Incidence of traumatic brain injury in New Zealand: a population-based study

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Summary

Background Traumatic brain injury (TBI) is the leading cause of long-term disability in children and young adults worldwide. However, accurate information about its incidence does not exist. We aimed to estimate the burden of TBI in rural and urban populations in New Zealand across all ages and TBI severities.

Methods We did a population-based incidence study in an urban (Hamilton) and rural (Waikato District) population in New Zealand. We registered all cases of TBI (admitted to hospital or not, fatal or non-fatal) that occurred in the population between March 1, 2010, and Feb 28, 2011, using multiple overlapping sources of information. We calculated incidence per 100 000 person-years with 95% CIs using a Poisson distribution. We calculated rate ratios [RRs] to compare the age-standardised rates between sex, ethnicity, and residency (urban, rural) groups. We used direct standardisation to age-standardise the rates to the world population.

Results The total incidence of TBI per 100 000 person-years was 790 cases (95% CI 749–832); incidence per 100 000 person-years of mild TBI was 749 cases (709–790) and of moderate to severe TBI was 41 cases (31–51). Children (aged 0–14 years) and adolescents and young adults (aged 15–34 years) constituted almost 70% of all TBI cases. TBI affected boys and men more than women and girls (RR 1·77, 95% CI 1·58–1·97). Most TBI cases were due to falls (38% [516 of 1369]), mechanical forces (21% [288 of 1369]), transport accidents (20% [277 of 1369]), and assaults (17% [228 of 1369]). Compared with people of European origin, Maori people had a greater risk of mild TBI (RR 1·23, 95% CI 1·08–1·39). Incidence of moderate to severe TBI in the rural population (73 per 100 000 person-years [95% CI 50–107]) was almost 2·5 times greater than in the urban population (31 per 100 000 person-years [23–42]).

Interpretation Our findings suggest that the incidence of TBI, especially mild TBI, in New Zealand is far greater than would be estimated from the findings of previous studies done in other high-income countries. Our age-specific and residency-specific data for TBI incidence overall and by mechanism of injury should be considered when planning prevention and TBI care services.

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Introduction

Traumatic brain injury (TBI) is the leading cause of long-term disability in children and adults younger than 35 years,[1–3] and has serious effects on the lives of patients, their families and friends, and society.[4–6] An estimated 10 million people worldwide are affected every year by a new TBI event.[3] Projections indicate that TBI will become the third largest cause of global disease burden by 2020.[7] In the USA, an estimated 1·7 million people sustain a TBI annually,[8] and about 5·3 million people live with a disability related to TBI.[1] The incidence of TBI is estimated to be 200–558 per 100 000 population,[9–11] with estimated overall economic cost in 2000 of about US$406 billion.[12]

Previous estimates of TBI incidence have been mainly based on official statistics (eg, patients admitted to hospital for TBI) and were prone to diagnostic and selection biases.[13,14] The true incidence of TBI is widely acknowledged to be higher than available estimates,[3,15,16] because 70–90% of all TBIs are mild,[4,16] with only a small proportion of those affected by TBI being admitted to hospital.[14,15,17,18] However, even so-called mild TBI can result in long-term deficits.[19–22] Indeed, the National Institutes of Health declared in 1999 that mild TBI is a major public health problem,[2] emphasising the importance of capturing the true burden of TBI in the population.[15,23] Available evidence also suggests ethnic inequalities in TBI incidence and outcomes,[24–26] but accurate community data for such disparities in TBI burden are scarce. TBI should, therefore, be studied in a population-wide context, providing more robust estimates of incidence, outcomes, and the true burden borne by various communities.[3,11,27–31] We aimed to estimate age-specific, sex-specific, and ethnic-specific rates of mild and moderate to severe TBI in the Brain Injury Outcomes New Zealand In the Community (BIONIC) study—a large, population-based, TBI incidence and outcomes study undertaken in New Zealand during 2010–11.

Methods

Study participants

The study population included people of all ages in a large geographical area in the central North Island of

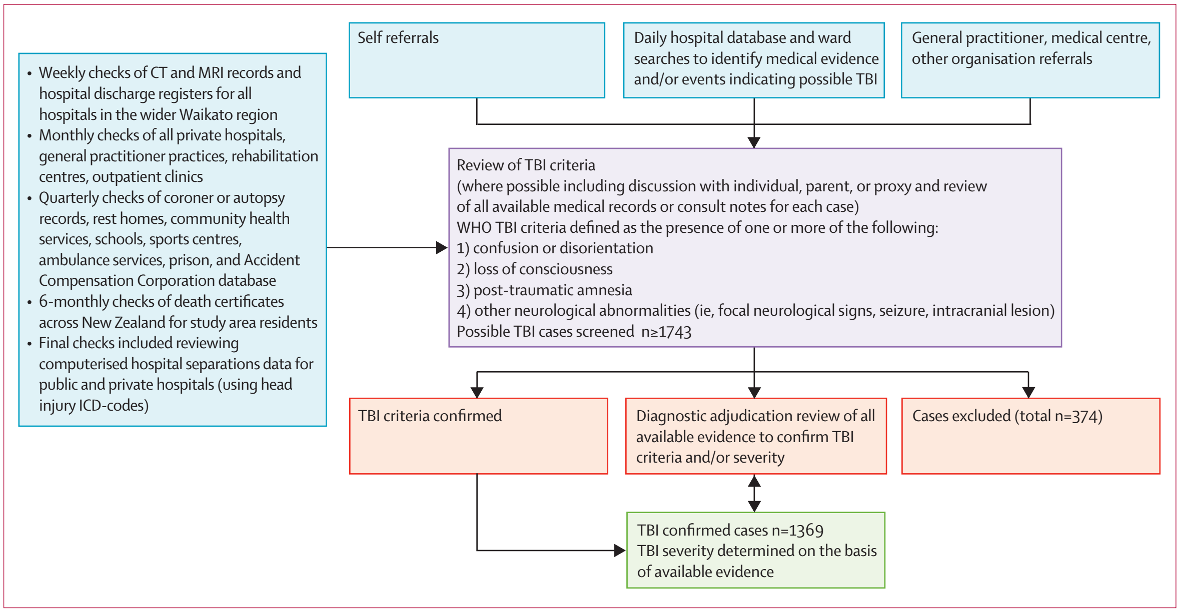

***Figure 1:* Overview of case ascertainment procedures**
TBI=traumatic brain injury. GP= general practitioners. ICD=international classification of diseases.

	Mild TBI (n=1298)	Moderate to severe TBI (n=71)	Total (n=1369)
Mean age in years (SD)	27·5 (21·3)	38·7 (25·7)	28·1 (21·7)
Median age in years (IQR)	21 (13–40)	28 (18–62)	22 (13–41)
Male	805 (62%)	51 (72%)	856 (63%)
Urban residency	965 (74%)	43 (61%)	1008 (74%)
Ethnic origin			
European	791 (61%)	46 (65%)	837 (61%)
Maori	404 (31%)	21 (30%)	425 (31%)
Pasifika	49 (4%)	2 (3%)	51 (4%)
Asian	42 (3%)	1 (1%)	43 (3%)
Other	12 (1%)	1 (1%)	13 (1%)
Site of case detection by study team			
Hospital	826 (64%)	56 (79%)	882 (64%)
Family doctor	108 (8%)	0	108 (8%)
Other	364 (28%)	15 (21%)	379 (28%)
History of TBI	358 (28%)	12 (17%)	370 (27%)
Cause of TBI			
Transport accident	249 (19%)	28 (39%)	277 (20%)
Fall	488 (38%)	28 (39%)	516 (38%)
Exposure to mechanical force	286 (22%)	2 (3%)	288 (21%)
Assault	218 (17%)	10 (14%)	228 (17%)
Other	13 (1%)	3 (4%)	16 (1%)
Unknown (not specified)	44 (3%)	0	44 (3%)

Data are n (%), unless otherwise stated. TBI=traumatic brain injury.

***Table 1:* Characteristics of study participants**

See Online for appendix

New Zealand, including the city of Hamilton (129 249 people, 98 km²) and the surrounding rural area (Waikato District, 43 956 people, 31 987 km²; appendix). In the study area, Europeans constituted 55% of the study population, Maori 20% (the indigenous population of New Zealand), Pasifika (Pacific Islands people living in New Zealand) 2%, and people of other ethnic origins 15%. By its demographic characteristics; ethnic, urban, and rural representation; and socio-economic structure, the study area was representative of New Zealand's total population, according to 2006 New Zealand census data. Ethnic origin was self-identified using 2006 New Zealand census definitions.[32]

Procedures

The methodology of the BIONIC study drew on the WHO Injury Surveillance Guidelines[33] and has been described in detail elsewhere.[30] We used prospective and retrospective surveillance systems to ensure registration of all TBI events in residents of all ages within a 1-year period (March 1, 2010, to Feb 28, 2011).

TBI was defined according to WHO criteria as an acute brain injury resulting from mechanical energy to the head from external physical forces.[34] Operational criteria for clinical identification included presence of one or more of the following: confusion or disorientation; loss of consciousness; post-traumatic amnesia; and other neurological abnormalities (eg, focal neurological signs, seizure, intracranial lesion).[19,35] Symptoms needed to be related to the TBI and not due to illicit drugs, alcohol, or medication use, nor caused by other injuries or treatments (eg, systemic injuries, facial injuries, intubation) or other problems (eg, psychological trauma, language barrier, coexisting medical disorders). When criteria and the potential effect of any of the above were unclear, all clinical evidence was reviewed by the study Diagnostic Adjudication Group, who were based in Auckland, on a weekly basis. TBI severity was defined using standard definitions.[35–37] Mild TBI was defined as Glasgow coma scale (GCS) 13–15 or post traumatic amnesia (PTA)[36] within 24 h of injury; moderate TBI was defined as GCS 9–12 or PTA within 1–6 days of injury; and severe TBI was defined as GCS 8 or lower or PTA 7 or more days from injury. If feasible, GCS scores were recorded at the scene of the injury, at admission to hospital or another medical service, or both. Individuals' worst GCS score, recorded in the medical notes within the first 4 weeks of injury, was also recorded when available to capture change in scores during admission. If GCS and PTA severities differed, the more severe category was assigned. If no information about PTA was available, severity was based on the GCS score. If neither PTA or GCS were available, patients were classified as mild TBI because GCS could not be assigned retrospectively. The reported cause of TBI was classified according to the ICD-10 external cause classification system and grouped into TBI due to falls (unintentional), transport accidents (traffic and non-traffic related), assaults due to interpersonal violence, exposure to external forces (eg, being struck accidentally by a person, animal, or inanimate object), and other causes (unknown or unspecified causes).

Before the study began, we visited all health-care providers (eg, health centres, family physicians, physiotherapists), hospital departments, ambulance services, TBI service providers, national health-care databases, the local prison, the death registry, and community services (eg, schools, residential facilities, sports clubs) to inform them about the study and to ask for their help in the identification of cases, and all parties were successfully enlisted. We contacted health-care providers monthly throughout the study by telephone or email, at scheduled visits to provide study updates, and with quaterly newsletters. Health professionals referred patients with TBI to the study using duplicate carbon-copy pads, detailing study criteria and indicating whether the person concerned agreed to be contacted about the study, agreed to a copy of consultation notes to be supplied to the study, or refused to pass on injury details or to be contacted by the study team. All participants provided written consent. We aimed to assure complete case ascertainment using multiple overlapping sources of information about all cases, admitted and not admitted to hospital, both fatal and non-fatal. This case

	Total population (n)	Mild TBI		Moderate to severe TBI		Total	
		Population (n)	Incidence per 100 000 person-years (95% CI)	Population (n)	Incidence per 100 000 person-years (95% CI)	Population (n)	Incidence per 100 000 person-years (95% CI)
Boys and men							
0–4 years	6603	102	1545 (1245–1845)	2	30 (0–72)	104	1575 (1272–1878)
5–14 years	13 596	136	1000 (832–1168)	1	7 (0–22)	137	1008 (839–1176)
15–34 years	26 298	351	1335 (1195–1474)	29	110 (70–150)	380	1445 (1300–1590)
35–64 years	29 790	174	584 (497–671)	12	40 (17–63)	186	624 (535–714)
≥65 years	7668	42	548 (382–713)	7	91 (24–159)	49	639 (460–818)
Total	83 952	805	959 (893–1025)	51	61 (44–77)	856	1020 (951–1088)
Standardised*	..	..	980 (915–1051)	..	60 (46–80)	..	1041 (973–1113)
Women and girls							
0–4 years	6468	63	974 (734–1215)	3	46 (0–99)	66	1020 (774–1267)
5–14 years	12 792	78	610 (474–745)	1	8 (0–23)	79	618 (481–754)
15–34 years	27 600	172	623 (530–716)	5	18 (2–34)	177	641 (547–736)
35–64 years	32 559	128	393 (325–461)	3	9 (0–20)	131	402 (333–471)
≥65 years	9822	52	529 (386–673)	8	81 (25–138)	60	611 (456–765)
Total	89 250	493	552 (504–601)	20	22 (13–32)	513	575 (525–625)
Standardised*	..	..	568 (519–620)	..	21 (13–33)	..	589 (539–642)
Total							
0–4 years	13 074	165	1262 (1069–1455)	5	38 (5–72)	170	1300 (1105–1496)
5–14 years	26 391	214	811 (702–920)	2	8 (0–18)	216	818 (709–928)
15–34 years	53 898	523	970 (887–1054)	34	63 (42–84)	557	1033 (948–1119)
35–64 years	62 352	302	484 (430–539)	15	24 (12–36)	317	508 (452–564)
≥65 years	17 490	94	537 (429–646)	15	86 (42–129)	109	623 (506–740)
Total	173 205	1298	749 (709–790)	71	41 (31–51)	1369	790 (749–832)
Standardised*	..	..	771 (730–814)	..	40 (32–51)	..	811 (769–855)

TBI=traumatic brain injury. *Standardised to the WHO World Standard Population.[39]

Table 2: **Traumatic brain injury incidence by age, sex, and severity of injury**

	Total population (n)	Mild TBI		Moderate to severe TBI		Total	
		Population (n)	Incidence per 100 000 person-years (95% CI)	Population (n)	Incidence per 100 000 person-years (95% CI)	Population (n)	Incidence per 100 000 person-years (95% CI)
European							
0–4 years	5478	93	1698 (1353–2043)	2	37 (0–87)	95	1734 (1385–2083)
5–14 years	11 712	123	1050 (865–1236)	2	17 (0–41)	125	1067 (880–1254)
15–34 years	26 289	313	1191 (1059–1323)	19	72 (40–105)	332	1263 (1127–1399)
35–64 years	37 221	187	502 (430–574)	9	24 (8–40)	196	527 (453–600)
≥65 years	13 626	75	550 (426–675)	14	103 (49–157)	89	653 (517–789)
Total	94 332	791	839 (780–897)	46	49 (35–63)	837	887 (827–947)
Standardised*	..	..	929 (865–998)	..	46 (34–62)	..	975 (909–1046)
Maori							
0–4 years	4383	59	1346 (1003–1690)	3	68 (0–146)	62	1415 (1062–1767)
5–14 years	8160	75	919 (711–1127)	0	0 (0–0)	75	919 (711–1127)
15–34 years	12 342	163	1321 (1118–1523)	13	105 (48–163)	176	1426 (1215–1637)
35–64 years	9198	94	1022 (815–1229)	4	43 (1–86)	98	1065 (855–1276)
≥65 years	1155	13	1126 (514–1737)	1	87 (0–256)	14	1212 (577–1847)
Total	35 244	404	1146 (1035–1258)	21	60 (34–85)	425	1206 (1091–1321)
Standardised*	..	..	1138 (1026–1262)	..	62 (39–97)	..	1200 (1085–1327)
Other							
0–4 years	3210	13	405 (185–625)	0	0 (0–0)	13	405 (185–625)
5–14 years	6522	16	245 (125–366)	0	0 (0–0)	16	245 (125–366)
15–34 years	15 276	47	308 (220–396)	2	13 (0–31)	49	321 (231–411)
35–64 years	15 915	21	132 (76–188)	2	13 (0–30)	23	145 (85–204)
≥65 years	2694	6	223 (45–401)	0	0 (0–0)	6	223 (45–401)
Total	43 638	103	236 (190–282)	4	9 (0–18)	107	245 (199–292)
Standardised*	..	..	240 (197–292)	..	8 (3–22)	..	248 (205–301)

TBI=traumatic brain injury. *Standardised to the WHO World Standard Population.[39]

Table 3: **Traumatic brain injury incidence by ethnic origin and injury severity**

	Total population (n)	Mild TBI		Moderate to severe TBI		Total	
		Population (n)	Incidence per 100 000 person-years (95% CI)	Population (n)	Incidence per 100 000 person-years (95% CI)	Population (n)	Incidence per 100 000 person-years (95% CI)
Hamilton (urban)							
Boys and men							
0–4 years	4836	80	1654 (1292–2017)	1	21 (0–61)	81	1675 (1310–2040)
5–14 years	9582	103	1075 (867–1283)	1	10 (0–31)	104	1085 (877–1294)
15–34 years	21 108	275	1303 (1149–1457)	16	76 (39–113)	291	1379 (1220–1537)
35–64 years	20 991	119	567 (465–669)	7	33 (9–58)	126	600 (495–705)
≥65 years	5568	29	521 (331–710)	6	108 (22–194)	35	629 (420–837)
Total	62 082	606	976 (898–1054)	31	50 (32–68)	637	1026 (946–1106)
Standardised*	..	..	985 (909–1067)	..	48 (34–68)	..	1033 (955–1116)
Women and girls							
0–4 years	4728	46	973 (692–1254)	1	21 (0–63)	47	994 (710–1278)
5–14 years	9108	55	604 (444–763)	1	11 (0–32)	56	615 (454–776)
15–34 years	22 239	129	580 (480–680)	2	9 (0–21)	131	589 (488–690)
35–64 years	23 556	86	365 (288–442)	1	4 (0–13)	87	369 (292–447)
≥65 years	7530	43	571 (400–742)	7	93 (24–162)	50	664 (480–848)
Total	67 164	359	535 (479–590)	12	18 (8–28)	371	552 (496–609)
Standardised*	..	..	547 (492–607)	..	16 (9–28)	..	562 (507–623)

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	Total population (n)	Mild TBI		Moderate to severe TBI		Total	
		Population (n)	Incidence per 100 000 person-years (95% CI)	Population (n)	Incidence per 100 000 person-years (95% CI)	Population (n)	Incidence per 100 000 person-years (95% CI)
(Continued from previous page)							
Total							
0–4 years	9564	126	1317 (1087–1547)	2	21 (0–50)	128	1338 (1106–1570)
5–14 years	18 690	158	845 (714–977)	2	11 (0–26)	160	856 (723–989)
15–34 years	43 350	404	932 (841–1023)	18	42 (22–61)	422	973 (881–1066)
35–64 years	44 547	205	460 (397–523)	8	18 (6–30)	213	478 (414–542)
≥65 years	13 092	72	550 (423–677)	13	99 (45–153)	85	649 (511–787)
Total	129 249	965	747 (700–794)	43	33 (23–43)	1008	780 (732–828)
Standardised*	..	..	762 (715–812)	..	31 (23–42)	..	794 (746–844)
European*	..	..	907 (834–987)	..	40 (27–58)	..	947 (872–1029)
Maori*	..	..	1165 (1029–1319)	..	43 (21–91)	..	1209 (1069–1366)
Other ethnicities*	..	..	273 (223–335)	..	8 (3–25)	..	281 (230–344)
Waikato (rural)							
Boys and men							
0–4 years	1767	22	1245 (725–1765)	1	57 (0–168)	23	1302 (770–1834)
5–14 years	4014	33	822 (542–1103)	0	0 (0–0)	33	822 (542–1103)
15–34 years	5190	76	1464 (1135–1794)	13	250 (114–387)	89	1715 (1359–2071)
35–64 years	8799	55	625 (460–790)	5	57 (7–107)	60	682 (509–854)
≥65 years	2100	13	619 (283–956)	1	48 (0–141)	14	667 (317–1016)
Total	21 870	199	910 (783–1036)	20	91 (51–132)	219	1001 (869–1134)
Standardised*	..	..	984 (854–1135)	..	109 (69–170)	..	1093 (954–1251)
Women and girls							
0–4 years	1740	17	977 (513–1441)	2	115 (0–274)	19	1092 (601–1583)
5–14 years	3684	23	624 (369–879)	0	0 (0–0)	23	624 (369–879)
15–34 years	5361	43	802 (562–1042)	3	56 (0–119)	46	858 (610–1106)
35–64 years	9003	42	467 (325–608)	2	22 (0–53)	44	489 (344–633)
≥65 years	2292	9	393 (136–649)	1	44 (0–129)	10	436 (166–707)
Total	22 086	134	607 (504–709)	8	36 (11–61)	142	643 (537–749)
Standardised*	..	..	641 (539–762)	..	39 (19–80)	..	680 (575–805)
Total							
0–4 years	3510	39	1111 (762–1460)	3	85 (0–182)	42	1197 (835–1558)
5–14 years	7701	56	727 (537–918)	0	0 (0–0)	56	727 (537–918)
15–34 years	10 548	119	1128 (925–1331)	16	152 (77–226)	135	1280 (1064–1496)
35–64 years	17 805	97	545 (436–653)	7	39 (10–68)	104	584 (472–696)
≥65 years	4398	22	500 (291–709)	2	45 (0–109)	24	546 (327–764)
Total	43 956	333	758 (676–839)	28	64 (40–87)	361	821 (737–906)
Standardised*	..	..	811 (727–905)	..	73 (50–107)	..	884 (796–983)
European*	..	..	1008 (877–1158)	..	68 (40–116)	..	1076 (941–1230)
Maori*	..	..	1075 (887–1302)	..	116 (65–205)	..	1191 (993–1428)
Other ethnicities*	..	..	89 (42–191)	..	16 (2–116)	..	106 (52–215)

*Standardised to the WHO World Standard Population.[39] TBI=traumatic brain injury.

Table 4: **Traumatic brain injury incidence by residency and injury severity**

ascertainment included the following: daily checks of all public hospitals and emergency departments (including surgery and neurosurgery departments) in the study region; monthly checks of CT and MRI records, hospital discharge registers for public and private hospitals in the wider Waikato region, family doctors, rehabilitation centres, and outpatient clinics; quarterly checks of coroner and autopsy records and rest homes; and a yearly check of ambulance services, the prison located within the study region, and the Accident Compensation Corporation (ACC) database. The ACC is a government-supported no-fault insurance agency that funds treatment and rehabilitation for all New Zealand residents with injuries. Cases were also identified from the national death register (we ascertained all death certificates with any mention of TBI). We made every effort to capture data for all individuals with mild TBI who were not admitted to hospital, by including those from family doctor practices providing direct referrals of new and suspected cases of TBI, and by doing checks of accident records of community health services, schools, and sport centres (within and just outside the catchment area), and through self-referrals (the study was widely advertised in the study area via television, newspaper articles, and newsletters and posters). Final checks for complete case ascertainment included reviewing computerised hospital separations data (deaths, discharge, and transfers) for public hospitals with ICD-10 S00-S09 codes for head injury (via the National Health Index number). All TBI cases were checked against existing cases in our TBI registry, to identify any duplicates.

	Transport accident		Fall		Exposure to mechanical force		Assault		Other or unknown	
	Number	Incidence per 100 000 person-years (95% CI)	Number	Incidence per 100 000 person-years (95% CI)	Number	Incidence per 100 000 person-years (95% CI)	Number	Incidence per 100 000 person-years (95% CI)	Number	Incidence per 100 000 person-years (95% CI)
Boys and men										
0–4 years	6	91 (18–164)	71	1075 (825–1325)	22	333 (194–472)	2	30 (0–72)	3	45 (0–97)
5–14 years	31	228 (148–308)	44	324 (228–419)	46	338 (241–436)	8	59 (18–100)	8	59 (18–100)
15–34 years	96	365 (292–438)	54	205 (151–260)	97	369 (295–442)	114	433 (354–513)	19	72 (40–105)
35–64 years	60	201 (150–252)	52	175 (127–222)	30	101 (65–137)	37	124 (84–164)	7	23 (6–41)
≥65 years	3	39 (0–83)	41	535 (371–698)	1	13 (0–39)	0	0 (0–0)	4	52 (1–103)
Total	196	233 (201–266)	262	312 (274–350)	196	233 (201–266)	161	192 (162–221)	41	49 (34–64)
Standardised*	..	236 (205–271)	..	320 (283–361)	..	242 (210–278)	..	194 (166–227)	..	50 (37–67)
Girls and women										
0–4 years	3	46 (6–99)	58	897 (666–1128)	4	62 (1–122)	0	0 (0–0)	1	15 (0–46)
5–14 years	11	86 (35–137)	36	281 (189–373)	19	149 (82–215)	8	63 (19–106)	5	39 (5–73)
15–34 years	37	134 (91–177)	51	185 (134–235)	41	149 (103–194)	40	145 (100–190)	8	29 (9–49)
35–64 years	27	83 (52–114)	61	187 (140–234)	20	61 (35–88)	19	58 (32–85)	4	12 (0–24)
≥65 years	3	31 (0–65)	48	489 (350–627)	8	81 (25–138)	0	0 (0–0)	1	10 (0–30)
Total	81	91 (71–111)	254	285 (250–320)	92	103 (82–124)	67	75 (57–93)	19	21 (12–31)
Standardised*	..	92 (74–115)	..	290 (256–329)	..	106 (86–131)	..	77 (61–98)	..	22 (14–35)
Total										
0–4 years	9	69 (24–114)	129	987 (816–1157)	26	199 (122–275)	2	15 (0–36)	4	31 (1–61)
5–14 years	42	159 (111–207)	80	303 (237–370)	65	246 (186–306)	16	61 (31–90)	13	49 (22–76)
15–34 years	133	247 (205–289)	105	195 (158–232)	138	256 (213–299)	154	286 (241–331)	27	50 (31–69)
35–64 years	87	140 (110–169)	113	181 (148–215)	50	80 (58–102)	56	90 (66–113)	11	18 (7–28)
≥65 years	6	34 (7–62)	89	509 (403–615)	9	51 (18–85)	0	0 (0–0)	5	29 (4–54)
Total	277	160 (141–179)	516	298 (272–324)	288	166 (147–185)	228	132 (115–149)	60	35 (26–43)
Standardised*	..	163 (144–183)	..	305 (280–333)	..	174 (155–195)	..	134 (118–153)	..	36 (28–46)
Hamilton (urban)										
0–4 years	5	52 (6–98)	98	1025 (822–1228)	21	220 (126–313)	2	21 (0–50)	2	21 (0–50)
5–14 years	28	150 (94–205)	64	342 (259–426)	46	246 (175–317)	14	75 (36–114)	8	43 (13–72)
15–34 years	86	198 (156–240)	84	194 (152–235)	105	242 (196–289)	124	286 (236–336)	23	53 (31–75)
35–64 years	62	139 (105–174)	70	157 (120–194)	33	74 (49–99)	43	97 (68–125)	5	11 (1–21)
≥65 years	6	46 (9–83)	69	527 (403–651)	7	53 (14–93)	0	0 (0–0)	3	23 (0–49)
Total	187	145 (124–165)	385	298 (268–328)	212	164 (142–186)	183	142 (121–162)	41	32 (22–41)
Standardised*	..	145 (125–167)	..	308 (279–341)	..	169 (148–194)	..	139 (120–161)	..	32 (24–44)
Waikato (rural)										
0–4 years	4	114 (2–226)	31	883 (572–1194)	5	142 (18–267)	0	0 (0–0)	2	57 (0–136)
5–14 years	14	182 (87–277)	16	208 (106–310)	19	247 (136–358)	2	26 (0–62)	5	65 (8–122)
15–34 years	47	446 (318–573)	21	199 (114–284)	33	313 (206–420)	30	284 (183–386)	4	38 (1–75)
35–64 years	25	140 (85–195)	43	242 (169–314)	17	95 (50–141)	13	73 (33–113)	6	34 (7–61)
≥65 years	0	0 (0–0)	20	455 (255–654)	2	45 (0–109)	0	0 (0–0)	2	45 (0–109)
Total	90	205 (162–247)	131	298 (247–349)	76	173 (134–212)	45	102 (72–132)	19	43 (24–63)
Standardised*	..	232 (188–287)	..	296 (249–353)	..	192 (152–241)	..	121 (89–162)	..	44 (28–69)

*Standardised to the WHO World Standard Population.[39]

Table 5: **Incidence of traumatic brain injury by cause, age, sex, and residency**

Remaining suspected cases (ie, cases for which the presence of TBI was not clear and needed to be verified) of TBI were cross checked with hospital discharge lists, hospital inpatient management records, lists of excluded cases (ie, TBI criteria not met, individuals who did not live in the study area at the time of injury), and lists from other sources (ie, schools, sports groups, rest homes). Once identified from a source, full medical records relating to the injury were obtained and patients were contacted by telephone, mail, or in person if possible for further details about the injury. Each diagnosis of TBI (including potential TBI) was verified by the Study Operations Group (at weekly meetings held in Auckland, with participation of the Waikato team via teleconference) and cases requiring clarification of criteria were additionally reviewed by the study Diagnostic Adjudication Group. Doctors dealing with any TBI cases were contacted by telephone for missing information. Figure 1 gives an overview of the case ascertainment procedures. One large hospital (about 600 beds) provided comprehensive acute, including neurosurgical, and rehabilitation care for all patients with TBI in the region. 43 family physician practices, two Accident and Medical Clinics, and 30 physicians and other clinicians in outpatient physiotherapy clinics provided care for patients with TBI in the study region at the time of the study. The study was approved by the Northern Y Regional Ethics Committee of New Zealand.

Statistical analysis

We calculated the crude annual incidence (all first new events) of TBI per 100 000 population with 95% CI using the Poisson distribution. Age and sex structures of the New Zealand population census data for 2006 for Hamilton city (urban residents) and Waikato District (rural residents) were used as denominators.[32] We used direct standardisation to age-standardise the rates to the world population.[38] Prioritised ethnic origin, with mixed ethnicity being allocated with the prioritisation system in accordance with the 2006 New Zealand census, was used to obtain a single ethnicity, and participants were grouped as Europeans, Maori, or other. The latter was a heterogeneous category that was aggregated because of small numbers of individuals with TBI in each of the remaining ethnic groups. We calculated age-specific, sex-specific, residency-specific (urban-Hamilton or rural-Waikato), and ethnic-specific incidence for TBI overall and by TBI severity (mild and moderate to severe) and causes of TBI. We combined the moderate and severe categories because of the small number of patients in these groups. We calculated rate ratios (RRs) to compare the age-standardised rates between sex, ethnicity, and residency (urban, rural) groups. Differences in participant characteristics and causes of TBI by TBI severity were assessed by χ^2 test (for categorical variables) or *t* test (for continuous variables). A level of $p<0\cdot05$ was considered statistically significant.

Role of the funding source

The sponsor of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Of the 1369 individuals with TBI, most were boys and men, individuals younger than 35 years (69% [943]), urban residents (74% [1008]), and of European ethnicity (61% [837], table 1). Most patients had mild TBI (95% [1298]). Moderate and severe TBI were most common in individuals older than 15 years (90% [64 of 71]); mild TBI was most prevalent in individuals aged 15–34 years (40% [523 of 1298]). A substantial proportion of patients with TBI (36% [487 of 1369]) did not present to hospitals at the acute stage of TBI (most having mild TBI), with many identified through non-hospital sources (table 1), including Accident and Medical Clinics (11% [54 of 487]), ACC and other databases (15% [73 of 487]), and self-referrals (1% [5 of 487]). Of patients with TBI who were admitted to hospital, 92% (811 of 882) had their GCS recorded on admission. GCS scores were available for 13% (14 of 108) of individuals who presented at their family doctor and for 13% (51 of 379) of patients who presented at a location other than a hospital or family doctor.

The overall incidence of TBI was 790 per 100 000 person-years (age-standardised rate 811 per 100 000 person-years), and the risk of sustaining mild TBI was more than 18 times greater than the risk for moderate to severe TBI (table 2). TBI was most common in two age groups: 0–4 years and 15–34 years (table 2). The incidence of moderate to severe TBI in people aged

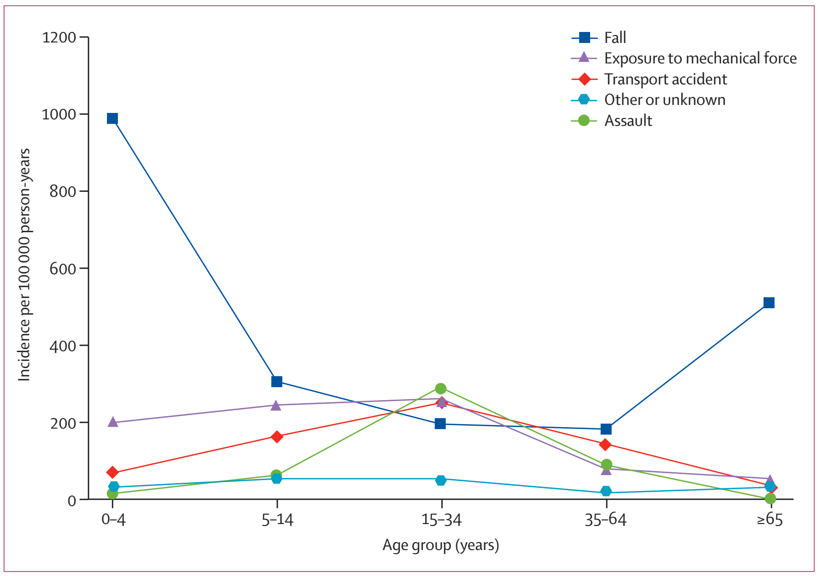

Figure 2: Age-specific incidence of traumatic brain injury by cause of injury

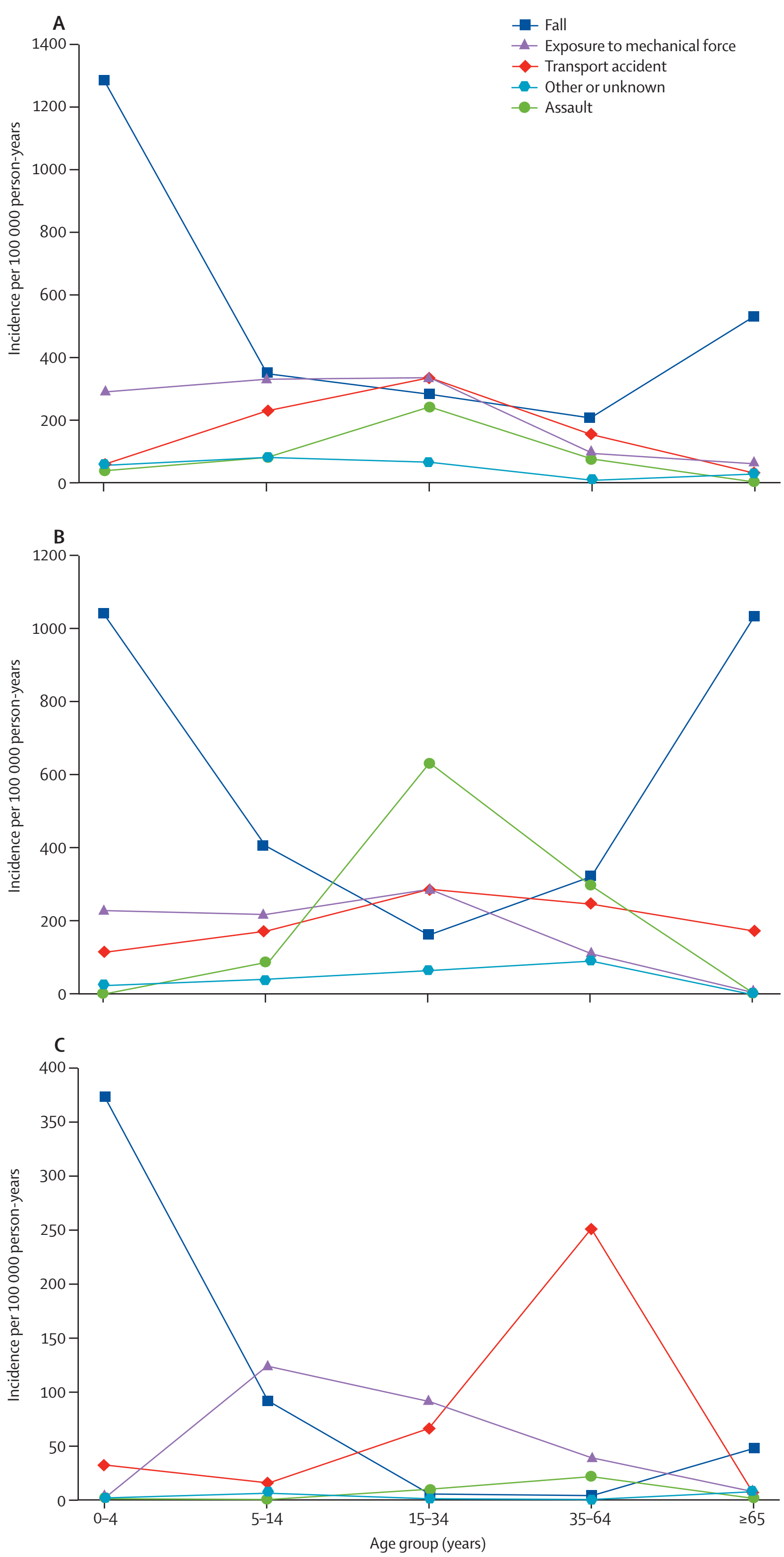

Figure 3: **Age-specific incidence of traumatic brain injury in European (A), Maori (B), and other ethnic origin (C) populations, by cause of injury**

15–34 years and in those aged 65 years or older was greater than it was in those aged 5–14 years, but the incidence of mild TBI was significantly greater in children aged 0–4 years than it was in all other age groups (table 2). The incidence of TBI in boys and men compared with that for girls and women was almost two times greater for mild TBI (RR 1·73, 95% CI 1·54–1·93) and total TBI (1·77, 1·58–1·97), and was almost three times greater for moderate to severe TBI (2·87, 1·70–4·85).

The total incidence of TBI was significantly higher in Maori people than it was in all other ethnic groups (table 3). This difference was largely attributable to higher TBI incidence in Maori people older than 35 years than in individuals of the same age in other ethnic groups (table 3). Compared with Europeans, Maori people had a greater risk of mild TBI (RR 1·23, 1·08–1·39).

Although we recorded no statistically significant difference in the risk of sustaining a TBI in general (mild, moderate to severe, or in total) between rural (Waikato District) and urban (Hamilton city) populations (table 4), rural residents had more than twice the risk of sustaining a moderate to severe TBI than did urban residents. We recorded no statistically significant urban-rural differences between Maori and Europeans (ie, between urban and rural Maories, and urban and rural Europeans); however, people of other ethnicities (eg, Asian, Pacific Islander) residing in the urban area were at significantly higher risk of TBI of any severity than those of European or Maori origin residing in the rural area.

Falls, exposure to mechanical forces, transport accidents, and assaults were the most common causes of TBI (table 1, table 5). Falls were the main cause of TBI in adults older than 65 years (82% [89 of 109]) and young children (76% [129 of 170]), whereas exposure to mechanical forces was the most common cause in children aged 5–14 years (30% [65 of 216]) and adolescents and young adults (48% [43 of 154]; figure 2). Transport accidents accounted for most TBI cases in people aged 15–64 (25% [220 of 874]). Male children and adolescents and young adults had a greater risk of TBI due to transport accidents and exposure to mechanical forces than did girls and women of the same age groups (table 5). Male adolescents and young adults had a higher risk of TBI due to assaults than did girls and women in the same age groups (table 5).

TBI due to assaults was more common in adolescents and young adults of Maori ethnicity than in those of European descent (incidence per 100 000 person-years 632, 95% CI 492–772 in Maori people; 243, 184–303 in Europeans) and in adults aged 35–64 years (294, 183–404 in Maori people; 70, 43–97 in Europeans), with Maori at three-to-four times greater risk than Europeans (figure 3). Young adult (aged 15–34 years) rural residents had more than twice the risk of TBI due to transport accidents than their urban counterparts (table 5). We recorded no other statistically significant differences by sex, ethnicity, or residency in the risk of TBI due to different mechanisms of injury (table 5).

Discussion

To our knowledge, this study is the first large population-based study to investigate TBI incidence across the spectrum of severity in all age groups in a geographical region with urban and rural populations. The most important finding of our study was that the incidence of TBI per 100 000 people per year (790 cases), especially mild TBI (749 cases), in New Zealand was substantially greater than in other high-income countries in Europe (47–453 cases)[29,39,40] and North America (51–618 cases).[3,10,11,15] A WHO systematic review of mild TBI epidemiology[15] showed an annual incidence of mild TBI in the range of 100–300 cases per 100 000 population. However, because mild TBI is usually not treated at hospitals, the true population-based incidence of mild TBI was estimated to be more than 600 cases per 100 000 per year.[15] To our knowledge, our population-based study is the first to substantiate this estimation, and to show that 95% of all TBI cases are mild and that the true incidence of mild TBI, in New Zealand at least, is almost 750 cases per 100 000 people per year. In 2011, a slightly lower TBI incidence (558 per 100 000 person-years) was estimated for Olmsted County (MN, USA) by use of a population-based medical record review system.[11] However, this study was retrospective and based on a random sampling of 16% of the population, which was predominantly white. Although potentially distinct contextual characteristics could affect TBI incidence in different countries,[3,11,41] the high TBI incidence in New Zealand recorded in the present study compared with available estimates from other high-income countries is most likely explained by our case ascertainment method (multiple overlapping sources of information) used on a population level. Much of the discrepancy between estimates is accounted for by the fact that we included people with mild TBIs who were not admitted to hospital—such cases are often overlooked in hospital-based studies.[23]

Although no one geographical area is representative of all others, and although our sample frame is from a high-income rather than a low-income or middle-income country, we believe that our results are comparable with those from other high-income settings because the study area was representative of New Zealand as a whole. New Zealand has a wide range of disparity in health access and outcomes across different sectors of the population. Additionally, the catchment area included urban and rural locations. Extrapolation of our estimates to the world population suggest that every year 54–60 million people have a TBI, of whom some 2·2–3·6 million people sustain moderate or severe TBI. Although these worldwide estimates are almost six times higher than previous estimates,[3] they are still likely to be conservative, because TBI incidence in low-income to middle-income countries is thought to be far greater than it is in high-income countries.[3,41]

The other important findings from our study were the greater than expected proportion of TBI in children and younger adults (<35 years old)—almost 70% of all TBI cases as opposed to the 40–60% reported elsewhere[42,43]—and the greater proportion of TBI due to falls (38%) and assaults (17%) compared with the 13–28% and 11–14%, respectively, reported elsewhere.[1,42,43] The peaks of TBI incidence rates in people aged 5–14 years and 15–34 years shown in our study are in line with most other studies of TBI incidence[3] although, unlike previous studies, we did not find a substantial peak of TBI in adults aged 35 years or older. Falls more often caused TBI in children, whereas transport accidents and assaults were more common causes of TBI in young adults. A similar age pattern of TBI causes was reported elsewhere.[1,3,23,41,44] Consistent with some previous observations,[3,44] we detected a greater risk of moderate to severe TBI in the rural population than in the urban population. Our results indicate that this difference is driven largely by the higher incidence rate of TBI due to transport accidents in the rural population, compared with the urban population. Our findings that most people with

Panel 1: Research in context

Systematic review

We searched Medline with the terms "traumatic brain injury", "epidemiology", "incidence", "ethnic/racial", and "population or community based" for population-based studies of traumatic brain injury (TBI). We analysed English-language articles published from 1960 to 2012. Reported traumatic brain injury (TBI) incidence rates in high-income countries varied from 47 per 100 000 to 618 per 100 000 person-years,[10,11,15,39–40,42] largely due to variations in diagnostic criteria and methods of case ascertainment in these studies. However, most of the studies were not population-based and largely confined to hospitalised TBI patients and there was a wide recognition of challenges in obtaining accurate estimates of the burden of TBI in a population.[13–16,28,30,40,45] A recent systematic review of mild TBI epidemiology[15] showed that the annual incidence of mild TBI is in the range of 100–600 per 100 000 population. Most studies showed that mild TBI is the most common type of TBI by severity,[2,11,15] male predominance in the TBI population,[2,11,18,23,31,41,46,47] three peaks of TBI incidence rates (early childhood and adolescents, early adulthood, and older adulthood),[3,11,48] with falls and transport accidenta as the leading causes of TBI,[1,23,41,44,49] greater risk of moderate to severe TBI in rural populations,[3,44] and ethnic disparities in the risk of TBI.[23–26,44]

Interpretation

To our knowledge, this study is the first large population-based study to assess the incidence of TBI across all age groups and in rural and urban populations.

TBI have mild TBI, that TBI occurs more often in boys and men than it does in women and girls, that falls are the major TBI cause in young children and people aged 65 years or older, and that moderate or severe TBI is most common in adolescents and older adults are in accordance with findings from previous studies of the epidemiology of TBI (panel 1).[1,11,15,23,29]

Our study confirms previous findings of substantial racial and ethnic disparities in the risk of TBI,[3,23–26] with Maori people sustaining TBI more often than people of European origin. Although the data for the ethnic category listed as other had a lower risk of TBI compared with Maori and European populations, the group was too heterogeneous to make any conclusions about ethnic-specific differences in TBI risk within this group. The reasons for higher incidence of TBI in Maori people compared with Europeans are not clear. Maori people aged 15–64 years old had a greater incidence of assault-related TBI incidence than did New Zealanders of European origin, which suggests increased exposure to interpersonal violence in this population (a high prevalence of interpersonal assaults in young adults has been reported in New Zealand in Maoris).[50] Future analysis of TBI risk by specific traffic-related and fall-related causes, including comorbidities, car safety restraints, and exposure to illicit drugs and alcohol, would provide further insight into the ethnic disparities in the risk of TBI detected in this study. The greater risk of TBI in men than in women is consistent with findings from previous studies[1,3,42,43,51] and might be indicative of differences between sexes in levels of risk-taking activities, exposure to occupational hazards and violence-related injuries.[3] Our age-specific and residency-specific data for TBI incidence overall and by cause of injury should be borne in mind when planning prevention and TBI-care services (eg, estimation of the number of hospital beds and types of services needed for acute TBI events in rural and urban populations). Clinicians dealing with patients with TBI should be aware of ethnic and sex disparities in TBI incidence when considering management and preventive strategies for such patients.

Our study had several strengths: the population-based design with case ascertainment at community level, the large size of the sample, allowing reliable subgroup analyses, the standard criteria to allow international comparisons, and the comprehensiveness (TBI ascertainment of data across all age groups, TBI severities, and ethnic origins, and inclusion of urban and rural populations). Study limitations included the small number of moderate and severe TBI cases, which precluded detailed analyses of these injuries as separate categories. Although our recording of TBI events over only 1 year is a potential limitation of the study, we believe it did not substantially affect our results because the population covered by the study was large (more than 170 000 residents), thus minimising random error. Because we did not include the term mental alteration in the operational criteria of TBI, this study might also have underestimated the true incidence of TBI. Furthermore, a small number of TBIs for ethnic groups other than Europeans and

Panel 2: Suggested criteria for population-based studies of traumatic brain injury incidence and outcomes (modified from Barker-Collo and Feigin)[30]

Standard definitions

Core criteria

- WHO criteria for TBI diagnosis[33]
- American Centres for Disease Control and Prevention and WHO criteria[19,33] for mild TBI
- First-ever and recurrent TBI defined
- TBI severity classified as mild (GCS score of 13–15), moderate (GCS of 9–12), and severe (GCS of 3–8)[34]
- NINDS Common Data Elements as harmonised, international standards for TBI clinical data collection[52]

Supplementary criteria

- First-ever and recurrent TBI presented separately
- TBI severity classification by GCS supplemented by duration of PTA determined from medical records or relevant PTA scale questionnaire[35] as mild (GCS 13–15 and PTA <24 h), moderate (GCS of 9–12 and PTA 1–6 days), and severe (GCS of 3–8 and PTA ≥7 days)

Standard methods

Core criteria

- Complete population-based case ascertainment from multiple overlapping sources of information (hospitals, outpatient clinics, general practitioners, and death certificates)
- Prospective study design
- Large, well defined and stable population study, allowing at least 100 000 person-years of data collection
- Follow-up of patients' vital status (ie, clinical outcomes) for at least 1 month
- Reliable method for estimation of denominator for frequencies (ie, census data from within the previous 5 years)
- Causes of TBI classified according to the ICD-10 classification system

Supplementary criteria

- Both so-called hot and cold pursuit of cases; cross-checking with national and official databases for completeness of case ascertainment
- Direct assessment of under-ascertainment by regular checking of general practitioners' databases and hospital admissions for acute trauma and CT or MRI investigations
- Follow-up of patients' vital and functional status for at least a year
- Data for TBI epidemiology reported by residence (urban, rural, total) and ethnic origin
- Collect record of treatment and rehabilitation services and resources in the study area at the time of the study

Standard data presentation

Core criteria

- Complete calendar year of data
- Data from both sexes presented separately
- Data presented according to mid-decade age bands (eg, 0–14 years, 15–24 years, 25–34 years, 35–64 years, ≥65 years)
- Incidence rates should be provided with 95% CI

Supplementary criteria

- 5-year age groups available for comparison with other studies

GCS=Glasgow coma scale. NINDS=National Institute of Neurological Disorders and Stroke. PTA=post-traumatic amnesia. TBI=traumatic brain injury.

Maori (such as Pasifika, Chinese, South Asians, etc) precluded reliable analyses of TBI incidence rates in these ethnic groups. We also acknowledge the challenge of using GCS for TBI classification for patients with TBI who did not have it recorded in their medical records, and the possible diagnostic bias of measuring GCS in patients with TBI who are, for example, under the influence of alcohol or recreational drugs, or who are unable to understand the spoken language. For those cases retrieved retrospectively from the search of national health databases (eg, ACC), there is an additional limitation because for these cases there might be a greater proportion of missing data, and potential introduction of information bias. However, we included few such cases (12% [159 of 1369]) and thus the effect of these factors on our study is likely to be small.

Finally, our study showed that a population-based study of TBI is feasible. Despite the huge and growing burden of TBI worldwide,[6,7,15] good quality, comparable population-based studies of TBI incidence and outcomes are scarce. The urgent need for such studies[6,7,27,28,34] and research guidelines to standardise epidemiological studies and reporting parameters[30] have been repeatedly emphasised.[3] On the basis of our experience with the BIONIC study, we propose that our previously suggested core and supplementary criteria for an ideal population-based TBI incidence study[30] be updated and used in future research (panel 2). Further similar population-based studies of TBI incidence, causes, and outcomes in other populations are urgently needed to establish reliable surveillance systems for the monitoring and evaluation of intervention strategies and to inform evidence-based health-care planning and effective treatment, prevention, and rehabilitation strategies.[1,3,11,15]

Contributors

VLF designed the study, obtained funding, assessed diagnosis of TBI events, participated in supervision of the study, planned analyses of the data, and wrote the first draft of the paper. AT, KJ, and AJ supervised the day-to-day running of the study, and contributed to discussions. SB-C, AT, KM, RK, AB, VP, AD, PB, NS, and MK participated in the design of the study and gaining of funding. VP was responsible for doing analyses and contributed to discussions. All authors contributed to the critical revision of the paper for important intellectual content.

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Conflicts of interest

We declare that we have no conflicts of interest.

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