Bicycle handlebar injuries - a systematic review of pediatric chest and abdominal injuries.

Roxanne Cheung MD
Lehigh Valley Health Network, roxanne.cheung@lvhn.org

Meghna Shukla
Children's Hospital of Michigan

Katherine G Akers
Wayne State University

Ahmad Farooqi
North Central Michigan College

Usha Sethuraman
Children's Hospital of Michigan

Published In/Presented At

Cheung R, Shukla M, Akers KG, Farooqi A, Sethuraman U. Bicycle handlebar injuries - a systematic review of pediatric chest and abdominal injuries. Am J Emerg Med. 2022 Jan;51:13-21. doi: 10.1016/j.ajem.2021.09.043. Epub 2021 Sep 28. PMID: 34649007.

American Journal of Emergency Medicine 51 (2022) 13–21

Contents lists available at ScienceDirect

American Journal of Emergency Medicine

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

Bicycle handlebar injuries – a systematic review of pediatric chest and abdominal injuries

Roxanne Cheung, MD [a,*], Meghna Shukla, MSN, RN CPNP-AC [a,b], Katherine G. Akers, PhD, MLIS [c], Ahmad Farooqi, PhD [d], Usha Sethuraman, MD [a,d]

[a] Division of Pediatric Emergency Medicine, Children's Hospital of Michigan, 3901 Beaubien Blvd, Detroit, MI 48201, USA
[b] Wayne State University, 42 W Warren St, Detroit, MI, USA
[c] Shiffman Medical Library, Wayne State University, 4325 Brush St, Detroit, MI 48201, USA
[d] Central Michigan University, 2520 S. University Park Dr., Bldg D, Mt Pleasant, MI 48859, USA

ARTICLE INFO

Article history:
Received 29 April 2021
Received in revised form 5 August 2021
Accepted 13 September 2021

Keywords:
Pediatrics
Abdominal injuries
Thoracic injuries
Bicycling

ABSTRACT

Objective: The severity of handlebar injuries can be overlooked due to subtle signs and wide range of associated internal injuries. Our objective was to describe thoracoabdominal injuries due to bicycle handlebars and their outcomes in children.
Methods: Articles that reported thoracoabdominal injuries were identified from database conception to March 3, 2019 using PubMed, EMBASE, Cochrane Library, CINHAHL Complete, Web of Science and Scopus. A systematic review of studies of thoracoabdominal handlebar injuries in children ≤21 years on human-powered bicycles in English was performed. Information on demographics, clinical features, injuries, interventions and outcomes was noted.
Results: A total of 138 articles were identified from 1952 to 2019. There were 1072 children (males, 85.1%) and 1255 thoracoabdominal injuries. Mean age was 9.7 ± 3.3 years old. Common clinical features included abdominal pain and guarding, vomiting, fever and a handlebar imprint. The liver was the most frequently injured organ. Surgery was performed in 338 children with a mean age of 10.0 ± 3.3 years. Twenty-seven children (2.5%) were discharged and returned due to worsening symptoms, of whom 23 (85.2%) required surgery. Thirty-one children (2.9%) transferred to a higher level of care due to injury severity. Two deaths were reported.
Conclusion: Bicycle handlebars can cause significant thoracoabdominal injuries. Presence of abdominal pain, vomiting, fever or a circular imprint on the chest or abdomen should prompt further workup. Future studies on diagnostic modalities and best practices are needed to lower the chance of missed injuries.

1. Introduction

Bicycle injuries constitute a large proportion of childhood trauma, with bicycles being the second most common consumer product associated with childhood injuries [1]. From 2006 to 2015, approximately 2 million children were seen in the emergency department (ED) for bicycle related injuries [2]. Though cycling injuries are common, handlebar injuries are rare with an estimated 1.15 per 100,000 cases [3]. Despite its rarity, handlebar injuries cause a broad spectrum of serious injuries are caused by handlebars including intraabdominal organ injuries [4], traumatic abdominal wall hernias [5], bladder rupture [6], and vascular damage [7-10]. These injuries pose a significant financial burden with approximately $9.6 million dollars related to hospital charges and cost up to potentially $10 million in lifetime medical costs [3].

The typical mechanism of injury occurs when a child riding a bicycle is stopped abruptly by an object, such as a rock or curb. As the child falls, the handlebar rotates towards the body of the child and strikes them on the way down [11,12] (see Fig. 1). The child's relatively thin body wall and larger surface area of internal organs place them at high risk of severe injury [13]. Studies show that the force transmitted through the small cross-sectional area of the handlebar can cause significant injuries, even at low speeds [4,14,15]. Children sustaining a handlebar injury are more likely than those with bicycle-related non-handlebar injuries to suffer severe intra-abdominal and intra-thoracic injuries [16,17]. Due to the wide variation in external injury appearance and often nonspecific complaints of pain from children, these injuries can go undiagnosed by clinicians, leading to treatment delays and thus potentially increasing morbidity and mortality [17-19].

* Corresponding author.
E-mail addresses: roxanne.cheung@lvhn.org (R. Cheung), av6363@wayne.edu (M. Shukla), katherine.akers@wayne.edu (K.G. Akers), faroo2a@cmich.edu (A. Farooqi), usethura@dmc.org (U. Sethuraman).

https://doi.org/10.1016/j.ajem.2021.09.043
0735-6757/

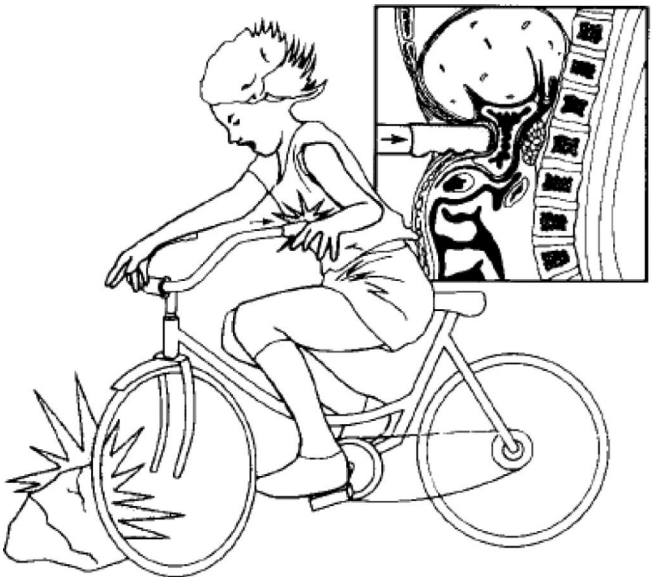

Fig. 1. Common mechanism on injury in children with pancreatic trauma (From Ford ED, Hardin WD, Mahour GH, Woolley MM. Pseudocysts of the pancreas in children. Am Surgeon. 1990;56:384–7. Reprinted under the STM Permissions Guidelines.)

To date, reports on handlebar injuries to the chest and abdomen involve single-center studies, case reports or studies with a small sample size. Currently, to our knowledge there is a lack of comprehensive reviews of the injury patterns, management, and outcomes of pediatric bicycle handlebar trauma to the thoracoabdominal area. Given the oftentimes, subtle presentation of thoracoabdominal handlebar trauma in children and its potential for significant morbidity, it is important for clinicians to be able to recognize injury patterns and presentations in order to achieve both timely diagnosis and clinical management. Our objective was to perform a systematic review using all extant literature to identify chest and abdominal injuries caused by bicycle handlebars in children. This review includes analysis of clinical features, injury patterns, diagnostic modalities, treatments, and outcomes.

2. Methods

This review was performed in accordance with the Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) guidelines. Literature searches were designed and conducted by a medical librarian in PubMed/MEDLINE, EMBASE, CINAHL Complete, Web of Science, Scopus, and Cochrane Library from database conception to March 3, 2019. Search terms related to handlebars (handlebar OR handlebars OR "handle bar" OR "handle bars" OR handle-bar OR handlebars) and injury (injur* OR wound* OR trauma*) were combined to identify relevant articles. Keywords and their associated MeSH or EMTREE terms were used as appropriate. The reference lists of included articles were hand-searched to locate additional articles not captured by our database search.

2.1. Inclusion criteria

All bicycle handlebar injury reports (full-length case reports, case series, or other article types reporting original data concerning human-powered bicycle handlebars as the etiology of injuries) were included. Patients up to 21 years of age were included as many pediatric EDs evaluate and treat patients up to that age.

2.2. Exclusion criteria

Duplicate articles, conference abstracts, review articles, commentaries, letters to the editor not reporting original data were excluded. Duplicates were removed using the Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia), which provided a standardized method of de-duplication. Articles that described injuries exclusively involving the head, face, neck, or extremities; focused on end-organ injuries from multiple etiologies and not just bicycle handlebar injuries; described injuries caused by motor-assisted bicycles (e.g., electric bicycles, mopeds) or by non-bicycle handlebars; did not report management or outcomes; or were not published in English were also excluded. Authors of articles that were missing vital information about the injury or aspects of management were contacted via available email, and articles were excluded if authors could not be reached.

Initial screening was by title and abstract for relevance performed by the first and second authors. Articles included in the secondary screening and final analyses were reviewed in full text. Conflicts between the two independent reviewers were resolved through discussion and consensus. If consensus could not be reached, the last author reconciled differences through an independent review of the article. Both rounds of screening were conducted using Covidence systematic review software.

2.3. Data collection and analysis

The primary data extracted included patients' gender, age, injury type(s), and management. When available, secondary information was collected on patients' ethnicity, symptoms, physical examination findings, type of imaging performed, return visits, and transfer to a higher level of care. All information was entered into an Excel spreadsheet (version 14.7.7).

Due to varied reporting of secondary data, missing or unreported data were excluded from final calculations. Studies that did not provide individual ages but only reported mean or median ages were not used in the calculation of age. As most single center studies reported gender, injury types, and management data in percentages, exact number of patients were calculated based on the availability of reported percentages and population size reported.

2.4. Statistics

Categorical data were reported using frequencies and percentages, and continuous data were reported using means and standard deviations. Crosstabs were constructed to determine the effect sizes using odds ratios (ORs) with a 95% confidence interval (CIs) to compare the difference in groups. SAS (version 9.4, SAS Institute Inc. Cary, North Carolina) was used to perform statistical analyses. Significance level was set at 0.05. A forest plot was created using MedCalc Version 19.6.4.

This systematic review was determined to be exempt from review by the Institutional Review Board.

3. Results

Our literature search retrieved 1305 articles and an additional 54 articles were identified through handsearching. After removing duplicates, 511 articles were screened by title and abstract, and the full text of 318 articles was reviewed against our inclusion and exclusion criteria, resulting in 138 articles published from 1952 to 2019 for data extraction (Fig. 2).

Across the 138 articles, 1072 patients were identified with 1212 abdominal injuries and 43 chest injuries from bicycle handlebar impact (Table 1). The mean age was 9.7 ± 3.3 years. Most patients were male (912; 85.1%), and 99.8% survived. The most common symptoms were abdominal pain (54.7%), vomiting (22.4%), and fever (11.2%), and the most common physical examination findings were rebound tenderness (24.5%), circular bruising on the chest or abdomen (20.6%), and guarding (20.0%). Computed tomography (CT) scan (52.0%) and ultrasound (20.7%) were the most frequently used modalities to diagnose

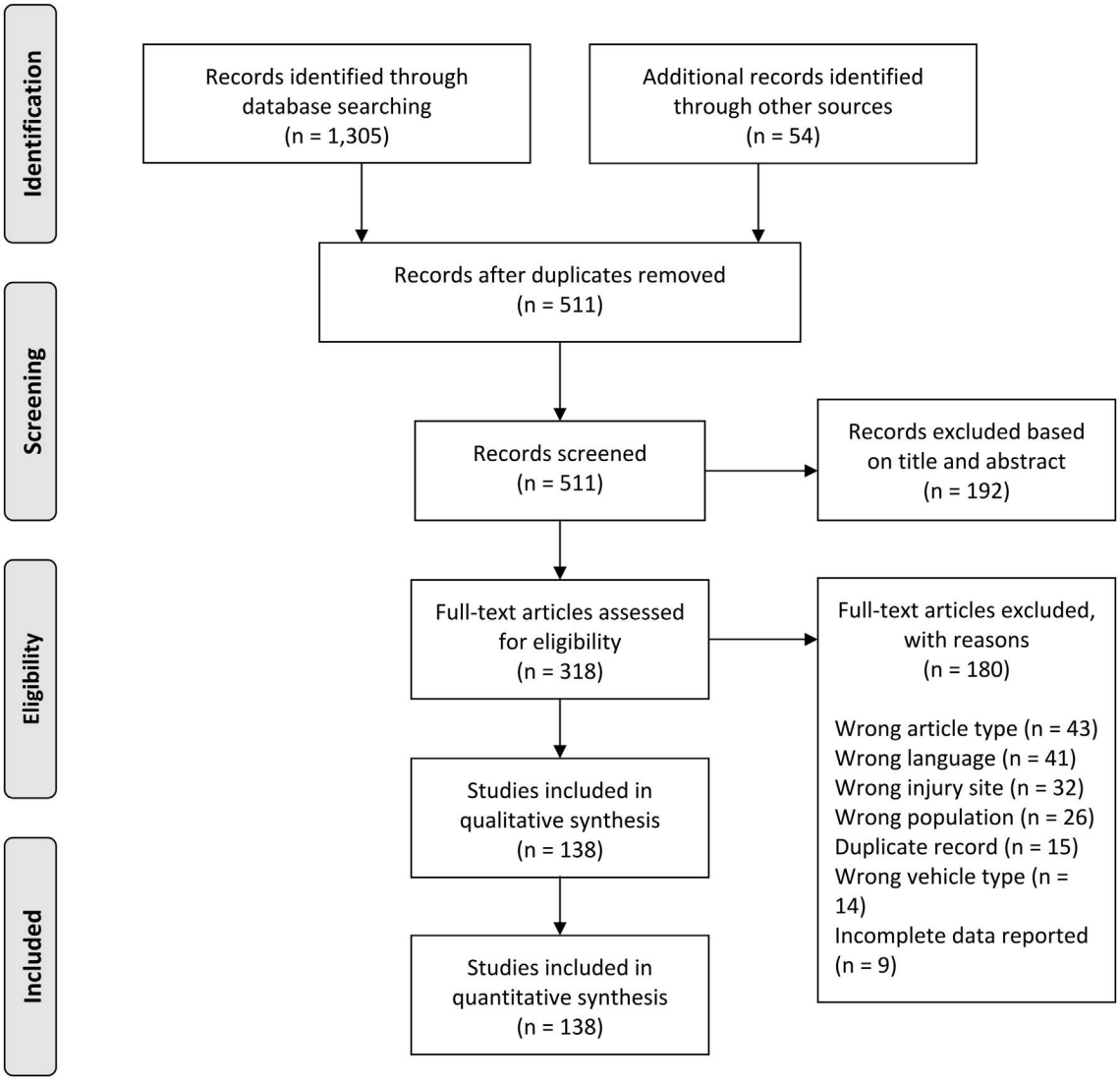

Fig. 2. PRISMA flow diagram.

injuries (Table 2). A summary of included studies is listed in Table A.1 as an appendix.

The most frequent organs injured are listed in Table 1. Abdominal injuries were most common, with the liver and pancreas being the most frequently injured. More rare etiologies included large bowel laceration (1.0%), stomach laceration (0.6%), femoral artery transection (0.2%), biloma (0.2%), bladder laceration (0.1%), ureter transection (0.1%), and hemocholecystitis (0.1%). In the chest, the most frequently injured organ was the lung.

A total of 338 (31.5%) surgeries and 21 (2.0%) procedures were performed (6 angioembolizations, 7 percutaneous drainages, and 8 stent placements) (Table 2). Patients requiring surgery had a mean age of 10.0 ± 3.3 years. Risk factors associated with surgical intervention included abdominal pain (OR 11.60; 95% CI 7.36 to 18.30), vomiting (OR 4.87; 95% CI 2.69 to 8.83), fever (OR 3.05; 95% CI 1.39 to 6.72), age ≤ 10 years (OR 1.78; 95% CI 1.37 to 2.31), and presence of a circular imprint on the body (OR 2.19; 95% CI 1.63 to 2.95) (Fig. 3).

Twenty-seven children (2.5%) were initially discharged home from the ED or primary care office and returned due to worsening symptoms. Among these patients, 23 (85.2%) required surgeries and 1 (3.7%) required a procedure. Thirty-one (2.9%) patients were transferred to a higher level of care due to injury severity, during either the initial or return visit. Among this group, 17 (54.8%) required surgery and 12 (38.7%) required a procedure.

Two deaths were reported. One was a 10 year-old male who sustained an injury to the right upper quadrant leading to a liver laceration. On exam, there was a circular imprint on the skin. Another was a 13 year-old male who sustained an injury to the abdomen and was found to have an aortic rupture at the infrarenal level that led to excessive internal hemorrhage.

A subgroup analysis was performed for articles published from the year 2000 and on. There were 100 included articles with 946 patients identified. The mean age of patients was 10.0 ± 3.3 years. A total of 259 surgeries were performed, and 687 were medically managed. Risk factors associated with surgical intervention included abdominal pain (OR 6.04; 95% CI 3.86 to 9.46), vomiting (OR 4.16; 95% CI 2.12 to 8.15), fever (OR 3.29; 95% CI 1.40 to 7.71), age ≤ 10 years (OR 1.78; 95% CI 1.37 to 2.31), and presence of a circular imprint on the body (OR 2.19; 95% CI 1.63 to 2.95).

4. Discussion

Our review shows that pediatric handlebar trauma to the chest and abdomen result in a wide range of injuries and occurred

Table 1
Demographics and clinical features of pediatric handlebar injuries

Demographics	Number of patients, n = 1072
Mean age (y)	9.7 ± 3.3
Males, n (%)	912 (85.1%)
Survival, n (%)	1070 (99.8%)
Injuries	**Number of injuries, n = 1255**
Abdominal injury, n (%)	1212 (96.6%)
Liver	320 (25.5%)
Pancreas	235 (18.7%)
Abdominal wall	182 (14.5%)
Small bowel	149 (11.9%)
Spleen	120 (9.6%)
Kidney	79 (6.3%)
Large bowel	20 (1.6%)
Blood vessels	17 (1.4%)
Miscellaneous	133 (10.6%)
Chest injury, n (%)	43 (3.4%)
Lung herniation	15 (34.9%)
Pneumothorax	11 (25.6%)
Rib fracture	6 (14.0%)
Unspecified	4 (9.3%)
Complex lacerations	2 (4.7%)
Pleural effusion	2 (4.7%)
Traumatic VSD*	1 (2.3%)
Torn triscuspid valve	1 (2.3%)
Bruise	1 (2.3%)
Presenting symptoms	**Total instances, n = 248**
Abdominal pain	127 (54.7%)
Vomiting	52 (22.4%)
Fever	26 (11.2%)
Pallor	7 (3.0%)
Bilious/hematemesis	6 (2.6%)
Diarrhea/melena	6 (2.6%)
Chest pain	3 (1.3%)
Tachypnea	2 (0.9%)
Anxious	2 (0.9%)
Dysuria	1 (0.4%)
Exam findings	**Total instances, n = 1165**
Guarding	233 (19.8%)
Rebound pain	286 (24.3%)
Circular imprint	240 (21.8%)
Bruise/hematoma	94 (8.1%)
Abdominal tenderness	79 (7.1%)
Palpable/visible mass	66 (5.5%)
Abrasion/laceration/puncture wound	55 (4.1%)
Peritonitis	34 (3.0%)
Abdominal distention	13 (1.1%)
Pericardiac arrest/cardiogenic shock/bradycardia	12 (0.6%)
Tachycardia	9 (0.7%)
Bowel/omental evisceration	7 (0.6%)
Absent/diminished bowel sounds	7 (0.5%)
Undetectable/diminished peripheral pulse	6 (0.6%)
Ascites/tense abdomen	5 (0.5%)
Coolness	5 (0.4%)
Dehydration	3 (0.3%)
Tender chest	3 (0.3%)
Delayed capillary refill	2 (0.2%)
Coarse/diminished breath sounds	2 (0.2%)
Altered mental status/loss of consciousness	2 (0.2%)
Hypoxia	1 (0.1%)
Scleral icterus	1 (0.2%)

* Ventricular septal defect (VSD).

Table 2
Diagnostic modalities and outcomes of pediatric handlebar injuries

Imaging	Number performed, n = 952
CT^	495 (52.0%)
Repeat CT	14 (2.8%)
Ultrasound	197 (20.7%)
Repeat ultrasound	4 (2.0%)
FAST^	41 (4.3%)
Echocardiogram	1 (0.1%)
Radiographs	168 (8.9%)
Repeat radiographs	2 (1.2%)
ERCP^	31 (3.3%)
Others	8 (0.9%)
Upper gastrointestinal fluoroscopy	6 (0.6%)
Endoscopy	5 (0.5%)
Management	**Number of patients, n = 1072**
Medical, n (%)	713 (66.5%)
Surgery, n (%)	338 (31.5%)
Procedures, n (%)	21 (2.0%)
Angioembolization	6 (28.6%)
Percutaneous drainage	7 (33.3%)
Stent placement	8 (38.1%)

^ Computed Tomography (CT); Focused Abdominal Sonography for Trauma (FAST); Endoscopic retrograde cholangiopancreatography (ERCP).

primarily in school-aged boys. Similar to previous studies [4,14,16,17,20,21], our review shows the majority of injuries involve the upper abdomen, with the liver being the most commonly affected organ followed by the pancreas. Similar to our findings, Dai et al [22] showed that the liver was the most frequently injured organ (184 injuries out of 219 pediatric patients) and Hirose et al [18] found that hepatic injuries were the most common among the 18 patients in the handlebar injury group. By contrast, another study [14] showed that splenic injuries were most common. This suggests that clinicians should be alert to the possibility of underlying severe injury to various organs of the upper abdomen.

Similar to a previous report [23], we found that chest injuries by bicycle handlebars are rare, constituting only 3.4% of the total. However, when they do occur, the requirement for an operation is high. Thus, chest trauma due to bicycle handlebar should prompt surgical consultation or transfer to a facility with available surgical subspecialities. Our review also found two pediatric deaths [24,25] due to bicycle handlebars, emphasizing the rare but potential risk of mortality associated with handlebar injuries.

While most patients were managed medically, a proportion of children required surgical or procedural intervention, underlining the potential severity of handlebar injuries to these anatomical areas. It is important to recognize that diagnosis and management of traumatic injuries have changed over the time frame of our study with the advent of Advanced Trauma Life Support, organized trauma centers, advanced imaging modalities, and a shift to more conservative approach to pediatric trauma [26]. These advances have helped decreased morbidity and mortality in children [27]. In spite of these advances, the results of our subgroup analysis suggest that the nature of serious handlebar injuries

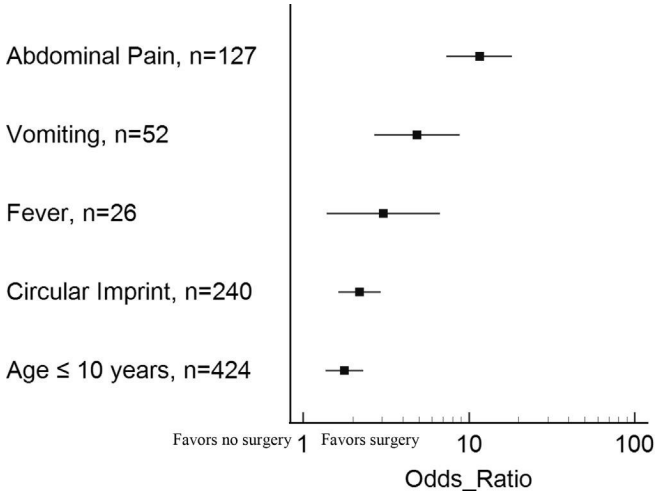

Fig. 3. Forest diagram of odds ratio comparing risk factors associated with patients managed surgically versus medically.

share the same risk factors over time and have a similar likelihood for surgery. Our surgical rates fall between Nadler's [17] and Nataraja's [20] studies, which reported surgical rates of 31.1% and 42.8%, respectively. The mechanism of the handlebar injury itself, a concentrated force over a small surface area, likely creates similar injuries throughout time. Studies have suggested dissipating this force with retractable handlebars [11] or wearing protective gear [28]. Thus, unless the nature of the handlebar changes, the injuries sustained and how they are managed will likely continue to be the same.

It is also important to point out with the varied nature of handlebar injuries, certain injuries such as bowel perforations [29], traumatic abdominal wall hernias [5], lung herniation [30], abdominal wall rupture [31,32], and large vessel lacerations [7-10], have a high likelihood of surgical intervention. Some will be case-dependent, such as duodenal hematomas [33] and pancreatic duct injuries [34], and others have evolved from invasive surgeries to closer monitoring, such as hepatic and splenic injuries [35-37]. Thus, depending on the injury sustained, surgical rates can vary.

An important finding in our study is the high morbidity associated with a missed diagnosis of thoracoabdominal injuries due to bicycle handle bar injuries. Cherniawsky et al [16] found that more than half of children with bicycle handlebar injury to the abdomen had a return visit due to misdiagnosis. This group of children had an average delay in treatment of 18.3 h and a longer length of stay than children with bicycle non-handlebar injuries. In a case series of two patients by Lam et al [19], one patient was seen, treated, and returned 18 days later, and one patient returned to another hospital in 36 h. Both patients required surgery. By contrast, our review shows that only a small proportion of patients (2.5%) returned for worsening symptoms after initial evaluation and discharge. However, a very high proportion of these children required a surgical or procedural intervention at the second visit. Thus, it is imperative that clinicians maintain a high index of suspicion when evaluating these children to avoid missing injuries to the thoracoabdominal areas. Furthermore, a child returning to the ED with persistent symptoms should warrant a thorough investigation.

While the symptoms can be nonspecific, we found that abdominal pain, vomiting, and fever were symptoms most commonly associated with significant handlebar injuries, and children with a circular handlebar imprint on the chest or abdomen had a two times higher odds of an intraabdominal injury requiring surgery. Thus, the presence of these clinical features should alert the clinician to prompt additional investigations. Additionally, children who are transferred to a higher level of care should be investigated thoroughly given their higher frequency of surgical and procedural requirements.

4.1. Limitations

All articles included in this systematic review were retrospective and limited by the information reported. Data may have been incomplete or missing. There was variation across the studies in how outcomes were reported and almost no articles reported on ethnicity and/or race, which may have led to underestimation in the data used for statistical analysis. Articles that focused on end-organ injuries were excluded, as many did not report injuries due to a bicycle handlebar and their management, likely underrepresenting some of the organ injuries. We also excluded articles with reported sample numbers but for which the authors did not respond to queries for further details or were unable to provide details. Therefore, these exclusion criteria likely contributed to a more limited sample and underrepresentation of the actual incidence of bicycle handlebar-related organ injuries present in the literature.

Further, while there was international representation in the articles, most studies were from the United States. Hence these results may not be generalizable depending on location. Finally, as the search strategy primarily retrieved academic journal articles, publication bias may be present.

5. Conclusion

Bicycle handlebars can cause significant thoracoabdominal injuries with more than one third requiring a surgical intervention. Presence of abdominal pain, vomiting, fever or a circular imprint on the chest or abdomen should prompt further workup. Future studies on diagnosis and best practices are needed to lower the chance of missed injuries.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Credit author statement

Dr. Cheung and Ms. Shukla conceptualized and designed the study, collected the data, drafted the initial manuscript, and reviewed and revised the manuscript.

Dr. Akers designed and performed the medical literature search, designed the data collection instrument, reviewed, and revised the manuscript.

Dr. Farooqi carried out the initial analysis, reviewed, and revised the manuscript.

Dr. Sethuraman conceptualized and designed the study, coordinated and supervised data collection, and critically reviewed the manuscript for important intellectual content.

All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

Declaration of Competing Interest

None.

Appendix

Table A.1
Summary of included studies.

Author, publication year	Patients, n	Gender (F or M)	Mean age, yrs	Abd or chest injuries reported	Management	Survival (yes or no)
Acton 1994	10	9 M, 1F	9.4	Pancreatic contusion, pancreatic laceration, splenic rupture, splenic bruise, kidney laceration, traumatic pancreatitis, small bowel laceration, mesenteric tears, liver laceration	5 surgeries, 5 medical	Yes
Adams 1966	1	M	7	Traumatic pancreatitis, pancreatic laceration, pancreatic contusion	Surgery	Yes
Aggelidou 2018	1	M	6	Traumatic abdominal wall hernia	Medical	Yes
Ahmed 2015	1	M	8	Traumatic abdominal wall hernia	Surgery	Yes
Alkan 2012	8	6 M, 2F	9.4	Small bowel laceration, pancreatic laceration, abdominal wall laceration, small bowel hematoma	7 surgeries, 1 medical	Yes

(continued on next page)

Table A.1 (*continued*)

Author, publication year	Patients, n	Gender (F or M)	Mean age, yrs	Abd or chest injuries reported	Management	Survival (yes or no)
Angel Bultrago 2015	1	M	14	Traumatic abdominal wall hernia	Surgery	Yes
Arkovitz 1996	1	M	8	Pancreatic transection	Surgery	Yes
Biemann 1968	3	1 M, 2F	9	Traumatic pancreatitis, pancreatic pseudocyst	3 surgeries	Yes
Bokhari 2008	1	M	9	Small bowel and omental evisceration, abdominal wall laceration	Surgery	Yes
CantySr 2001	1	F	9	Pancreatic duct lac	Stent placement	Yes
Carrouget 2015	1	M	9	Lung herniation	Medical	Yes
Cevik 2013	59	51 M, 8F	n/a	Pancreatic laceration, pancreatic contusion, kidney laceration, small bowel perforation, small bowel hematoma, splenic laceration, liver laceration abdominal wall laceration, abdominal wall hematoma, omental evisceration	14 surgeries, 45 medical, 2 stent placements	Yes
Chen 2005	1	M	9	Traumatic abdominal wall hernia	Surgery	Yes
Cherniawsky 2014	42	30 M, 12F	n/a	Unspecified pancreatic injury, unspecified hollow organ injury, unspecified abdominal injury	4 surgeries, 38 medical	Yes
Chien 2008	1	M	6	Small bowel hematoma, obstruction	Surgery	Yes
Choi 2014	1	M	6	Liver laceration, biloma, hemocholecystitis	surgery, percutaneous drainage, stent placement, angioembolization	Yes
Clarnette 1997	25	22 M, 3F	n/a	Small bowel perforation, small bowel hematoma, traumatic pancreatitis, pancreatic transection, pancreatic pseudocyst, unspecified liver injury, kidney hematoma, unspecified splenic injury, abdominal wall laceration	6 surgeries, 19 medical	Yes
Dai 2015	219	176 M, 32F	n/a	Small bowel perforation, small bowel hematoma, traumatic pancreatitis, pancreatic pseudocyst, splenic hematoma, stomach laceration, unspecified liver injury, kidney contusion, unspecified pancreatic injury	24 surgeries, 192 medical, 3 percutaneous drainage	Yes
Damschen 1994	1	M	5	Traumatic abdominal wall hernia	Surgery	Yes
Debbink 2017	1	F	13	Abdominal wall laceration, large bowel perforation, ureter transection, mesenteric vein injury	Surgery, stent placement	Yes
Decker 2012	1	M	13	Traumatic abdominal wall hernia	Surgery	Yes
Deepak 2015	7	7 M	9.6	Traumatic abdominal wall hernia, small bowel perforation, traumatic pancreatitis, pancreatic laceration, pancreatic duct laceration, pancreatic pseudocyst, abdominal wall laceration	5 surgeries, 2 medical	Yes
Doley 2010	2	2 M	17.5	Pancreatic transection, pancreatic hematoma	2 surgeries	Yes
Dreyfuss 1986	1	M	11	Traumatic abdominal wall hernia	Surgery	Yes
England 2004	1	M	13	Small bowel hematoma, abdominal wall laceration, iliac vessel hematoma	Surgery	Yes
Erez 2001	76	64 M, 12F	n/a	Small bowel hematoma, traumatic pancreatitis, kidney laceration, splenic rupture, abdominal hematoma, kidney contusion, liver rupture	5 surgeries, 71 medical	Yes
Fernández 2015	2	2F	10	Small bowel perforation	2 surgeries	Yes
Forty 1990	1	M	13	Lung herniation	Surgery	Yes
Fraser 1969	1	M	7	Pancreatic laceration, pancreatic pseudocyst	Surgery	Yes
Fraser 2002	1	M	11	Traumatic abdominal wall hernia	Surgery	Yes
Garside 2018	1	M	11	Small bowel perforation, large bowel laceration, common bile duct transection	Surgery, stent placement	Yes
Gerstenbluth 2002	3	1 M, 2F	9.7	Kidney laceration, kidney contusion	1 surgery, 2 medical	Yes
Goliath 2004	1	M	11	Traumatic abdominal wall hernia	Surgery	Yes
Griffin 2013	1	M	11	Traumatic abdominal wall hernia	Surgery	Yes
Gross 2002	1	M	6	Pancreatic hematoma	Surgery	Yes
Haimovici 2007	1	M	15	Traumatic abdominal wall hernia, small bowel perforation, mesenteric laceration	Surgery	Yes
Hall 1986	2	2 M	8	Traumatic pancreatitis, pancreatic transection, pancreatic pseudocyst	2 surgeries	Yes
Hatti 2011	1	M	5	Traumatic abdominal wall hernia	Surgery	Yes
Hebra 2011	1	M	13	Lung herniation	Surgery	Yes
Hennington 1991	1	M	12	Appendicitis	Surgery	Yes
Hirose 2015	16	15 M, 1F	9.9	Small bowel perforation, abdominal wall hematoma, unspecified liver trauma, unspecified pancreatic injury, retroperitoneal hematoma, unspecified splenic injury, unspecified kidney injury, bladder rupture, chest bruise	5 surgeries, 7 medical, 4 angioembolizations	Yes
Hirzinger 2017	1	M	8	Traumatic abdominal wall hernia, bladder rupture	Surgery	Yes
Holgersen 1977	2	1 M, 1F	5	Small bowel hematoma, obstruction, traumatic pancreatitis	2 medical	Yes
Holmes 2002	1	M	15	Lung herniation	Surgery	Yes
Houben 2007	8	7 M, 1F	8.8	Pancreatic transection, pancreatic duct laceration, pancreatic hematoma, pancreatic pseudocyst	2 surgeries, 1 medical, 3 percutaneous drainages, 5 stent placements	Yes
Houston 2012	1	M	14	External iliac artery transection, external iliac vein laceration	Surgery	Yes
Huang 2012	1	M	12	Small bowel perforation, small bowel contusion	Surgery	Yes
Hulscher 2006	1	M	7	Traumatic abdominal wall hernia	Surgery	Yes
Iinuma 2005	1	M	8	Traumatic abdominal wall hernia	Surgery	Yes
Iuchtman 1997	1	M	7	Traumatic Spigelian hernia	Surgery	Yes
Karaman 2009	14	11 M, 3F	n/a	Traumatic abdominal wall hernia, splenic laceration, small bowel perforation, abdominal wall laceration, stomach laceration	4 surgeries, 10 medical	Yes

Table A.1 (*continued*)

Author, publication year	Patients, n	Gender (F or M)	Mean age, yrs	Abd or chest injuries reported	Management	Survival (yes or no)
Kawahara 2014	2	2 M	10	Traumatic pancreatitis, pancreatic transection, pancreatic pseudocyst	2 surgeries	Yes
Khor 2018	1	M	12	Traumatic abdominal wall hernia, presacral hematoma	Surgery	Yes
Kimble 1999	1	M	9	Traumatic pancreatitis, pancreatic duct laceration, pancreatic pseudocyst	Stent placement	Yes
Klimek 2013	40	29 M, 11F	n/a	Traumatic abdominal wall hernia, small bowel perforation, splenic rupture, abdominal wall hematoma, abdominal wall laceration, iliac vessel hematoma, liver rupture, pancreas rupture, liver contusion, kidney rupture, bladder contusion, lung herniation	8 surgeries, 32 medical	Yes
Klin 2011	5	5 M	8.2	Liver laceration, splenic laceration, small bowel laceration, traumatic pancreatitis, kidney laceration, pancreatic transection, pancreatic contusion, stomach laceration, kidney contusion, unspecified pancreatic injury, stomach contusion	3 surgeries, 2 medical	Yes
Klin 2016	89	82 M, 7F	n/a	Small bowel laceration, bladder laceration, unspecified liver injury, unspecified pancreatic injury, large bowel laceration, unspecified splenic injury, kidney rupture, rib fracture, pleural effusion	8 surgeries, 81 medical	Yes
Koestner 1999	1	F	6	Traumatic pancreatitis, pancreatic transection	Surgery	Yes
Kolar 2018	9	8 M, 1F	8.9	Lung herniation	5 surgeries, 4 medical	Yes
Krishnan 2002	1	F	8	Iliac wing fracture, iliopsoas muscle laceration	Surgery	Yes
Kubalak 1994	6	5 M, 1F	10.5	Traumatic abdominal wall hernia, large bowel laceration, omental hemorrhage	6 surgeries	Yes
Kubota 1999	1	M	9	Traumatic abdominal wall hernia	Surgery	Yes
#1292 – Lackgren 1988	1	F	6	Hemobilia	Medical	Yes
Lam 2001	2	2 M	10.5	Pancreatic duct lac, pseudocyst	2 surgeries	Yes
Lehto 1985	1	F	9	Liver laceration, common bile duct transection	Surgery	Yes
Leva 2008	1	M	7	Pancreatic duct lac, pseudocyst	Surgery	Yes
Litton 2008	1	M	13	Traumatic abdominal wall hernia	Medical	Yes
Lopez 2010, Lopez 2011	1	M	14	Traumatic Spigelian hernia	Surgery	Yes
Lovell 1992	2	2 M	12	Pancreatic transection, pancreatic hematoma, fat necrosis, colon hematoma, abdominal wall laceration, small bowel evisceration, mesenteric hematoma	2 surgeries	Yes
Luu 2018	1	M	15	Pancreatic transection	Surgery	Yes
Madan 2003	1	M	14	Femoral artery and femoral vein injury	Surgery	Yes
Mancel 2003	1	M	7	Traumatic abdominal wall hernia	Surgery	Yes
Marjanovic 2012	1	M	9	Liver laceration, pancreatic laceration, stomach laceration, pancreatic duct laceration, pancreatic pseudocyst	Surgery	Yes
Matsuo 2007	1	M	9	Traumatic abdominal wall hernia	Medical	Yes
Maunola 1965	2	1 M, 1F	14	Traumatic abdominal wall hernia, large bowel laceration	2 surgeries	Yes
Mayr 2015	2	2 M	6.25	Pancreatic laceration, pancreatic duct laceration, pancreatic pseudocyst	2 stent placements	Yes
Mehta 1993	1	M	4	Small bowel contusion	Medical	Yes
Mezhir 2007	1	M	7	Traumatic abdominal wall hernia, unspecified spleen injury, unspecified kidney injury	Surgery	Yes
Min 1999	1	M	7	Lung herniation	Surgery	Yes
Mitchell 2011	1	M	14	Traumatic abdominal wall hernia	Surgery	Yes
Mitchiner 1990	1	M	7	Traumatic abdominal wall hernia	Surgery	Yes
Moslemi 2013	1	M	13	Appendix laceration, mesenteric laceration	Surgery	Yes
Munshi 2003	1	M	11	Liver laceration	Medical	Yes
Muthumucaru 2012	31	31 M	n/a	Traumatic abdominal wall hernia, small bowel perforation, abdominal wall hematoma, abdominal wall laceration, pancreatic duct lac, pancreatic pseudocyst, unspecified liver trauma, omental wall infarct, spleen injury, kidney injury, large bowel hematoma, large bowel devascularization	10 surgeries, 21 medical, 1 stent placement	Yes
Nadler 2005	61	49 M, 12F	n/a	Small bowel perforation, pancreatic transection, small bowel evisceration, renal pelvis rupture	19 surgeries, 42 medical	Yes
Narci 2008	1	M	12	Traumatic abdominal wall hernia	Surgery	Yes
Narataja 2014	86	79 M, 7F	n/a	Unspecified abdominal injury unspecified injury	27 surgeries, 59 medical	Yes
Nguyen 2009	1	M	6	Abdominal wall laceration, small bowel evisceration, omental evisceration	Surgery	Yes
Nosanov 2011	1	M	15	Large bowel laceration, mesenteric laceration	Surgery	Yes
Ohno 1995	1	M	7	Pancreatic transection, pancreatic pseudocyst	Percutaneous drainage	Yes
Orbell 2006	1	M	9	Extrahepatic biliary duct laceration	Surgery	Yes
Pederiva 2016	1	M	9	Traumatic abdominal wall hernia, small bowel perforation	Surgery	Yes
Perez 1998	1	M	11	Traumatic abdominal wall hernia	Surgery	Yes
Peters 1988	1	M	9	Traumatic abdominal wall hernia, small bowel perforation, mesenteric laceration	Surgery	Yes
PradaArias 2004	2	1 M, 1F	8	Traumatic abdominal wall hernia	2 surgeries	Yes
Pruitt 2007	1	M	13	Traumatic ventricular septal defect, torn tricuspid valve	Surgery	Yes
Ramesh 2002	1	M	11	Appendix laceration	Surgery	Yes
Ramos 2008	1	M	6	Hemoperitoneum, omental infarct	Surgery	Yes
Rathore 2012	5	5 M	12.6	Traumatic abdominal wall hernia, small bowel contusion, pancreatic contusion, pancreatic pseudocyst, colon hematoma	Surgery	Yes
Rescoria 1990	2	2 M	7	Pancreatic pseudocyst, pancreatic transection	2 surgeries, 2 percutaneous drainage	Yes
Rinaldi 2017	2	2 M	12.5	Traumatic abdominal wall hernia	2 surgeries	Yes
Roberts 1964	1	M	9	Traumatic abdominal wall hernia, rectus abdominal muscle rupture	Surgery	Yes

(*continued on next page*)

Table A.1 (*continued*)

Author, publication year	Patients, n	Gender (F or M)	Mean age, yrs	Abd or chest injuries reported	Management	Survival (yes or no)
Rohatgi 1987	1	M	10	Common bile duct transection, rectus abdominal muscle rupture	Surgery	Yes
Roik 2008	1	M	12	Hepatic vein laceration	Surgery	Yes
Rowell 2011	1	M	14	Traumatic abdominal wall hernia, mesenteric laceration	Surgery	Yes
Saad 2005	1	F	11	Pancreatic laceration, pancreatic pseudocyst	Surgery	Yes
Saeb-Parsy 2006	1	M	15	Gastric mucosal injury	Medical	Yes
Schimpl 1992	17	16 M, 1F	8.2	Small bowel perforation, small bowel hematoma, traumatic pancreatitis, pancreatic pseudocyst, colon laceration, ileus, colon hematoma, mesenteric hematoma	17 surgeries	Yes
Sheridan 2006	1	M	11	Liver laceration, biloma, hemoperitoneum	Percutaneous drainage	Yes
Shukla 2018	1	M	14	Traumatic abdominal wall hernia, small bowel laceration, mesenteric laceration, omental infarction	Surgery	Yes
Singla 2015	1	M	15	External iliac artery occlusion	Surgery	Yes
So 2018	1	M	10	Traumatic abdominal wall hernia	Surgery	Yes
Solomon 2011	1	M	17	Traumatic abdominal wall hernia, small bowel perforation, colon devascularization	Surgery	Yes
Sparnon 1986	30	24 M, 6F	n/a	Small bowel perforation, small bowel hematoma, traumatic pancreatitis, kidney laceration, splenic rupture, wall hematoma, pancreatic pseudocyst, unspecified liver trauma, kidney contusion	12 surgeries, 18 medical	Yes
Spitz 1999	1	M	10	Liver laceration, hemoperitoneum	Medical	No
Stanton 1986	1	M	11	External iliac artery occlusion	Surgical	Yes
Stavrou 2008	1	F	5	Traumatic pancreatitis, pancreatic pseudocyst, pancreatic injury	Percutaneous drainage	Yes
Stiekema 2018	1	M	6	Small bowel contusion, intestinal obstruction	Surgical	Yes
Talutis 2015	3	2 M, 1F	9	Traumatic abdominal wall hernia, small bowel perforation, small bowel contusion	Surgical	Yes
Talwar 2007	1	M	20	Traumatic abdominal wall hernia, liver laceration, kidney laceration, perinephric hematoma, rectus abdominal muscle rupture, liver herniation	Surgery, percutaneous drainage	Yes
Thakur 2013	1	M	9	Traumatic Spigelian hernia	Surgery	Yes
Tonsi 2010	1	M	14	Traumatic abdominal wall hernia, small bowel perforation, mesenteric laceration, rectus abdominal muscle rupture	Surgery	Yes
Tracy 1996	1	M	13	Aortic laceration, renal artery laceration, renal vein laceration, lumbar artery avulsion, retroperitoneal hematoma	Surgery	No
Tytgat 2010	1	M	9	Stomach laceration, pneumoperitoneum	Surgery	Yes
Upasani 2013	1	M	12	Traumatic abdominal wall hernia, wall hematoma	Medical	Yes
van Bemmel 2011	1	M	7	Traumatic abdominal wall hernia, rectus abdominal muscle rupture	Surgery	Yes
Vandewalle 2019	77	57 M, 20F	n/a	Traumatic abdominal wall hernia, liver laceration splenic laceration small bowel perforation, kidney laceration, abdominal wall hematoma, abdominal wall laceration pancreatic transection, unspecified pancreatic injury, retroperitoneal hematoma, mesenteric hematoma, unspecified hollow organ injury, adrenal hematoma, unspecified appendix injury, pneumothorax, complex chest laceration	27 surgeries, 48 medical, 2 angioembolization	Yes
Vincent 2018	1	M	12	Traumatic abdominal wall hernia, presacral hematoma	Surgery	Yes
Volpe 2016	2	2 M	10	Traumatic abdominal wall hernia	2 medical	Yes
Wallis 2010	1	M	10	Liver laceration, hepatic artery pseudoaneurysm, hemoperitoneum, ileus	Surgery	Yes
White 2017	1	M	7	Small bowel perforation, mesenteric hematoma	Surgery	Yes
Winston 1998	1	M	6	Liver laceration, splenic laceration, kidney laceration, pancreatic laceration, kidney bruise, pneumothorax	Surgery	Yes
Yan 2011	1	M	8	Traumatic abdominal wall hernia	Surgery	Yes
Yaylaci 2014	1	M	11	Traumatic abdominal wall hernia, small bowel perforation, pneumoperitoneum	Surgery	Yes
Yegane 2010	1	M	4	Traumatic abdominal wall hernia	Surgery	Yes
Zarin 1952	1	M	4	Small bowel contusion, hemoperitoneum	Surgery	Yes

References

[1] Mehan TJ, Gardner R, Smith GA, McKenzie LB. Bicycle-related injuries among children and adolescents in the United States. Clin Pediatr. 2009;48(2):166–73. https://doi.org/10.1177/0009922808324952.

[2] McAdams RJ, Swidarski K, Clark RM, Roberts KJ, Yang J, Mckenzie LB. Bicycle-related injuries among children treated in US emergency departments, 2006–2015. Accid Anal Prev. 2018;118:11–7. https://doi.org/10.1016/j.aap.2018.05.019.

[3] Winston FK, Weiss HB, Nance ML, et al. Estimates of the incidence and costs associated with handlebar-related injuries in children. Arch Pediatr Adolesc Med. 2002;156(9):922–8. https://doi.org/10.1001/archpedi.156.9.922.

[4] Winston FK, Shaw KN, Kreshak AA, Schwarz DF, Gallagher PR, Cnaan A. Hidden spears: handlebars as injury hazards to children. Pediatrics. 1998;102(3):596–601. https://doi.org/10.1542/peds.102.3.596.

[5] Schmidt M, Rosenberg J, Tolver M. Traumatic bicycle handlebar hernia in children: a systematic review. Dan Med J. 2018;65(1).

[6] Hirzinger C, Heil C, Metzger R, Bensard DD. Pediatric handlebar injury. J Trauma Acute Care Surg. 2017;82(6):1184–5.

[7] Stanton PE, Brown R, Rosenthal D, Clark M, Lamis PA. External iliac artery occlusion by bicycle handle injury. J Cardiovasc Surg. 1986;27(6):728–30.

[8] Singla A, McPherson D, Singla A, Cross J, Leslie A. External iliac artery occlusion in a paediatric patient following handlebar trauma. J Surg Case Rep. 2015;2015(3). https://doi.org/10.1093/jscr/rjv015.

[9] Wallis A, Rogers T, Pope I, Callaway M. Blunt abdominal trauma - an important cause of portal venous pseudoaneurysm. J Radiol Case Rep. 2010;4(5):27–31. https://doi.org/10.3941/jrcr.v4i5.368.

[10] Madan A, Raafat A, Hewitt R. Complete femoral artery transection from blunt trauma. J La State Med Soc Off Organ La State Med Soc. 2003;155(4):215–6.

[11] Arbogast KB, Cohen J, Otoya L, Winston FK. Protecting the child's abdomen: a retractable bicycle handlebar. Accid Anal Prev. 2001;33(6):753–7. https://doi.org/10.1016/S0001-4575(00)00089-0.

[12] Ford Edward G, et al. Pseudocysts of the pancreas in children. Am Surg. 1990;56(6):384–7.

[13] Klimek P, Lutz T, Stranzinger E, Zachariou Z, Kessler U, Berger S. Handlebar injuries in children. Pediatr Surg Int. 2013;29(3):269–73. https://doi.org/10.1007/s00383-012-3227-y.

[14] Clarnette TD, Beasley SW. Handlebar injuries in children: patterns and prevention. Aust N Z J Surg. 1997;67(6):338–9. https://doi.org/10.1111/j.1445-2197.1997.tb01986.x.

[15] Fraser GC. Handlebar injury of pancreas - report of a case complicated by pseudocyst formation with spontaneous internal rupture. J Pediatr Surg. 1969;4(2). https://doi.org/10.1016/0022-3468(69)90394-7 216-+.

[16] Cherniawsky H, Bratu I, Rankin T, Sevcik W. Serious impact of handlebar injuries. Clin Pediatr. 2014;53(7):672–6. https://doi.org/10.1177/0009922814526977.

[17] Nadler E, Potoka D, Shultz B, Morrison K, Ford H, Gaines B. The high morbidity associated with handlebar injuries in children. J Trauma. 2005;58(6):1171–4.

[18] Hirose T, Ogura H, Kiguchi T, et al. The risk of pediatric bicycle handlebar injury compared with non-handlebar injury: a retrospective multicenter study in Osaka, Japan. Scand J Trauma Resuscitation Emerg Med. 2015;23(1):66.
[19] Lam JPH, Eunson GJ, Munro FD, Orr JD. Delayed presentation of handlebar injuries in children. BMJ. 2001;322(7297):1288–9. https://doi.org/10.1136/bmj.322.7297.1288.
[20] Nataraja RM, Palmer CS, Arul GS, Bevan C, Crameri J. The full spectrum of handlebar injuries in children: a decade of experience. Injury. 2013;45(4):684–9.
[21] Sparnon A, Ford W. Bicycle handlebar injuries in children. J Pediatr Surg. 1986;21(2):118–9.
[22] Dai L, Chen C, Lin X, et al. Abdominal injuries involving bicycle handlebars in 219 children: results of 8-year follow-up. Eur J Trauma Emerg Surg (Munich: 2007). 2015;41(5):551–5.
[23] Vandewalle R, Barker S, Raymond J, Brown B, Rouse T. Pediatric handlebar injuries: more than meets the abdomen. Pediatr Emerg Care. 2019. https://doi.org/10.1097/PEC.0000000000001690.
[24] Spitz D. Unrecognized fatal liver injury caused by a bicycle handlebar. Am J Emerg Med. 1999;17(3):244.
[25] Tracy T, Silen M, Graham M. Delayed rupture of the abdominal aorta in a child after a suspected handlebar injury. J Trauma. 1996;40(1):119–20.
[26] O'Neill JA. Advances in the management of pediatric trauma. Am J Surg. 2000;180(5):365–9. https://doi.org/10.1016/S0002-9610(00)00488-8.
[27] AAP Committee on Pediatric Emergency Medicine, Council on Injury, Violence, and Poison Prevention, Section on Critical Care, Section on Orthopaedics, Section on Surgery, Section on Transport Medicine, Pediatric Trauma Society, Society of Trauma Nurses, Pediatric Committee. Management of pediatric trauma. Pediatrics. 2016;138(2). https://doi.org/10.1542/peds.2016-1569 e20161569.
[28] Yan J, Wood J, Bevan C, Cheng W, Wilson G. Traumatic abdominal wall hernia—a case report and literature review. J Pediatr Surg. 2011;46(8):1642–5.
[29] Schimpl G, Schmidt B, Sauer H. Isolated bowel injury in blunt abdominal trauma in childhood. . 1992;2(6):341–4. https://doi.org/10.1055/s-2008-1063474.
[30] Kolar M, Toprak A, Winthrop A, Sly L, Soboleski D. Surgical vs. nonsurgical management of post-traumatic intercostal lung herniation in children. J Pediatr Surg Case Rep. 2018;28:51–8.
[31] Bokhari SAJ, Paw R. An unusual abdominal injury in a child. Emerg Med J. 2008;25(3):181.
[32] Alkan M, Iskit S, Soyupak S, et al. Severe abdominal trauma involving bicycle handlebars in children. Pediatr Emerg Care. 2012;28(4):357–60. https://doi.org/10.1097/PEC.0b013e3181acd30f.
[33] Peterson MLAP, Fallon SC, Naik-Muthuria BJ, Rodriguez JR. Management of traumatic duodenal hematomas in children. J Surg Res. 2015;199(1):126–9. https://doi.org/10.1016/j.jss.2015.04.015.
[34] Houben CH, Ade-Ajayi N, Patel S, et al. Traumatic pancreatic duct injury in children: minimally invasive approach to management. J Pediatr Surg. 2007;42(4):629–35. https://doi.org/10.1016/j.jpedsurg.2006.12.025.
[35] Bond SJ, Eichelberger MR, Gotschall CS, Sivit CJ, Randolph JG. Nonoperative management of blunt hepatic and splenic injury in children. Ann Surg. 1996;223(3):286–9. https://doi.org/10.1097/00000658-199603000-00009.
[36] Stylianos S. APSA Trauma Committee. Evidence-based guidelines for resource utilization in children with isolated spleen or liver injury. J Pediatr Surg. 2000;35(2):164–9. https://doi.org/10.1016/S0022-3468(00)90003-4.
[37] Wisner DH, Kuppermann N, Cooper A, et al. Management of children with solid organ injuries after blunt torso trauma. J Trauma Acute Care Surg. 2015;79(2):206–14. https://doi.org/10.1097/TA.0000000000000731.