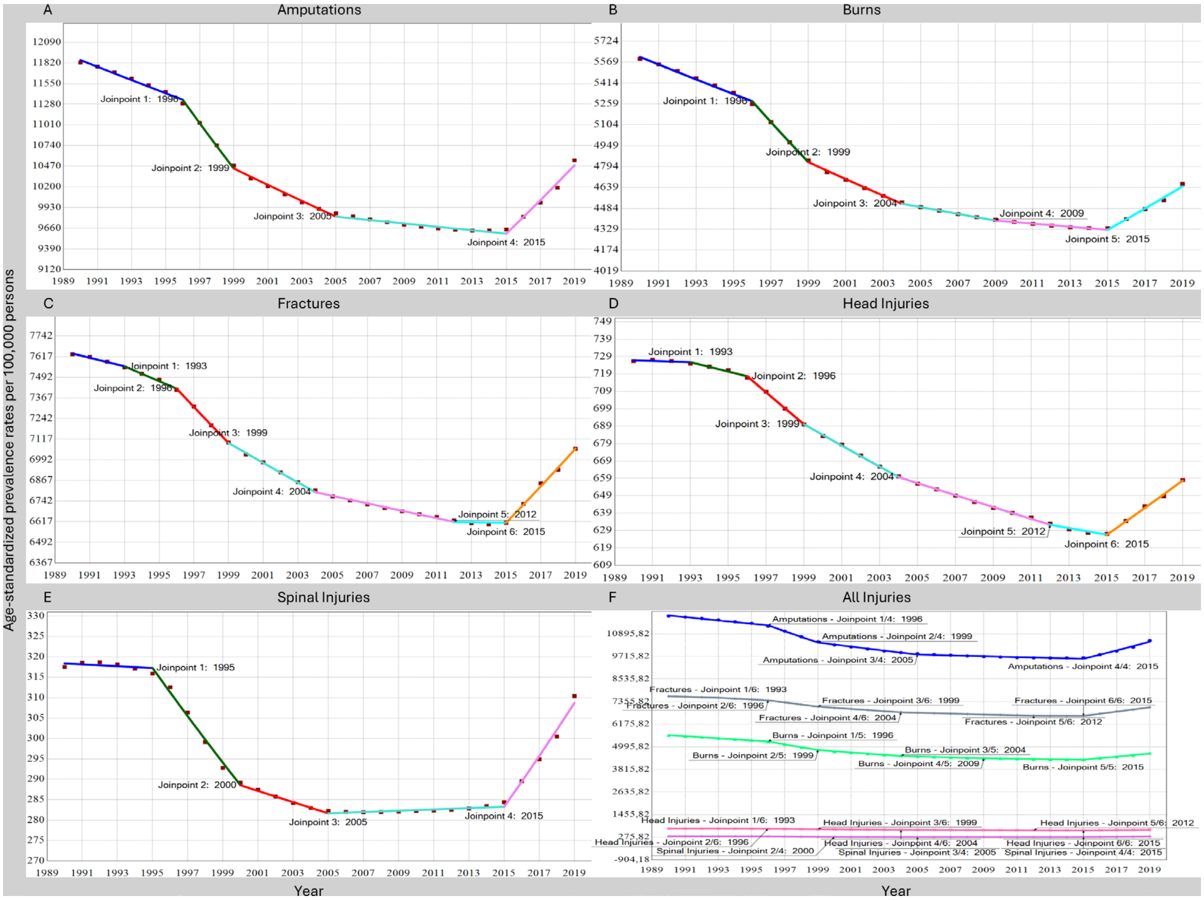

Figure 1 Trends PIRs in high-income countries between 1990 and 2019. (A) Amputations, (B) burns, (C) fractures, (D) head injuries, (E) spinal injuries and (F) all injuries projected and scaled accordingly. Note that annotations of joinpoints are given to mark the year in which a different trend occurs. PIR, prevalence injury rate.

cross-validation was performed. Bias-corrected mean point forecasts (henceforward: point forecasts) were then generated up to 2030, along with 95% forecast intervals (FIs), which were estimated based on the residual variance of the model and the forecast horizon, representing the range within which future values are expected to fall. It should be noted that FIs may not fully account for population changes, advancements in healthcare delivery, social infrastructure, preventive measures, etc. The year 2030 was chosen as too long projections into the future tend to regress to the (moving) average, a constant prediction or zero, since time series analysis is mainly dependable on the number of hyperparameters to be estimated and the amount of randomness in the data.[27] Statistical analysis was performed in RStudio and with the R package fable.[28]

RESULTS

Past PIR trends 1990–2019

The temporal trends in all PIRs decreased in the long term (figure 1). The results of the joinpoint regression model showed that the numbers of change points were different during 1990–2019, and the trend of each stage decreased given the negative AAPC per injury (table 1). The greatest and smallest decrease in PIR in the full-time period was found with an AAPC of −0.6 (95% CI −0.7 to −0.6) and −0.1 (95% CI −0.1 to −0.1) for burns and spinal injuries, respectively. Most injuries had the greatest APC decrease in the second time interval, only PIRs of fractures and head injuries had this in the third time interval. All injuries increased in their last time interval, the greatest being in amputations with 2.3 (95% CI 2.1 to 2.4). Additionally, amputations always had a higher absolute PIR than other injuries (figure 1F). The PIR trends were statistically not parallel nor identical in pairwise comparison of all injuries (online supplemental appendix S4B).

Expected PIRs 2020–2030

For amputation, burns, head injuries (Box-Cox transformed) and spinal injuries, an ARIMA(0, 2, 1) model was found optimal, while for fractures, ARIMA (0, 2, 0) was chosen (online supplemental appendix S5B). After checking for white noise and performing time series cross-validation, point forecasts up to 2030 with 95% FIs are presented in table 2. Based on the estimates of forecast models, over the following 10 years (2020–2030), PIR of amputations will be at 15 319 (95% FI 12 365–18 825), burns will be at 6327 (95% FI 4985–7849), fractures will be at 8444 (95% FI 7472–9779), head injuries will be at 818 (95% FI 551–1101) and spinal injuries will be at 442 (95% FI 359–539). This is a relative percentage increase from 2019 to 2030 of 47% for amputations, 37% for burns, 20% for fractures, 25% for head injuries and 44% for spinal injuries. The relative trajectory of growth of all injuries can be appreciated in figure 2.

DISCUSSION

This study presented the trends in PIRs of different injuries in HICs across a three-decade interval and provided projections

Table 1 Temporal trends of age-standardised prevalence injury rates per 100 000 in high-income countries from 1990 to 2019

	Time interval 1		Time interval 2		Time interval 3		Time interval 4		Time interval 5		Time interval 6		Time interval 7		Full time period 1990–2019
Injury	Years	APC (95% CI)	Years	APC (95%CI)	Years	APC (95% CI)	Years	APC (95% CI)	Years	APC (95% CI)	Years	APC (95% CI)	Years	APC (95% CI)	AAPC (95% CI)
Amputations	1990–1996	−0.7 (−0.9 to −0.6)	1996–1999	−2.7 (−2.9 to −2.3)	1999–2005	−1.0 (−1.2 to −0.8)	2005–2015	−0.2 (−0.3 to −0.1)	2015–2019	2.3 (2.1 to 2.4)					−0.4 (−0.4 to −0.4)
Burns	1990–1996	−1.0 (−1.1 to −0.9)	1996–1999	−2.9 (−3.1 to −2.8)	1999–2004	−1.3 (−1.5 to −1.2)	2004–2009	−0.6 (−0.9 to −0.4)	2009–2015	−0.3 (−0.3 to −0.1)	2015–2019	1.8 (1.7 to 1.9)			−0.6 (−0.7 to −0.6)
Fractures	1990–1993	−0.3 (−0.5 to −0.2)	1993–1996	−0.6 (−1.5 to −0.5)	1996–1999	−1.5 (−1.6 to −0.8)	1999–2004	−0.9 (−0.9 to −0.3)	2004–2012	−0.3 (−0.4 to −0.3)	2012–2015	0.0 (−0.1 to 0.0)	2015–2019	1.7 (1.6 to 1.7)	−0.3 (-0.3 to −0.3)
Head injuries	1990–1993	−0.1 (−0.1 to 0.1)	1993–1996	−0.4 (−0.5 to −0.3)	1996–1999	−1.3 (−1.4 to −1.2)	1999–2004	−0.9 (−1.0 to −0.8)	2004–2012	−0.5 (−0.6 to −0.5)	2012–2015	−0.3 (−0.4 to −0.2)	2015–2019	1.2 (1.2 to 1.3)	−0.3 (−0.4 to −0.3)
Spinal Injuries	1990–1995	−0.1 (−0.2 to 0.1)	1995–2000	−1.9 (−2.0 to −1.8)	2000–2005	−0.5 (−0.8 to −0.3)	2005–2015	0.1 (0.0 to 0.1)	2015–2019	2.2 (2.0 to 2.3)					−0.1 (−0.1 to −0.1)

95% CI indicates whether APC is significantly different from zero at the alpha=0.05 level, thus if zero is in 95%CI, then APC for given time interval is not statistically significant.
Note that time intervals are based on the joinpoints. Each joinpoint means a statistically significant change in trend, starting with 0 joinpoints, that is, a straight line, a single trend and tests whether more joinpoints must be added to the model to find time intervals that differ from each other.
AAPC, average annual per cent change; APC, annual per cent change.

for the next decade. It offers a scientific basis by analysing past trends, highlighting the need for more comprehensive projections and suggesting strategies to address PIRs in HICs.

Several noteworthy findings emerge from the joint regression analysis. First, despite previous declines, recent years have seen a rise in injury rates, indicated by APCs across all injuries. Conversely, the average APCs are negative, signifying an overall decrease in PIRs for all injuries. Moreover, observed trends are not identical nor parallel among the injuries.

Projections reveal a notable surge in amputation rates from 2019 to 2030, raising concerns due to already elevated absolute rates, warranting immediate preventive and management actions. To illuminate possible forthcoming challenges and underscore the necessity of focused injury prevention, to ensure that the healthcare system in HICs can plan for the required personnel, facilities and goods to meet rising rates.

Note that the COVID-19 pandemic altered behaviours significantly, with curfews, policy changes and illness impacting individuals.[29] Additionally, restrictions on healthcare services, including elective procedures and resource allocations, may have caused a misalignment with our data for 2020 and 2021. Moreover, global occurrences like the 2008 economic recession might have indirectly influenced our PIRs projections. It is crucial to acknowledge that our model cannot accurately anticipate future national or global disruptive events.

On forecast methodology, considerations and limitations

In our case, forecasting is based on a short time series. ARIMA is able to accurate short-term and long-term forecasts from modest data.[25] There is no predetermined sample size for time series analysis; it hinges on the number of model hyperparameters and the data's randomness, as explained by Hyndman and Athanasopoulos.[23 27] Ideally, we compare chosen model performance against simpler out-of-sample approaches. Opting for the model with the lowest AIC value enables consideration of both parameter count and noise level. Ultimately, the aim is to minimise in-sample one-step-ahead forecast errors while penalising overfitting. With short series, AIC typically favours simpler models, as those with more than one or two parameters often produce inaccurate forecasts due to estimation errors.[23 27 30] Thus, the modelling approach employed in this study is justified within a likelihood framework from a frequentist perspective, using AIC to ensure model simplicity. The rationale is that extending forecasts to 2030 introduces greater deviations, as longer projections are subject to increasing uncertainty. This uncertainty arises primarily from the accumulation of errors that compound with each additional year in the forecast period. On the topic of averaging, literature suggests that averaging time series models, incorporating multiple approaches for prediction, might outperform the traditional statistical method of relying on a single type of time series model.[30] Using a weighted average to combine forecasts is considered effective in mitigating the risk associated with model misspecification.[31] Note that, in our modelling study, the future trends are all rising. While ARIMA accurately captures recent trends, the sensitivity towards the most recent past trends of forecasted data highlights the need for additional, among others, robustness checks or scenario analyses to validate long-term projections. Thus, for future projection models, with more data (eg, more time-units, exogenous predictors) analysis as suggested by Montero-Manso *et al* in their R package FFORMA is recommended.[31] Additionally, stratification by gender, age and location is recommended, as injury can significantly differ based on past literature.[6 7 11] Noteworthy,

Table 2 Projection of age-standardised prevalence injury rates per 100 000 in high-income countries from 2020 to 2030

	Amputations			Burns			Fractures			Head injuries			Spinal injuries		
Year	Projection	95% FI, lower	95% FI, upper	Projection	95% FI, lower	95% FI, upper	Projection	95% FI, lower	95% FI, upper	Projection	95% FI, lower	95% FI, upper	Projection	95% FI, lower	95% FI, upper
2020	10 981	10 884	11 118	4816	4772	4877	7184	7137	7287	670	657	678	322	320	326
2021	11 414	11 149	11 780	4967	4844	5131	7310	7213	7506	682	649	703	334	327	344
2022	11 848	11 403	12 437	5118	4913	5381	7436	7278	7723	694	643	730	346	334	363
2023	12 282	11 629	13 113	5269	4969	5639	7562	7332	7947	707	635	759	358	340	381
2024	12 716	11 815	13 845	5421	5007	5914	7688	7375	8181	721	627	793	370	345	401
2025	13 150	11 967	14 619	5572	5029	6209	7814	7410	8423	735	618	830	382	349	423
2026	13 584	12 090	15 419	5723	5039	6518	7940	7437	8676	749	607	873	394	352	445
2027	14 018	12 191	16 241	5874	5039	6837	8066	7456	8938	765	595	921	406	355	467
2028	14 451	12 269	17 082	6025	5030	7165	8192	7468	9210	782	581	974	418	357	491
2029	14 885	12 328	17 943	6176	5012	7502	8318	7474	9491	799	567	1034	430	358	515
2030	15 319	12 365	18 825	6327	4985	7849	8444	7472	9779	818	551	1101	442	359	539

See also Source: Hyndman RJ, Athanasopoulos G. Forecasting: principles and practice: OTexts; 2018 for the mathematics and explanation on how to FIs are calculated.
FI, forecast interval.

the nature of time-series models does not allow for prediction of new future different trends, or future medical advances, or political or socioeconomic changes, or natural disasters and war; however, long-term projections including historical and current trends are helpful for long-term planning and policy-making.

Although the global injuries research community has developed various methodological innovations and advancements to address quality of primary data sources, our study shares certain limitations present in the GBD 2019 study.[2] Notably, data on outpatient, inpatient and emergency room discharge were available from a limited number of countries.[2 4] Previous research into the completeness and quality of primary input studies on low back pain and depression has also highlighted similar limitations.[32 33] However, in certain instances, national-level data sources are not considered in the GBD study either due to inaccessibility to the GBD researchers or because they do not meet the predefined quality standards.[34]

Lastly, a recent GBD forecasting study on burden trajectories at global and lower geological levels showed increased life expectancy at birth for both males and females in HICs but also increased burden of injury in 2030 and 2050.[35] Furthermore, the authors conclude that while improvement in the health status of the world is forecasted, the shift to non-communicable diseases and injury will progress and burden will grow. Prompting the same urgency as our study, healthcare utilisation focuses on injury.

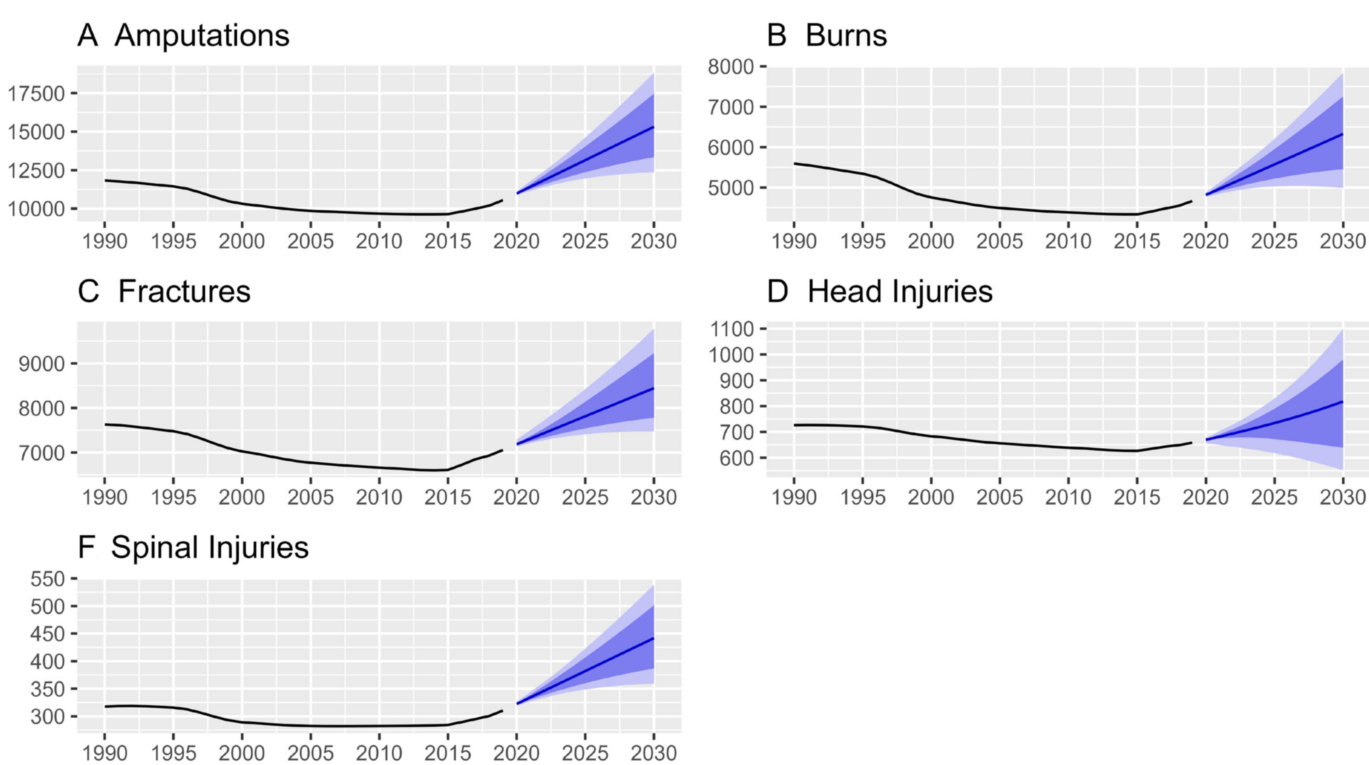

Figure 2 Projections of PIRs in high-income countries. (A) Amputations, (B) burns, (C) fractures, (D) head injuries and (E) spinal injuries. Note that the blackline presents modelled ARIMA fitted values of observed rates of the GBD data (1990–2019), the blue line presents the point forecasts (2020–2030), the dark blue area is the 80% forecast interval and the light blue area is the 95% forecast interval. ARIMA, autoregressive integrated moving average; GBD, Global Burden of Disease Study; PIRs, prevalence injury rates.

Implications of modelled projections for injury prevention in HICs

This article examined injury patterns at the macrolevel, but no explanations or relationships were studied. However, most injuries are avoidable, and an inverse injury trend should be seen when accurate measures are made.[18] In order to effectively reduce the occurrence of injuries and increase the efficiency of its management, comprehensive trauma systems need to be established. The burden of injury, both in terms of surgery and economics, is still high in HICs.[36] Healthcare utilisation in HICs regarding injury should include preventative programmes, triage and transfer processes, stepped and specialised hospital treatments and posthospital care.

Preventive measures such as road safety programmes and stringent enforcement of speeding regulations have been beneficial. Additionally, efforts can be impactful but are not yet universally implemented in all HICs.[6] Systematic surveillance of characteristics of injury, its magnitude, scope and consequences can give insights on how to prevent injury. Currently, qualitative and quantitative deficiencies in injury data limit understanding and management of injury. Injury can have many causes (eg, traffic crashes, falls, self-harm, conflict and terrorism, and exposure to forces of nature). Research on factors that change risks can reduce the chance of an injury happening.

Stepped trauma activation, which includes rapid evaluation by an emergency department physician and early consultation with a trauma surgeon, has been shown to reduce resource use and hospital charges while not increasing length of stay, time to disposition or in-hospital mortality rates.[37 38] Furthermore, evidence-based and pragmatic treatments for injuries that occur, such as enhanced first-aid response in the form of basic to more sophisticated ABCDE methodologies, may help to reduce morbidity.[37–39] Finally, the concentration of injury specialised teams at the mesolevel and macrolevel may improve postinjury treatment. On mesolevel, multidisciplinary teams should play a crucial role in the postacute and long-term care of patients. Integrating such an approach into trauma systems could help mitigate the adverse effects. On macrolevel, the categorisation of distinct trauma-centre levels based on volume and injury severity has been demonstrated to be associated with better outcomes for injured patients.[37 38 40]

CONCLUSION

The PIRs positively declined in past trends, with decreases in all injuries in HICs. However, the latest past trends up to 2019 showed an increase in all injuries. Moreover, the projection model indicated a rising trend. It is essential to reflect on and advocate for strategies to mitigate the potential rise in PIRs. This proactive approach will form the foundation for future resource allocation and planning. Additionally, there may be a need to adjust current treatment strategies and standards to address the expected increase in demand.

Contributors S-KMS: conceptualisation, methodology, software, validation, formal analysis, investigation, resources, data curation, writing–original draft and visualisation. PC: conceptualisation, methodology, validation, investigation, resources and writing–review and editing. MGVV: writing–review and editing. JAH: writing–review and editing. MV: writing–review and editing, and supervision. OVW: writing–review and editing, supervision and project administration, guarantor. JAH: conceptualisation, methodology, validation, resources, writing–review and editing, supervision and project administration. OVW acted as guarantor.

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