



Book Review

The association of helmet use with the risk of death for occupants of motorcycles involved in traffic crashes: A meta-analysis.

1. Introduction

Road traffic injuries cause considerable economic losses to individuals, their families, and to nations as a whole. These losses arise from the cost of treatment as well as lost productivity for those killed or disabled by their injuries, and for family members who need to take time off work or school to care for the injured. In many countries, the use of two-wheeled motor vehicles has increased rapidly, and the casualty rate of users has also increased (Kim et al., 2015). Relative to four-wheeled vehicles, motorcycles pose a greater threat of death or serious injury to drivers and passengers. Per vehicle mile traveled in 1994, motorcycles were 11 times more likely than passenger cars to be involved in fatal collisions (Nunn, 2011). By 2007, motorcycles were 27.5 times as likely to be part of a fatal collision. Almost half of all deaths on the world's roads are among those with the least protection – motorcyclists, cyclists and pedestrians (Fatality Analysis Reporting System (FARS), 2019; Nunn, 2011)

Given the high trauma rate associated with motorcycle-related crashes, any effort to reduce the number and severity of these collisions is an important duty for us. However, motorcycle accidents are caused by various complicated reasons (Törő et al., 2005). The mechanism of injury resulting in death usually comes from severe blunt force trauma, creating internal and external damage to the motorcyclist, especially head, neck, thoracic, and other axial-skeletal injuries (Lemieux et al., 2008; Ndiaye et al., 2009). It is generally believed that proper wearing of the helmet during driving of the motorcycle is beneficial to the safety of driver and passenger. Motorcycle helmets are accepted as an effective strategy for reducing the incidence of motorcycle deaths and therefore the cost of motorcycle crashes. For instance, the meta-analysis of Liu et al. (2004) showed helmets were estimated to reduce the odds of head injury of head injury by 69% (OR = 0.31, 95% CI: 0.25 to 0.38). A meta-analysis by Kim et al. (2015) demonstrated that motorcycle helmet use reduced morbidity and contributes to significant health care cost savings (Kim et al., 2015).

However, according to information provided by World Health Organization (WHO) (2019), only 44 countries, representing 1.2 billion people, have helmet laws that: apply to all drivers and passengers, all roads and engine types, require the helmet to be fastened, and make reference to a particular helmet standard. This could be because the helmet effectiveness was not certain and data on helmet law effectiveness are inconclusive. To date, many relevant studies have been published but there has been no meta-analysis of the relationship be-

tween motorcycle helmet use and mortality. In addition, in some case-control studies, it seems that there was still controversy about the protective effect of helmets on motorcycle occupants' mortality (Ramli et al., 2014; Siddiqui et al., 2016; Hothem et al., 2017; Lee et al., 2017). Therefore, we performed a meta-analysis to estimate whether helmet wearing would have an impact on motorcycle occupant mortality. Subgroup analysis was used to assess differences of helmet protection between countries, occupant seats (driver or passenger), methods and duration of studies. A comprehensive literature search was completed in English and Chinese databases. The synthesis of these findings would be helpful to improve the statistical power of the results and provided more evidence for relevant decisions.

2. Materials and methods

2.1. Identification and selection of studies

The review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher et al., 2009). Data were collected from all eligible scholarly scientific studies of motorcycle helmets in relation to mortality.

For electronic searches, a comprehensive search strategy was used to find eligible studies for this meta-analysis. The PubMed, ScienceDirect database, Springer Link, Web of Science, CBM (China Biomedical Database), CNKI (China National Knowledge Infrastructure), and VIP (Chinese) databases were searched. All selected studies were published before September 2018. The PubMed search strategy was (Motorcycle OR Scooter OR auticycle OR autobike OR motor vehicle) AND (helmet OR helm OR head protective devices OR protective devices) AND (mortality OR death OR fatal injury).

Applicable Chinese technical terms are used when searching Chinese databases. Lastly, we retrieved and searched the references of every relevant article and review for additional eligible studies.

2.2. Inclusion and exclusion criteria

The inclusion criteria were as follows: (1) Studies comparing helmet groups and control groups were considered. This included any cross-sectional analyses, case-control studies, cohort or retrospective cohort studies and On-scene investigations; (2) motorcycle occupants of all types who have been involved in any type of crash; and (3) articles providing data of occupants using helmets and control groups or an odds ratio (OR) with a 95% confidence interval (CI). If the same population was considered in multiple publications, only the most recent was included. The exclusion criteria were: 1) Did not include motorcycle occupant death; 2) the data were incomplete and could not be obtained from the authors; 3) studies with duplicate data published in a later paper; 4) studies neither in English nor Chinese.

2.3. Data extraction

Two authors examined the titles and abstracts obtained through the search strategy and identified potentially eligible studies. A more inclusive strategy was employed at this stage. The full text of all potentially eligible articles was obtained. Study authors were contacted for clarification if necessary. Full text articles were independently examined by two authors for eligibility, based on inclusion criteria. Duplicate studies were excluded. Any disagreements were resolved by discussion. Two reviewers (Mingming Liang and Yun Zhang) independently screened the studies and extracted data onto predesigned forms according to the Cochrane Handbook. The following standard information was extracted from each eligible study: surname of first author, year of publication, country, total sample size, source of controls, seat of the occupant and the number of helmets worn in cases and controls.

2.4. Study quality assessment

The Newcastle–Ottawa Scale (NOS) used to evaluate the quality of each article: study ratings of seven to nine stars indicated high quality, five to six stars indicated moderate quality, and four stars or fewer indicated low quality (Wells et al., 2014). Three members of the review team completed assessments independently, and any disagreements were resolved by discussion.

2.5. Statistical analysis

The association between helmet and motorcycle occupant death was assessed with ORs and 95% CIs. *P* values < 0.05 were considered statistically significant. Heterogeneity across studies was assessed with the *I*² statistic, which can show the variation between studies with a percentage. Heterogeneities of 25%, 50%, and 75% were considered as low-, moderate-, and high-level heterogeneity, respectively (Higgins et al., 2003). If the study lacked heterogeneity, we used the fixed-effects model to calculate the pooled OR estimate, and the random-effects model otherwise (Ades et al., 2005).

Subgroup analyses by country, method, duration and occupant’s seat were performed to address heterogeneity. Publication bias was evaluated by Egger’s test and a visual inspection of the funnel plot. The significance cut-off value was set at a *P* value of less than 0.05. If bias existed, the ‘Trim and Fill’ method was used to adjust the publication bias (Duval and Tweedie, 2000). Additionally, sensitivity analysis (omitting each study and rerunning the meta-analysis) was performed to test the influence of every study on the pooled estimate. All statistical calculations were performed using Stata (version 14.0; Stata Corporation, College Station, Texas, USA).

3. Results

3.1. Characteristics of eligible studies

Fig. 1 summarized the process for selecting eligible studies. After

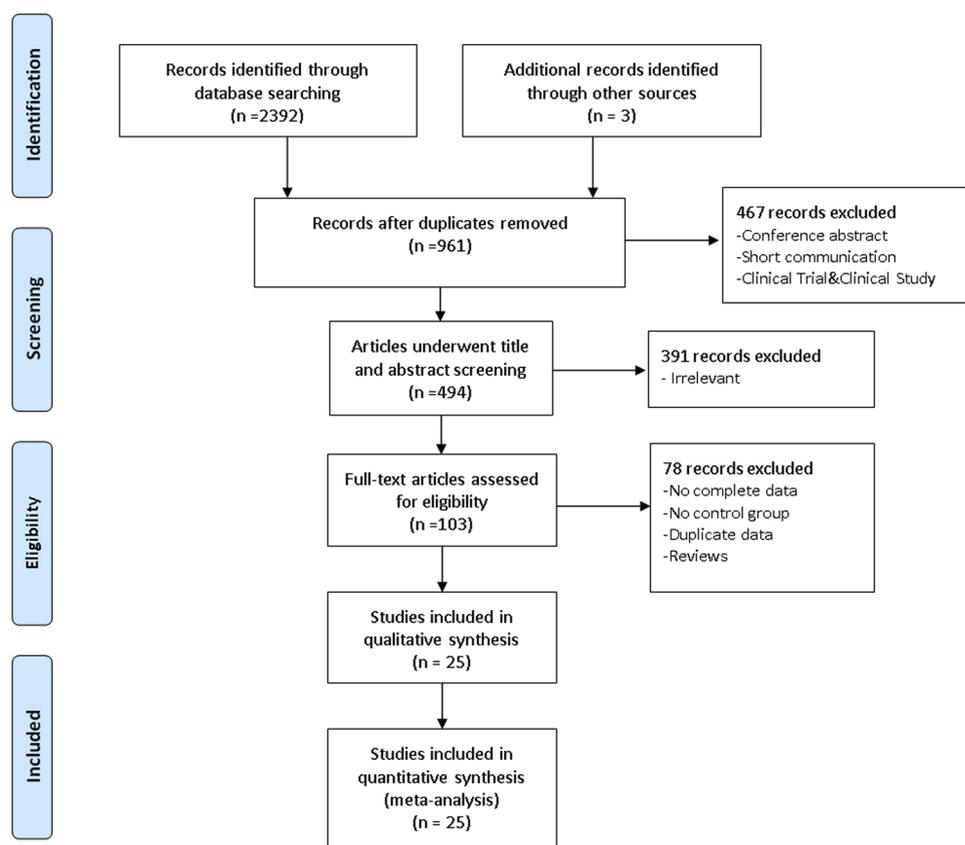


Fig. 1. Flow diagram of the study selection process.

Table 1
Characteristics of articles included in this meta-analysis.

Study	Country	Method	Source	Total	Helmet use	Fatal	Not helmet	Fatal	NOS*
Kim et al., 2018 (High-speed group)	Korea	Cross-sectional analysis	Emergency medical services	185	42	8	143	33	7
Kim et al., 2018 (Low-speed group)	Korea	Cross-sectional analysis	Emergency medical services	310	63	9	247	33	7
Kuo et al., 2017	China	Case-control study	Trauma Registry System	8598	7735	83	863	36	7
Khor et al., 2017	USA	Case-control study	National Trauma Data Bank	270525	155877	3825	114648	4479	6
Hsieh et al., 2017 (Male group)	China	Case-control study	Trauma Registry System	3930	3379	41	551	22	6
Hsieh et al., 2017 (Female group)	China	Case-control study	Trauma Registry System	2870	2595	15	275	8	6
Rice et al., 2016	USA	On-scene investigation	Direct observation	882	352	12	530	40	8
Wiznia et al., 2016	USA	Cohort study	Hospital	986	335	14	651	49	5
Hothem et al., 2017 (OR = 0.5 95%CI:0.3-1.1)	USA	Case-control study	Trauma database	–	3	0	194	34	7
Siddiqui et al., 2016 (Female group)	India	Case-control study	Trauma Center	269	108	5	161	21	7
Siddiqui et al., 2016 (Male group)	India	Case-control study	Trauma Center	2868	2714	50	154	6	7
Lee et al., 2017	China	Cross-sectional analysis	Registration database	–	–	–	–	–	–
Burns et al., 2015 (OR = 2.28,95%CI:1.13-4.58)	USA	Case-control study	Trauma center database	–	–	–	–	–	–
Ramil et al., 2014	Malaysia	Cross-sectional analysis	Police files & hospitals	702	654	125	48	5	8
Gupta et al., 2014	India	Case-control study	Hospital trauma registry	2718	1323	52	1395	98	8
Donate-López et al., 2010 (Drivers group)	Spain	Cohort study	Traffic crash registry	48016	38775	706	9241	401	7
Donate-López et al., 2010 (Passengers group)	Spain	Cohort study	Traffic crash registry	48016	36241	523	11775	409	7
Fizharris et al., 2009	India	Case-control study	Hospital	378	74	6	304	36	6
Crompton et al., 2010	USA	Case-control study	National Trauma Databank	44847	34829	1219	10018	621	9
Eastridge et al., 2006 (Prehospital group)	USA	Case-control study	General Estimates System (GES) database	5328	3474	135	1854	162	7
Eastridge et al., 2006 (Hospital group)	USA	Case-control study	General Estimates System (GES) database	9033	6119	264	2914	205	7
Ouellet and Kasantikul, 2006 (USA group)	USA&Thailand	On-scene investigation	National Trauma Data Bank	1724	862	7	862	33	6
Ouellet and Kasantikul, 2006 (Thai group)	USA&Thailand	On-scene investigation	Accident scene	1870	935	9	935	52	6
Hundley et al., 2004 (NO-Alcohol/Drug Use group)	USA	Case-control study	National Trauma Data Bank	9769	6756	287	3013	213	8
Hundley et al., 2004 (Alcohol/Drug Use group)	USA	Case-control study	National Trauma Data Bank	2277	1318	58	959	63	8
Ichikawa et al., 2003 (OR = 0.65 95%CI:0.31-1.35)	Thailand	Case-control study	Khon Kaen Regional Hospital	–	–	–	–	–	–
Kasantikul et al., 2003	Thailand	On-scene investigation	Accident scene	1305	482	9	823	44	7
Brandt et al., 2002	USA	Case-control study	Accident scene	216	174	7	42	2	8
Norvell and Cummings, 2002 (OR = 0.61 95%CI:0.54-0.70)	USA	Cohort study	Fatality Analysis Reporting System data	–	–	–	–	–	–
Petridou et al., 1998 (Drivers group)	Greece	Case-control study	The Statistical Department of the Hellenic Road Traffic Police records	6942	1021	36	5921	254	7
Petridou et al., 1998 (Drivers group)	Greece	Case-control study	The Statistical Department of the Hellenic Road Traffic Police records	8886	1367	37	7519	385	7
Petridou et al., 1998 (Passengers group)	Greece	Case-control study	The Statistical Department of the Hellenic Road Traffic Police records	1954	165	2	1789	65	7
Petridou et al., 1998 (Passengers group)	Greece	Case-control study	The Statistical Department of the Hellenic Road Traffic Police records	1907	143	3	1764	58	7
Braddock et al., 1992	USA	On-scene investigation	Death certificates, hospital discharge data, and police accident reports	2000	1000	8	1000	27	8
Heilman et al., 1982 (1977–1978 group)	USA	Case-control study	Certificate of Death	682	372	4	310	11	5
Heilman et al., 1982 (1978–1988 group)	USA	Case-control study	Certificate of Death	705	321	2	384	7	5

NOS, Newcastle-Ottawa scale score.

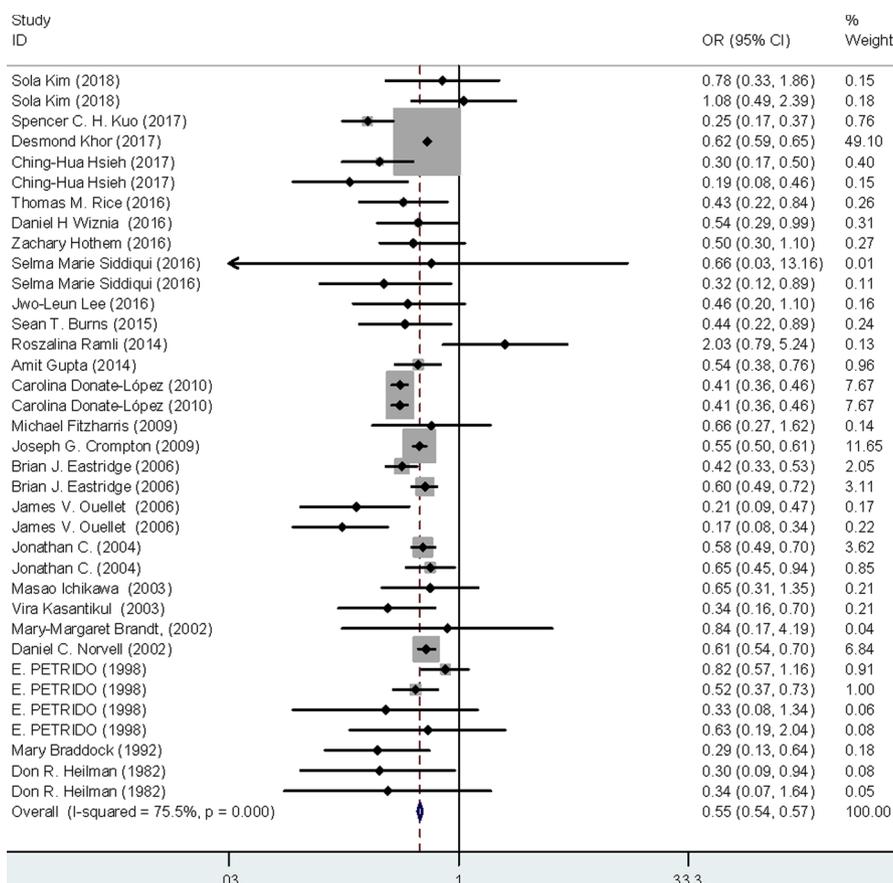


Fig. 2. Forest plot on helmet wearing and mortality risk. CI, confidence interval.

searching and subsequent screening, 25 articles were included (Heilman et al., 1982; Braddock et al., 1992; Petridou et al., 1998; Brandt et al., 2002; Norvell and Cummings, 2002; Ichikawa et al., 2003; Kasantikul et al., 2003; Hundley et al., 2004; Eastridge et al., 2006; Ouellet and Kasantikul, 2006; Fitzharris et al., 2009; Crompton et al., 2010; Donate-López et al., 2010; Gupta et al., 2014; Ramli et al., 2014; Burns et al., 2015; Rice et al., 2016; Siddiqui et al., 2016; Wiznia et al., 2016; Hothem et al., 2017; Hsieh et al., 2017; Khor et al., 2017; Kuo et al., 2017; Lee et al., 2017; Kim et al., 2018). As shown in Table 1, the NOS scores for all articles were between five and nine stars. These studies were published between 1982 and 2018. With regard to study location, 13 studies were conducted in the USA, other studies were conducted in China, South Korea, India, Spain, Thailand, Greece and Malaysia. Only Ouellet and Kasantikul (2006) included two countries, the United States and Thailand.

Of these, 15 studies used case-control methods, 3 were cross-sectional analysis, 4 were on-scene investigation, and 3 were retrospective cohort studies. There are several different groups in Kim et al. (2018) and other 8 studies, and we extracted the relevant data separately for the meta-analysis.

3.2. Quantitative synthesis and subgroup analyses

In general, death was more common among motorcycle occupants who were not wearing helmets. The correlation between motorcycle

occupants' mortality and helmet wearing was significant: the pooled OR was 0.55 (95% CI 0.54–0.57) using the random-effect model, $I^2 = 75.5%$ (Fig. 2). To explore the study heterogeneity, we performed subgroup analyses across a number of key study characteristics (Table 2). The subgroup analyses were conducted based on stratification by different countries, occupant's seats(driver or passenger), methods and duration. The finding of protective effect on the mortality of the motorcyclists was consistently found in all of the subgroup analyses. The geographical characteristics seem to markedly influence the results. In the study conducted in the United States, the protection of the helmet was slightly lower compared with the overall, the OR was 0.59 (95% CI: 0.57-0.62, $I^2 = 44.7%$). In China, the effect of the helmet might be most protective, the OR was 0.27 (95% CI: 0.21-0.36, $I^2 = 0%$) (Fig. 3).

According to the subgroup analysis of occupant's seat group, the protection from of the passengers helmet (OR = 0.41, 95% CI: 0.36-0.46, $I^2 = 0%$) might be more than the protection of the drivers (OR = 0.49, 95% CI: 0.46-0.52, $I^2 = 77.9%$). In the passengers and drivers group, the pool OR was 0.61 (95% CI: 0.59-0.64, $I^2 = 48.9%$) and the pool OR was 0.60 (95% CI = 0.43-0.84, $I^2 = 0%$) in the group that did not describe the seats of occupants (Fig. 4).

In a subgroup analysis of different methods, the OR of the cross-section group was 0.91 (95% CI: 0.59–1.40, $I^2 = 45.7%$), the case-control group OR was 0.59 (95% CI: 0.57-0.61, $I^2 = 59.7%$), the on-scene group OR was 0.28 (95% CI: 0.20-0.39, $I^2 = 3.4%$) and the cohort

Table 2
Characteristics of articles subgroups.

Study	Location	Method	Period	Occupant
Kim et al., 2018 (High-speed group)	Korea	Cross-sectional analysis	2013-2014	NA
Kim et al., 2018 (Low-speed group)	Korea	Cross-sectional analysis	2013-2014	NA
Kuo et al., 2017	Southern Taiwan	Case-control study	2009-2015	Drivers
Khor et al., 2017	USA	Case-control study	2007-2014	Drivers and passengers
Hsieh et al., 2017 (Male group)	South Taiwan	Case-control study	2009-2013	Drivers and passengers
Hsieh et al., 2017 (Female group)	South Taiwan	Case-control study	2009-2013	Drivers and passengers
Rice et al., 2016	Los Angeles	On-scene investigation	1976-1978	Drivers
Wiznia et al., 2016	City of New Haven	Cohort study	2002-2013	NA
Hothem et al., 2017 (OR = 0.5 95%CI:0.3-1,1)	Michigan	Case-control study	2010-2014	Drivers and passengers
Siddiqui et al., 2016 (Female group)	New Delhi	Case-control study	2009-2011	Passengers
Siddiqui et al., 2016 (Male group)	New Delhi	Case-control study	2009-2011	Passengers
Lee et al., 2017	Taiwan	Cross-sectional analysis	2005-2008	NA
Burns et al., 2015 OR = 2.28,95%CI:1.13-4.58).	Texas	Case-control study	1999-2008	NA
Ramli et al., 2014	Klang Valley	Cross-sectional analysis	2010-2011	Drivers and passengers
Gupta et al., 2014	India	Case-control study	2011-2012	Drivers and passengers
Donate-López et al., 2010 (Drivers group)	Spain	Cohort study	1993-2007	Drivers
Donate-López et al., 2010 (Passengers group)	Spain	Cohort study	1993-2007	Passengers
Fitzharris et al., 2009	Hyderabad	Case-control study	2005-2006	Drivers and passengers
Crompton et al., 2010	USA	Case-control study	2002-2006	Drivers
Eastridge et al., 2006 (Prehospital group)	USA	Case-control study	1994-2002	Drivers
Eastridge et al., 2006 (Hospital group)	USA	Case-control study	1994-2002	Drivers
Ouellet and Kasantikul, 2006 (USA group)	Los Angeles	On-scene investigation	NA	Drivers
Ouellet and Kasantikul, 2006 (Thai group)	Thailand	On-scene investigation	NA	Drivers
Hundley et al., 2004 (NO-Alcohol/Drug Use group)	USA	Case-control study	1994-2002	Drivers and passengers
Hundley et al., 2004 (Alcohol/Drug Use group)	USA	Case-control study	1994-2002	Drivers and passengers
Ichikawa et al., 2003 (OR = 0.65 95%CI:0.31-1.35)	Khon Kaen	Case-control study	1994-1997	Drivers
Kasantikul et al., 2003	Six different regions within Thailand	On-scene investigation	NA	Drivers
Brandt et al., 2002	Michigan	Case-control study	1996-2000	Drivers and passengers
Norvell and Cummings, 2002 (OR = 0.61 95%CI:0.54-0.70)	USA	Cohort study	1980-1998	Drivers and passengers
Petridou et al., 1998 (Drivers group)	Greece	Case-control study	1985-1986	Drivers
Petridou et al., 1998 (Drivers group)	Greece	Case-control study	1994-1995	Drivers
Petridou et al., 1998 (Pillion group)	Greece	Case-control study	1985-1986	Passengers
Petridou et al., 1998 (Pillion group)	Greece	Case-control study	1994-1995	Passengers
Braddock et al., 1992	Connecticut	On-scene investigation	1985-1987	Drivers
Heilman et al., 1982 (1977-1978 group)	North Dakota	Case-control study	1977-1978	Drivers and passengers
Heilman et al., 1982 (1978-1988 group)	North Dakota	Case-control study	1978-1988	Drivers and passengers

NA, not available.

study group OR was 0.46 (95% CI: 0.43-0.50, $I^2 = 88.1\%$) (Fig. 5).

There were no significant differences between different study duration. When the duration of the study was more than 5 years, the pool OR of the group was 0.56 (95% CI: 0.54-0.57, $I^2 = 89.2\%$), otherwise OR was 0.53 (95% CI: 0.49-0.58, $I^2 = 51.5\%$) (Fig. 6).

3.3. Sensitivity analysis and publication bias

We conducted a sensitivity analysis to assess the effect of omitting individual studies on the pooled values. The results indicated that data from each individual study had no influence on pooled OR values. This indicated the meta-analysis was generally robust.

Egger's test and Begg's funnel plot were firstly used to evaluate whether publication bias was existing. The results of Egger's test suggest that there might be publication bias ($p = 0.050$) (Fig. 7), although there was no publication bias in the Begg's test results ($\alpha = 0.04$; $p = 0.978$). Because of this, we undertook a sensitivity analysis using the trim and fill method (Duval and Tweedie, 2000). The trim and fill algorithm was based on a formalization of the qualitative approach using the funnel plot. Simply put, we trim off the asymmetric outlying part of the funnel after estimating how many studies are in the asymmetric part, estimate the true center of the funnel and then replace the

trimmed studies and their missing counterparts around the center. The final estimate of the true mean, and also its variance, are then based on the filled funnel plot. According to the Trim and Fill method, there were no potential studies (unpublished or missed by language limitation) estimated to be missing (Fig. 8).

4. Discussion

Motorcycles, which are an alternative mode of transportation for motor transport, are still one of the most important modes of transportation in many countries and regions. To estimate whether helmet wearing has an impact on motorcycle occupants' mortality, increase the statistical power of the results, and provide more evidence for relevant decisions, we conducted a meta-analysis of all 25 available articles. Meta-analysis is thought to be an important tool for more precisely defining the impact of risk. The strict screening and rigorous analyses ensured that our meta-analysis estimation of helmet use outcome is valid. Results of this meta-analysis indicated that there was an obvious association of helmets with decreased risk of motorcycle occupant mortality. The overall risk of death for motorcycle occupants wearing helmets was reduced by 45%. These associations are biologically plausible because the helmets are usually constructed of a layer of

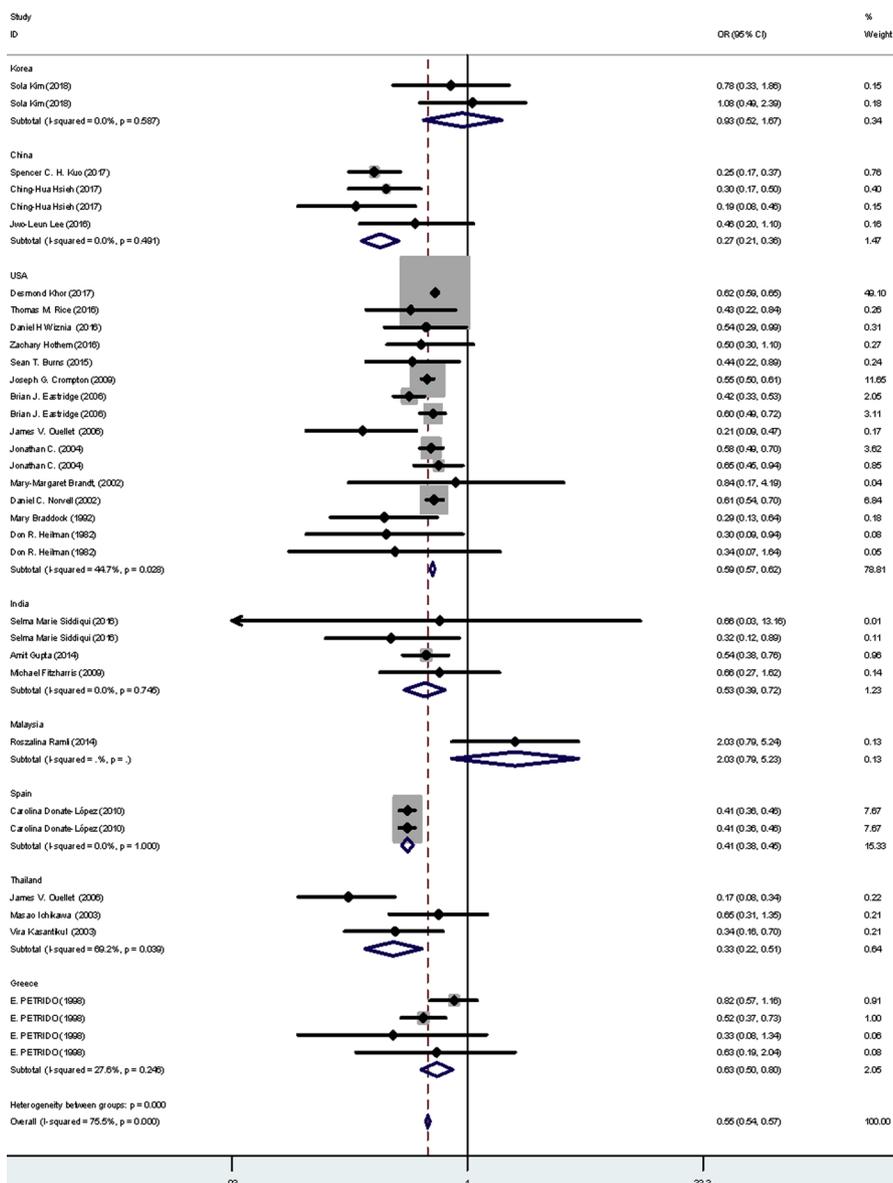


Fig. 3. Forest plot on study countries of mortality risk. CI, confidence interval.

expanded polystyrene covered with a thin shell of plastic or similar material, and is designed to absorb and redistribute energy from impacts to the head, thereby preventing head and brain injury during traffic collisions (Rice et al., 2017).

To the best of our knowledge, there were already some other meta-analyses that explore the effects of helmets. Olivier and Creighton (2016) have determined that bicycle helmets reduce fatal injuries (OR = 0.35, 95% CI: 0.14-0.88). However, no clear evidence of an association between bicycle helmet use and neck injury was found. Compared to our study, wearing a bicycle helmet seems to be more effective in reducing mortality. It might be because motorcycle and bicycle crashes involve different speeds and vehicle masses which could affect the protective capacity of the helmets considerably. Kim et al. (2015) conducted a meta-analysis of the economic impact of helmet use

on motorcycle accidents. They found that the use of motorcycle helmets could reduce accident mortality and contributes to significant health care cost savings. In addition, Liu et al. (2004) combined 16 articles to give an overall unadjusted estimate of helmet effectiveness. They estimated that helmets could reduce the risk of motorcycle driver death by 42% (OR = 0.58, 95% CI 0.50-0.68) from four higher quality studies, and not enough evidence was found to estimate the effect of motorcycle helmets compared with no helmet on facial or neck injuries. This meta-analysis estimated that helmets could reduce the driver mortality risk by 51%. The difference might exist because there were some differences in the inclusion criteria between the two studies. More recently published articles have been included in our study, and we prefer the article about the mortality of motorcycle occupants (including drivers and passengers). Liu et al. (2004) were more concerned about the

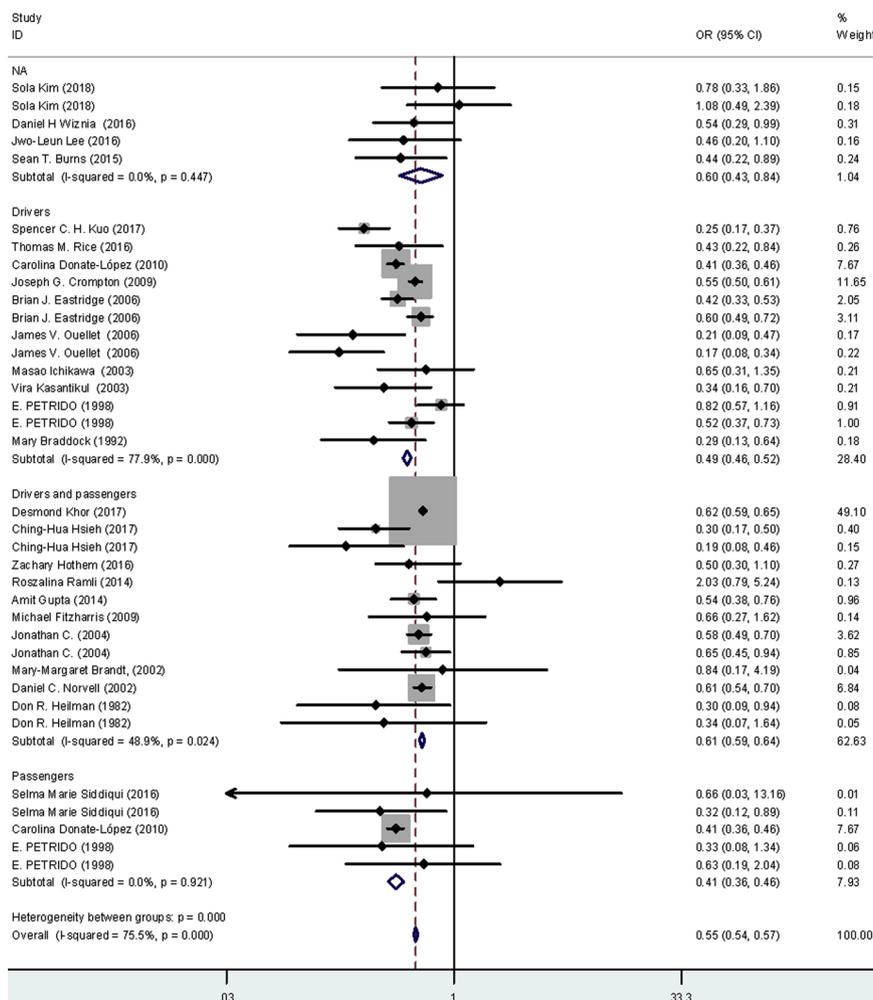


Fig. 4. Forest plot on different motorcycle occupants. CI, confidence interval.

relationship between motorcycle riders and various types of head and neck injuries.

As shown in the results of this meta-analysis, the helmet could better protect the lives of passengers than the drivers. Although the reason is not particularly clear, it might be related to different risk of death in motorcycle crash between passengers and drivers (Peng et al., 2017). It has been reported that the fatality risk in the driver seat exceeds that in the passenger seat by 26% (Evans and Frick, 1988). According to the results of Manan and Várhelyi (2012), motorcycle riders account for a high proportion of deaths and serious injuries, with motorcycle rider fatalities being three times higher compared to passenger fatalities.

Different countries have different social and traffic conditions, so wearing helmets also showed different protective effects. The meta-analysis showed that helmets reduced mortality by 41% in the United States. It is more effective than the previous estimates of helmet effectiveness by the National Highway Traffic Safety Administration (NHTSA). NHTSA have estimated that helmets reduce fatalities by 29% (Evans and Frick, 1988), a figure later revised to 34% (Deutermann, 2004). Despite the benefits of helmet use, the United States has gained renewed support for the abolition of universal mandatory helmet laws in the past 2 decades. Currently, only 19 states and the District of

Columbia enforce universal mandatory helmet laws (Insurance Institute for Highway Safety (IIHS), 2019). The argument for repeal included that helmet use should be a personal choice instead of state policy, helmet effectiveness is not certain, and data on helmet law effectiveness are inconclusive (Peng et al., 2017). However, repeals have contributed to substantial losses, much of which was preventable (Blincoe et al., 2015). In 2013, an estimated 1,630 lives were saved by motorcycle helmets in the US, and an additional 715 lives could have been saved if all motorcyclists were wearing helmets (National Highway Traffic Safety Administration, 2015). Michigan has evaluated this law change. The repeal resulted in decreased helmet use, increased fatalities and fatalities per crash, and increased medical care costs to the state (Highway Loss Data Institute, 2013).

In addition, we also found that the protection effect of helmets in China is the most effective. This might be related to the local motorcycle driver preferring to wear a modern helmet (Yu and Wang, 2009). Modern helmets consist of a thicker layer of polystyrene covered with a thin shell of plastic or similar material. Softer foam material is added to improve fit and comfort and to reduce noise, and to provide anchoring points for the helmet strap, wind visor, or other accessories. The protection effect was better than the novel helmet (Rice et al., 2017).

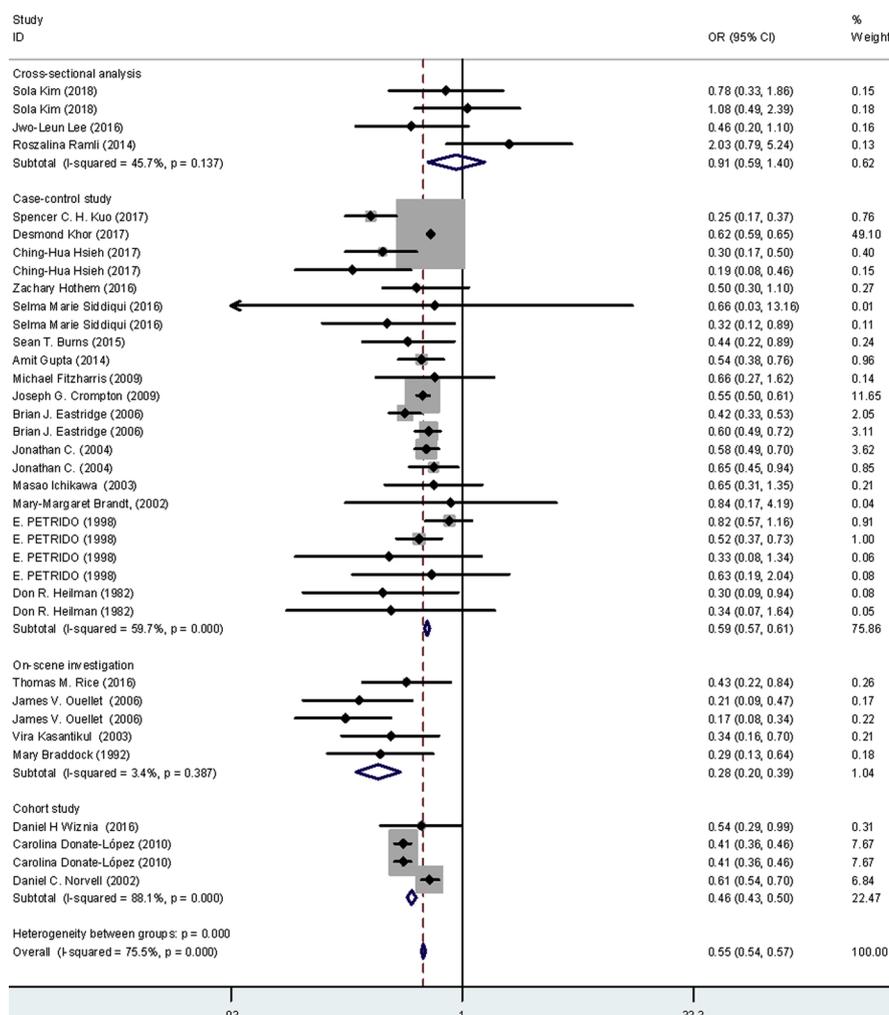


Fig. 5. Forest plot on study methods of mortality risk. CI, confidence interval.

There are also some differences in the protection of motorcycle helmets in other regions. By reviewing the included studies, we speculated that is because of different study design, as well as different traffic conditions, meteorological factors, helmet types, and other factors. In spite of these differences, the close correspondence of the helmet and injury data reflect the effectiveness of a wide range of very basic helmets and suggest that little has changed in helmet performance and human response to impact over those years.

Most of the studies included in this review were case-control studies, which made the case-control subgroup results more similar to the overall results. The protection of the helmet in the on-scene investigation result was most effective. This might be related to problem that most on-scene investigations lacked information about the motorcyclist survival in the hospital after the crash.

Although this is the first meta-analysis encompassing a large sample size of the motorcycle occupants' mortality, the limitations should be acknowledged. Firstly, this meta-analysis is to estimate whether helmet wearing has an impact on motorcycle occupants' mortality, but many studies did not separate the driver from the passengers. Some studies reported the death rate of the motorcycle wearing a helmet, but did not

describe the seat of the occupant. This did not affect the interpretation of the overall results. Secondly, we only screened majority studies in English and Chinese, the publications in other languages were not included. A more comprehensive analysis based on more languages would make the results more credible and further reduce the publication bias. Thirdly, we were unable to assess some potential factors, such as helmet type and occupant information. Different helmets might also relate to different traffic accident outcomes, but the included studies did not provide sufficient helmet information for subgroup analysis. The characteristics of occupant might also be a confounding factor. In fact, the occupant's gender, age, and cultural background have not been studied in most articles. Further studies that take these factors into account are required to clarify whether there is an association between these characteristics of the occupants and motorcycle mortality.

5. Conclusions

In conclusion, our findings supported the relationship between lower risk of motorcycle mortality and helmet use. Further high-quality research is needed to address the question of whether different types of

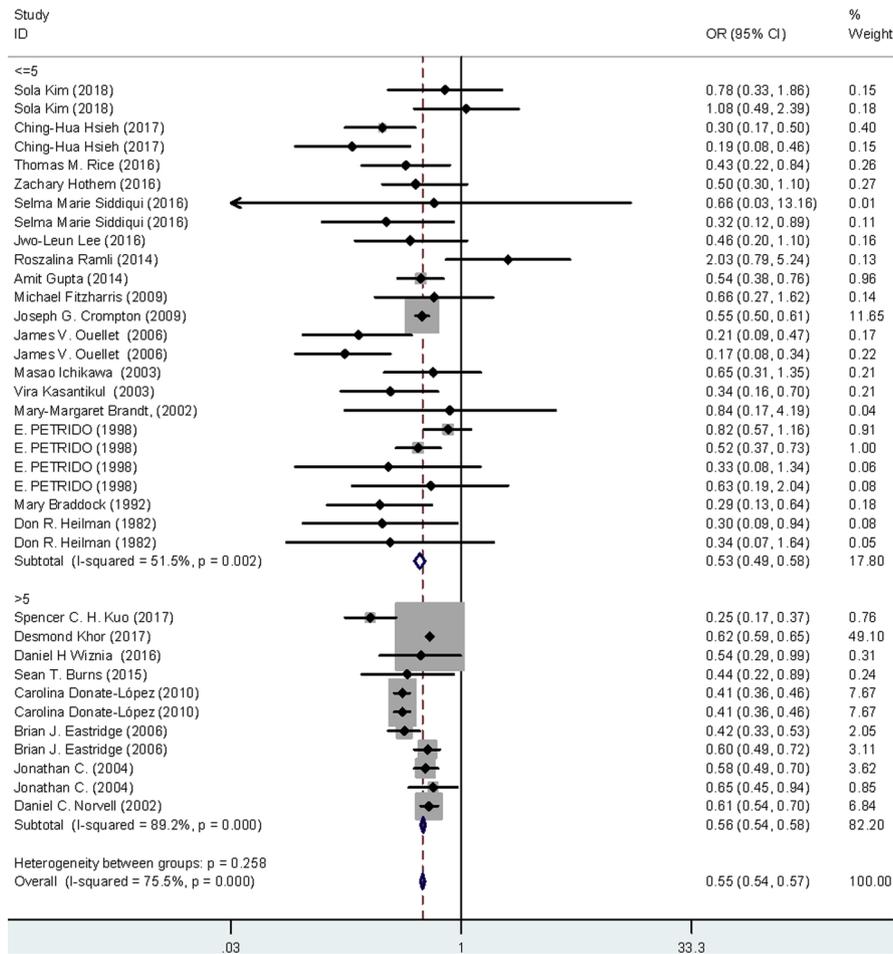


Fig. 6. Forest plot on study duration of mortality risk. CI, confidence interval.

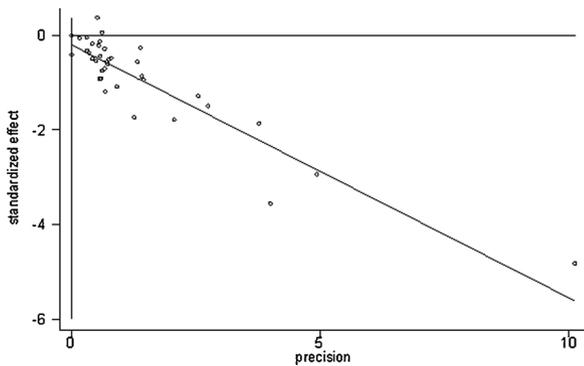


Fig. 7. Egger's funnel plot.

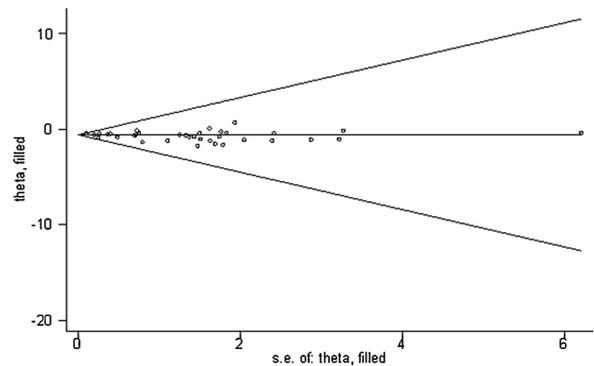


Fig. 8. Filled funnel plot with pseudo 95% confidence limits.

motorcycle helmets will affect the impact of motorcycle occupant death risk. But there is no doubt that the law on mandatory wearing of helmets should be strengthened and intensive education of relevant motorcycle occupants should continue.

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