Accident Analysis and Prevention 80 (2015) 193–200

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Burden of road traffic injuries: Disability-adjusted life years in relation to hospitalization and the maximum abbreviated injury scale

Suzanne Polinder [a,*], Juanita Haagsma [a], Niels Bos [b], Martien Panneman [c], Karin Klein Wolt [c], Marco Brugmans [c], Wendy Weijermars [b], Ed van Beeck [a]

[a] Erasmus MC, Department of Public Health, P.O. Box 2040, 3000 CA Rotterdam, The Netherlands
[b] SWOV Institute for Road Safety Research, P.O. Box 93113, 2509 AC Den Haag, The Netherlands
[c] Consumer and Safety Institute, P.O. Box 75169, 1070 AD Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 4 March 2014
Received in revised form 16 March 2015
Accepted 12 April 2015
Available online 22 April 2015

Keywords:
Road traffic injury (RTI)
Maximum abbreviated injury scale (MAIS)
Disability adjusted life years (DALY)
Disease burden
Injury severity

ABSTRACT

Background: The consequences of non-fatal road traffic injuries (RTI) are increasingly adopted by policy makers as an indicator of traffic safety. However, it is not agreed upon which level of severity should be used as cut-off point for assessing road safety performance. Internationally, within road safety, injury severity is assessed by means of the maximum abbreviated injury scale (MAIS). The choice for a severity cut-off point highly influences the measured disease burden of RTI. This paper assesses the burden of RTI in terms of disability adjusted life years (DALYs) by hospitalization status and MAIS cut-off point in the Netherlands.
Methods: Hospital discharge register (HDR) and emergency department (ED) data for RTI in the Netherlands were selected for the years 2007–2009, as well as mortality data. The incidence, years lived with disability (YLD), years of life lost (YLL) owing to premature death, and DALYs were calculated. YLD for admitted patients was subdivided by MAIS severity levels.
Results: RTI resulted in 48,500 YLD and 27,900 YLL respectively, amounting to 76,400 DALYs per year in the Netherlands. The largest proportion of DALYs is related to fatalities (37%), followed by admitted MAIS 2 injuries (25%), ED treated injuries (16%) and admitted MAIS 3+ injuries (18%). Admitted MAIS 1 injuries only account for a small fraction of DALYs (4%). In the Netherlands, the diseases burden of RTI is highest among cyclists with 39% of total DALYs. One half of all bicycle related DALYs are attributable to admitted MAIS 2+ injuries, but ED treated injuries also account for a large proportion of DALYs in this group (28%). Car occupants are responsible for 26% of all DALYs, primarily caused by fatalities (66%), followed by admitted MAIS 2+ injuries (25%). ED treated injuries only account for 5% of DALYs in this group.
Conclusions: When using admitted MAIS 3+ or admitted MAIS 2+ as severity cut-off point, 54% and 80% of all DALYs are captured respectively. Assessing the influence of different severity cut-off points by MAIS on the proportion and number of DALYs captured gives valuable information for guiding choices on the definition of serious RTI.

1. Introduction

Road traffic crashes are a global and increasing public health concern (Peden et al., 2004; Lozano et al., 2010). Road safety performance has traditionally been measured by the reduction of fatalities (European Commission, 2013b), but road traffic crashes also cause very large numbers of nonfatal injuries, leading to huge economic and human costs to society. In 2011, on roads within the European Union, for example, almost 1,5 million people were reported to have a non-fatal injury (European Commission, 2013b) compared to about 30.000 fatalities (CARE database) (2014). Around one sixth of the reported non-fatal injuries were estimated to be serious (European Commission, 2013b).

Moreover, the number of road injury casualties shows a less positive development than the number of fatalities in various countries, such as in Sweden, Spain, United Kingdom and Japan (IRTAD 2012). In the Netherlands, the number of fatalities decreased on average by almost 5% annually between 1996 and

* Corresponding author at: Erasmus MC, P.O. Box 2040, 3000 CA Rotterdam, The Netherlands. Tel.: +31 107043954; fax: +31 102743309.
E-mail addresses: s.polinder@erasmusmc.nl (S. Polinder), j.haagsma@erasmusmc.nl (J. Haagsma), niels.bos@swov.nl (N. Bos), m.panneman@veiligheid.nl (M. Panneman), k.kleinwolt@veiligheid.nl (K.K. Wolt), m.brugmans@veiligheid.nl (M. Brugmans), wendy.weijermars@swov.nl (W. Weijermars), e.vanbeeck@erasmusmc.nl (E. van Beeck).

http://dx.doi.org/10.1016/j.aap.2015.04.013
0001-4575/

2011, whereas the number of road injuries decreased by only 1% annually between 1993 and 2006 and increased from 2006 to 2011 (Reurings and Bos, 2011).

Since the number of serious RTI is relatively high in relation to the number of fatalities and it shows a less positive trend in many countries, serious RTIs are increasingly adopted by policy makers as an indicator of traffic safety. Reducing the number of serious road injuries is one of the key priority actions in the road safety programe 2011–2020 of the European Commission (European Commission, 2010).

A problem, however, in relation to setting an international target is the lack of a common definition of a serious road injury. Internationally, within road safety, injury severity is assessed by means of the maximum abbreviated injury scale (MAIS), i.e., the maximum score of a six-point scale ranging from 1 (minor injury) to 6 (fatal injury) (Petrucelli et al., 1981). However, it is not agreed upon which MAIS level should be used to define serious road injuries as a policy indicator. In Dutch road safety policy, a serious road injury is defined as a hospitalized non-fatal casualty with an injury score of MAIS 2+. The OECD working group on injury data, IRTAD, proposes to define a 'seriously injured road casualty" as a person with an injury score of MAIS 3+ (IRTAD, 2012). Research to guide further choices in this area is scarce. A main issue in relation to the definition of a serious road injury as a policy indicator is the burden of road injury that is captured when a specific severity cut-off point is selected. To gain insight in the burden of road injuries distinguished by severity cut-off point, state-of-the-art methods to quantify the impact of diseases and injuries on population health may be helpful (Polinder et al., 2012a). Currently, the international standard measure for integrating the fatal and non-fatal consequences of diseases is the disability-adjusted life-year (DALY) (Peden et al., 2002, 2004; Murray et al., 2013; Gabbe et al., 2014), a summary measure of population health that combines the effects of mortality, morbidity and disability into a single measure. Though mortality is an essential indicator of the magnitude of RTI, it is important to realize that for each injury death, there are several thousand injury survivors, with short-term and often also lifelong consequences due to the injury. These non-fatal outcomes should also be measured in order to describe accurately the burden of disease due to RTI. The indicator used to quantify the loss of healthy life due to disease is the DALY).

Priority setting in healthcare, surveillance and intervention is based increasingly on burden-of-disease and injury studies using the DALY approach (Murray 1994). This method, which combines premature years of life lost (YLL) with years lived with disability (YLD), has been applied in general injury populations in different countries (Polinder et al., 2012a) and has been adapted to the needs and availability of data on the temporary and permanent consequences of non-fatal injuries (Haagsma et al., 2012). The DALY adaptation of Haagsma et al. (2012) was recently used in a study specifically designed to quantify the combined burden of road traffic injuries and fatalities (Dhondt et al., 2013). This study focused on DALYs per kilometer traveled by mode of transport, and confirmed more general previous work showing the highest disease burden per kilometer in case of motorcycling (Holtslag et al., 2008). But so far the impact of road traffic injuries on population health by MAIS severity has not been quantified.

This paper assesses the burden of road traffic injuries and fatalities in terms of DALYs by MAIS cut-off point in the Netherlands. No prior exclusions of low severity levels are made in our analysis, since previous studies have shown the large potential impact of minor injuries on population health. In the Netherlands we found that almost one fifth of the DALYs of road crashes are caused by low severity injuries that are only treated at the ED without subsequent hospital admission (Polinder et al., 2012b). In Sweden it was observed that 10% of injuries from road crashes with MAIS 1 suffers from permanent consequences and that the majority of permanent consequences of road injuries results from MAIS 1 or MAIS 2 injuries (Malm et al., 2008). Furthermore, several studies conducted in New-Zealand concluded that exclusion of non-hospitalized injuries leads to underestimation of the population impact of injuries (Ameratunga et al., 2006; Derrett et al., 2011; Langley et al., 2011).

Therefore, this paper looks at the combined burden of fatalities due to road crashes and medically treated RTI, including both ED treatments and hospitalizations and including all MAIS severity levels 1–6.

Our paper presents a comprehensive set of tables and figures on the burden of road traffic injuries in the Netherlands. We calculated DALYs in relation to hospitalization and the MAIS. To increase the relevance of our analysis from a policy perspective, a specific focus on MAIS cut off was chosen. This may support choices of traffic safety policy makers on indicators of 'road safety performance' to be preferred or avoided.

We will assess the influence of different severity cut-off points on the proportion and number of DALYs covered.

2. Data and methods

2.1. Data sources

Several data sources were used to provide national data on mortality, the incidence of RTI and their consequences. For road fatalities, data were obtained from Statistics Netherlands for the years 2007–2009 by age group, gender and mode of transport (CBS, 2010). The numbers were multiplied by the Life Expectancy of the respective age group from the Global Burden of Diseases study (Global Burden of Disease, 2010).

Data from the hospital discharge register (HDR, 2007–2009) with full national coverage were used to assess the injuries and their consequences of admitted injury patients. The Dutch injury surveillance system (2007–2009) provides a national representative sample of injured patients who were treated in the emergency department (ED) that was scaled to national level. ED patients consisted of both non-admitted and admitted patients visiting an ED. To avoid double counting of HDR and ED registry, admitted ED patients were excluded from the analysis.

A selection of external causes of the *International Classification of Diseases*, 9th revision was used in the HDR to select RTI (ICD9: E810-E817, E819 + E826, E827, E829, extended with other patients that could be matched to police reports). The mean annual incidence for the period 2007–2009 was used. Readmissions and persons dying within 30 days of the crash were excluded from the HDR data and YLD calculations to prevent double counting with the mortality statistics.

In the HDR and ED system, data by age group, gender, injury type, and mode of transport were available. For the HDR, the mode of transport was checked with matched police reports, which overruled the mode that was present in the HDR E-codes (Reurings and Bos, 2011). Seven main road user groups were identified: pedestrian, bicycle (with and without involvement of a motor vehicle in the crash), moped, motorcycle, car/van and other/unknown.

In the HDR also the abbreviated severity score (AIS) was available. The AIS is developed specifically for the classification of injuries (Gennarelli and Wodzin 2006), describing the type of injury, affected body region, and injury severity in a 7-digit code for each injury that the trauma patient has sustained. To classify trauma patients according to injury severity level AIS scores of each injury can be combined into a single score with the maximum AIS (MAIS), which determines severity level by taking the highest

AIS score in a patient with multiple injuries (Gennarelli and Wodzin 2006). The MAIS is the preferred measure in road safety research, as it showed good performance in classifying road injuries, and is internationally comparable, well established, and widely used by medical staff (European Commission, 2013a). The MAIS-score was obtained by mapping all reported injuries (up to 10) in ICD-9 to AIS-1990 (Johns Hopkins University, 1998). The MAIS is a six-point scale ranging from 1 (minor injury) to 6 (maximum injury) (Petrucelli et al., 1981). MAIS 0 (no injury after examination) and MAIS 9 (unknown) were excluded from the analysis.

To link the injury incidence data to disability information, it is key to use an anatomical classification system that is able to link each injury grouping to a disability weight and to distinguish the nature and localization of the injury. Therefore, the previously derived European injury classification EUROCOST was used (Lyons et al., 2006). The 39 EUROCOST injury groups allow to aggregate the original ICD-9 codes into fewer groups with a higher number of patients and offer a clear link with disability (Haagsma et al., 2009, 2012). For the injury coding in ED a similar grouping into EUROCOST groups was used.

2.2. Disability adjusted life years

The total burden of RTI in the Netherlands was expressed in DALYs and its constituent components, namely premature death (years of life lost, YLL) and years lived with disability (YLD).

The DALY is calculated by adding the number of years of life lost due to mortality (YLL) to time spent in less than perfect health due to morbidity and disability, expressed in healthy year equivalents lost to disability (YLD) ((Murray and Acharya 1997)). YLL is calculated by summation of the number of fatal cases (d) due to health outcome (h) in a certain period multiplied by the residual expected life expectancy (e) at the age of death:

$$\mathrm{YLL} = d_{\mathrm{h}} \times \mathrm{e}$$

YLD is calculated by multiplying the number of incident cases (Inc) at a certain age with health outcome (h) by the duration of the health outcome (t) and the disability weight (dw) assigned to health outcome h:

$$\mathrm{YLD} = \mathrm{Inc}_{\mathrm{h}} \times t_{\mathrm{hl}} \times \mathrm{dw}_{\mathrm{h}}$$

YLL values were calculated by counting the number of fatalities in each age group and by multiplying deaths by the residual expected

Table 1
Mean annual numbers (HDR, 2007–2009) of road traffic injuries by age intervals in the Netherlands.

	0–17		18–34		35–64		65+		Total	
	N	(%)	*N*	(%)	*N*	(%)	*N*	%	*N*	(%)
Gender										
Male	2355	64	3400	67	5145	62	1976	45	12876	60
Female	1330	36	1651	33	3095	38	2451	55	8527	40
Type of road user										
Pedestrian	385	10	229	5	384	5	319	7	1318	6
Bicycle without motorvehicle	1410	38	1042	21	3304	40	2473	56	8229	38
Bicycle with motorvehicle	487	13	371	7	732	9	513	12	2103	10
Moped	863	23	695	14	848	10	270	6	2676	13
Motorcycle	115	3	498	10	790	10	44	1	1447	7
Car/van	288	8	1979	39	1807	22	609	14	4683	22
Other/unknown	137	4	237	5	374	5	200	5	948	4
Type of injury										
Skull–brain injury	1131	31	1278	25	1767	21	934	21	5109	24
Facial fracture, eye injury	119	3	249	5	312	4	96	2	776	4
Spine, vertebrae	37	1	216	4	387	5	139	3	779	4
Internal organ injury	189	5	308	6	674	8	352	8	1523	7
Upper extremity fracture	681	18	642	13	1509	18	587	13	3418	16
Upper extremity, other	32	1	66	1	146	2	38	1	283	1
Hip fracture	68	2	143	3	658	8	1156	26	2025	9
Lower extremity fracture	692	1	736	15	1252	15	474	11	3155	15
Lower extremity, other	43	1	57	1	95	1	38	1	234	1
Superficial injury, open wounds	431	12	716	14	866	11	429	10	2443	11
Other injury	261	7	629	12	569	7	185	4	1640	8
ISS										
0/99	378	10	778	15	736	9	241	5	2.133	10
1–3	667	18	1090	22	1396	17	642	14	3794	18
4–5	1997	54	2165	43	3982	48	1682	38	9826	46
6–8	73	2	140	3	291	4	114	3	618	3
9–11	258	7	372	7	1000	12	1309	30	2939	14
12–15	33	1	116	2	218	3	87	2	453	2
16–31	268	7	360	7	577	7	341	8	1547	7
32+	9	0	31	1	41	1	11	0	92	0
MAIS										
No injury after examination	273	7	546	11	477	6	152	3	1.448	7
Unknown	105	3	232	5	259	3	89	2	685	3
1	667	18	1090	22	1396	17	642	14	3794	18
2	2085	57	2343	46	4345	53	1827	41	10600	50
3	293	8	490	10	1213	15	1397	32	3393	16
4+	261	7	350	7	551	7	321	7	1483	7
Total	3684	17%	5051	24%	8240	39%	4428	21	21403	100

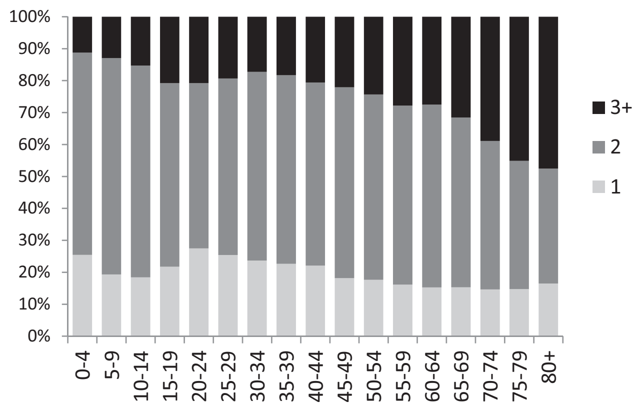


Fig. 1. Distribution of MAIS scores for admitted RTI by age category (HDR, the Netherlands, 2007–2009).

individual life span as derived from the GBD 2010 standard model life table for age (Murray et al., 2012). For the purpose of this study, we used the standardized Integris method for calculating YLD after injury (Haagsma et al., 2012). This method is slightly different compared to the standard (GBD) method to assess DALYs. Major differences are the disability weights and the method to calculate the proportion of patients with permanent functional impairments.

YLD was obtained by linking the incidence data (subdivided into injury diagnosis groupings) with temporary and lifelong disability information, that is the proportion of injury cases with lifelong consequences, and injury-specific disability weights of acute and lifelong consequences (Haagsma et al., 2012). The disability weight reflects the impact of a health condition in terms of health-related quality of life; it has a value ranging from 1, indicating worst imaginable health state, to 0, indicating full health. Overall, 87 weights and proportions for 27 injury diagnoses involving lifelong consequences were included in the Integris method. These disability weights were assessed using functional outcome data of a large sample of injury patients. An advantage of this method is that the heterogeneity in duration and functional consequences of each injury diagnosis is included in the disability weight (Haagsma et al., 2009).

The proportion of injuries that resulted in lifelong consequences was also derived from patient data and determined for ED treated and hospitalized patients separately, because of the variety of injury severity and associated disability (Haagsma et al., 2012). These proportions are based on 2-year follow-up data of a large sample of Dutch injury patients that were treated at the ED and/or admitted to hospital. A detailed description of the assessment of the proportion of cases with permanent health loss is described in Haagsma et al. Durations of lifelong disability were estimated by the age- and gender-specific life expectancies from the same table (Haagsma et al., 2012). The YLD of lifelong injury were calculated by multiplying the number of patients (in an age/gender/injury group) with lifelong injury with the corresponding disability weight and duration. Age weights or discounting were not applied in the calculations, because this practice is controversial (Anand and Hanson 1997; Murray et al., 2012).

The incidence, years lived with disability (YLD), years of life lost (YLL) owing to premature death, and DALYs resulting from RTI's were calculated. For admitted injury patients the resulting YLD could be split by their MAIS severity level.

3. Results

3.1. Incidence

In the Netherlands, in the period from 2007 to 2009, (population approximately 16.4 million inhabitants) on average 127,700 patients visited a hospital due to RTI per year. Of the RTI patients 83% were discharged to the home environment after their treatment at the ED, whereas on average 21,400 RTI patients were admitted to hospital. Of the hospitalized patients that were younger than 65 years old the majority of patients were males (64%). In the age group above 65 years old females were overrepresented (55%) (Table 1). More than half (68%) of these 65+ patients were bicyclists. The age group 18–34 years was the only age group of admitted patients where more than half (63%) of the RTI were due to an injury with a motorized vehicle (moped, motorcycle, car). One fourth of admitted patients sustained skull-brain injury. Other common injury types were upper and lower extremity fractures (16% and 15% respectively). Subdivision of admitted patients into MAIS severity levels showed that MAIS 1, 2, 3 and 4+ consisted of 20%, 54%, 18% and 8%, respectively, of the admitted cases (after excluding MAIS 0/9).

Looking at the distribution of MAIS severity level by age, the percentage of MAIS 1 is similar in the different age groups, whereas the percentage of MAIS 3+ increases by age (Fig. 1). The MAIS score does not significantly differ between males and females (data not shown).

3.2. Disability adjusted life years

Annually, in total, RTI resulted in 76,400 DALYs in the Netherlands (4.7 DALY per 1000 inhabitants), 64% of which resulted from non-fatal injury (48,500 YLD versus 27,900 YLL) (Table 2).

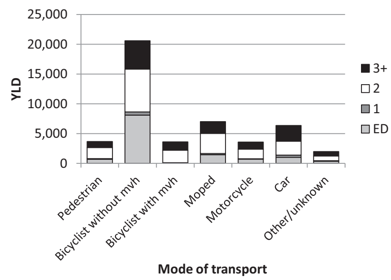
Looking at the YLD by type of road user, bicycle injuries without involvement of a motor vehicle in the crash have by far the largest share in total YLDs (13,000 YLD) (Fig. 2).

RTI patients that were treated at the ED represented 83% of RTI incidence, but accounted for 26% of total YLD (Fig. 3b). For the admitted patients, MAIS 1, MAIS 2, MAIS 3+ accounted for 3%, 41% and 39% of total YLD, respectively (Fig. 3b).

In the Netherlands, the disease burden of RTI is highest among cyclists with 39% of total DALYs (Fig. 4). More than half of all bicycle related DALYs were MAIS 2+ injuries, but ED treated injuries also

Table 2
Annual numbers and DALY's by mode of transport, hospitalization status and MAIS category in admitted patients (the Netherlands, 2007–2009).

Mode of transport	Annual RTI cases					Injury burden				
	Fatalities	MAIS 2+	MAIS < 2	ED	Total incidence	YLL	YLD MAIS 2+	YLD MAIS < 2	YLD ED	DALY
Pedestrian	74	1012	306	3965	5357	2457	2876	267	698	6299
Bicyclist	185	8258	2073	62,002	72,518	5220	15,460	1403	8123	30,205
Moped rider	58	2015	661	13,078	15,812	2398	5358	342	1475	9573
Motorcyclist	67	1158	289	5298	6812	2936	2802	122	735	6595
Car occupant	310	2337	2346	18,542	23,535	12,925	4983	756	1018	19,682
Other	59	696	252	3425	4432	1970	1553	197	375	4096
Total	754	15,476	5927	106,310	128,467	27,906	33,032	3087	12,424	76,449



Footnote: For ED patients no subdivision for bicyclists 'without or with motor vehicle' is made.

Fig. 2. Total YLD for admitted and ED treated RTI by type of road user (the Netherlands, 2007–2009).

account for a large proportion of DALYs in this group (28%). Car occupants are responsible for 26% of all DALYs, primarily caused by fatalities (66%), followed by MAIS 2+ injuries (25%). ED treated injuries account for 5% of DALYs in this group.

Even though the overall incidence of fatal road traffic injuries was low (<1%), the largest proportion of DALYs is related to fatalities (37%), followed by admitted MAIS 2 RTI (25%), admitted MAIS 3+ RTI (18%), and ED treated RTI (16%). Admitted MAIS 1 RTI only account for a small fraction of DALYs (2%). But all road traffic injuries of low severity levels combined (ED treated and admitted MAIS 1-2) are responsible for 46% all DALYs (Fig. 3c).

In all age groups, except the elderly (65+), males were responsible for higher numbers of DALYs than females (Fig. 5). This was partly due to the higher number of YLDs of admitted MAIS 3+ patients in males.

4. Discussion

In this paper we assessed the burden of RTI in terms of disability adjusted life years (DALYs) by hospitalization status and MAIS severity levels in the Netherlands.

The combined impact of road traffic injuries and road traffic fatalities on disease burden has been assessed in several previous studies. In the present study, we found that RTIs resulted in 4.7 DALY per 1000 inhabitants in the Netherlands. A study from a Dutch cohort of major trauma patients reported 3.9 DALY per 1000 inhabitants for RTIs (Holtslag et al., 2008). A French study, which also included both emergency department and hospital register and mortality data, reported to have 5.4 and 1.7 DALY per 1000 for men and women respectively (Lapostolle et al., 2009). The much higher number of DALYs in Dutch women (3.2 versus 6.0/1000 for males) is probably due to the high incidence and disease burden of bicycle injuries in the Netherlands compared to France. Comparable with findings from Belgium (Dhondt et al., 2013), we found that approximately 60% of the burden of road traffic injury is caused by vulnerable road users (i.e., those unprotected by an outside shield). Our study has confirmed results of previous studies from the Netherlands, New-Zealand and the UK, concluding that the exclusion of non-hospitalized injuries leads to a underestimation of the population impact of injuries (Ameratunga et al., 2006; Derrett et al., 2011; Langley et al., 2011; Lyons et al., 2011; Polinder et al., 2012b).

This paper looked at the burden of fatalities due to road crashes and medically treated RTI, including both ED treatments and hospitalizations and including all MAIS severity levels 1–6.

Burden of injury estimates that cover the broad severity spectrum of RTI injuries, and that are based on high quality data, are critical for strengthening health metrics and assessing the total burden of RTI on society. Generally, only mortality and hospital register data are used to quantify the burden of RTI. This study shows that admitted MAIS 2+ victims (including fatalities) account

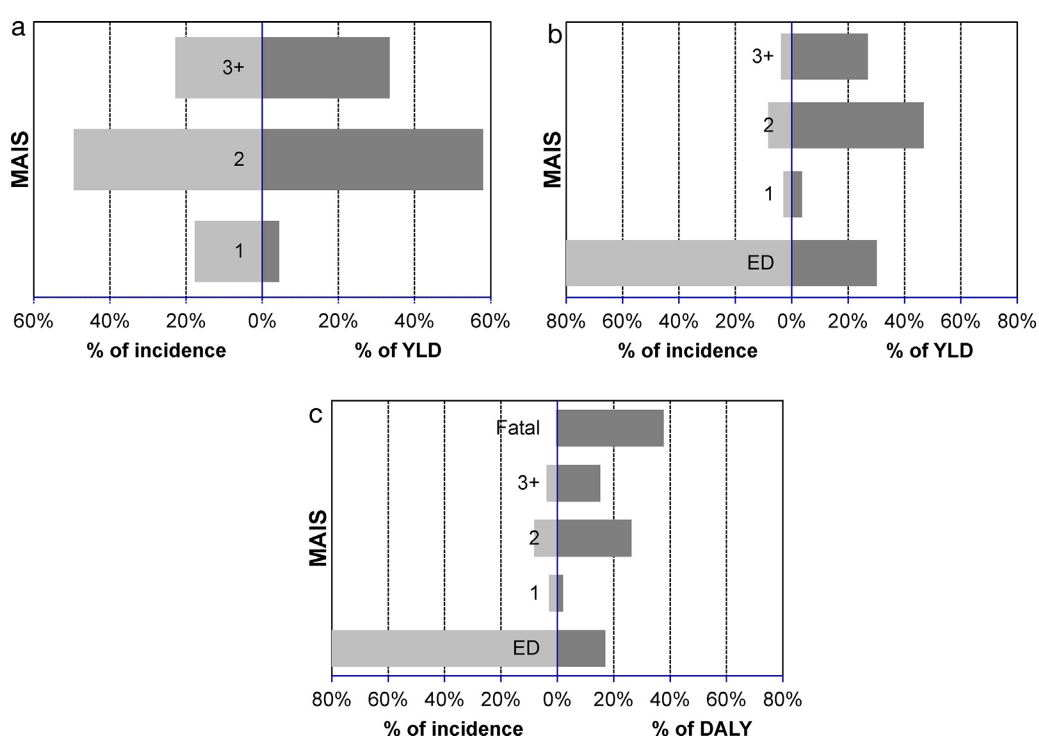


Fig. 3. Contribution of MAIS severity levels to incidence and disease burden for RTI (the Netherlands, 2007–2009). (a) Incidence and YLDs of admitted RTI. (b) Incidence and YLDs of admitted and ED treated RTI. (c) Incidence and DALYs of admitted, ED treated and fatal RTI.

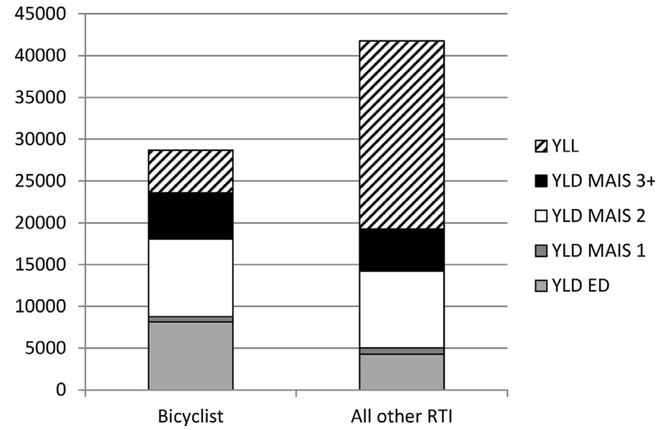


Fig. 4. Total DALY (YLD and YLL) for bicyclists compared to all other RTI (the Netherlands, 2007–2009).

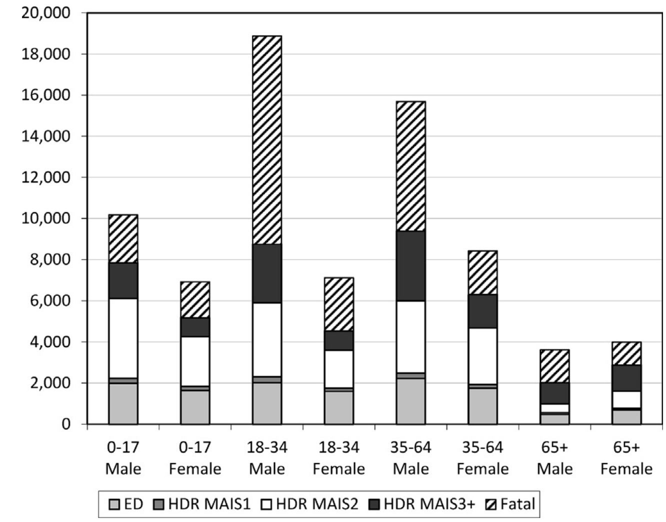


Fig. 5. DALYs following RTI per year according to age and gender (the Netherlands, 2007–2009).

for 80% of the DALYs caused by road crashes. This finding is comparable with the outcomes of a recent paper from Tainio et al. (2014) in which they found that 82.4% of YLDs due to RTI in Sweden were caused by AIS2+ injuries. Injured RTI patients not admitted to hospital are responsible for 16% of the total injury burden of road crashes. Based on this we can conclude that the use of incidence data or burden estimates that are restricted to hospitalized patients inevitably leads to an underestimation of the public health impact of injury.

Our DALY calculations have some limitations related to the databases used. The mortality data, derived from the CBS mortality database, represent only persons who die within 30 days following injury. This is in agreement with the international definition of a road fatality (Un-Ece, 1968). Delayed mortality is not taken into account and the YLL are therefore slightly underestimated.

Within the HDR about 15% of admitted RTI patients are still missing. This explains the lower incidence used in this paper, compared to official statistics of Severe Injuries MAIS 2+ in The Netherlands (Reurings and Stipdonk, 2011). For that reason, the calculated YLD for MAIS 2+ casualties admitted to the hospital reported in this paper is also about 15% lower than it actually is.

LIS represents a sample of all RTI patients treated at the emergency department of Dutch hospitals. Bias may arise if the registered ED visits are extrapolated to a national level due to differences in injury type. However, LIS hospitals consist of a representative sample of Dutch hospitals with respect to type of hospital, geography and the catchment areas (rural versus urban). However, the use of a sample may have involved some overestimation or underestimation of the DALYs related to ED treated RTI (Polinder et al., 2012b). Moreover, no MAIS information was available in our ED surveillance system. We could therefore only make a distinction of admitted patients by MAIS severity in our analyses.

Furthermore, our study did not include patients who consulted a general practitioner because of a RTI. Previous research has shown that the number of patients that visit a GP because of an RTI in the Netherlands is almost twice as high as those who visit the ED (approximately 200,000 cases). However, the burden of disease of RTI patients who consulted a GP is considerably lower (approximately 1% of total RTI YLDs), because of the lower severity level of their injuries (Polinder et al., 2012b). Tainio found in a present study that 2.7% of total YLDs were due to minor injuries (AIS = 1) (Tainio et al., 2014).

This points out that exclusion of GP cases has a very limited effect on burden of injury estimates. These cases may therefore be neglected in defining an indicator of serious road injury.

Internationally, within road safety, injury severity is assessed with the MAIS, but there is an ongoing debate which MAIS level should be used as cut-off point for reducing the health burden of RTI. A main issue in relation to the definition of a serious road injury is the burden of road injury that is captured and/or missed when a specific severity cut-off point is selected. In Europe a serious RTI is defined as a person with an injury score of MAIS 3+ (Oecd/Itf, 2013; Irtad, 2012). In Dutch road safety policy, a serious road injury is defined as a hospitalized non-fatal casualty with an injury score of MAIS 2+. The results of this paper underpin that the proportion of DALY that is captured when using different severity cut-off points (MAIS) gives valuable information for guiding choices on the definition of serious RTI. We found that when using admitted MAIS 3+ or admitted MAIS 2+ as severity cut-off point, respectively 54% and 80% of all DALYs are captured. For policy making this implicates that using MAIS 3+ instead of MAIS 2+ as traffic safety indicator will result in almost 50% better ‘road safety performance’ in the Netherlands. Although the proportion of DALY captured varies by mode of transport, nonetheless the effect of the choice of severity cut-off point is enormous. From a burden of disease perspective, hospital admission and MAIS 3+ as cut-off to define serious RTI should be avoided. Whether using hospital admission and MAIS 2+ as cut-off point is adequate has yet to be resolved. For one this depends on the purpose of the analysis, e.g. overall road safety performance or prevention policies targeted at specific road users.

The effect of the MAIS severity cut-off level depends on the distribution of RTI by mode of transport, and, consequently will vary by country. This illustrates that for policy making the choice for severity cut-off point should not be too straight.

Our results may not be generalized to other countries, since the Netherlands is known for its large share of bicycle injuries (Oecd/Itf, 2013) leading to large numbers of ED treated injuries and related DALYs. But if we exclude bicycle injuries from the calculations the proportion of DALYs missed with a MAIS 2+ cut-off point would drop from 21% to 13%. This shows that the effect of the MAIS severity cut-off point will depend on the distribution of RTI by mode of transport, and that the 21% missed disease burden in the Netherlands should probably be interpreted as an upper boundary of possible estimations. We therefore conclude that using MAIS 2+ as severity level for road traffic policy making includes both infrequently occurring severe and the more common less severe injuries and the lion's share of the total burden of RTI. In countries where cycling is a popular form of transport, using MAIS 2+ as cut-off point, imply that a specific RTI group with significant disease burden will be missed. Using emergency department visits as cut-off point for severity in these countries might be considered.

Another issue to be considered is the adequacy of an indicator for analyses of time trends and/or geographical comparisons. In order to analyze time trends or regional differences in disease burden with the help of hospital data, the potential influence of variation in health care consumption behavior and hospital admission policies should be minimized (Polinder et al., 2008). Lyons et al. (2006) have advised against including all ED treated injuries and recommend a restriction to selected radiological verified fractures (SRVF). This provides focus on injuries with an objective need for hospital treatment and largely eliminates the influence of patient factors and social factors that may differ widely by time and place.

It must also be recognized that trend analyses of hospital discharge data without any severity cut-off point are often flawed. Langley et al. (2002) have shown that significant overestimates of incidence and incorrect conclusions about trends would lurk, if the crude hospital discharge data were used for estimating injury incidence. If crude hospital discharge data are used, injuries of low severity are also included, which introduces bias resulting from changes in health care consumption patterns. Therefore, Langley et al. (2002) provided a set of selection criteria, including the restriction to injuries of moderate and high severity: MAIS 2+.

This is the first analysis in road safety research on the association between MAIS and DALYs. Both measures have been developed for different purposes. MAIS is an indicator of acute severity, while DALY takes into account short- and long-term disability following the injury. Therefore, a high MAIS, such as MAIS 3+, does not necessarily result in high burden of disease, as confirmed by our results. Some injuries may be very severe at the moment of the crash (leading to high MAIS), but do not necessarily lead to high disability or death if the patient rehabilitates completely after the acute phase. The reverse also holds and is clearly demonstrated by our results: injuries with low MAIS severity levels during the acute phase can lead to long term severe burden of disease and their exclusion leads to underestimation of the impact of RTI on population health. Using a MAIS 2+ indicator for serious RTI is a pragmatic choice, in which policy making of RTI will be guided by acute severity and not on the burden of injury. Alternatively, using DALYs as indicator for road safety performance as input for policy making should be considered.

5. Conclusion

When using admitted MAIS 3+ or admitted MAIS 2+ as severity cut-off point, respectively 54% and 80% of all DALYs are captured. Assessing the influence of different severity cut-off points by MAIS on the proportion and number of DALYs covered gives valuable information for guiding choices on the definition of serious RTI. Using MAIS 2+ as severity level for road traffic policy making includes both infrequently occurring severe and the more common less severe injuries and the lion's share of the total burden of RTI. From a burden of disease perspective, hospital admission MAIS 3+ as cut-off to define serious RTI should be avoided.

Conflict of interests

The authors declare that they have no competing interests.

References

Ameratunga, S., Norto, N.R., Connor, J., Robinson, E., Civil, I., Coverdale, J., Bennett, D., Jackson, R., 2006. A population-based cohort study of longer-term changes in health of car drivers involved in serious crashes. Ann. Emerg. Med. 48 (6), 729–736.

Anand, S., Hanson, K., 1997. Disability-adjusted life years: a critical review. J. Health Econ. 16, 685–702.

Cbs, 2010. http://statline.Cbs.Nl/statweb/publication/?Vw=t&dm=slnl&pa=71936ned&d1=a&d2=1-2&d3=1-9&d4=11-13&hd=140218-1441&hdr=t&stb=g3,g1,g2.

Derrett, S., Davie, G., Ameratunga, S., Wyeth, E., Colhoun, S., Wilson, S., Samaranayaka, A., Lilley, R., Hokowhitu, B., Hansen, P., Langley, J., 2011. Prospective outcomes of injury study: recruitment, and participant characteristics, health and disability status. Inj. Prev. 17 (6), 415–418.

Dhondt, S., Macharis, C., Terryn, N., Van Malderen, F., Putman, K., 2013. Health burden of road traffic accidents, an analysis of clinical data on disability and mortality exposure rates in flanders and brussels. Accid. Anal. Prev. 50, 659–666.

European Commission, 2010. Road safety program 2011–2020: Detailed measures. Memo/10/343, 20 July 2010. European Commission, Brussels.

European Commission, 2013. Commission staff working document, on the implementation of objective 6 of the european commission's policy orientations on road safety 2011–2020–first milestone towards an injury strategy. European Commission, Brussels.

European Commission, 2013. Commission staff working document: On the implementation of objective 6 of the european commission's policy orientations on road safety 2011–2020–first milestone towards an injury strategy, European Commission, Brussels.

Gabbe, B.J., Lyons, R.A., Harrison, J.E., Rivara, F.P., Ameratunga, S., Jolley, D., Polinder, S., Derrett, S., 2014. Validating and improving injury burden estimates study: the injury-vibes study protocol. Inj. Prev. 20 (3), e4.

Gennarelli, T.A., Wodzin, E., 2006. Ais 2005: a contemporary injury scale. Injury 37 (12), 1083–1091.

Global Burden of Disease, I., 2010. Life expectancy western europe in http://ghdx.Healthmetricsandevaluation.Org/sites/ghdx/files/record-attached-files/ihme_gbd_2010_hale_1990_2010.Csv.

Haagsma, J., Polinder, S., Lyons, R., Lund, J., Ditsuwan, V., Prinsloo, M., Veerman, J., Van Beeck, E., 2012. Improved and standardized methods to assess disability adjusted life years after injury. Bull. World Health Organ. 90 (7), 513–521.

Haagsma, J.A., Polinder, S., Van Beeck, E.F., Mulder, S., Bonsel, G.J., 2009. Alternative approaches to derive disability weights in injuries: do they make a difference? Qual. Life Res. 18 (5), 657–665.

Holtslag, H., Van Beeck, E., Lichtveld, R., Leenen, L., Lindeman, E., Van Der Werken, C., 2008. Individual and population burdens of major trauma in the Netherlands. Bull. World Health Organ. 86, 111–117.

Irtad, 2012. Reporting on Serious Road Traffic Casualties: Combining and Using Different Data Sources to Improve Understanding of Non-fatal Road Traffic Crashes, International Traffic Safety Data and Analysis Group, oecd/itf, Paris. Paris.

Johns Hopkins University, 1998. Icdmap-90 User's Guide. The Johns Hopkins University & Tri-Analytics, Baltimore.

Langley, J., Derrett, S., Davie, G., Ameratunga, S., Wyeth, E., 2011. A cohort study of short-term functional outcomes following injury: the role of pre-injury socio-demographic and health characteristics, injury and injury-related healthcare. Health Qual. Life Outcomes 18 (9), 68.

Langley, J., Stephenson, S., Cryer, C., Borman, B., 2002. Traps for the unwary in estimating person based injury incidence using hospital discharge data. Inj. Prev. 8, 332–337.

Lapostolle, A., Gadegbeku, B., Ndiaye, A., Amoros, E., Chiro, N.M., Spira, A., Laumon, B., 2009. The burden of road traffic accidents in a french departement: the description of the injuries and recent changes. BMC Public Health 13 (9) doi: http://dx.doi.org/10.1186/1471-2458-9-386.

Lozano, R., Naghavi, M., Foreman, K., Lim, S., Shibuya, K., Aboyans, V., Abraham, J., Adair, T., Aggarwal, R., Ahn, S., Alvarado, M., Anderson, H., Anderson, L., Andrews, K., Atkinson, C., Baddour, L., Barker-Collo, S., Bartels, D., Bell, M., et al., 2010. Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the global burden of disease study 2010. Lancet 380 (9859), 2095–2128.

Lyons, R., Kandrick, D., Towner, E., Christie, N., Macey, S., Coupland, C., Gabbe, B., 2011. Uk burden of injuries study group. Measuring the population burden of injuries, implications for global and national estimates: a multi-centre prospective uk longitudinal study. PLoS Med. 8 (12), e1001140.

Lyons, R.A., Polinder, S., Larsen, C.F., Mulder, S., Meerding, W.J., Toet, H., Van Beeck, E., Eurocost Reference, G., 2006. Methodological issues in comparing injury incidence across countries. Int. J. Inj. Contr. Saf. Promot. 13 (2), 63–70.

Malm, S., Krafft, M., Kullgren, A., Ydenius, A., Tingvall, C., 2008. Risk of permanent medical impairment (rpmi) in road traffic accidents. Ann. Adv. Automot. Med. 52, 93–100.

Murray, C.J., 1994. Quantifying the burden of disease: the technical basis for disability-adjusted life years. Bull. World Health Organ. 72 (3), 429–445.

Murray, C.J., Acharya, A.K., 1997. Understanding dalys (disability-adjusted life years). J. Health Econ. 16 (6), 703–730.

Murray, C.J., Vos, T., Lozano, R., Naghavi, M., Flaxman, A.D., Michaud, C., Ezzati, M., Shibuya, K., Salomon, J.A., Abdalla, S., Aboyans, V., Abraham, J., Ackerman, I., Aggarwal, R., Ahn, S.Y., Ali, M.K., Alvarado, M., Anderson, H.R., Anderson, L.M., Andrews, K.G., Atkinson, C., Baddour, L.M., Bahalim, A.N., Barker-Collo, S., Barrero, L.H., Bartels, D.H., Basanez, M.G., Baxter, A., Bell, M.L., Benjamin, E.J., Bennett, D., Bernabe, E., Bhalla, K., Bhandari, B., Bikbov, B., Bin Abdulhak, A., Birbeck, G., Black, J.A., Blencowe, H., Blore, J.D., Blyth, F., Bolliger, I., Bonaventure, A., Boufous, S., Bourne, R., Boussinesq, M., Braithwaite, T., Brayne, C., Bridgett, L., Brooker, S., Brooks, P., Brugha, T.S., Bryan-Hancock, C., Bucello, C., Buchbinder, R., Buckle, G., Budke, C.M., Burch, M., Burney, P., Burstein, R., Calabria, B., Campbell, B., Canter, C.E., Carabin, H., Carapetis, J., Carmona, L., Cella, C., Charlson, F., Chen, H., Cheng, A.T., Chou, D., Chugh, S.S., Coffeng, L.E., Colan, S.D., Colquhoun, S., Colson, K.E., Condon, J., Connor, M.D., Cooper, L.T., Corriere, M., Cortinovis, M., De Vaccaro, K.C., Couser, W., Cowie, B.C., Criqui, M.H., Cross, M., Dabhadkar, K.C., Dahiya, M., Dahodwala, N., Damsere-Derry, J., Danaei, G., Davis, A., De Leo, D., Degenhardt, L., Dellavalle, R., Delossantos, A., Denenberg, J., Derrett, S., Des Jarlais, D.C., Dharmaratne, S.D., et al., 2013. Disability-adjusted life years (dalys) for 291 diseases and injuries in 21 regions, 1990–2010: a systematic analysis for the global burden of disease study 2010. Lancet 380 (9859), 2197–2223.

Murray, C.J.L., Ezzati, M., Flaxman, A.D., Lim, S.H., Lozano, R., Michaud, C., Maghavi, M., Salomon, J.A., Shibuya, K., Vos, T., Wikler, D., Lopez, A.D., 2012. Gbd 2010: design, definitions, and metrics. Lancet 380 (9859), 2063–2066.

Oecd/Itf Cycling, health and safety. Paris, 2013.

Peden, M., Mcgee, K., Sharma, G., 2002. The Injury Chart Book: A Graphical Overview of the Global Burden of Injuries. World Health Organization, Geneva.

Peden, M., Scurfield, R., Sleet, D., Mohan, D., Hyder, A.A., Jarawan, E., Mathers, C., 2004. World Report on Road Traffic Injury Prevention. World Health Organization, Geneva.

Petrucelli, E., States, J., Hames, L., 1981. The abbreviated injury scale: evolution, usage and future adaptability. Accid. Anal. Prev. 13, 29–35.

Polinder, S., Haagsma, J., Lyons, R., Gabbe, B., Ameratunga, S., Cryer, C., Derrett, S., Harrison, J., Sequi-Gomez, M., Van Beeck, E., 2012a. Measuring the population burden of fatal and non-fatal injury. Epid. Rev. 34, 17–31.

Polinder, S., Haagsma, J., Toet, H., Van Beeck, E., 2012b. Epidemiological burden of minor, major and fatal trauma in a national injury pyramid. Br. J. Surg. 99 (1), 114–121.

Polinder, S., Meerding, W., Lyons, R., Haagsma, J., Toet, H., Petridou, E., Mulder, S., Van Beeck, E., 2008. International variation in clincial injury incidence: exploring the performance of indicators based on health care, anatomical an outcome criteria. Accid. Anal. Prev. 40 (1), 182–191.

Reurings, M.C.B., Bos, N.M., 2011. Ernstig verkeersgewonden in de periode 1993–2009SWOV, Leidschendam. . (in Dutch) www.swov.nl/rapport/r-2011-05.pdf.

Reurings, M.C.D., Stipdonk, H.L., 2011. Estimating the number of serious road injuries in the Netherlands. Ann. Epidemiol. 21, 648–653.

Tainio, M., Olkowicz, D., Teresinski, G., De Nazelle, A., Nieuwenhuijsen, M.J., 2014. Severity of injuries in different modes of transport, expressed with disability-adjusted life years (dalys). BMC Public Health 14, 765.

Convention of Road Traffic. United Nations, Economic Commission for Europe Ece. Inland Transport Committee, vienna.