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FACTORS AFFECTING CHANGES IN ROAD TRAFFIC COLLISION RELATED INJURIES AND DEATHS OVER TIME: THE GLOBAL AND THE UNITED ARAB EMIRATES PERSPECTIVES

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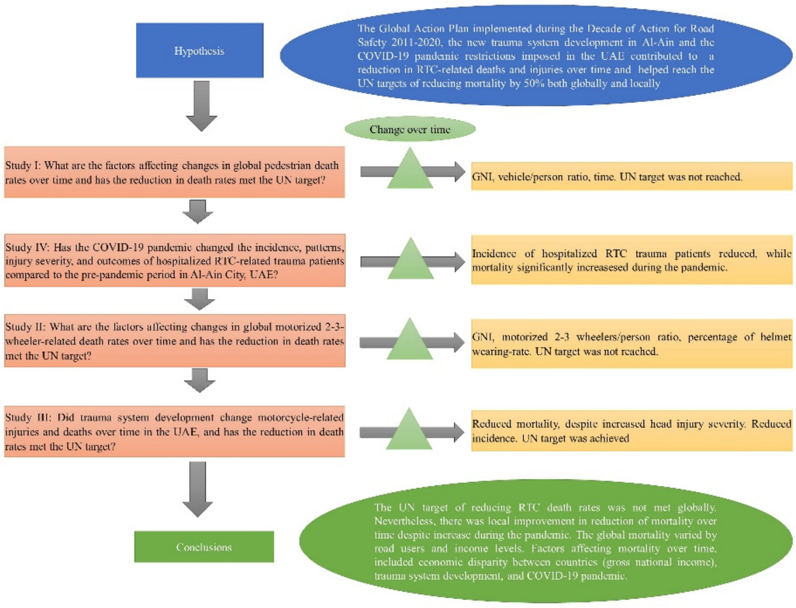

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Yasin Jemal Yasin

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Declaration of Original Work

I, Yasin Jemal Yasin, the undersigned, a graduate student at the United Arab Emirates University (UAEU), and the author of this dissertation entitled "*Factors Affecting Changes in Road Traffic Collision Related Injuries and Deaths Over Time: the Global and the United Arab Emirates Perspectives*", hereby, solemnly declare that this dissertation is my own original research work that has been done and prepared by me under the supervision of Professor Michal Grivna, in the College of Medicine and Health Sciences at UAEU. This work has not previously formed the basis for the award of any academic degree, diploma or a similar title at this or any other university. Any materials borrowed from other sources (whether published or unpublished) and relied upon or included in my dissertation have been properly cited and acknowledged in accordance with appropriate academic conventions. I further declare that there is no potential conflict of interest with respect to the research, data collection, authorship, presentation and/or publication of this dissertation.

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Abstract

Road traffic collisions (RTCs) cause 1.35 million deaths per year worldwide. Approximately 50% of these deaths were among pedestrians and motorized 2-3-wheeler users. In the United Arab Emirates (UAE), RTC deaths were higher compared to other high-income countries (HICs). The United Nations (UN) Decade of Action for road safety 2011-2020, aimed to reduce road traffic deaths by 50% by the year 2020. The aim of this dissertation was to investigate factors affecting changes in RTC-related injuries and deaths over time at global and UAE levels. Multiple research methods were used to investigate the research questions. Global data on pedestrian and motorized 2-3-wheeler users were retrieved from World Health Organization (WHO) Global Status Reports on Road Safety (GSRRS), published from 2009 to 2018. The primary data on the impact of the COVID-19 pandemic on RTCs for the UAE and the data on the impact of trauma system development on motorcycle-related deaths were obtained from the trauma registries of the two major hospitals in Al-Ain: Al-Ain and Tawam hospitals. A mixed linear model and univariate and multivariate regression analysis were performed. Global pedestrian mortality decreased by 28% over the 10-year period of the study. Factors that reduced pedestrian death rates included time, gross national income (GNI), and vehicle/person ratio. There was a significant drop over time in both HICs and middle-income countries (MICs), but not in low-income countries (LICs). In contrast, the global mean motorized 2-3-wheeler-related death rates increased from 2.37/100,000 population to 3.23/100,000 population during the same period (a relative ratio of 1.36) which was not statistically significant. Factors that affected motorized 2-3-wheeler-related mortality included GNI, motorized 2-3-wheelers/person ratio, helmet wearing rate, and the interaction between vehicle/person ratio and motorized 2-3-wheelers/person ratio. A significant increase in motorized 2-3-wheeler-related death rates was observed over time in LICs and MICs, compared to a significant decrease in the rate in HICs. The incidence of hospitalized RTC trauma patients was significantly reduced by 33.5% during the COVID-19 pandemic. Nevertheless, mortality from RTCs increased significantly during the pandemic. The factors that predicted mortality were low Glasgow Coma Scale (GCS), admission to the Intensive Care Unit (ICU), and high Injury Severity Score (ISS). The COVID-19 pandemic had a strong tendency for increases in mortality due to RTC. The trauma system development in Al-Ain has reduced the incidence of motorcycle injuries by 37% over 15 years. It has significantly decreased mortality in Al-Ain. This study is the first attempt to identify potential factors and conditions – including previously unknown ones (such as the COVID-19 pandemic) that change RTC-related injuries and deaths at the global and UAE levels over time, mainly during the Decade of Action for Road Safety 2011-2020. Our findings can serve as a baseline for future evaluations of RTCs and for improvements in road traffic-related injury prevention and intervention strategies during both normal and pandemic periods. The economic disparities between countries, the maturity of the trauma system, and the COVID-19 pandemic restriction measures, along with the obtained results are consistent to give a clearer picture in understanding the difference in RTC-related deaths and injuries locally and globally over time, both during normal times and pandemic periods.

Keywords: Global, Pedestrian, 2–3-wheelers, Motorcycle, COVID-19, Death, Trauma, Road traffic collision, United Arab Emirates, UAE.

Title and Abstract (in Arabic)

العوامل المؤثرة في التغيرات في الإصابات والوفيات الناجمة عن حوادث الطرق عبر الزمن: من المنظور العالمي والإماراتي

الملخص

تتسبب حوادث الطرق (RTCs) في حوالى 1.35 مليون حالة وفاة سنويا في جميع أنحاء العالم. وما يقارب ال 50٪ من هذه الوفيات تحدث بين المشاة وسائقي المركبات ذات العجلتين أو الثلاث. أما في الإمارات العربية المتحدة، فقد كان معدل وفيات حوادث الطرق أعلى مقارنة بالبلدان الأخرى ذات الدخل المرتفع (HICs). وكان عقد الأمم المتحدة (UN)للعمل من أجل السلامة على الطرق (2011-2020)، يهدف إلى تقليل الوفيات الناجمة عن حوادث المرور على الطرق بنسبة 50٪ بحلول العام 2020. إن الهدف من هذه الدراسة هو التحقيق في العوامل التي تؤثر على التغيرات في الإصابات والوفيات المرتبطة بحوادث المرور(RTC) مع مرور الوقت، وذلك على المستويين العالمي والإماراتي. تم استخدام طرق بحث متعددة للتحقيق في أسئلة البحث. تم استرجاع البيانات العالمية عن مستخدمي المشاة والمركبات ذات العجلات 2-3 من التقارير العالمية لمنظمة الصحة العالمية بشأن السلامة على الطرق (GSRRS)، والتي نُشرت في الفترة من 2009 إلى 2018. البيانات الأولية عن تأثير وباء أنفلونزا الكورونا COVID-19 على حوادث الطرق في دولة الإمارات العربية المتحدة، والبيانات المتعلقة بتأثير تطوير نظام تسجيل الإصابات الرضية على معدل الوفيات المرتبطة بالدراجات النارية، تم الحصول عليها من سجلات الإصابات الرضية في مستشفيين رئيسيين في العين: مستشفى العين ومستشفى توام. تم دراسة تحليل الانحدار باستخدام نموذج خطي مختلط مع تحليل الانحدار أحادي المتغير ومتعدد المتغيرات. انخفض معدل وفيات المشاة عالميا بنسبة 28٪ خلال فترة الدراسة البالغة 10 سنوات. وشملت العوامل التي ساهمت في خفض معدلات وفيات المشاة: الوقت، والدخل القومي الإجمالي(GNI) ، ونسبة المركبات / عدد السكان. كان هناك انخفاض كبير بمرور الوقت في كل من البلدان مرتفعة الدخل والبلدان متوسطة الدخل(MICs) ، ولكن ليس في البلدان منخفضة الدخل (LICs). وفي المقابل، ارتفع المعدل العالمي للوفيات المرتبطة بالمحركات ذات العجلتين أو الثلاث من 2.37 / 100،000 نسمة إلى 3.23 / 100،000 نسمة خلال نفس الفترة (بنسبة 1.36) والتي لم ترقي الى دلالة إحصائية. العوامل التي أثرت على معدل الوفيات ذات الصلة بالمحركات ذات العجلتين أو الثلاث شملت الدخل القومي الإجمالي، ونسبة المركبات الآلية ذات العجلتين أو الثلاث لكل شخص، ومعدل ارتداء الخوذة، والتفاعل بين نسبة السيارة / عدد السكان ونسبة المركبات الآلية ذات العجلتين أو الثلاث إلى عدد السكان. ولوحظت زيادة كبيرة في معدل الوفيات المرتبطة بالمحركات ذات العجلتين أو الثلاث بمرور الوقت في البلدان منخفضة الدخل والبلدان المتوسطة الدخل، مقارنةً بانخفاض كبير في نفس المعدل في البلدان المرتفعة الدخل. انخفض معدل حدوث الإصابات لدى ضحايا الإصابات الرضية في المستشفى بشكل كبير بنسبة 33.5 ٪ خلال جائحة كرونا COVID-19، ومع ذلك، ازداد معدل الوفيات في حوادث المروربشكل ملحوظ أثناء الجائحة. كانت العوامل التي تنبأت بالوفيات هي انخفاض مقياس غلاسكو للغيبوبة (GCS) ، وسرعة القبول في وحدة العناية المركزة (ICU) وارتفاع درجة خطورة الإصابة (ISS). وكان لوباء COVID-19 تأثير قوي على سرعة دخول المستشفى وزيادة

الوفيات بسبب حوادث الطرق. وقد أدى تطوير نظام تسجيل الإصابات الرضية في العين إلى تقليل حدوث إصابات الدراجات النارية بنسبة 37 ٪ على مدار 15 عامًا. فقد أدى إلى انخفاض كبير في معدل الوفيات في العين. هذه الدراسة هي المحاولة الأولى لتحديد العوامل والظروف المحتملة - بما في ذلك غير المعروفة سابقًا ، مثل وباء COVID-19 التي تغير الإصابات والوفيات المرتبطة بحوادث الطرق على المستويين العالمي والإماراتي بمرور الوقت، خاصة خلال عقد العمل من أجل السلامة على الطرق 2011-2020. وقد تكون النتائج التي توصلنا إليها بمثابة الأساس للتقييمات المستقبلية للوفيات الناجمة عن حوادث الطرق ولتحسين استراتيجيات الوقاية من الإصابات المتعلقة بالطرق وبرامج السلامة المرورية خلال الأوقات العادية وأوقات الوبائيات. الفوارق الاقتصادية بين البلدان، واعتماد نظام تسجيل الإصابات الرضية، وتدابير الحد من جائحة كرونا COVID-19، إلى جانب النتائج التي تم الحصول عليها، متسقة لإعطاء صورة أوضح في فهم الاختلاف في الوفيات والإصابات المرتبطة بحوادث الطرق محليًا وعالميًا بمرور الوقت، سواء خلال الأوقات العادية وأوقات الوبائيات.

مفاهيم البحث الرئيسية: عالمية، مشاة، 2–3 عجلات، دراجة نارية، COVID-19، وفاة، صدمة، تصادم مروري على الطرق، الإمارات العربية المتحدة.

List of Publications

This dissertation is based on the work presented in the following papers:

I. Yasin YJ, Grivna M, Abu-Zidan FM. Reduction of pedestrian death rates: a missed global target. World J Emerg Surg. 2020 May 19; 15:35. Available from: https://doi.org/10.1186/s13017-020-00315-2.

II. Yasin YJ, Alao DO, Grivna M, Abu-Zidan FM. Impact of the COVID-19 pandemic on road traffic collision injury patterns and severity in Al-Ain City, United Arab Emirates. World J Emerg Surg. 2021 Nov 19; 16:57. Available from: https://doi.org/10.1186/s13017-021-00401-z.

III. Yasin YJ, Grivna M, Abu-Zidan FM. Motorized 2-3-wheelers death rates over a decade: a global study. World J Emerg Surg. 2022 Jan 26; 17:7. Available from: https://doi.org/10.1186/s13017-022-00412-4.

IV. Yasin YJ, Eid HO, Aloa DO, Grivna M, Abu-Zidan FM. Reduction of motorcycle-related deaths over 15 years in developing country. World J Emerg Surg. 2022 Apr 29; 17:21. Available from: https://doi.org/10.1186/s13017-022-00426-y.

Author’s Contribution

The contribution of Yasin Jemal Yasin to the papers included in this dissertation was as follows:

I. Participated in planning of the work, had main responsibility in designing the study, data collection and processing, evaluation and interpretation of results, and manuscript writing.

II. Participated in planning of the work, had main responsibility for the study work, data collection and analysis, evaluation and interpretation of results, and manuscript writing.

III. Had the sole responsibility in planning the research, main responsibility in designing and conducting the study, data collection and analysis, evaluation and interpretation of results, and preparing the manuscript.

IV. Had the sole responsibility in planning the research, main responsibility in designing and conducting the study, data collection and analysis, evaluation and interpretation of results, and writing the manuscript.

Author Profile

Yasin Jemal Yasin is a faculty member at the School of Public Health, College of Health Sciences, Mekelle University, Ethiopia. He has more than 15 years of teaching and research experience in several public universities in Ethiopia. Yasin published 5 papers as a first author in the World Journal of Emergency Surgery, which is a top 3% journal (impact factor of 8.17) during his Ph.D. studies. All five papers were submitted for the first time to this journal, none was rejected, two were accepted without revision, and three were accepted after minor revision. Overall, he has published 15 articles in highly ranked international medical journals. He is also the winner of a Harvard Medical School – Dubai Harvard Foundation of Medical Research (DHFMR) Scholarship Award in 2020; a UAE University Ph.D. Scholarship Award in 2019; and a King Fahd University of Petroleum and Minerals (KFUPM) MSc Scholarship Award in 2013. Yasin lives in Al-Ain during his Ph.D. studies while his family lives in Stockholm, Sweden. He received his BSc in environmental health from Haramaya University (Ethiopia) in 2006, master's degree in public health (MPH) from Addis Ababa University (Ethiopia) in 2010, and MSc in Environmental Sciences from King Fahd University of Petroleum and Minerals (KFUPM) (Saudi Arabia) in 2016. He also received a Postgraduate Certificate in Clinical Research from Harvard Medical School, Harvard University (United States of America (USA)) in 2020.

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Dedication

To innocent victims of genocidal war in Tigray

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List of Abbreviations

AIS	Abbreviated Injury Scale
ASCOT	American College of Surgeons Committee on Trauma
ATLS	Advanced Trauma Life Support
CI	Confidence Interval
COVID-19	Coronavirus Disease 2019
DALY	Disability Adjusted-Life Year
EMS	Emergency Medical Services
EU	European Union
GCS	Glasgow Coma Scale
GDP	Gross Domestic Product
GNI	Gross National Income
GSRRS	Global Status Report on Road Safety
HIC	High-income Countries
ICU	Intensive Care Unit
IQR	Interquartile Range
ISS	Injury Severity Score
LIC	Low-income Countries
LMICs	Low-and Middle-income Countries
MDG	Millennium Development Goal
MHICs	Middle-and High-income Countries
MIC	Middle-income Countries
MLM	Mixed Linear Model
MTOS	Major Trauma Outcome Study
MVC	Motor Vehicle Collision

NISS	New Injury Severity Score
NTDB	National Trauma Data Bank
OECD	Organization for Economic Cooperation and Development
PCR	Polymerase Chain Reaction
POCUS	Point-of-Care Ultrasound
RR	Respiratory Rate
RTC	Road Traffic Collision
SBP	Systolic Blood Pressure
SD	Standard Deviation
SDG	Sustainable Development Goal
UAE	United Arab Emirates
UAEU	United Arab Emirates University
UK	United Kingdom
UN	United Nations
USA	United States of America
USD	United States Dollar
VRU	Vulnerable Road User
WHO	World Health Organization

Chapter 1: Introduction

1.1 Overview

The period 2011 – 2020 was proclaimed as the "Decade of Action for Road Safety", which aimed to reduce road traffic deaths by half by 2020 [1, 2]. During this period, the issue of road traffic safety received considerable attention the need for concerted global action in the contemporary injury prevention arena.

However, the effect of the Decade of Action in stabilizing road traffic deaths was neither uniform nor deterministic [3–7]. In particular, the RTC burden on global pedestrians and motorized 2-3-wheeler users is unacceptably high [6] and remains a public health issue [6, 8] despite concerted global action to improve road safety over the last decade [1, 2]. What caused or led to this situation? Focus on the disparity between the global plan and the evidence accumulated in the WHO GSRRS should shed light on this fundamental question [2, 6, 7, 9, 10].

Furthermore, the ambition of the Decade of Action to stabilize global road traffic-related deaths remains far from meeting the target of reducing traffic deaths by half in 2020 [3–6]. Thus, whether the Decade of Action alters pedestrian and motorized 2-3-wheeler user deaths over time is not known. There remains also the question of how much change there can be in pedestrian and motorized 2-3-wheeler user mortality over time. Lastly, the occurrence of the COVID-19 pandemic had a major impact. Who would have imagined the emergence of the COVID-19 pandemic in late December 2019 [11, 12], a phenomenon which is still not yet over, could be followed by the announcement of the Second Decade of Action for Road Safety 2021 – 2030 [13]? The effect of the COVID-19 pandemic preventive measures on RTC injury patterns, severity, management, hospitalization, and outcomes during the final year of the First Decade of Action 2011 – 2020, and during the beginning of the Second Decade of Action 2021 – 2030, needs to be studied.

Considering the above points, it is essential to understand the factors affecting changes in road traffic deaths and injuries over time. In addition, continuous monitoring is important to establish whether the UN action plan is progressing as envisaged [3, 14, 15] as the action plan has a clear target to reduce road deaths by 50% in 2020 [1, 2].

The WHO GSRRS [6, 7, 9, 10], and government reports [16] serve a vital role in monitoring the action plan. Nevertheless, they are not based on systematic evidence. Second, although previous studies from the Trauma Research Group at our university have examined the factors affecting changes in global pedestrian death rates [17] and motorized 2-3-wheeler-related death rates [18], these studies are relatively old and need updating and follow-up. Third, none of the WHO GSRRS evaluates the impact of post-trauma response/care. Fourth, there is a lack of studies that evaluate the effect of trauma system maturity on injury outcomes both globally and locally [19]. Fifth, the impact of the COVID-19 pandemic on RTC has been little studied both globally and locally [20].

Given the epidemiological gaps noted above, we used several criteria to define the research questions for our studies. First, resource constraints, such as budget, time, personnel. Second, relevance and impact. Third, availability of data and practicality. For example, it was difficult to obtain trauma registry data on hospitalized RTC trauma patients (i.e., by types of road user) at global levels to assess the effect of trauma system development on injury outcomes and to assess the impact of the COVID-19 pandemic on RTC globally. Fourth, road user mortality, which has seen a recent increase both globally and locally. The percentage of motorized 2-3-wheeler-related mortality is rising both globally and locally [6, 7]. Additionally, the number of motorized 2-3-wheeler-related mortality is predicted to increase by 11% worldwide in the coming 10 years [21]. Fifth, considering local research priorities and contributions. Selecting research projects that would fill the national knowledge gaps and that simultaneously answer research questions that are both novel and that are relevant both in a national and global context during the normal and pandemic periods. Such studies can help clarify the RTC problems, traffic safety management, and post-trauma response at local levels during both normal and pandemic periods, and would also facilitate the comparison of local findings with global findings.

Accordingly, these epidemiological gaps became incorporated in the development of the overarching research question: what are the factors affecting changes in RTC-related injuries and deaths at global and UAE levels over time, and has the reduction in death rates met the UN target? To approach this question, we designed four separate research questions to address the following gaps:

- What are the factors affecting changes in global pedestrian death rates over time and has the reduction in death rates met the UN target?
- What are the factors affecting changes in global motorized 2-3-wheeler-related death rates over time and has the reduction in death rates met the UN target?
- Did trauma system development change motorcycle-related injuries and deaths over time in the UAE, and has the reduction in death rates met the UN target?
- Has the COVID-19 pandemic changed the incidence, patterns, injury severity, and outcomes of hospitalized RTC-related trauma patients compared to the pre-pandemic period in Al-Ain City, UAE?

These important research questions were the final ones that prompted me to embark on a comprehensive systematic study, and eventually led me to undertake this research dissertation. This dissertation is therefore composed of four epidemiological studies: two at the global level and two at the local level.

Thus, the need for global studies was identified by means of repeated measures data over time. The need for such data prompted the development and implementation of two of the studies reported here, namely "Reduction of pedestrian death rates: a missed global target" (Paper I) and "Motorized 2-3-wheeler-related death rates over a decade: a global study" (Paper III). The other two studies, namely "The impact of the COVID-19 pandemic on road traffic collision injury patterns and severity in Al-Ain City, United Arab Emirates" (Paper II), and "Reduction of motorcycle-related deaths over 15 years in a developing country" (Paper IV), are identified to help clarify the RTC problems and traffic safety management at local levels. Additionally, these local studies helped to complement the global findings by exploring the impact of the development of a new trauma system on vulnerable road users (VRUs) and the impact of COVID-19 pandemic on RTC-related injury patterns and severity in Al-Ain, UAE.

Our findings contributed significantly to existing knowledge and highlighted the potential factors and conditions affecting changes in road traffic injuries and deaths as well as evaluating the progress of the global action plan, including the effects of the development of the new trauma system in Al-Ain, and also the impact of the COVID-19 pandemic on road traffic injuries and deaths both globally and locally over time, covering the period from March 2003 to March 2021.

1.2 Statement of the Problem

RTC is a global public health challenge, causing significant deaths and injuries for many years [22, 23]. The economic cost of RTCs is considerable [24]. Tremendous efforts have been made to address the road safety crisis both globally and locally over the last two decades. However, few studies attempted to examine the country/community level factors which contribute to changes in road traffic injuries and deaths over time, whether globally or locally. The WHO, through its GSRRS, regularly evaluates whether the action plan is properly progressing, supported by national data [6, 7, 9, 10]. However, these reports did not use advanced multivariate analysis to identify the factors affecting changes in RTC-related deaths and injuries globally over time. Furthermore, we wanted to study these changes locally using data from our own setting. Hence, this study is intended to bridge the information gap to improve road safety intervention measures.

1.3 Aim and Objectives

The main aim of this dissertation is to study factors affecting changes in RTC-related injuries and deaths at the global and UAE levels over time, and to establish whether the reductions in RTC death rates have met the UN target. The specific objectives include:

- To study risk factors affecting changes in global pedestrian death rates over the recent decade and whether the reduction in death rates has met the UN target;
- To study the factors affecting changes in global motorized 2-3-wheeler-related death rates over the recent decade and whether the reduction in death rates has met the UN target;
- To study the impact of the trauma system on the incidence, injury pattern and severity, and outcomes of hospitalized motorcycle-related injured patients and whether the reduction in deaths has met the UN target in Al-Ain City, United Arab Emirates; and
- To study the effects of the COVID-19 pandemic on the incidence, patterns, injury severity, and outcomes of hospitalized RTC trauma patients in Al-Ain City, United Arab Emirates.

1.4 Research Hypothesis

The hypothesis of this study is that the Global Action Plan implemented during the Decade of Action for Road Safety 2011-2020, the new trauma system development in Al-Ain and the COVID-19 pandemic restrictions imposed in the UAE contributed to a reduction in RTC-related deaths and injuries over time and helped reach the UN targets of reducing mortality by 50% both globally and locally. Specifically, it is hypothesized that

- The Global Action Plan implemented during the Decade of Action for Road Safety 2011-2020 contributed to a reduction in global pedestrian deaths over time and helped reach the UN target of reducing death rates by 50%;
- The Global Action Plan implemented during the Decade of Action for Road Safety 2011-2020 contributed to a reduction in global motorized 2-3-wheeler-related deaths over time and helped reach the UN target of reducing death rates by 50%;
- The maturity of the new trauma system in Al-Ain contributed to a reduction in motorcycle-related injury mortality over time and helped the UAE to reach the UN target of reducing injury and death rates by 50%; and
- The restrictions of the COVID-19 pandemic imposed in the UAE contributed to a reduction in the incidence, patterns, severity, and outcomes of RTC-related injuries in Al-Ain City, UAE.

Chapter 2: Background

2.1 Global Burden of Road Traffic Collisions

RTC is a global health challenge, causing significant deaths and disability-adjusted life years (DALYs) [22, 23]. In 2016, it was ranked as the eighth cause of death among all ages and as the number one killer among children and young adults aged 5-29 years [6]. Over the last two decades, RTCs caused more than 25 million deaths or 13 million deaths per decade – approximately 1.35 million deaths per year, and up to 50 million non-fatal injuries and disabilities, worldwide annually [6, 7, 9, 10]. The estimated cost of these deaths and injuries is approximately USD 1.8 trillion each year, equivalent to an annual tax of 0.12% on global gross domestic product (GDP), with an average per capita burden of USD 231 [24].

During the same period, the number of vehicles on global roads increased to well above 2 billion, with the death rate per 100,000 vehicles declining from 135 deaths in 2000 to 64 deaths in 2016, while the rate per 100,000 population remained almost stable at around 18 deaths [6, 25]. Despite these comparative improvements, the burden of road traffic-related deaths varied significantly across WHO regions, income levels, countries, and road user types [6, 7, 9, 10].

Regionally, Africa experienced the highest road traffic death rate at 27 per 100,000 population, followed by South-East Asia and Eastern Mediterranean, with 21 and 18 per 100,000 population, respectively [6]. By income level, more than 90% of global road traffic-related deaths were in low– and middle–income countries (LMICs), although these countries have only 60% of the world’s registered vehicles [6]. It is somewhat paradoxical to note that the rate of death in road traffic per 100,000 population decreases sharply as the income level of the country increases. For example, the risk of death in RTC in HICs is 8.3/100,000 population, whereas the equivalent death rate is 2 times higher in the MICs at 18.4/100,000 population, and 3 times higher in the LICs at 27.5/100,000 population [6, 7, 9, 10].

When classifying road traffic deaths by road user type, in 2016 approximately 50% of all global road traffic-related deaths were among VRUs (with pedestrians, motorized 2-3-wheelers and cyclists accounting for 23%, 28% and 3%, respectively) compared with approximately 30% among car occupants [6]. The types of road users most affected also varied across WHO regions and countries. For example, pedestrian deaths were highest in Africa, followed by the Eastern Mediterranean and the European regions [6, 7, 9]. On the other hand, RTC mortality among motorized 2-3-wheeler users was the highest in Southeast Asia, Western Pacific and American regions compared with other regions [6, 7, 9].

2.2 The Burden of Road Traffic Collision in the United Arab Emirates

As noted above, road traffic death per 100,000 population decreased as the income level increased, but this is not the situation when it comes to the HICs in the Eastern Mediterranean Region, where the rates of road traffic death per 100,000 population were found to increase as income levels increased [6]. This is particularly apparent in the UAE, where the road safety situation differs markedly from that in other HICs. Given this important difference, it is essential to analyze the country's sociodemographic characteristics to understand the hidden reasons for these differences.

The UAE is a rich Middle Eastern country, with high levels of car ownership [6, 26]. The country possesses a superior roadway network, characterized by high-speed highways and dense intercity roadway networks in the major cities [26, 27]. The rapid economic growth in the UAE has contributed significantly to the increasing number of motor vehicles [27]. For example, during 2016, around 3.39 million vehicles were used in the UAE of which 1.6% were motorized 2-3-wheelers [6].

The UAE population is young, with a majority of males (70%) [28]. Due to its rapid economic growth, the country witnessed an influx of foreign workers in the past few decades, and this group now makes up 87% of the total population [29]. Most of the workforce (both expatriates and Emiratis) are young workers, in the working age group (20 – 49 years) [28].

Many of the expatriate workers in the UAE are employed in low-income occupations [30] and use walking, cycling and motorized 2-3-wheelers as cheap means of transportation [6, 7, 27, 31, 32]. Among UAE nationals, it is mostly young males who use bicycles and motorcycles for sporting and recreational activities as well as walking [27, 33]. However, the pedestrian and bicycle infrastructure available for the population in the

UAE is poor, in contrast with what is provided for occupants of motorized vehicles [34]. This is possibly because pedestrians and cyclists are not considered to be important components of traffic safety systems. However, recently measures aiming to support walking and cycling in the various cities in the UAE have been introduced [27, 34], and major efforts are currently under way specifically in line with the 2030 national goal to promote a sustainable environment for all road users [34].

In the UAE the burden of RTC as measured by fatality and DALY rates was reduced considerably between 2000 and 2019. Road traffic death rates per 100,000 population dropped by 44% (from 16 deaths in 2000 to 9 deaths in 2019); similarly, DALY rates per 100,000 population declined by 42% (from 1078 DALYs in 2000 to 626 DALYs in 2019) [35, 36]. This is attributed to the significant improvements in road safety measures (e.g., installation of speed cameras, signaled pedestrian crossings, enforcement of safety regulations, use of safety devices) and injury prevention, including deployment of efficient emergency medical services (EMS), prehospital care, in-hospital care, trauma registries, trauma education and trauma research [37–39]. However, despite these efforts, RTC remains a leading public health issue in the UAE. The problem is ranked as the seventh cause of death and as the fifth cause of DALY, with both of these rates higher than the equivalent rates in other HICs [6, 35, 36].

During 2016 approximately 31% of all road traffic-related deaths in the UAE were among VRUs, with 24.3%, 1.5%, and 5.5% among pedestrians, cyclists, and motorized 2-3-wheeler users respectively, compared to 54.5% among car occupants [6]. The annual estimated cost of these RTC injuries to the UAE economy is approximately 0.263% of its total GDP, with an average per capita burden of USD 1895 [24]. This cost is nearly 2.5 times higher than the cost in other HICs [24].

Car occupants were the most injured road users in the UAE, followed by pedestrians [6, 40]. Interestingly, however, there has been a steady decline in mortality among car occupants in recent years, falling by 4.9% over 3 years (from 57.3% in 2013 to 54.5% in 2016), and among pedestrians falling by 6.9% (from 26.1% in 2013 to 24.1% in 2016). In contrast, mortality among cyclists increased by 400% during the same period, from 0.3% in 2013 to 1.5% in 2016, and also among motorized 2-3-wheeler users by 111.5%, from 2.6% in 2013 to 5.5% in 2016 [6, 7].

RTCs account for more injuries and deaths among the younger age groups in the UAE [41–44]. About 45% of all RTCs in the UAE are caused by young drivers aged 18 – 30 years [41, 45, 46]. This proportion increased to 63% in the Emirate of Abu Dhabi, and resulted in 34% of deaths in this particular age group [41, 45, 46]. Indeed, the RTC burden varied by road user type and age across the individual emirates constituting the UAE [6, 40]. Importantly there were significant variations in the burden of RTC across the individual emirates, with the majority of road traffic injuries and deaths occurring in the Emirate of Abu Dhabi, followed by the Emirate of Dubai [26]. In 2016, about 49% of all road traffic-related deaths in the UAE occurred in the Emirate of Abu Dhabi compared to 27% in the Emirate of Dubai and 24% in other Emirates, including Sharjah, Ajman, Fujairah, Ras Al Khaimah, and Umm Al Quwain [6, 16, 47]. RTC was also the leading cause of trauma deaths in the Emirate of Abu Dhabi, causing 47% of all trauma deaths [16]. Among pedestrians, cyclists, and motorcyclists, RTC mortality accounted for 23.3%, 0.8%, and 1.6% of all road traffic deaths in the emirate, respectively, compared to 72% among car occupants [16]. It is worth mentioning that there were more than 1 million registered vehicles in the emirate in 2016 [48].

Given those disproportionate figures, it is clear that the road traffic safety is an alarming problem in the UAE. The most common risk factors contributing to the reported injuries and deaths include over speeding [26, 49], sudden turns [26], low use of safety devices like seatbelts, child restraints and helmets [27, 32, 50–52], lack of driving experience or novice drivers [50], high level of distraction caused by using mobile phones, talking to others, deep thinking [50, 53], age of driver (being young male) [50], alcohol/drug intoxication [54], sleepiness [55], serious depression [50], low visibility during night time, such as walking at night [31, 49], adverse weather conditions [49], and inappropriate or prohibited pedestrian behavior, such as crossing roads outside designated areas (i.e. outside Zebra crossing) [56, 57]. Note that the majority of road traffic accidents occurred on streets/roads, around homes in residential areas, off road and in other public areas [58].

2.3 Risk of Exposure and Death by Road User Types

In contrast to protected car occupants, pedestrians, cyclists and motorized 2-3-wheelers travel on unsafe roads [59]. Such exposure to hazards contributes to increased RTCs. In most cases, death is caused by high-energy transfer from the vehicle to the road traffic users during the crash. Pedestrians, cyclists, and motorized 2-3-wheelers lack crash protection devices that could absorb the energy of the impact [60]. As a consequence, pedestrians, cyclists and motorized 2-3-wheeler user mortality is significantly higher compared with that of car occupants in the same setting because of the high energy transfer to their exposed bodies when colliding with a high-speed vehicle [60–64]. In other words, their body size cannot tolerate the load and acceleration applied by parts of the car [61]. Thus, pedestrians, cyclists and motorized 2-3-wheeler users are considered to be VRUs [60, 65, 66].

2.3.1 Pedestrian Injuries

Walking is a common mode of transport everywhere around the world. It has health, physical and environmental benefits [64, 67]. However, walking is unsafe on roads that lack pedestrian facilities, especially when combined with increased numbers of vehicles moving at high speed in crowded areas [8, 17, 68, 69]. A report by the International Road Assessment Program (iRAP) found that around 88% of global pedestrians travel on unsafe roads compared to 44% of car occupants [59]. Pedestrians who travel on such roads had more injuries and deaths. For example, in the USA, 67% of pedestrian deaths occurred where there was no sidewalk [70]. One way to reduce mortality in places where vehicles and pedestrians encounter each other is to restrict traffic speed [60, 71]. Without this measure, the risk of pedestrian death increases significantly as the impact speed increases [60, 71–73]. For example, pedestrians have 5% risk of death at an impact speed of 30 kph, 10% at 37 kph, 50% at 59 kph, 75% at 69 kph, and 90% at 80 kph [73]. This rise in mortality risk as impact speed increases is chiefly due to the quantity of energy transferred to the exposed body of the pedestrian [74].

Pedestrians involved in RTCs have higher rates of mortality than vehicle occupants [74, 75]. Head injury is the main cause of death among injured pedestrians [31, 64]. One fifth of the global road traffic deaths involve pedestrians, with about 2.5 million deaths over the last decade worldwide – equivalent to 270,000 deaths per year [6, 7, 9, 64]. In the UAE, a quarter of people who die as a result of road traffic injuries are pedestrians [6].

2.3.2 Motorized 2-3-Wheeler-Related Injuries

Motorized 2-3-wheeler use is one of the main modes of transportation. It has become an increasingly common means of transport in most parts of the world over the last decade [76, 77]. However, riding a motorized 2-3-wheeler is very risky because of the high speed and the exposed bodies of the driver and passenger. Most motorized 2-3-wheeler riders (67%) travel on unsafe roads compared to car occupants (44%) [59]. The risk of death from a crash is 28 to 34 times higher than for car occupant [62, 63]. A quarter of global road traffic deaths involve motorized 2-3-wheelers, with approximately 3.2 million deaths over the past decade worldwide, which is equivalent to 330,000 deaths per year [6, 7, 9, 77]. In the UAE, both the number of motorized 2-3-wheelers and the number of concomitant deaths are on the rise [6]. Head injury is the main cause of severe morbidity and mortality in motorized 2-3-wheeler crashes [33, 63, 78]. For example, motorcycle-related injuries had the highest mortality of hospitalized trauma patients in Al-Ain city, and more than 40% of those affected had head injuries [33].

2.3.3 Bicycle Injuries

Cycling is an important common mode of urban transportation worldwide. Like walking, it is cheap, environmentally friendly, improves physical fitness, and promotes health [79–81]. Despite these benefits, cycling causes injuries and deaths, especially when riding on unsafe roads [81, 82]. According to the International Road Assessment Program (iRAP), worldwide about 86% of cyclists travel on unsafe roads compared to 44% of car occupants [59]. In the UAE, there is a lack of separate lanes for cycling [34].

2.3.4 Car Occupants

In the UAE, the majority of injured road users are car occupants, with drivers being the majority within this group [40]. Compared to other HICs and the global average, the proportion of deaths is higher [6]. Head injury is the main cause of hospitalization and death, chiefly among unrestrained occupants [40]. Injury severity in RTC increases in the following sequence: rear impact, front impact, side impact rollover, and ejection [43].

Among young UAE national male drivers, rollover crashes with a high risk of ejection were the most frequent cause of injury [51].

2.4 Managing Road Safety

RTCs are predictable and preventable. This has led to the identification, development, and implementation of several road safety interventional strategies, programs, and policies. Road safety management is under continuous improvement at global, regional and national levels [2, 6, 83, 84]. The global effort to address the road safety crisis began by first acknowledging the problem. On 22 May 2003, the United Nations General Assembly adopted resolution A/RES/57/309 which recognized the global road safety crisis and noted the rapid increase in road traffic deaths and injuries [85]. This was followed by resolution 58/9 on the global road safety crisis [86].

The recommendations of the World Report on Road Safety Injury Prevention were the first step in the global response to this growing concern [61]. This joint WHO and World Bank report on road safety injury prevention, issued on World Health Day 2004, summarized best practices and recommended that countries implement national road safety strategies with achievable performance targets, supported by national action plans that set out specific interventions to achieve these targets [61, 83, 84]. The report also played an important role in reaching consensus for concerted action at national, regional, and global levels [61], and was subsequently endorsed by United Nations General Assembly Resolutions 58/289, 60/5 and 62/244 on improving global road safety [87–89].

Following the 58/289 resolution, the UN mandated the WHO to coordinate road safety efforts among United Nations agencies [87]. Thereafter, the WHO endorsed resolution 58/289 in World Health Assembly Resolution 57.10 on Road Safety and Health, "recognizing that road traffic injuries constitute a major but neglected public health problem that has significant consequences in terms of mortality and morbidity and considerable social and economic costs, and that in the absence of urgent action this problem is expected to worsen" [90]. Shortly afterwards, in 2004, the WHO established the United Nations Road Safety Collaboration (UNRSC) to encourage efforts to address the global road safety crisis [91, 92].

However, weak road safety management capacity and ineffective institutional management functions within LMICs limited progress in implementing the recommendations of the world report on road safety injury prevention [84]. To address such challenges, recent works from the World Bank and Organization for Economic Cooperation and Development (OECD) are showing how systemic approaches are developed and stress the importance of effective management function to improve road safety [83, 84]. For example, the World Bank stresses how the essential institutional management functions should initiate interventions, which in turn produce results [84].

The United Nations followed similar steps to the World Bank and the OECD when it issued resolution 64/255 of 2 March 2010. This resolution initiated the First Decade of Action for Road Safety 2011-2020 which aimed to reduce road traffic-related deaths by half by 2020 [1]. The Decade of Action for Road Safety 2011 – 2020 was launched on 11 May 2011 [2]. It encourages countries to implement activities according to five pillars of road safety, including road safety management, safer roads and mobility, safer vehicles, safer road users, and post-crash care [2]. This innovative strategy is outstanding in the field of injury prevention. It has ensured that the global road safety agenda benefits from increased global advocacy, attention, investment, and efforts in road safety [2, 93].

Further developments in road safety strengthened the ‘Decade of Action’. Currently, road injury prevention is included in the Sustainable Development Goals (SDGs) agenda via two road safety targets (SDG targets 3.6 and 11.2) [94]. The SDGs, which replaced the Millennium Development Goals (MDGs), recognized RTC as a global public health challenge and the need to address it. This demonstrates not only the relevance of SDG for road injury prevention but also the relevance of road injury prevention to the efforts of SDG agenda beyond the health goal [95]. It is worth noting that road safety was absent in MDGs [96].

There are also other developments that strengthened the efforts of road safety, including the ‘UN Road Safety Trust Fund’ in 2016 to facilitate investments in road safety [97], networks of legislators in Africa and the Eastern Mediterranean region, setting the 12 voluntary global road safety performance targets for road safety risk factors and service delivery mechanisms, and regional data observatories to facilitate better reporting of road traffic deaths [6]. In line with the targeted action plan, countries also made significant progress in policy improvements and strengthening of road traffic laws during the last decade [6].

In the UAE, road safety management is developing rapidly [6, 98]. The UAE is a federal entity, hence there are both federal and local systems with responsibility for road safety [98, 99]. The authorities have introduced several road safety intervention strategies to address the road safety crisis [100–102]. The major components are engineering, legislation and law enforcement, public awareness programs and post trauma care [98, 100]. These interventions encompassed frameworks, most commonly applied in accident prevention work, which focus on reducing injuries and deaths [98]. Examples of such interventions include, road design, installation of road speed cameras [98, 100], use of safety devices (such as helmets and seatbelts) [6, 7, 9, 10, 51], strict law enforcement and safety regulations (such as helmet, speed, seatbelt, and alcohol/drug law enforcement) [6, 7, 9, 10, 98, 100], emergency medical services/pre-hospital care and in-hospital care trauma [37, 103]. However, the level of implementation, law enforcement and focus varied across emirates [98, 100].

2.5 Factors Affecting RTC-Related Injuries and Deaths

RTCs are caused by many complex, interlinked and overlapping human, vehicle and environmental risk factors [61, 91, 104, 105]. There are various analytical frameworks that can be used to identify and analyze the various components involved in RTCs, from defining the problem to analyzing the risk factors, identifying, and implementing intervention strategies, and evaluating interventions [91, 104]. In relation to our study, two analytical frameworks (i.e., the Haddon matrix, and the systems approach), and the public health approach (which is a procedure), will be presented in this section.

Haddon (1980), developed a matrix that identifies risk factors according to a sequence of events in three phases – pre-crash, crash, and post-crash in relation to the epidemiological triad (host/human, agent/vehicle, and environment) [106]. This matrix is useful to analyze the genesis of injuries from a truly public health perspective by showing where the epidemiological triad (host, agent, and environment) and the opportunities for prevention (primary, secondary, and tertiary) meet in relation to phases of injury (pre-crash, crash, and post-crash). Haddon also outlined 10 countermeasure strategies for injury prevention and control that could be implemented in short and longer periods [91, 107–110]. For example, using the Haddon matrix, factors that contribute to motorized 2-3-wheeler-related injuries and deaths include those that impact exposure to risk (such as vehicles, GNI, national legislation and law enforcement measures, and population density during the pre-crash phase), factors that affect the severity of the crash (such as failure to wear helmets during the crash phase), and factors that influence the severity of post-crash outcomes (such as poor access to trauma care or a lack of appropriate prehospital and in-hospital care). Moreover, the matrix can be used to outline corresponding prevention strategies, such as reducing exposure to traffic environments through primary prevention strategies like restricting the use of motorized 2-3-wheelers and implementing national legislation and law enforcement measures. Secondary prevention strategies include reducing the impact of energy transfers during a crash through helmet use, while tertiary prevention strategies focus on reducing the severity of injuries through trauma care.

Similarly, the Haddon matrix can be applied to other injury mechanisms to explain which factor relates to each mechanism, followed by combining these with the three levels of prevention (primary, secondary, and tertiary) in relation to phases of injury (pre-crash, crash, and post-crash). In general, the matrix is useful to illustrate how the factors affecting RTC-related injuries and deaths operate and interact in injury causation together with injury prevention strategies during pre-crash, crash, and post-crash phases. However, the matrix has limitations. it lacks a systematic plan of action [111].

In contrast, the systems approach, which is built on Haddon's insights, views each system as an integrated whole rather than a set of individual components; it considers the interaction between the components, and implements a comprehensive set of interventions that have the potential to be applied to all relevant components to achieve the desired outcomes [91, 104, 112, 113]. Unfortunately, common practice in road safety strategies is not based on the principles of a systems approach. Instead, practice tends to be based on specific measures to be applied to one individual component, without considering the interaction between elements [104]. This means that in systems approach some components, not all components, can only be addressed adequately, taking into account the interdependencies of components or interactions of relevant measures [113]. A typical example of a systems approach is Vision Zero, a model for road safety that illustrates how the different components of the system interact [113]. Also, note that the 'First Decade of Action for Road Safety 2011 – 2020' and the 'Second Decade of Action for Road Safety 2021 – 2030' are based on a systems' approach [1, 2, 13]. On the other hand, the public health approach is a procedure proposed to systematically define and measure problems, identify their risk factors, and then to development and implement measures and programs for their prevention [91, 111, 114]. However, it is not without limitation. It "lacks a systematic point of application" [111].

Full understanding of and familiarity with the above analytical frameworks/approaches helps to understand the causes and characteristics of the broad and complex nature of the factors affecting RTCs. In the following sections, we will present and discuss some of the factors affecting RTCs, with more focus on those which have strong evidence for influencing changes in RTC-related injuries and deaths over time.

2.5.1 Vehicles

As noted above, around 2 billion registered vehicles are used globally [6, 25]. The number of registered vehicles per 100,000 population increased from 20235 in 2007 to 27712 in 2016 worldwide [6, 10]. These numbers represent an improvement in the accessibility of transportation. Motorized 2-3-wheelers account for 30% of global vehicles [77]. LMICs use 88% of these 2-3-wheelers of which 75% are in Southeast Asia [77]. There has been a rapid increase in the use of motorized 2-3-wheelers worldwide because of their availability, flexibility, and affordability, with the highest growth rate in Southeast Asia (39%) [76, 77, 115, 116]. In the UAE, motorized 2-3-wheelers account for 1.6% of all registered vehicles, with a recent rising trend [6]. The increase in the number of vehicles is one of the kay factors contributing to RTC-related outcomes [61, 117].

Smeed (1949) was the first to demonstrate the correlation between death rates and the number of registered vehicles [118]. Other studies have also shown a correlation between death rates and vehicle per person ratio [17]. Although global deaths per 100,000 vehicles declined over the last decades, from 135 in 2000 to 64 in 2016 [6], death rate varies by country and fluctuates over time [6, 7, 9, 10]. Furthermore, mortality varies by the types of vehicles involved [61].

Meanwhile, the introduction of self-driving vehicles has the potential to improve road traffic safety and reduce traffic accidents [119–122]. Such vehicles are expected to reduce human error which contribute to road traffic accidents [123–125]. For example, human error (such as distraction and poor anticipation) contributes to 90% of road traffic accidents [123, 126, 127]. In contrast, using self-driving vehicles is predicted to reduce road traffic accidents by 90% [124, 125, 127].

2.5.2 Gross National Income

Gross National Income (GNI) is an economic indicator measured in U.S. dollars [128]. According to the World Bank "Gross national income is the sum of value added by all resident producers plus any product taxes (less subsidies) not included in the valuation of output plus net receipts of primary income (compensation of employees and property income) from abroad." Further, "GNI per capita is the gross national income divided by the midyear population" [128]. However, both indicators change over time [128].

Studies have found that improvements in GNI tend to increase the number of motor vehicles and also lead to safer roads with signaled pedestrian crosswalks, road traffic cameras, and humps for the users [129–132]. Several studies also found that improvement in GNI and vehicle per person ratio reduces pedestrian deaths, while lower GNI predicts poor helmet use [3, 17, 18]. There is also a relationship between income level of countries and road traffic deaths and injuries. The rate of road traffic deaths, disabilities and injuries per 100,000 population decreases as income increases [133, 134]: hence high-income is ultimately associated with lower mortality.

2.5.3 Speed

Speed is at the center of every RTC [105]. It affects exposure to risk, crash involvement, and severity of injury [91]. Jurewicz et al. (2016) found that fatality risk for car occupants in car-to-car side impacts at a 65 km/hr speed is 85% [135]. Martin and Wu (2018) reported that the risk of pedestrian death rises by 4.5 times if hit by a car front moving at speed ranging from 50 km/hr to 65 km/hr [136]. To address such effects, speed management and setting speed limits are the core of most speed intervention strategies for safe travel [137, 138]. For example, a 5% reduction in average speed can result in a 30% reduction in the number of fatal crashes [137]. However, without proper speed management, a one percent increase in every average speed can cause 4% and 3% increases in fatal and serious crash risks, respectively [139].

2.5.4 Helmet Use

Helmet use is vital in reducing head injuries and associated deaths among motorized 2-3-wheeler users and bicyclists [18, 27, 32, 33, 52, 140]. Not using helmets, on the other hand, is a risk factor for crash severity [33, 91, 141]. Liu et al. (2002) found that proper helmet use among motorcycle riders can lead to a reduction of 42% and 69% in the risk of fatal injuries and head injuries respectively [141]. Another study found that a 10% increase in helmet usage saves one person per 100,000 population per year [18]. Note that GNI and law enforcement levels correlate with helmet usage [18, 142–144]. Additionally, lack of helmet standards correlates with increased motorcycle-related mortality [18]. In the UAE, there has been an improvement in helmet usage among motorcycle riders [6, 7, 9], but usage remains low among bicyclists despite helmet legislation [27].

2.5.5 National Legislation and Law Enforcement

The presence of national legislation is vital for law enforcement [6, 145]. Globally, countries have made significant progress in improving legislation across the five key risk factors [6]. Such legislative measures are important to save lives. A recent study found that 75% of the lives saved from road traffic deaths in LMICs during the period 2007-2018 can be attributed to legislative changes alone [145].

However, enforcement remains a considerable challenge in most countries as the number of countries with laws meeting best practices is low worldwide: speed (46 countries), seat belt use (105 countries), drink-drive (45 countries), helmet use (49 countries), and child restraint (33 countries) [6]. Studies indicate that national legislation supported by effective law enforcement on speed limits, helmet use, seat belt use, child restraint, and drink-driving, reduce road traffic mortality [145]. In contrast, lack of national legislation and poor law enforcement contribute to increased road traffic deaths and injuries. For example, not wearing a helmet increases motorized 2-3-wheeler-related mortality [18]. Furthermore, a lack of national legislation contributes to pedestrian deaths [17].

In the UAE, enacting and enforcing legislation on key risk factors (such as speed, helmets, seatbelts, child restraint, and drink driving law) are critical components of an integrated traffic safety strategy to prevent road traffic injuries and deaths [98, 146]. However, compliance remains a major challenge in the UAE, mainly among young adults [26, 27, 50, 51, 54, 147].

2.5.6 Time

Time is an important environmental factor. It is a constant independent factor against which changes in a system can be measured. The importance of including time sequence in the Haddon matrix, as pre-crash, crash, and post-crash indicates that RTC is predictable and preventable [106, 111]. Time is important to implement activities, monitor progress and evaluate changes in road traffic deaths and injuries over time. However, time as a factor is less studied despite its significant role in RTCs [17, 106, 111]. It is crucial to consider time as a potential factor in the RTCs and to assess its cumulative effect on RTC-related outcomes over time.

2.5.7 Environmental Factor: COVID-19 Pandemic

The world has recently been bearing the impact of the COVID-19 pandemic. The name COVID-19 is short for "coronavirus disease 2019" [148], which was first identified in late December 2019 [11]. The disease spread swiftly and globally from Wuhan, China, the epicenter of the coronavirus, to the rest of the world [11, 12], this being facilitated by rapid transportation methods [149]. In the UAE, the first case of COVID-19 was confirmed on 29 January 2020 [150]. The WHO declared the outbreak a "public health emergency of international concern" on 30 January 2020 [151] and a "pandemic" on 11 March 2020 [152].

Efforts to contain the spread of repeated waves of the COVD-19 infection continue. The dynamics of infectious pandemics are different from those observed in other natural disasters [153–155]. Although they do not cause mass destruction to the infrastructure, they directly and indirectly affect the community [156–159]. The lack of strong evidence about the transmission routes of the virus at the beginning of the pandemic [12] and the inadequate preventive measures increased the rapid spread of the virus [12, 153]. Over time, however, with better understanding of the infection routes as well as improved diagnostic tools, reporting and tracing the disease became more feasible [160–163].

From February 2020, like other countries, the UAE government has implemented a series of measures in response to the COVID-19 pandemic [150]. These included lockdown, closure of schools, staying at home, quarantine, avoiding public gatherings, physical distancing, and working from home [150], and were enforced by law with severe penalties for violations [164, 165]. These measures affected road mobility, transport, traffic congestion, and RTCs in the UAE.

We have shown in a recent review that the restrictions on road mobility and transport reduced road traffic deaths and injuries worldwide, despite a relative increase of severity of injury and deaths [20]. However, the most important factors that affected RTCs during the COVID-19 pandemic were reduced traffic volume, empty lanes, increased speeding, not wearing seatbelts, less law enforcement, and alcohol/drug abuse (Figure 1) [20]. There is also evidence for significant disruption to healthcare services [166], with critical supply shortages [167] and reduced and delayed access to emergency care departments during the pandemic [168–170]. Such delays can also be expected to adversely affect post-crash care, particularly prehospital and in-hospital care among RTC injured patients. However, the impact of the COVID-19 pandemic has been little studied in the UAE. It is therefore important to study the effects of the COVID-19 pandemic on the incidence, patterns, injury severity and outcomes of RTCs in order to better plan future responses to similar pandemics.

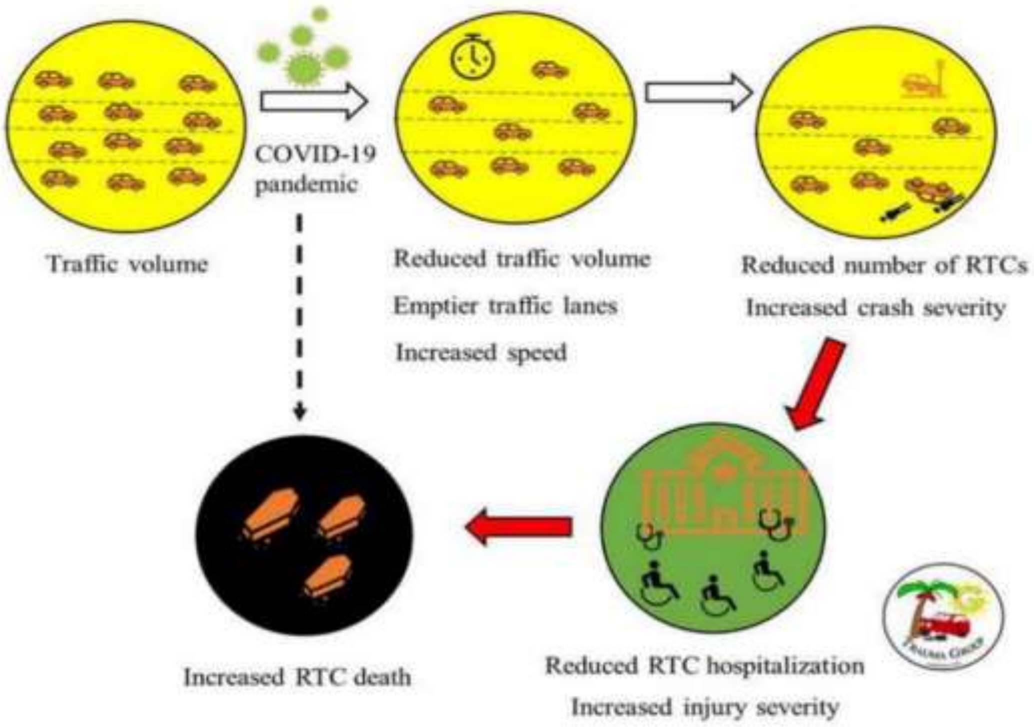

Figure 1: Global impact of COVID-19 pandemic on traffic volume, traffic lanes, vehicle speed, number of RTCs, injury severity, hospitalization, and road traffic deaths. Reproduced from Yasin YJ, Grivna M, and Abu-Zidan FM. Global impact of COVID-19 pandemic on road traffic collisions [20].

2.5.8 Trauma System

The burden of injury is global and requires effective measures for prevention and treatment. In response to this challenge, countries establish a trauma system, which is a pre-planned, comprehensive, organized, and coordinated injury control effort to be implemented from their local perspective [171, 172]. It has been two decades now since the UAE implemented this system to tackle the burden of trauma [37–39]. A trauma system is a potential factor that improves the patient care process, and reduces prehospital time, in-hospital complications, length of hospital stay, severity, mortality and cost of care [19, 37–39, 173–176]. However, these trauma outcomes are dependent on the effectiveness of multiple trauma system components, trauma maturity, data capture (before and after system implementation), population and supportive legislation [173, 176–180]. It is important to note that studies on long-term trends suggest that trauma systems need up to 10 years after implementation to mature before they will have a positive effect on patient mortality [176, 178, 180, 181].

Al-Ain City which is located in Abu Dhabi Emirate has an advanced trauma system providing trauma care for more than 750,000 residents [16, 43, 182]. In 2001, a Trauma Group was established in Al-Ain City with a clear organized and coordinated plan to improve trauma outcomes. Since then, there have been major developments in the trauma system in our city, including injury prevention, prehospital care, in-hospital trauma management, trauma registries, trauma research and trauma education. This included establishing Al-Ain Hospital Trauma Registry [38, 39], which generated a significant amount of useful data on trauma management and epidemiology that resulted in numerous high-quality scientific publications. These publications were used, through the media, to promote and improve road, work-related and home safety [183, 184] as a step toward establishing a trauma system [185]. Injury prevention interventions included installation of speed cameras, high penalties for violations, and enforcement of labor safety [98, 100, 186]. Educational activities included establishing the Advanced Trauma Life Support (ATLS) [187] and Point-of-Care Ultrasound (POCUS) courses [188] which became an integral part of our clinical practice [189]. Improvements occurred in the prehospital transport system, and in-hospital trauma management with an increased number of EMS trained staff [16], mandatory ATLS training for trauma teams [187], providing 24-h angioembolization and interventional radiology, following trauma management updates including hypotensive resuscitation, using POCUS, and damage control surgery [189–191].

We have previously shown that the maturity of our trauma system reduced trauma death [37], but we did not study its effects on motorcycle-related injuries. Furthermore, little information is available on the long-term effects of trauma system maturity on motorcycle-related injuries and deaths both globally and locally.

Chapter 3: Material and Methods

The dissertation consists of four epidemiological studies – two at the global levels (papers I and III) and two at the UAE level (papers II and IV). These studies use different sources of data and methods. Papers I and III were based on data from WHO GSRRS, while papers II and IV were based on prospectively collected data from Al-Ain and Tawam Hospitals. An overview of the study methodologies is shown in Table 1.

3.1 Study Area

Papers I and III are global studies. However, for papers II and IV, Al-Ain City was the study area. Al-Ain City is in Abu Dhabi Emirate, UAE. It has about 767,000 residents, the majority of them young males (59%) and non-UAE nationals (70.5%) [192]. Al-Ain is the second largest city in Abu Dhabi Emirate, which covers almost 87% of the country's territory and is home to approximately 31% of the total population of the UAE [28, 192]. Al-Ain and Tawam hospitals are the only two major public hospitals, where patients involved with RTCs in the Al-Ain region are admitted and treated [43]. Al-Ain hospital used to treat around 80% of trauma patients in our city before the COVID-19 pandemic (27 March 2020), after which it was allocated to treat only COVID-19 patients [37, 40, 43, 193]. Al-Ain hospital trauma registry was established in 2003 [38]. Overall, the hospital provides a wide range of general and specialized clinical services and has 412 beds [182]. Tawam hospital, in contrast, is a highly specialized tertiary care facility with 461 beds [182]. Its registry was established in 2006 [39, 54]. Tawam hospital was designated as a non-COVID-19 hospital in Al-Ain and was the only trauma receiving hospital during the Pandemic (i.e., since 28 March 2020).

Table 1: Overview of study methodologies.

Paper	Objective	Design	Data	Number of countries or number of patients	Time period that the data covers
Paper I	Factors affecting changes in global pedestrian death rates over time.	Longitudinal study.	Repeated measures data on pedestrian deaths for the years 2007, 2010, 2013 and 2016, collected from WHO GSRRS.	136, 134, 140 and 129 countries for years 2007, 2010, 2013 and 2016, respectively.	2007 – 2016.
Paper II	Effect of the COVID-19 pandemic on incidence, severity, and outcomes of hospitalized RTCs patients.	Prospective study.	Prospectively collected data of two cohorts of patients collected from Al-Ain and Tawam Hospitals trauma registries.	Pre-COVID-19 pandemic (n = 750 patients) versus COVID-19 pandemic (n = 499 patients).	Pre-pandemic period (28 March 2019 to 27 March 2020) versus pandemic period (28 March 2020 to 27 March 2021).
Paper III	Factors affecting changes in global motorized 2-3-wheeler death rates over time.	Longitudinal study.	Repeated measures data on motorized 2-3-wheeler deaths for the years 2007, 2010, 2013 and 2016, collected from WHO GSRRS.	115, 123, 117 and 122 countries for years 2007, 2010, 2013 and 2016, respectively.	2007 – 2016.
Paper IV	Effect of trauma system development on hospitalized motorcycle-injured patients.	Prospective study.	Prospectively collected data of two separate periods collected from Al-Ain Hospital trauma registry.	First period (n = 68 patients) versus Second period (n = 94 patients).	First period (March 2003 to March 2006) versus Second period (January 2014 to December 2017.

3.2 Study Period and Population

Papers I and III: 2007 – 2016, covers a 10 years period. All participant countries in the WHO GSRRS for the years 2007, 2010, 2013, and 2016, published in 2009, 2013, 2015, and 2018, respectively, were included.

Paper II: The pre-pandemic period (28 March 2019 to 27 March 2020) and the pandemic period (28 March 2020 to 27 March 2021). All RTC trauma patients who died in the hospital or who were admitted at both Al-Ain and Tawam hospitals from 28 March 2019 to 27 March 2020 (pre-pandemic period), and those who died in the hospital or who were admitted at Tawam hospital from 28 March 2020 to 27 March 2021 (pandemic period) were studied. During the pandemic period, all trauma patients that presented to Tawam Hospital (the non-COVID-19 hospital) were screened by a reverse transcriptase-PCR COVID-19 test on arrival at the Emergency Department. They would be continuously managed in the Emergency Department until the PCR result arrived. They would be admitted to Tawam Hospital only if the PCR result was negative, which would take around 4 hours. If the test was positive, they would be directly transferred to Al-Ain Hospital (the COVID-19 hospital) for further care. If a trauma patient needed urgent lifesaving or limb saving surgery, then this procedure would be performed in Tawam Hospital under strict personal protective equipment and disinfection precautions without waiting for the PCR result. The patient would wait in the operating recovery room until the PCR result was received before deciding whether to admit the patient to Tawam Hospital or transfer him/her to Al-Ain Hospital.

Paper IV: First period (March 2003 to March 2006) was 3 years, while the second period (January 2014 to December 2017) was 4 years. The interval period from 2003 to 2017 covers 15 years. All motorcycle-related injured patients who were admitted for more than 24 hours or who died on arrival at the Emergency Department or after hospitalization from March 2003 to March 2006 (first period, 3 years) and from January 2014 to December 2017 (second period, 4 years) were studied.

3.3 Definitions

One of the issues with road traffic is the variation in definitions, terminologies, and classification standards [61]. In this dissertation, road traffic collision (RTC) is defined as "fatal and non-fatal injury incurred as a result of a road traffic crash" [61].

For paper I and paper II, a pedestrian was defined as any person who travels on foot for at least part of his/her journey, whether walking, jogging, running, hiking, sitting, or lying down in the roadway [64]. The pedestrian may use various modifications and aids while travelling. These usually include canes, walkers, crutches, wheelchairs, skateboards, and roller blades [64]. The person may carry items on the head, back, shoulder, or hold items in the hands [64]

In papers II, III and IV, the term motorized 2-3-wheelers refers to powered 2-3-wheelers [77]. According to the WHO definition, "motorized 2-3-wheelers or powered two- and three-wheelers (PTWs) are motor-operated two- and three-wheeled vehicles, powered by either a combustion engine or rechargeable batteries." These include motorcycles, scooters, e-bikes, tricycles motor-rickshaws, or e-rickshaws [77].

In papers I and III, repeated measures data refers to multiple observations or measurements of the same outcome variable over time on the same experimental unit [194, 195]. Such repeated measures data are referred to as longitudinal data [194, 196] or otherwise it should be specified [197]. The experimental unit could be a country, household, person, or animal [197]. In papers I and III, the experimental unit is a country.

In paper II, COVID-19 pandemic refers to "coronavirus disease 2019 pandemic" caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [11, 148, 198].

For paper IV, a trauma system was defined as a "preplanned, organized and coordinated injury-control effort in a defined geographic area" [171].

3.4 Longitudinal Studies (Paper I and Paper III)

Paper I and Paper III were based on longitudinal study designs. Data collected from the WHO GSRRS were repeated measures data, covering the period 2007 to 2016. They were multiple measurements of estimated pedestrian deaths (paper I) and motorized 2-3-wheeler-related deaths (paper III) of each participating country for the years 2007, 2010, 2013 and 2016, published in 2009, 2013, 2015 and 2018, respectively [6, 7, 9, 10]. These measures were taken every 2 – 3 years, covering the period 2007 to 2016. Every report also had repeated measures of baseline covariates of each participating country in each reporting year.

Since both pedestrian and motorized 2-3-wheeler-related death rates were skewed to the right, they were log-transformed to fulfill the requirements of the normal distribution. Note that each report had missing data (incomplete data or unbalanced data), and the time of reports (observations) was not in the same interval or spacing. Additionally, the number of participating countries varied in each report. The 2007, 2010, 2013 and 2016 reports had data on 178, 182, 180 and 175 countries, respectively, with complete data on pedestrian mortality on 136 (76%), 134 (74%), 140 (78%) and 129 (74%) countries, respectively, while the data on motorized 2-3-wheeler-related death was available on 115 (65%), 123 (68%), 117 (65%), and 122 (70%) countries, respectively. The area of countries was retrieved using the website of Infoplease.com [199].

In paper I, the studied variables included country population, estimated road traffic death rate per 100,000 population, percentage of pedestrian deaths, effectiveness of speed law enforcement, presence of policies to promote alternative transport (walking and cycling), gross national income (GNI) per capita in US Dollars, population density, time (years) and the number of registered vehicles in each country. Information on the presence of policies to promote alternative transport (walking and cycling) was ranked from 0 to 2, where no = 0 for countries that had no policy, subnational = 1 for countries having a partial policy, and yes = 2 for countries that had a clear policy. The effectiveness of enforcement levels of speed limits was scored on a scale of 0 to 10, where 0 is "not effective" and 10 is "highly effective" based on professional opinion of government respondents.

In paper III, the studied variables were country population, estimated road traffic death rate per 100,000 population, percentage of motorized 2-3-wheeler-related deaths, percentage of estimated helmet-wearing rate, effectiveness of helmet law enforcement, effectiveness of speed law enforcement, gross national income (GNI) per capita in US Dollars, population density, time (years), number of registered vehicles, and percentage of motorized 2-3-wheelers in each country. The percentage of motorized 2-3-wheeler-related deaths included all riders (drivers or passengers). The estimated percentage of helmet-wearing in our study included all riders. However, if data was not available on all riders, we used instead the reported estimate helmet-wearing percentage of drivers. Information on the overall effectiveness levels of both helmet law enforcement and speed limit enforcement were scored on a scale of 0 to 10, where 0 is “not effective” and 10 is “highly effective” based on professional consensus in each country.

3.5 Prospective Studies (Paper II and Paper IV)

Paper II was based on a retrospective analysis of prospectively collected trauma registry data. Time series analysis was also performed to see whether there was change over time. Paper II covers data of two cohorts of patients in the pre-pandemic period (28 March 2019 to 27 March 2020) and the pandemic period (28 March 2020 to 27 March 2021). Data on demography, mechanisms of injury, physiological and anatomical severity markers, ISS, hospital and ICU admission, length of stay, and death were obtained from 750 hospitalized RTC trauma patients during the pre-pandemic period at both Al-Ain and Tawam Hospitals, and from 499 hospitalized RTC trauma patients during the pandemic period at Tawam hospital.

Similarly, Paper IV was based on a retrospective analysis of prospectively collected trauma registry data. Paper IV covers data of two separate periods, referred to herein as the First period (March 2003 to March 2006), and the Second period (January 2014 to December 2017). Data on demography, incident location, mode of arrival, vital signs, Glasgow Coma Scale (GCS), severity of the injury of regions by Abbreviated Injury Scale (AIS), Injury Severity Score (ISS), New Injury Severity Score (NISS), length of ICU stay, length of ventilation days, length of hospital stay, and clinical outcome were obtained from 68 motorcycle-injured patients in the First period and from 94 patients in the Second period. Data for Paper IV was collected only from Al-Ain hospital trauma registry, which was established in 2003 [38]. This provides the opportunity to evaluate the effect of trauma system maturity over 15 years, covering the period 2003 – 2017. 10 years from the implementation of a trauma system is considered to be the trauma maturity period as noted in many studies [176, 178, 180]. Furthermore, as noted above more than 80% of trauma patients in the city were treated at Al-Ain Hospital during this study period [37, 40, 43, 193].

3.6 Calculations

The population density was calculated by dividing the total population by country area (number of people/square miles). Pedestrian death rate was calculated by multiplying the estimated road traffic death rates per 100,000 population by percentage of pedestrian deaths. Motorized 2-3-wheeler-related death rate was calculated by multiplying the estimated road traffic death rates per 100,000 population by percentage of motorized 2-3-wheeler-related deaths. Vehicle per person ratio was calculated by dividing the total number of registered vehicles by total population. The number of motorized 2-3-wheelers was calculated by multiplying the percentage of motorized 2-3-wheelers by the total number of registered vehicles. Motorized 2-3-wheelers per person ratio was calculated by dividing the total number of motorized 2-3-wheelers by total population.

3.7 Data Entry and Management

For papers I and III, data collected during all studied years were coded and entered into the MS Excel program in two formats: vertical data format (the same variables in all studied years were entered into a single column in order of years with an added year variable), and horizontal data format (each variable in each studied year entered into a separate column). Data were coded and entered by the principal investigator. For papers II and IV, data were collected prospectively, coded, and entered by the full-time trained research fellows, trained registry nurses and principal investigator. All data were verified for accuracy and consistency and exported into SPSS for analysis.

3.8 Physiologic and Anatomic Predictors of Injury Severity

The description, ranges and cut points of the physiological and anatomical injury severity markers, such as Systolic Blood Pressure (SBP) [200, 201], respiratory rate (RR) [202], heart rate (pulse rate) [203], GCS [204–206], AIS [204, 207, 208], and ISS/NISS [209] are summarized below (Table 2).

Table 2: Descriptions, ranges, cut points and indications of physiological and anatomical predictors of injury severity markers.

Physiologic/anatomic predictor	Description	Range	Cut-offs /scale	Indicator	Reference
SBP	SBP is a physiologic predictor that measures the pressure the heart exerts on the walls of arteries each time the heart beats. It is measured in millimeters of mercury (mmHg).		< 90	Low	(200,201)
RR	RR is number of breaths per minute		< 12 12-20 > 20	Bradypnea Normal Tachypnea	(202)
HR	HR is number of beats per minute		< 60 60-100 >100	Bradycardia Normal Tachycardia	(203)
GCS	GCS is the sum of the three coded values: motor, verbal, and eye opening indicating traumatic brain injury.	3-15	≤ 8 9-12 13-15	Severe Moderate Mild	(204–206)
AIS	AIS is an anatomically based injury severity scoring system that divides the body into 6 anatomical regions and codes each body region (head, face, neck, thorax, spine, abdomen/pelvis, upper extremities, lower extremities, whole body and other) on a 6-point scale that is from 1 (minor) to 6 (undesirable).	1-6	1 2 3 4 5 6	Minor Moderate Serious Severe Critical Undesirable	(204, 207,208)
ISS/NISS	ISS is the sum of the square of the three highest AIS scores from the most severely injured body regions, while NISS is the sum of the square of the three highest AIS scores from the most severe injuries regardless of body regions injured	1-75	1-3 4-8 9-15 16-24 25-75	Minor Moderate Serious Severe Critical	(209)

SBP systolic blood pressure, RR respiratory rate, HR heart rate, GCS Glasgow Comma Scale, ISS Injury Severity Score, NISS New Injury Severity Score, AIS Abbreviated Injury Scale

3.9 Statistical Methods

The incidence rate per 100,000 was calculated by dividing the actual number of annual patients by the total population.

The standardized incidence rate per 100,000 was calculated by multiplying the correction factor by the annual number of patients divided by the total population.

The relative ratio was calculated by dividing the mean death per 100,000 population of the last period by the mean death per 100,000 population of the first period.

3.10 Statistical Analysis

Each individual study that forms part of this dissertation was analyzed in line with the study objective as it appears in the respective papers (I – IV).

Data are presented as numbers (percentages) for categorical variables, mean (standard deviation) and/or median (interquartile range/range) for continuous variables and median (interquartile range/range) for ordinal variables.

Mixed linear model (MLM) was performed to define factors affecting death rate change over time. The MLM model used was a strict unstructured, main effects model with repeated measures. A fixed effect, type III sum of squares error (due to the unbalanced data), and random effects for the independent variables (factors and covariates) were also included.

Several univariate analyses were performed. Spearman rank correlation test was used to study the correlation between different continuous or ordinal variables. Wilcoxon signed-rank test was used to compare the continuous or ordinal data of two dependent groups. Friedman test was used to compare continuous or ordinal data of more than two dependent groups. Mann–Whitney U test was used to compare the continuous or ordinal data of two independent groups, while Kruskal–Wallis test was used to compare continuous or ordinal data of more than two independent groups. Multivariate regression models were performed to measure the association between independent and outcome variables. Time series analysis (exponential smoothing model) was performed to examine change over time. Data were analyzed with the IBM SPSS Statistics version 26 (SPSS Inc, Chicago, IL, USA). A p-value of less than 0.05 was considered statistically significant.

3.11 Ethical Considerations

The data used for papers I and III are publicly available data from the WHO GSRRS and do not need approval from the Human Research Ethics Committee. However, for papers II and IV, ethical approval was obtained. For paper II, ethical approval was obtained from Abu Dhabi Health Research and Technology Ethics Committee, The Department of Health, Abu Dhabi Emirate (Ref: DOH/CVDC/2021/650). For paper IV, ethical approval was obtained from the Human Research Ethics Committee of Al-Ain Hospital, Al-Ain, United Arab Emirates (AAHEC-03-20-008). In addition, written informed consent was obtained from the patients or their caregivers to use the data for both studies (papers II and IV).

Chapter 4: Results

4.1 Pedestrian Death Rates (Paper I)

Global pedestrian deaths decreased by 28% over the last 10 years. The decrease was statistically significant between 2007 and 2010 ($p = 0.034$) and between 2013 and 2016 ($p = 0.002$), but not between 2010 and 2013 ($p = 0.06$). This was confirmed using the post hoc analysis (Figure 2A). There was a statistically significant fall in the pedestrian death rate over time ($p < 0.001$, Friedman test, Figure 2A). Factors that reduced pedestrian death rates included time ($p < 0.001$), GNI ($p < 0.001$), and vehicle/person ratio ($p < 0.001$) (Table 3). There was a significant fall in pedestrian deaths over time in both MICs and HICs ($p < 0.001$, Friedman test), but not in the LICs ($p = 0.035$, Friedman test) (Figure 3A).

4.2 Global Motorized 2-3-Wheeler-Related Death Rates (Paper III)

The global mean motorized 2-3-wheeler-related mortality increased from 2.37 to 3.23 deaths per 100,000 population over the studied decade (a relative ratio of 1.36) which was not statistically significant. Factors that affected mortality included motorized 2-3-wheelers per person ratio ($p < 0.001$), GNI ($p = 0.025$), percentage of helmet wearing ($p = 0.046$), and the interaction between vehicle/person ratio and motorized 2-3-wheelers/person ratio ($p = 0.016$) (Table 4). No significant differences in mortality were seen over time. This was confirmed using post hoc analysis ($p = 0.38$, Friedman test) (Figure 2B). Nevertheless, there was a significant difference in the death rates depending on the country income level. There was a significant increase in the death rates over time in LICs (a relative ratio of 2.52, $p = 0.019$, Friedman test) and MICs (a relative ratio of 1.46, $p < 0.001$, Friedman test), compared with a significant decrease in HICs (a relative ratio of 0.72, $p < 0.001$, Friedman test) (Figure 3B).

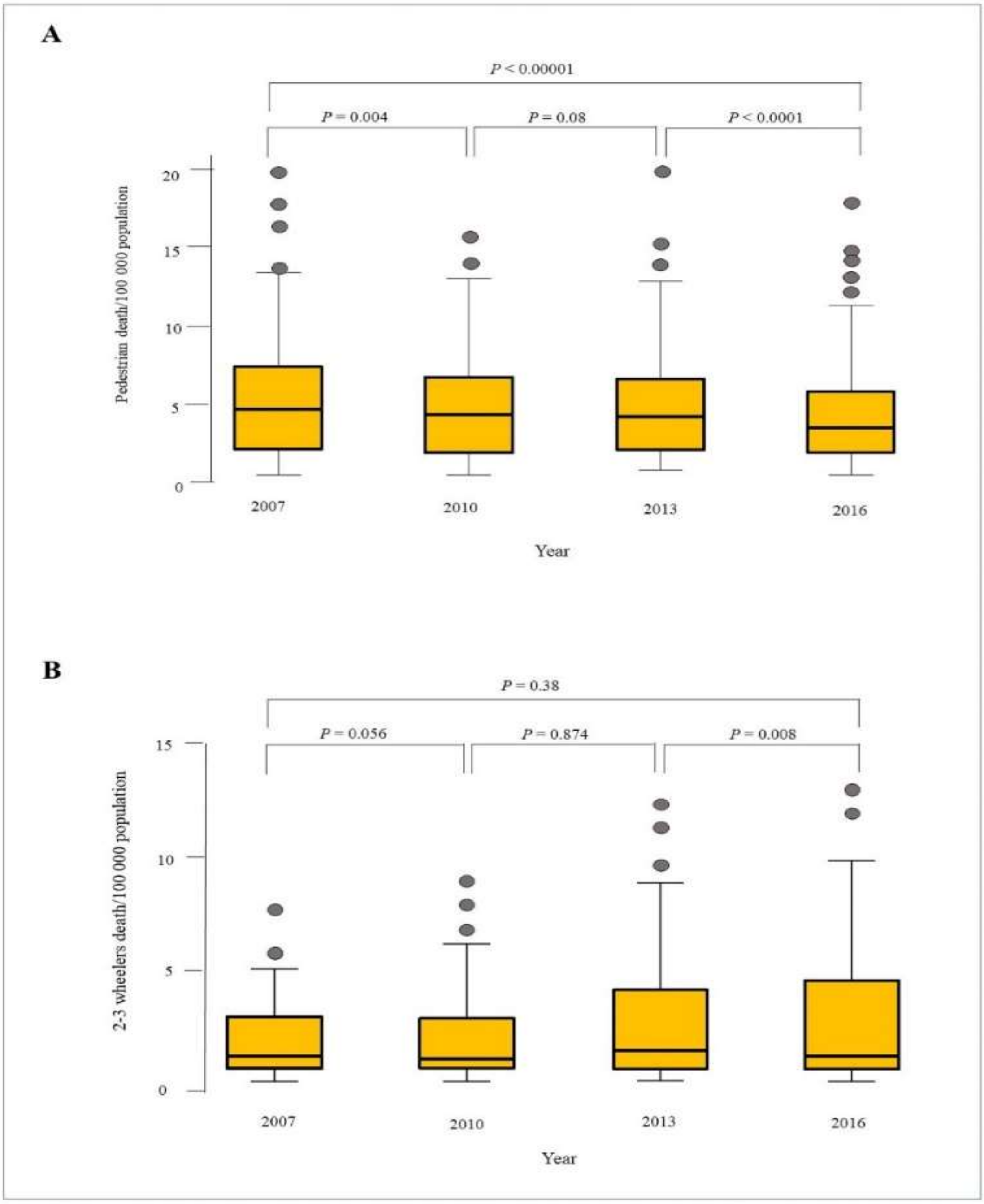

Figure 2: Global pedestrian and motorized 2-3-wheeler-related death rates per 100,000 population for years 2007–2016.

Box-and-whiskers plot of (A) global pedestrian death rate per 100,000 population (B) global motorized 2-3-wheeler-related death rate per 100,000 population for years 2007–2016. The box represents the 25th percentile and the 75th percentile Interquartile Range (IQR), while the line within the box represents the median. Black circles represent the outliers. *p*-value = Friedman test for comparison of more than two dependent groups and Wilcoxon signed-rank test for comparison of two dependent groups.

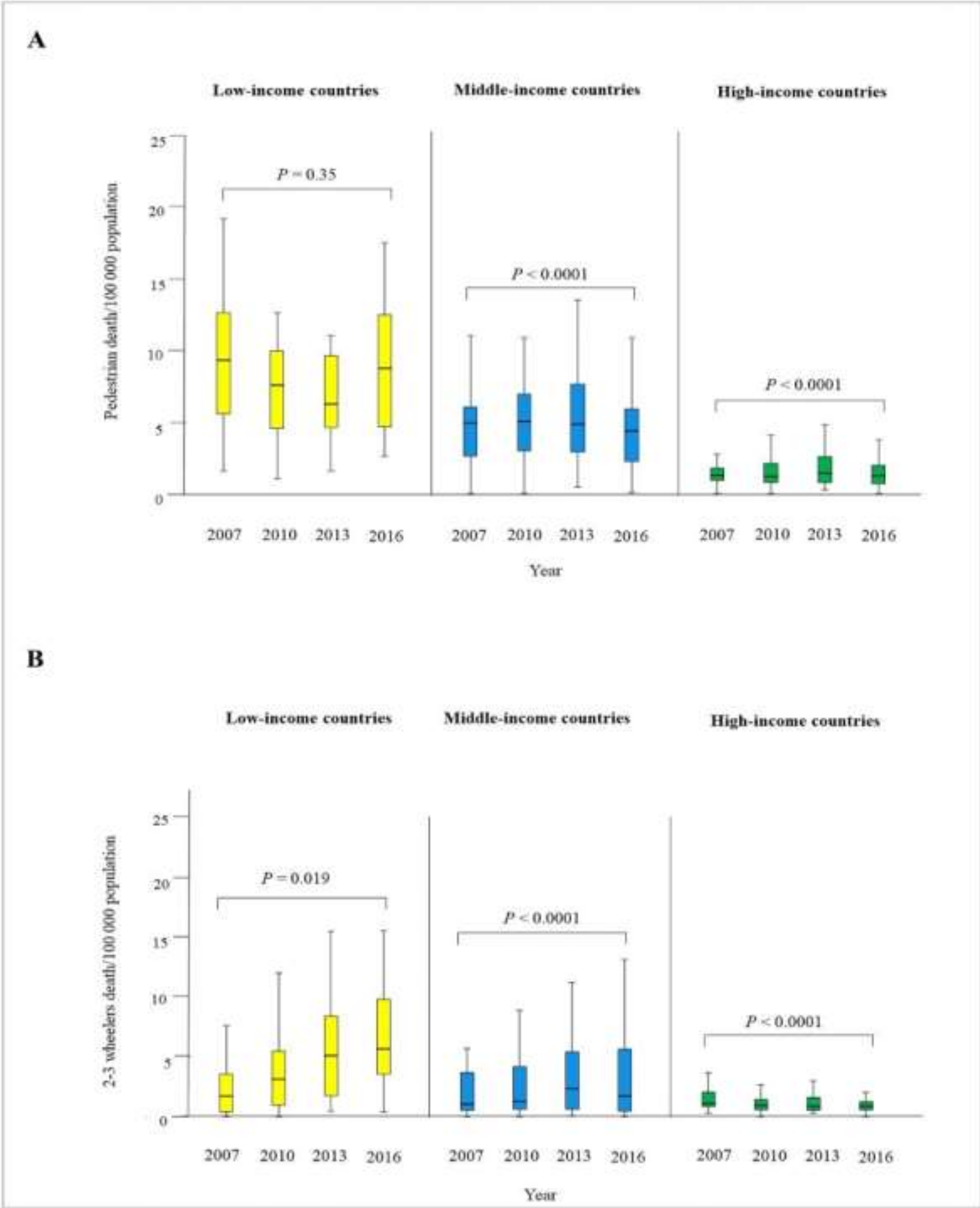

Figure 3: Global pedestrian and motorized 2-3-wheeler-related death rates per 100,000 population of years 2007–2016 by level of income of countries.

Box-and-whiskers plot of (A) global pedestrian death rate/100,000 population (B) global motorized 2-3-wheeler-related death rate per 100,000 population of years 2007–2016 by level of income of countries. The box represents the 25th percentile and the 75th percentile Interquartile Range (IQR). The line within the box represents the median. P-value = Friedman test for comparison of more than two dependent groups.

Table 3: Linear mixed effect model of factors affecting log transformation of pedestrian death rate globally over a decade 2007-2016.

Variable	Estimate	Standard error	*t*-value	*p*-value	95% CI lower limit	95% CI upper limit
Year 2007	0.069	0.032	2.155	0.034	0.006	0.133
Year 2010	0.046	0.024	1.876	0.064	-0.003	0.094
Year 2013	0.075	0.024	3.190	0.002	0.029	0.122
Gross national income/capita	-7.893^{-6}	1.428^{-6}	-5.526	< 0.0001	-1.071^{-5}	-5.078^{-6}
Enforcement of speed legislation	-0.007	0.006	-1.163	0.246	-0.019	0.005
Promoting alternative transport	-0.021	0.014	-1.525	0.128	-0.048	0.006
Density of population	-2.143^{-5}	1.231^{-5}	-1.742	0.084	-4.578^{-5}	2.914^{-6}
Vehicle / person ratio	-0.441	0.091	-4.855	< 0.0001	-0.619	-0.262
Intercept	0.781	0.049	15.985	< 0.0001	0.685	0.879

CI confidence interval

Table 4: Linear mixed effect model of factors affecting log transformation of motorized 2-3-wheeler-related death rate globally over 2007–2016.

Variable	Estimate	Standard error	*t*-value	*p*-value	95% CI lower limit	95% CI upper limit
Year 2007	0.017	0.130	0.133	0.896	-0.266	0.301
Year 2010	0.059	0.100	0.591	0.558	-0.144	0.262
Year 2013	-0.003	0.083	-0.041	0.968	-0.170	0.163
Density of population	5.779^{-5}	5.536^{-5}	1.044	0.302	-5.370^{-5}	0.169^{-3}
GNI	-1.220^{-5}	5.239^{-6}	-2.329	0.025	-2.280^{-5}	-1.602^{-6}
Vehicle per person ratio	0.545	0.489	1.114	0.268	-0.427	1.517
Motorized 2-3 wheelers/person ratio	7.851	1.725	4.552	0.000	4.433	11.270
Enforcement of speed	-0.039	0.023	-1.666	0.103	-0.087	0.008
Enforcement of helmet	0.011	0.021	0.531	0.599	-0.031	0.053
Percentage of helmet wearing rate	-0.004	0.002	-2.047	0.046	-0.008	-7.898^{-5}
Vehicle/person ratio * motorized 2-3 wheelers/person ratio	-4.792	1.953	-2.454	0.016	-8.667	-0.916
Intercept	0.637	0.249	2.558	0.012	0.143	1.131

CI confidence interval

4.3 Effects of Trauma System Development on Hospitalized Motorcycle Injured Patients (Paper IV)

There were 68 hospitalized motorcycle injured patients during the First period and 94 patients during the Second period. This gives an annual incidence for the First and Second periods of 6.2/100,000 and 3.9/100,000 population respectively, hence a decrease of 37.1%. There were no significant differences in age, gender, nationality of patients, or mode of arrival. However, there were significant differences in incident location between the two periods ($p = 0.02$, Fisher's Exact test), with relatively fewer street/highway injuries during the second period (69.1% compared with 85.3%), and more injuries in areas such as homes (7.4% compared with 0%), workplaces (3.2% compared with 0%), and public areas (4.3% compared with 0%) (Table 5). The anatomical injury severity of the head increased significantly over time ($p = 0.03$) (Table 6), while GCS on arrival significantly improved ($p < 0.001$) (Table 7), indicating improvements in prehospital care. The mortality of hospitalized motorcycle-related injured patients decreased significantly during the second period (0% compared with 6%, $p = 0.002$, Fisher's Exact test).

Table 5: Demographic characteristics and incident location of hospitalized motorcycle-injured patients during the period 2003 – 2006 (n = 68) and 2014 – 2017 (n = 94), Al-Ain Hospital, Al-Ain United Arab Emirates.

Variable	**Years 2003-2006 (n = 68)**	**Years 2014-2017 (n = 94)**	***p*-value**
Age (years)	27 (4 – 64)	27.5 (3 – 86)	0.49
Gender			0.99
Male	66 (97.06%)	90 (95.74%)	
Nationality			0.87
UAE nationals	26 (38.24%)	34 (36.17%)	
Non-UAE	41 (60.29%)	58 (61.7%)	
Incident location			0.02
Home	0 (0%)	7 (7.4%)	
Street/highway	58 (85.3%)	65 (69.1%)	
Workplace	0 (0%)	3 (3.2%)	
Off-roads	10 (14.7%)	14 (14.9%)	
Public area	0 (0%)	4 (4.3%)	
Other	0 (0%)	1 (1.1%)	
Mode of arrival			0.16
Ambulance	42 (61.76%)	61 (64.89%)	
Private car	26 (38.24%)	22 (23.40%)	

Data are presented as number (percentage) or median (range), p-value = Fisher's Exact test, or Mann–Whitney U test as appropriate

Table 6: Comparison of injured anatomical regions of motorcycle-related injured hospitalized patients during the period 2003–2006 (n = 68) and 2014–2017 (n =94), Al-Ain Hospital, Al-Ain, United Arab Emirates.

	Anatomical region			Abbreviated Injury Scale (AIS)		
Region	**Years 2003 - 2006 (n = 68)**	**Years 2014 - 2017 (n = 94)**	***p*-value**	**Years 2003 - 2006 (n = 68)**	**Years 2014 - 2017 (n = 94)**	***p*-value**
Head	24 (35.3%)	18 (19.2%)	0.03	1.5 (1 – 4)	3 (1 – 5)	0.03
Face	20 (29.4%)	19 (20.2%)	0.20	1 (1 – 2)	1 (1 – 2)	0.13
Neck	0 (0%)	9 (9.6%)	0.01	—	1 (1 – 1)	—
Chest	14 (20.6%)	22 (23.4%)	0.71	2 (1 – 3)	2 (1 – 4)	0.95
Abdomen	3 (4.4%)	12 (12.8%)	0.10	1 (1 – 2)	2 (1 – 3)	0.63
Spine	5 (7.4%)	10 (10.6%)	0.59	2 (2 – 2)	2 (1 – 2)	0.99
Upper extremities	35 (51.5%)	41 (43.6%)	0.34	1 (1 – 2)	2 (1 – 3)	0.0001
Lower extremities	32 (47.1%)	45 (47.9%)	0.99	2 (1 – 3)	2 (1 – 3)	0.51

Data are presented as number (percentage), p-value = Fisher's Exact test

Table 7: Injury severity markers of motorcycle-injured hospitalized patients during the period 2003–2006 (n = 68) and 2014–2017 (n = 94), Al-Ain Hospital, Al-Ain, United Arab Emirates.

Variable	**Years 2003-2006 (n = 68)**	**Years 2014-2017 (n = 94)**	***p*-value**
SBP mmHg	138 (96 – 180)	135 (94 – 197)	0.54
Heart rate (bpm)	90 (60 – 155)	88 (62 – 168)	0.79
RR per minute	22 (15 – 27)	18 (12 – 28)	0.11
GCS*	15 (3 – 15)	15 (5 – 15)	< 0.0001
	13.29 (3.69)	14.69 (1.52)	
ISS	4 (1 – 29)	5 (1 – 41)	0.04
NISS	5.5 (1 – 41)	9 (1 – 41)	0.01
ICU stay (days)	4 (1 – 19)	0 (0 – 32)	< 0.0001
Ventilation (days)	1.5 (0 – 12)	0 (0 – 32)	< 0.0001
Total hospital stay (days)	5 (1 – 79)	4 (2 – 43)	0.12
Death	4 (5.9%)	0 (0%)	0.002

Data are presented as number (percentage) or median (range), p-value = Fisher's Exact test, or Mann–Whitney U test as appropriate
SBP systolic blood pressure, RR respiratory rate, GCS Glasgow Coma Scale, ICU intensive care unit, ISS Injury Severity Score, NISS New Injury Severity Score, bpm beats per minute
**GCS presented both as median (range) and mean (SD)*

4.4 Impact of COVID-19 Pandemic on RTC Injured Hospitalized Patients (Paper II)

There were 750 hospitalized RTC trauma patients before the pandemic and 499 patients during the pandemic. This gives the annual incidence of RTC hospitalization of 97.9/100,000 population in the pre-pandemic period and 65.1/100,000 population during the pandemic period. There was a 33.5% reduction in annual RTC hospitalization in Al-Ain City. Figure 4 shows results of time series analysis for the weekly number of hospitalized RTC patients. The model shows there was a significant change in the number of hospitalized RTC patients being significantly less in the COVID period, with a low R squared ($p < 0.028$, exponential smoothing model, R = 0.228). That R square indicates that model only explains 28% of the variation of the data. Notably, the largest reduction was in the first five months (April-August 2020, Figure 5) when there was a lockdown with severe restriction of outdoor movement.

Only 3 RTC patients were COVID-19 positive during the study period. They had non-threatening limb fractures and soft tissue injuries. They were transferred to Al-Ain Hospital (the COVID-19 hospital) for further care; all survived and were discharged home. The mechanism of injury varied significantly between the two periods ($p < 0.001$, Fisher's Exact test). There were fewer motor vehicle collisions (MVCs) during the pandemic (60.5% compared with 72%) while there were more motorcycle injuries (23.3% compared with 11.2%). The mortality of hospitalized RTC patients was significantly higher during the pandemic (4.4% compared with 2.3%, $p = 0.045$, Fisher's Exact test) (Table 8). Significant factors that predicted mortality included low GCS ($p < 0.001$) admission to the ICU ($p < 0.001$), and high ISS ($p = 0.045$). During the COVID-19 pandemic there was a strong tendency ($p = 0.058$) for increased mortality (Table 9).

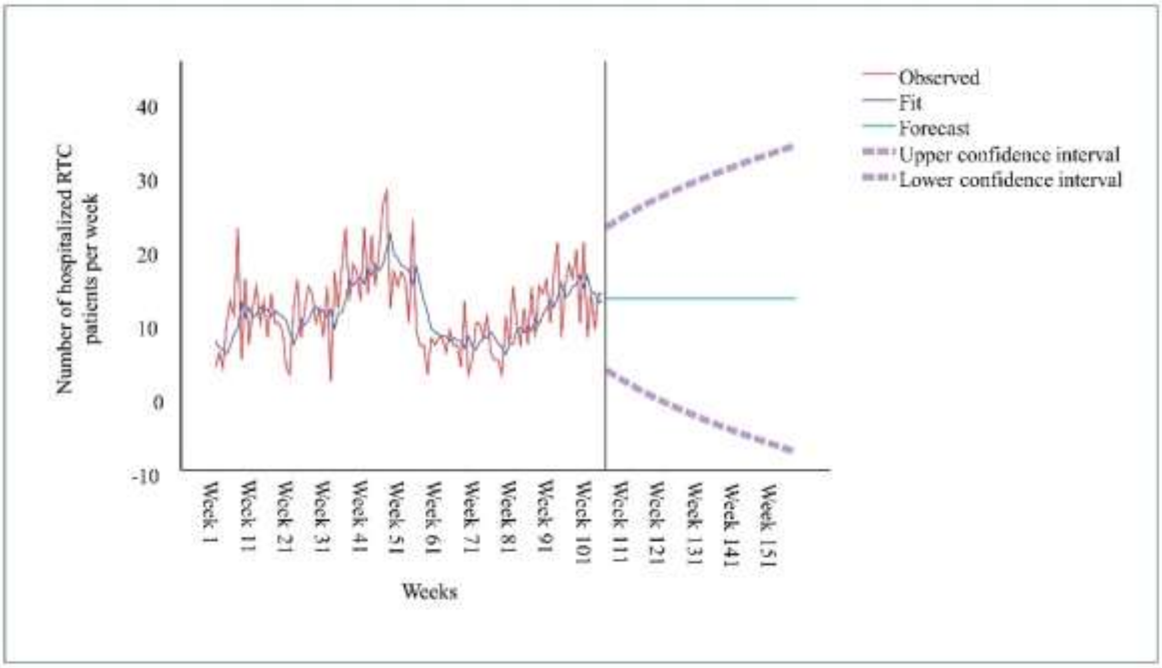

Figure 4: Results of time series analysis for the weekly number of hospitalized road traffic collision trauma patients during the periods March 2019–February 2021, in Al-Ain City, UAE.

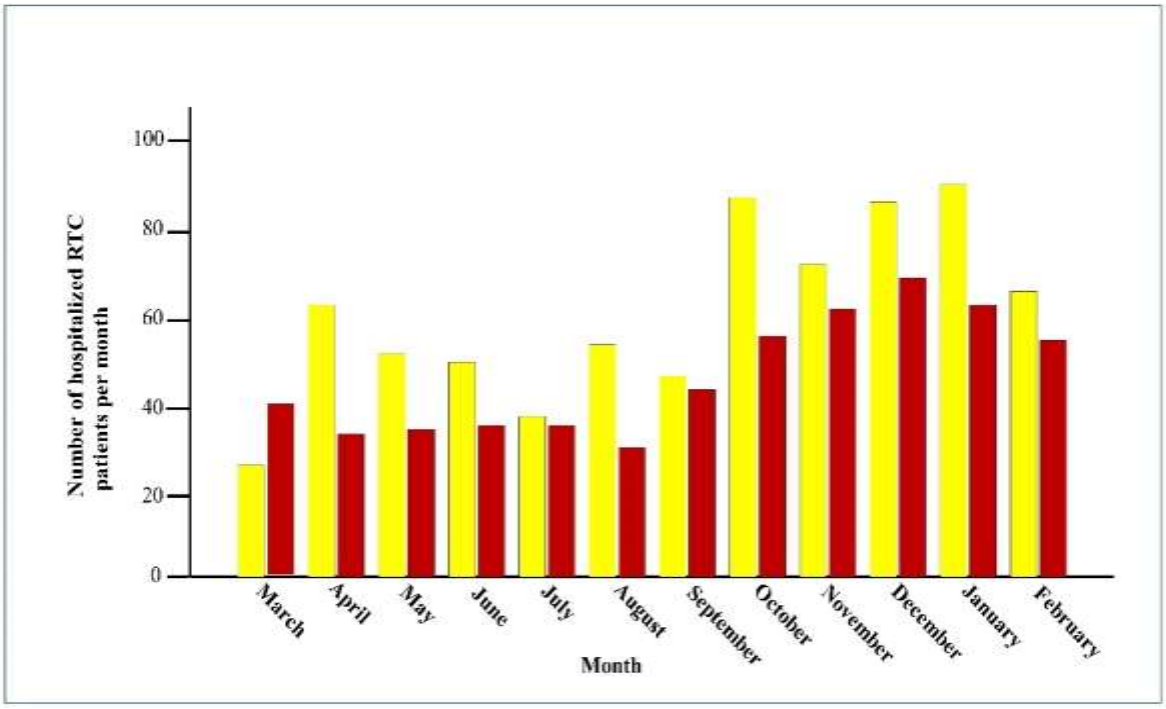

Figure 5: Monthly number of hospitalized road traffic collision trauma patients during the periods March 2019–February 2020 (yellow bars) and March 2020–February 2021(red bars), in Al-Ain City, UAE.

Table 8: Demography of hospitalized patients involved with road traffic collision during the periods of March 2019-February 2021 in those who survived (n= 1210) and those who died (n= 39), in Al-Ain City, United Arab Emirates.

Variable	Alive (n=1210)	Dead (n=39)	*p*-value
Age	29.7 (5.7)	27.6 (14.7)	0.56
Male	996 (82.3)	33 (84.6)	0.83
Nationality			0.87
United Arab Emirates	562 (47.6)	16 (45.7)	
Non-UAE	618 (52.4)	19 (54.3)	
Mechanism of injury			0.03
Motor vehicle collision	816 (67.4)	26 (66.7)	
Motorcycle	196 (16.2)	4 (10.3)	
Bicycle	77 (6.4)	0 (0)	
Pedestrian	121 (10)	9 (23.1)	
Mode of arrival			0.06
Ground ambulance	996 (82.5)	35 (89.7)	
Private car/walking-in	190 (15.7)	2 (5.1)	
Helicopter ambulance	21 (1.7)	2 (5.1)	
Period			0.045
Pre-COVID	733 (60.6)	17 (43.6)	
COVID	477 (39.4)	22 (56.4)	

Data are presented as mean (SD) for continuous data and number (percentage) for categorical data
p-value = Mann–Whitney U test or Fisher's Exact test as appropriate

Table 9: Backward logistic regression model defining the significant factors affecting RTC mortality during the periods of March 2019 – February 2021, Al Ain City, United Arab Emirates.

	Coefficient	**Standard error**	**Wald**	***p*-value**	**OR**	**OR 95% CI lower limit**	**OR 95% CI upper limit**
GCS	-0.82	0.14	35.54	< 0.0001	0.44	0.34	0.58
ICU admission	-4.46	1.22	13.36	< 0.0001	0.01	0	0.13
ISS	0.08	0.04	4.00	0.045	1.08	1	1.16
Pandemic period	1.48	0.78	3.60	0.058	4.37	0.95	20.05
Constant	3.94	1.65	5.74	0.017	51.42		

GCS Glasgow Coma Scale, ICU intensive care unit, ISS Injury Severity Score, OR odds ratio, CI confidence interval

Chapter 5: Discussion

The overall aim of this dissertation was to define factors affecting changes in RTC-related injuries and deaths at global and UAE levels over time. Papers I and III are global studies, while papers II and IV are UAE level studies. In this chapter, the validity of the data sources, epidemiological data and methodological issues related to study designs followed by the main findings of each study together with their limitations will be discussed.

5.1 Validity of Data Source

The two global papers (I and III) are based on data from WHO GSRRS [6, 7, 9, 10], which are publicly available data sources. The data are collected as part of monitoring the progress towards the UN target, following the implementation of the Decade of Action for Road Safety 2011 – 2020 [2, 93]. The WHO GSRRS, comprise country level data on road traffic deaths by road user types with a set of baseline covariates, and are published every 2 – 3 years in accordance with regular routines. Papers II and IV are UAE level studies based on prospectively collected data from the trauma registries of Al-Ain and Tawam Hospitals. Such registries provide useful and reliable sources of information on injury patterns in the population groups [210]. Nevertheless, the gap in registry between 2007 and 2014 due to financial constraints may contribute to unmeasured injuries in the study population (Paper IV).

5.2 Epidemiological Data and Study Designs

5.2.1 Repeated Measures Data and Longitudinal Study Design

Longitudinal data, comprising repeated measurements are common in clinical and public health research [194, 196, 197, 211–214]. They are multiple measurements of the same outcome variable over time on the same experimental unit [194, 196]. Such data are collected for several reasons including to obtain more precise estimates of the outcome variables across observations, for monitoring purposes, and to evaluate the effect of interventions over time [211].

In papers I and III, we used data from WHO reports for the years 2007, 2010, 2013, and 2016, published in 2009, 2013, 2015, and 2018, respectively [6, 7, 9, 10], because they are repeated measures of estimated pedestrian and motorized 2-3-wheeler user deaths, with a set of baseline covariates over time for each participant country in each reporting year. These reports cover the period 2007 to 2016.

The advantages of using data from WHO reports are numerous. First, they are publicly available data. Second, they provide precise estimates across observations over time. Third, WHO-estimated road traffic deaths are more accurate than government-reported road traffic deaths because WHO-estimated road traffic deaths were calculated based on adjustments made to account for potential under-reporting. This consideration resulted in WHO-estimated road traffic deaths being much higher than official government statistics [6, 7, 9, 10]. Fourth, these WHO data are verified and validated against source documents for logical inconsistencies by the respective National Data Coordinators and governments of each participating country [6, 7, 9, 10].

Nevertheless, WHO reports are not without limitations. Firstly, the WHO estimates may carry risks resulting from theoretical assumptions and modeling [115, 215, 216]. Secondly, there were some missing data, which may be for several reasons, such as skipped assessments, withdrawal (discontinuity/dropouts), loss to follow-up, or omitting date of report (observation) [194, 196, 211].

The longitudinal study with repeated measures of data is popular for examining changes in outcome over time and for comparing these changes among participating countries [194, 195, 212, 217]. Additionally, it is useful to define and relate events to particular factors or exposures, and reduces some potential bias like recall bias [217]. However, missing data is common in longitudinal studies and may affect the validity of the results and the power of studies [194, 196, 211]. Fortunately, most advanced statistical analyses control for incomplete data [214, 218] and avoid bias related to both small and large samples [219].

Paper I and Paper III were based on longitudinal studies. We used a mixed linear model (MLM) to assess the factors affecting global pedestrian death rates and motorized 2-3-wheeler user death rates over time. The MLM model used was a strict unstructured, unbalanced, main-effects model with repeated measures. The main advantage of using this model was to accommodate missing data or incomplete data [196, 212]. This model can also reduce bias resulting from sample size (small or large sample size) [219], measurement error, confounding, and selection bias [214].

The term “longitudinal data” should not be confused with the term “continuous measurements/observations” over time as used in other studies [194, 211]. Nor should “continuous measurements/observations" be confused with the type of “continuous” data used in statistical analysis. The term “longitudinal data” must be used with caution, otherwise it may be misinterpreted/misused as “continuous measurements/observation” over prolonged periods of time – often years or decades [196, 217]. Similarly, caution is needed for the terms “repeated measurements or multiple measurements” over time, which otherwise may be misinterpreted/misused as “repeated measurements or multiple measurements” at a point in time [196, 197]. Furthermore, the term “longitudinal data” should not be confused with the term “longitudinal databases” as used in trauma registries [39, 220] because data in these databases are not repeated measures over time on the same individual. Instead, trauma registries are independent continuous observations/measurements.

5.2.2 Trauma Registry Data and Prospective Study Design

Trauma registries have been recognized as useful clinical databases since their inception [220–225]. They are designed to document patient information, which can be used for several purposes, including quality improvement, epidemiology, planning, policy, and clinical research [220, 224–229]. As a valuable source of information, a significant number of trauma registry-based studies have been done in many countries worldwide for many years [226, 227, 230–233]. There has been an increase in trauma research recently although many studies are observational studies with low research evidence [232]. The American College of Surgeons Committee on Trauma (ASCOT) first studied injured patients using trauma registry data in the Major Trauma Outcome Study (MTOS) in 1982 [234]. The MTOS was a pioneering study in the history of trauma registry-based research [234].

Papers II and IV are UAE level studies. They are based on trauma registry data collected prospectively to help clarify RTC problems at the local level, with the particular emphasis on RTC-related injuries and deaths which occurred during the COVID-19 pandemic, and motorcycle-related injuries and deaths that occurred after the establishment of a trauma system.

We used the trauma registry data because they are inexpensive, and straightforward to collect and retrieve; they provide reliable data; they are useful in evaluating trauma outcomes; and they facilitate generalizability of findings [223, 227, 232, 235]. Nevertheless, they are not without shortcomings. Recoding errors, missing entries, keystroke errors and misclassification of variables may limit data quality in terms of completeness, accuracy, consistency and validity [224, 226, 227, 236].

Variability among trauma centers is common. There may be variability in terminology, data collection, collected variables, inclusion and exclusion criteria, data cleaning strategies (validated versus non-validated data), data collectors (trauma trained registrars versus health information specialist), registry software, and/or computerized versus filled repository [223, 226].

Different study designs can be utilized in trauma registry-based studies [230, 232, 237, 238], but most studies were predominantly retrospective [226, 232]. For example, MTOS was a retrospective study based on retrospectively collected data [223, 234]. On the other hand, studies that utilized the National Trauma Data Bank (NTDB), established by ASCOT in 1989, were based on prospectively collected data [223, 227]. Similarly, papers II and IV were based on prospectively collected data as supported by other studies [223, 227], but the analysis was retrospective. This indicates that the two distinct terms ‘retrospective’ and ‘prospective’ can both be applied in one study because registries can be prospective regarding the collection of data and retrospective with regard to analysis of data [230].

As noted earlier, there is much variation in data collection among trauma centers. In some centers, data are collected retrospectively [223, 234], while in others prospectively [223, 226, 236]. For example, the MTOS data were collected retrospectively [223, 234], while the NTDB data are collected prospectively [223]. Furthermore, data can also be collected prospectively either at one time point or at multiple time points [230]. For example, data on age, sex, nationality, and mechanisms of injury are collected at one time point, while data on symptoms are collected at multiple time points [230].

It is also important to note that although trauma registries provide a longitudinal database for analysis, there is a lack of longitudinal studies using trauma registry data [239]. There is also common confusion in classifying the design of trauma research as trauma registry-based study [230, 237]. "Trauma registry-based study" on its own is not a study design because registries have no inherent design features [230]. For this reason, the selection and classification of study design for trauma registry research must follow the general rules and principles of epidemiological study design, which are based on design features such as time points, methods of data collection (sampling method/technique), definition of study groups, number of groups (source population), source of data, measurements before and after intervention, outcome measurement, and analysis [230, 237].

5.3 Main Findings of the Studies

5.3.1 Pedestrian Death Rates (Paper I)

Global pedestrian mortality has dropped by more than 25% over the recent decade. This fall is affected by GNI which is reflected in the vehicle per person ratio. However, the reduction is not consistent across all countries: it was greater in middle- and high-income countries (MHICs) compared with the LICs. Pedestrian injuries cause 23% of RTC mortality worldwide [6], yet 45%, of these deaths occurred in LICs compared with 29% and 18% in MICs and HICs respectively [240]. The decrease in mortality by 25% over the recent decade indicates partial success of the global plan, as the defined target of 50% was not reached. It is predicted that pedestrian deaths will increase in LICs and decrease in MHICs in the coming 10 years, with an overall global decrease of 10% [21]. In this study, high GNI was an important factor in reducing pedestrian deaths. This is because an increase in GNI increases the number of motor vehicles [130] and improves the construction of safer roads with signaled pedestrian crosswalks, humps, and road traffic cameras [129, 131, 132]. The increased vehicle per person ratio is associated with reduced pedestrian road user numbers and reduced pedestrian death rates. GNI is associated with a long-term decrease in road traffic deaths because of economic development, despite the initial early increase in deaths [241]. This is attributed to there being an increased number of transport users at the beginning of the economic transition [22]. Following the period of economic development, investment in the health care system such as pre-hospital transportation, trauma centers, surgical care, and rehabilitation will reduce pedestrian deaths [241, 242]. Our study is similar to other studies, showing that increased GNI reduces pedestrian death rate [17, 243]. Nevertheless, this was not consistent through the whole decade. There was a slowdown of this effect during the period 2010–2013, possibly related to the economic slowdown during that period. Furthermore, our previous study showed that speed control and decreased population density significantly reduced pedestrian death rates [17] a finding supported by others [4, 244]. This effect is not observable in the current study. This indicates that these effects have stabilized over time and other important factors were recognized.

We have to acknowledge that our study has certain limitations. Firstly, our analysis depended on the WHO reports. The availability and accuracy of this data can be affected by the political agenda and the health informatics infrastructure [14, 245, 246]. This may affect our estimation. The World Bank highlighted a profound difference between government-reported road traffic deaths and WHO-estimated road traffic deaths, with under-reporting by 84% in LICs, 51% in MICs, and 11% in HICs [115]. Understandably, under-reporting of VRU deaths is particularly high in official reports [247–249]. We have used the estimated death rates of the WHO reports as it is more accurate. Nevertheless, this carries the risk of theoretical assumptions and modelling and may lead to biased estimation. Secondly, publishing WHO reports takes up to 3 years. The report for the most recent 3 years has not yet been published and is therefore not included in our current analysis which limits the generalizability. This is directly related to the effects of the COVID-19 pandemic, as most WHO resources were used to address pandemic challenges. We are awaiting this global report as it may highlight the impact of the COVID-19 pandemic on RTC safety [20]. Thirdly, GNI is a single collective factor that reflects other embedded factors such as education, road user behavior, and risk perception of danger [17]. And may confounded with other variables. Finally, the WHO reports included limited variables. Certain key individual factors are missing, such as educational level, gender, age, alcohol use [8, 250, 251], use of visibility aids at night [252], pedestrian behavior [67, 253], and pedestrian friendly vehicle bumpers [254, 255]. This may limit factors predicting mortality. Nevertheless, this is a global study on country levels, not individual levels, and such factors are difficult to quantify at this level.

5.3.2 Motorized 2-3-Wheeler-Related Death Rates (Paper III)

Our study has shown that there was no significant reduction in global motorized 2–3 wheeler-related death rates over the studied period: the rate in fact increased by a relative ratio of 1.36. The UN target was not met. The death rate increased because of the increase in motorized 2–3 wheelers and was reduced by helmet compliance and wealth. Nevertheless, there were significant differences in death rates between the three income levels of countries, with a relative ratio increase of 2.52 in LICs and 1.46 in the MICs, while it decreased by a relative ratio of 0.72 in HICs. These variations in the direction of change between the three levels of income of countries explain why there was no overall significant global difference in death rates when data were combined. Other studies showed that the UN target was not met [3–5] and even suggested that mortality from motorized 2–3 wheelers could increase globally by 11% over the coming 10 years [21]. In our study, increased death rates were related to increased motorized 2–3 wheeler use a finding supported by others [18, 256, 257]. The use of motorized 2–3 wheelers increase the chances of mortality from 2–3-wheeler-related injuries [18, 63]. Low GCS, indicating severe head injury, is one of the most important factors predicting mortality in RTCs [40, 258].

The increased GNI reduced the overall mortality overtime in our study. Overall mortality depends on multiple factors that are correlated to each other. Finding a significant single univariate correlation with mortality is not enough to indicate that it is a predictor of mortality because it can be a confounder of another factor. Although an increase in GNI significantly increased the number of 2–3 wheelers, it was highly correlated with an increase in helmet use in the population within each studied year. It is also possible that motorcycle drivers in HICs respect the speed limits and follow traffic regulations more strictly, which reduces collision and death rates. Nevertheless, the mixed linear model is a strong model which depends on the slope of change within each country, can compensate for the missing data, and will consider all these interactions to properly define predictors of mortality. Several previous studies showed that the increase in motorized 2-3-wheeler per person ratio is associated with an initial rise of GNI. This ratio declines later when the GNI increases further. Cars will be preferred at this stage because they are safer and more comfortable [116, 257, 259–261]. The increased GNI is also related to the effective implementation of road safety regulations (including helmet laws), and improvement in medical care [259, 262].

Our study has certain limitations. Firstly, our analysis was based on the WHO reported data on motorized 2-3-wheeler-related mortality and other covariates. This may affect the estimated results and omit potential factors affecting mortality. Secondly, the WHO reports take up to 3 years to publish and due to this the report for the most recent 3 years is not included in our analysis. This may limit the generalizability. Thirdly, some important risk factors related to road traffic deaths were not included in this analysis, such as driver behavior, age, gender, drug/alcohol use, educational level, riding experience, and using visibility aids [63, 263]. Our study is based on country level rather than individual level data. The factors that apply to a particular person are difficult to quantify at a country level. Fourthly, the GNI is a single collective factor with varying effects at different stages of economic development. Although GNI in general was associated with reduced motorized 2–3 wheeler user deaths in our study, the rise of GNI at early stages would increase motorized 2–3 wheeler per person ratio, while enforcement of safety regulations usually follows the initial increase in mortality. Finally, data on other safety devices that can reduce motorcycle-related deaths, such as Anti-Lock Brake Systems which may enable the driver to stop within a short distance [264, 265] were missing. We were limited to the data available in the WHO reports where these data were not available.

5.3.3 The Reduction of Motorcycle-Related Deaths Over 15 Years in a Developing Country (paper IV)

Our study has shown a significant improvement in the outcome of hospitalized motorcycle-related injured patients over the last 15 years. The anatomical injury severity of the head doubled: meanwhile, GCS on arrival improved. This indicates better prehospital and in-hospital trauma care. Mortality decreased from 6% to none. Furthermore, the incidence of motorcycle-related injuries dropped by almost 40% in Al-Ain city, indicating improvements in injury prevention in the city. These findings highlight the impact a developed trauma system may have on reducing the injury incidence and improving the clinical outcomes of motorcycle-related injured patients.

Globally, motorcycle-related deaths represent a quarter of all RTC deaths [6, 7, 9, 10, 77]. However, the rate is expected to increase by 11% worldwide over the coming 10 years [21]. The United Nations' global aim was to reduce road traffic deaths by half during the decade 2011 to 2020 [2]. Interestingly, this was achieved in our setting [19, 179, 180] but not globally (Paper III). The effect size and time of improvement vary between different countries [179, 180]. The effect size in our study is large compared with a multicenter study from Israel which showed mortality reduced by 43% [19]. However, our study was based on data from a single hospital. These results can be attributed to improvements in the EMS prehospital care in Abu Dhabi Emirate [19, 103], which was evidenced by the improved GCS of injured patients on arrival. The reduced mortality, despite the increased anatomical severity of head injuries, reflects the improvement in trauma care within Al-Ain hospital over the last 15 years. These developments include establishing a trauma team to attend each major trauma; following a trauma management protocol; 24 hour availability of a 16-slice CT scanner and radiologist adjacent to the Emergency Department; development of a trauma CT protocol; availability of 24/7 angioembolization suite run by expert interventional radiologists; presence of an on-call neurosurgical team; establishing an expanded state-of-the-art intensive care unit that follows well-developed guidelines; collecting data on trauma management; continuous clinical audit; and following a quality improvement program.

Over the last two decades, there have been tremendous improvements in injury prevention measures in the UAE. These included enforcement of safety regulations (such as helmet and speed law enforcement), use of safety devices (such as helmet usage), installation of road speed cameras, penalties for speeding violations, and educational programs [6, 7, 9, 10, 98, 100]. This explains the 25% reduction in the percentage of head injuries in the second period in our study. Although the population in Al-Ain city previously used fewer motorcycles compared to four-wheel vehicles [33, 40], we have observed a recent increase in their use as a cheap transportation mode and food delivery tool. The motorcycle-related death rate increased sharply in the UAE from 2013 to 2016, which cannot be explained by the slight increase in the number of motorcycles used in the UAE [6, 7, 9, 10]. The modernization, improvement, and maturity of our trauma system in all its components contributed to improved clinical outcomes in the current study [37].

The increased severity of head injuries in our study may indicate low helmet compliance, low-quality helmets, or improperly fastened helmets [266–268]. Collisions on high-speed streets/highways became less frequent and increased in low-speed residential areas, which may explain this finding because riders may be less careful about using their helmets in these areas. Developing an injury prevention strategy to address the concerns regarding the quality of the helmets and collisions in the residential areas is essential.

It may be surprising to note that around 7% of motorcycle-related injuries in Al-Ain city occurred at homes in the second period. Al-Ain City is unique. Despite the small its population, it covers a large area approximately 30 × 20 kilometers. Houses in residential areas are limited in height to a maximum of four storeys and they have large walled areas around them. These are not public areas and are considered legally to be part of the homes. Motorcycles, which are commonly used for sport activities or for food delivery, enter the areas inside the walls and may be involved in crashes causing injuries. Understandably, developing an injury prevention strategy for these specific crashes needs thorough understanding of the context, following which special educational campaigns and interventional policy legislation could be tailored and introduced.

This study has certain limitations. Firstly, it is based on the data obtained from a single hospital, which limits its generalizability to the whole of the UAE. Secondly, there was a gap in the trauma registry from 2007 to 2014 due to a lack of research funding at that time. This may contribute to unmeasured injuries and affect our estimation. Thirdly, some key data was missing from trauma registry, such as data on use of special safety gear (helmet, personal protective safety clothing and boots) at the time of the incident in addition to circumstances which led to the crash. In addition, we did not evaluate other important factors such as rider behavior, rider experience, presence of passive safety technology on the motorcycle (for example, Anti-Lock Brake systems), biomechanism of injury, and road characteristics, which would have provided further insight into the cause of injury and mortality. This may omit potential factors predicting mortality. Fourthly, the study was based on a small sample size which may give rise to type II statistical errors and may affect the analysis and validity of results. However, these patients represent the majority of those treated following RTC over seven years in Al-Ain city, home to three quarters of a million people. Further, this small sample enabled us to collect, analyze and infer high-quality statistical parameters with a minimum of missing data. Finally, the study did not include patients treated at the emergency department who were discharged home following treatment, or those with minor injuries who did not seek any medical advice, and those who died on the spot at the accident scene, which may entail the risk of selection bias.

5.3.4 Impact of COVID-19 Pandemic on RTC Injured Hospitalized Patients (Paper II)

Our study has shown that the COVID-19 lockdown measures reduced the annual incidence of RTC hospitalization by 33.5%. The mortality of hospitalized RTC patients doubled during the COVID-19 pandemic. Both the absolute number and relative proportions of motorcycle injuries increased during the pandemic compared to motor vehicle collisions where numbers and proportions fell. Although the absolute numbers of bicyclist and pedestrian injuries decreased, their relative proportions remained almost the same compared with other road users.

The reported decline in the incidence of RTCs varied in different studies. Although some studies reported some reduction in the incidence [269–271], others found that it did not change [272, 273]. Similarly, the incidence of bicyclist injuries in other studies varied depending on whether the use of bicycles was encouraged as the preferred mode of exercise/transport during the pandemic [271, 274–277].

There were fewer motorcyclists, bicyclists, and pedestrians in the UAE compared with 4-wheel vehicle users before the COVID-19 pandemic [40], which is reproduced in the current study. Commercial food delivery was allowed during the pandemic, predominantly using motorcycles, which explains the increased incidence of motorcycle injuries. The changes in the mechanisms of injury during the pandemic are obviously related to the restrictions on motor vehicle use [278–280]. Furthermore, there was a significant decrease in the number of hospitalized UAE nationals. In fact, most UAE nationals, who commonly work as government officials, opted to comply with restrictions and stay at home during the lockdown. In contrast, most non-UAE nationals work as manual workers in essential daily duties and, contrary to the nationals, had to continue to work as usual. Police reports from other UAE emirates support the findings of our current study. Road traffic collisions declined in Sharjah by 84% [281], in Dubai by 46% [282], and in Ajman by 45% [283]. These reductions in turn reduced road traffic deaths to zero in Sharjah [281], by 42% in Dubai [282] and by 33% in Ajman [283].

Numerous studies worldwide demonstrated a reduction in the incidence of RTCs and hospitalization rate during the COVID-19 pandemic restrictions [278, 279, 284–287], together with an overall decline in the number of RTCs presentations in trauma centers worldwide [286].

However, the mortality of hospitalized RTC trauma patients doubled during the pandemic. This is most probably related to the difference in health care provision between the two periods [156, 166–170]. We anticipate that during the COVID-19 period the delay to admissions when waiting for patients' PCR results (around 4 hours on average) had a negative effect on patients' outcomes especially for severely injured patients needing admissions to the ICU. This association showed a strong tendency in the logistic regression model ($p = 0.058$) but which did not reach statistical significance possibly due to the small sample size (Type I statistical error).

Systolic blood pressure and respiratory rate were significantly worse during the pandemic in our study, although ISS and GCS were unchanged. Other authors reported significant changes both in the anatomical and physiological markers of injury severity between the two periods [270, 271, 288]. Our current study has shown that low GCS, higher ISS, and admission to ICU are the most significant clinical predictors of mortality among RTC injury patients who died following admission, similar to the findings reported in studies undertaken before the pandemics [37, 193, 289].

We acknowledge that our study has certain limitations. Firstly, the reduction in numbers of RTC patients during the COVID-19 pandemic may not be solely due to COVID-19 lockdown measures but also as a continuation of the decreasing trend of RTCs in Al-Ain city over the last decade [37]. This may affect the estimation of relationships. Secondly, the data for this study came from a single city in the UAE and may not represent the whole UAE. This limits the generalizability of the finding. Thirdly, our study did not include RTC trauma patients treated in the emergency department who were discharged home, nor those having minor injuries who did not seek medical advice, or those who died on the scene. This may cause biased estimate resulting from the risk of selection bias.

Fourthly, our study does not indicate that the pandemic increased mortality of RTCs, despite the strong tendency, due to the relatively small sample size. Finally, the detailed mechanism of the RTCs and environmental conditions, for example the speed of the vehicles, were not available.

5.4 General Discussion

The available evidence indicates that the UN target of reducing deaths by half was not met [3–5]. Furthermore, our findings have shown that the effect of the Decade of Action in stabilizing mortality among pedestrians and motorized 2-3-wheelers is neither uniform nor deterministic globally (Papers I and III). While the rate of global pedestrian deaths declined (Paper I), the rate of global motorized 2-3-wheeler-related mortality increased (Paper III). Accordingly, the results of these studies (Paper I and Paper III) do not support the hypothesis that the measures implemented during the Decade of Action would reduce pedestrian and motorized 2-3-wheeler-related deaths globally and help reach the UN target of reducing death rates by 50%. It is also important to note that there is no difference in meeting the UN target by income level.

However, there is variation in pedestrian and motorized 2-3-wheeler-related death rates between the three levels of income. This could largely be attributed to the economic gap between countries. For example, in LICs, pedestrian deaths remain unchanged while motorized 2-3-wheeler user deaths increased. In MICs, pedestrian deaths declined while motorized 2-3-wheeler user deaths increased. However, in HICs, both pedestrian and motorized 2-3-wheeler user deaths declined. This is also reflected in our own setting. The reduction in motorcycle-related injuries and deaths due to improvements in trauma system development reflects and supports the effect of high GNI (Paper IV). Injury prevention intervention strategies and healthcare in the UAE have benefited from the country's rapid economic growth [290]. For example, the construction of first class roads, implementation of speed cameras, effective enforcement of safety regulations (such as helmet use), and the expansion of healthcare facilities, trauma system centers, trauma registries, healthcare professionals, and the various improvements in EMS/prehospital care, in-hospital medical care and health service utilization are all improved as a result of the high GNI [18, 259, 262, 290].

Most importantly, our findings support the concept of 'trauma system maturity' [37, 173, 176–180]. It is evident that the improvements in trauma outcomes in the UAE are attributable to the effectiveness of both multiple trauma system components, and trauma registries (data capture before and after system implementation) [37, 38]. Our findings (Paper IV) therefore support the hypothesis that trauma system maturity reduces mortality among hospitalized motorcycle injured patients in comparison to the initial implementation phase of the trauma system, which may help the UAE to reach the UN target of reducing injury and death rates by 50%.

Another important aspect is the significant increase in mortality during the COVID-19 pandemic, which was attributable to the increased ISS and reduced GCS (Paper II). We have shown in a recent review reported elsewhere that there was a similar increasing trend in the severity of injury and deaths during the COVID-19 pandemic [20]. The reported increase in mortality may be due to a significant disruption to health care services during the pandemic period, including reduced and delayed access to emergency departments [166, 168–170].

Overall, there was very little progress worldwide over the last decade despite concerted actions [3]. Pedestrian and motorized deaths remain a public health issue in LMICs [6, 8]. Meanwhile, there has been significant progress in the UAE over the last 15 years, despite the impact of the COVID-19 pandemic. Any positive progress at global and local levels is clearly affected by GNI, helmet wearing rate, vehicle/person ratio, interaction between vehicle/person ratio and motorized 2-3-wheeler/person ratio, time, and trauma system development. Yet at the same time, the increase in motorized 2-3-wheeler per person ratio and the COVID-19 pandemic restriction measures increased deaths. This is unsurprising when travel is on unsafe roads and in the absence of safety rules (such as speed control and helmet use) combined with increased numbers of vehicles [64, 76, 291–293].

It is thus clear that there is a need for safe and sustainable transportation, (including safe walking, cycling and public transport, and a reduction in the shift to motorized 2-3-wheelers) [3, 6], comprehensive trauma systems [172], and cost-effective road safety initiatives (such as helmet use, speed control, drink driving laws, restraint use, legislative changes, law enforcement, and traffic safety awareness campaigns) [4, 145] to address the growing road safety crisis both during normal and pandemic periods. Countries would benefit from these measures. For example, one recent study found large benefits (more than 25% reduction in road traffic deaths and DALYs) from speed control in LMICs [4] and another study found that legislative changes alone accounted for 75% of the lives saved in these countries [145].

Chapter 6: Conclusions and Future Perspectives

The overall aim of this dissertation was to define factors affecting changes in RTC-related deaths and injuries at the global and UAE levels over time, and to establish whether reductions in death rates had met the UN target. We present evidence that the UN target has not been met. Meanwhile, the economic disparities between countries, trauma system maturity, and COVID-19 pandemic restriction measures significantly impacted the changes in RTC-related deaths and injuries over time both globally and locally. Specifically:

- Global pedestrian mortality fell by 28% over the last decade. It dropped in both MICs and HICs, but not in LICs. Factors affecting these changes include GNI, vehicle/person ratio, and time. The UN target was not reached.
- Global motorized 2-3-wheeler-related mortality increased by a relative ratio of 1.36 over the recent decade. It increased in both LICs and MICs but declined in HICs. Factors affecting these trends include motorized 2-3-wheelers/person ratio, GNI, helmet wearing rate, and the interplay between vehicle/person ratio and motorized 2-3-wheelers/person ratio. The UN target was not reached.
- The maturity of the trauma system in Al-Ain significantly reduced mortality of hospitalized motorcycle injured patients; in addition, the incidence of motorcycle injuries declined by almost 40% over the last 15 years. The UN target was met.
- The COVID-19 pandemic restriction measures in our setting significantly increased mortality of hospitalized RTC trauma patients. However, the measures led to a reduction in the number of hospitalized RTC trauma patients by 33.5%.

6.1 Practical Implications

This research focused on studying the factors related to changes in road traffic deaths over time both globally and locally, and identifying whether the reduction in RTC-related death rates had met the UN target. However, there are several areas that require further research.

First, our findings have shown that pedestrian and motorized 2-3-wheeler-related deaths remain a public health issue in LMICs despite concerted global action [3, 6, 8].

Given the disproportionate number of road traffic deaths in LMICs, there is a need for relevant research in these countries. Furthermore, LMICs would need to move well beyond the experience sharing or learning from HICs countries [4]. Instead, they should embark on new research more relevant to their own contexts. However, the main challenge for such research is the lack of data, because many of these countries do not have national databases or registries of RTC injuries [6, 105, 172], which in turn leads to underreporting [115, 247]. A comparison between government reported road traffic deaths and WHO estimated road traffic deaths indicates a high level of under-reporting in LMICs [115], as noted above (Papers I and III). Accordingly, un-reported VRU injuries are considerably higher [247–249]. For example, in the European Union (EU), police records only capture 48% of VRU injuries compared to 70% reported in hospital records [247]. This suggests that 52% of VRU injuries are not captured in police records as opposed to 30% being unrecorded in hospital records. It is essential to consolidate available data sources in order to address this issue [248, 249, 294].

Second, it is necessary to conduct similar studies into the factors affecting RTC death rates over time at the global level, across WHO regions, regional blocs (such as EU countries, OECD countries, Gulf Cooperation Council (GCC) countries), income levels and national levels (by jurisdiction/states, and urban versus rural levels). This is because there may be differences between how the various factors come into play in different contexts. We provided new insights by using the WHO GSRRS data [6, 7, 9, 10] as repeated measures data (Papers I and III), which are used with a longitudinal study to examine changes in RTC outcome over time and compare these changes among participating countries [194, 195, 212, 217].

The 5th GSRRS report, covering the most recent years, will be published in 2023 [295] and the Second Decade of Action for Road Safety 2021 – 2030 is currently ongoing [13]. There is therefore the opportunity to conduct similar longitudinal studies using repeated measures data and the same procedures to define factors affecting RTC-related deaths and injuries, and to focus on and monitor their impact and progress over time. Such studies will help to identify potential key factors and evaluate progress over time. For example, in the previous studies speed control and reduced population density significantly reduced pedestrian deaths [4, 17, 244], but these effects were not observed in the current pedestrian study (Paper I), indicating that these effects stabilized over time; meanwhile, other important factors were recognized. Additionally, such research will also help to monitor the progress between years and the factors affecting the changes (Paper I and III).

Third, our findings relating to the effects of trauma system development (Paper IV) are transferable to other countries. We observed that the trauma system contributes to reductions in motorcycle-related deaths and injuries. However, injury prevention interventions, and post-trauma response (EMS/prehospital and in-hospital care) may vary between countries. In addition, factors such as road user behavior, engineering, and economic development (such as GNI as discussed above in Papers I and III) may have multiple, mixed, or varying effects [105, 296]. This suggests a need for further research.

Fourth, the number of RTC patients decreased during the COVID-19 pandemic although there was a significant increase in mortality (Paper II). The impact of the pandemic may have varied between developed and developing countries, and between urban and rural areas. There is lack of studies that investigated the impact of the COVID-19 pandemic from LMICs and rural areas [20]. Even among developed countries, the decrease in the number of RTC patients during the COVID-19 pandemic could be in part a continuation of the decreasing trend in RTCs due to the ongoing road safety measures rather than solely due to the restriction measures imposed [37]. The global impact of the COVID-19 pandemic on RTC-related deaths and injuries (by road user types) should also be evaluated separately, using an appropriate methodological approach, and this impact should be clearly understood prior to drawing any conclusions concerning the impact of the Decade of Action for Road Safety 2011-2020. Similarly, the role of the COVID-19 pandemic on RTC-related deaths and injuries during the Second Decade of Action for Road Safety 2021-2030 should also be studied. There is a clear need to investigate the effect of COVID-19 restriction measures in different countries [20].

Finally, further research is needed to examine the effects of other factors on pedestrian mortality, in particular pedestrian friendly vehicle bumpers [254, 255], and the effect of safety devices such as Anti-Lock Brake Systems [264, 265] on motorized 2-3-wheeler user mortality, with studies carried out over time both globally and locally. In addition, the impact of self-driving vehicles on RTC injury pattern and severity needs investigation [119, 121, 122].

6.2 Research Implications

Our studies will contribute to the research into road traffic injuries and healthcare in several ways. The findings are important for RTC prevention and for intervention programs aiming to reduce and/or control RTC injuries, and will provide the basis for evaluation of the progress resulting from targeting different road users, in particular VRUs at the global, regional, national, and local levels, during both the normal and pandemic periods. The research may also motivate public health practitioners, emergency physicians, trauma surgeons, nurses and other professionals to be part of the solution by becoming actively involved in evaluation of the impact of interventions, through studying the epidemiology of injuries as well as by contributing to the development of special trauma education courses, providing personal expert opinions, and supporting and promoting health and road safety policy reforms [17, 297–299].

The findings of the global pedestrian and motorized 2-3-wheeler studies have become a regular part of the WHO GSRRS. The findings of these studies have contributed to the assessment of progress towards the UN global target [2]. The findings reflect the level of road safety standards for VRUs, mainly pedestrians and motorized 2-3-wheeler users [59, 83, 115]. Our findings also serve as a baseline in evaluating progress and defining factors affecting changes in road traffic deaths and injuries in both the First and Second Decades of Action for Road Safety.

The findings of the study into the impact of trauma system development and the COVID-19 pandemic restrictions helped clarify the extent of the RTC problem at the local UAE level, during both normal times and disease outbreaks such as the COVID-19 pandemic. These findings also clarify the differences in the provision of health care in normal times and pandemic periods. For example, post-crash health care services, such as EMS/prehospital and in-hospital care and referral systems operated differently in the two periods. Specifically, the disruption to healthcare services [166], including critical supply shortages [167], reduced and delayed access to emergency care departments [168–170] and delayed PCR test results during the pandemic led to an increase in RTC mortality.

This suggests there is a need for in-depth analysis of the nature of RTC trauma in the two periods to facilitate preparedness for trauma response in the future. Most importantly, understanding the impact of outbreaks and pandemics on RTC is relevant to trauma surgeons, safety scholars and leaders in disaster medicine [20].

The findings of these studies are the outcome of a multidisciplinary Trauma Group, which was established in 2001 at the UAEU [37–39], with the mission of promoting trauma research and education to improve patient care. The results have also reaffirmed the importance of a comprehensive trauma system [37, 38, 171, 172]. Our findings serve as a baseline for injury prevention in current and future pandemics.

According to our findings, we also suggest the following recommendations:

- It is necessary to conduct similar studies at various levels because there may be differences between how the various factors come into play in different contexts.
- It is essential to support safe transportation methods such as walking, cycling and public transport and to reduce shift to motorized 2-3-wheelers.
- Further research is needed to assess the effect of the COVID-19 pandemic with appropriate methodological approach (such as interrupted time series design, multicenter study) to better understand the true effect of the pandemic on RTC injury patterns and severity.
- Multicenter study to verify the impact of trauma system on hospitalized motorcycle-related injured patients.
- Proper helmet compliance is essential to tackle motorized 2-3-wheeler-related mortality.
- Developing an injury prevention strategy, such as special educational and legal consideration to address motorcycle injuries that occur around homes, workplaces and public areas.
- It is imperative to establish, develop, and improve comprehensive trauma systems, in particular pre-hospital and in-hospital care.

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List of Other Publications

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Factors affecting changes in road traffic collision-related injuries and deaths over time: the global and the United Arab Emirates perspectives.

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