

Multimodal Analysis of Liver Injuries in Children with Road Traffic Injuries Using Artificial Intelligence and Digital Morphometry

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Abstract

Road traffic injuries remain a major cause of morbidity and mortality among children and young people worldwide. Abdominal trauma associated with road traffic accidents may result in clinically significant liver injuries, ranging from minor parenchymal lesions to extensive lacerations and vascular damage. Early and accurate assessment of hepatic trauma is essential for selecting an appropriate treatment strategy and preventing complications. Conventional diagnostic approaches, including ultrasonography and computed tomography (CT), remain central to the evaluation of pediatric abdominal trauma; however, interpretation of complex imaging findings may be challenging, particularly in emergency settings. Recent advances in artificial intelligence (AI), medical image segmentation, radiomics, and digital morphometry provide opportunities for more objective and quantitative assessment of traumatic liver damage. This article reviews the potential role of AI-assisted multimodal analysis in children with liver injuries caused by road traffic accidents. Particular attention is given to automated liver segmentation, measurement of liver volume and injury dimensions, assessment of lesion morphology, radiomics-based characterization, and integration of imaging parameters with clinical data. Digital morphometry may complement conventional qualitative radiological interpretation by providing reproducible quantitative indicators of tissue damage. AI-based machine learning models have already demonstrated promising results in the identification of traumatic liver injuries on CT images, although most available evidence is derived from adult or mixed-age populations. Pediatric-specific validation remains necessary because anatomical proportions, imaging protocols, and clinical management differ from those of adults. A multimodal framework integrating clinical, laboratory, ultrasonographic, CT, and quantitative morphometric information could improve diagnostic consistency, support injury grading, facilitate monitoring, and potentially assist clinical decision-making. Nevertheless, issues related to data quality, radiation exposure, algorithmic bias, explainability, and external validation must be addressed before routine clinical implementation.

Keywords: Artificial intelligence; pediatric trauma; liver injury; road traffic injury; digital morphometry; computed tomography; ultrasonography; radiomics; medical image segmentation; machine learning.

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1. Introduction

Road traffic injuries represent one of the most important global public health challenges. According to the World Health Organization (WHO), approximately 1.19 million people die annually as a result of road traffic crashes, while between 20 and 50 million people experience non-fatal

injuries. Road traffic injuries are the leading cause of death among children and young adults aged 5–29 years. Children are particularly vulnerable because of their anatomical, physiological, cognitive, and behavioral characteristics.

In pediatric trauma, blunt abdominal injury is an important clinical problem. The liver is among the abdominal organs

that can be damaged following high-energy trauma, including vehicle collisions, pedestrian accidents, and other road traffic events. Hepatic injuries may include contusions, subcapsular hematomas, parenchymal lacerations, active hemorrhage, vascular injuries, and complex destruction of hepatic tissue. The severity of liver injury varies considerably, and clinical manifestations may not always correspond directly to the anatomical extent of the lesion.

Modern pediatric trauma management increasingly emphasizes non-operative treatment in hemodynamically stable patients. Updated guidelines from the American Pediatric Surgical Association (APSA) support structured management of blunt liver and spleen injuries based on clinical condition, injury characteristics, and the patient's subsequent course. Similarly, the World Society of Emergency Surgery (WSES) emphasizes that management of liver trauma should take into consideration anatomical injury, hemodynamic status, and associated injuries.

Imaging plays a central role in this process. Ultrasonography is widely available and does not expose children to ionizing radiation, making it particularly attractive in pediatric emergency care. Contrast-enhanced ultrasound has also been investigated as a useful technique for assessing pediatric blunt abdominal trauma. However, CT remains an important reference imaging modality in appropriately selected hemodynamically stable patients because it can demonstrate the location, extent, and characteristics of hepatic injuries and associated intra-abdominal abnormalities.

Despite the diagnostic value of CT, interpretation of trauma images is often time-consuming. Manual delineation of the liver and traumatic lesions can also be affected by observer experience and inter-observer variability. These limitations create an opportunity for artificial intelligence and digital morphometry.

Artificial intelligence can process large quantities of imaging information and identify complex patterns that may not be immediately apparent during conventional visual assessment. In medical imaging, deep learning algorithms have demonstrated considerable potential for automated organ segmentation and quantitative image analysis. A recent review of AI-based medical image segmentation emphasized the rapid development of automated segmentation techniques while also highlighting the importance of explainability, robustness, and trustworthy clinical implementation.

The purpose of this article is therefore to examine the

potential of AI and digital morphometry for multimodal assessment of liver injuries in children following road traffic accidents and to identify the main directions for future pediatric trauma research.

2. Literature Review

2.1. Pediatric liver injury following road traffic accidents

The liver is particularly susceptible to blunt abdominal trauma because of its size, anatomical position, and relatively fixed relationship to surrounding structures. In children, anatomical and physiological characteristics differ from those of adults, which may influence both injury patterns and clinical assessment.

Historically, severe abdominal trauma was frequently treated surgically. However, improvements in diagnostic imaging, critical care, transfusion protocols, and interventional radiology have contributed to the widespread adoption of non-operative management in hemodynamically stable patients. The updated APSA guidelines specifically organize pediatric blunt liver and spleen injury management around admission, procedures, activity-related recommendations, and aftercare.

Anatomical grading systems remain important for describing injury severity. The American Association for the Surgery of Trauma (AAST) maintains an Organ Injury Scale for liver injuries, with the 2018 revision providing a standardized anatomical framework. However, anatomical grade alone cannot determine the complete clinical picture. WSES guidelines emphasize that treatment decisions should integrate injury anatomy with hemodynamic status and associated injuries.

This distinction is important for AI-assisted systems. An algorithm designed only to recognize an anatomical lesion may have limited clinical usefulness if it cannot contextualize the lesion with the patient's physiological condition and other injuries.

2.2. Conventional imaging and its limitations

Ultrasonography is an attractive first-line imaging modality for pediatric trauma because it is portable, relatively inexpensive, and free from ionizing radiation. It can help detect free intraperitoneal fluid and some hepatic abnormalities. Contrast-enhanced ultrasound may provide additional information about parenchymal perfusion and traumatic lesions. A systematic review by Pegoraro et al. demonstrated growing interest in contrast-enhanced

ultrasound for pediatric blunt abdominal trauma.

Nevertheless, ultrasound is operator-dependent and may be limited by bowel gas, patient cooperation, body habitus, and the complexity of injuries. CT provides more comprehensive anatomical information and remains highly valuable when significant intra-abdominal injury is suspected.

The challenge is that CT examinations generate large volumes of image data. Emergency radiologists must rapidly determine whether there is liver damage, identify its location and extent, assess active bleeding, and recognize associated injuries. Digital analysis could potentially support this process by converting visual information into measurable parameters.

2.3. Artificial intelligence in medical image analysis

AI-based medical image analysis commonly involves several stages: image preprocessing, segmentation, feature extraction, classification, and prediction. Deep learning, particularly convolutional neural networks, has become an important approach for automated segmentation.

Automated liver segmentation is particularly relevant to digital morphometry. Once the liver is accurately segmented, its volume, dimensions, shape, surface characteristics, and relationship to surrounding structures can be quantified. Earlier deep-learning studies demonstrated that automated liver segmentation from CT images could achieve high segmentation accuracy, establishing a technological foundation for quantitative hepatic analysis.

More recent reviews emphasize that segmentation is increasingly moving toward explainable and trustworthy AI rather than simply maximizing numerical accuracy. This is especially important in pediatric trauma, where an incorrect segmentation or lesion classification could influence clinical decisions.

2.4. AI and traumatic liver injury

Of particular relevance to the present topic is the recent study by Dehbaghi et al., which directly investigated machine learning and radiomics for detecting traumatic liver injury on CT. The study used 600 CT images and extracted radiomics features from radiologist-defined regions of interest. Several machine-learning models were evaluated, including Light Gradient-Boosting Machine, Ridge Classifier, and Extreme Gradient Boosting. The authors reported promising diagnostic performance,

particularly for identifying severe traumatic liver injury, and suggested that AI could help prioritize positive examinations and accelerate assessment in emergency settings.

This research is highly relevant because it demonstrates that AI-based analysis of liver trauma is not merely theoretical. Nevertheless, its applicability to children cannot automatically be assumed. Pediatric populations require dedicated validation because children differ from adults in body size, organ proportions, tissue characteristics, imaging protocols, and patterns of trauma.

Therefore, a major research gap exists between proof-of-concept AI models for traumatic liver injury and clinically validated pediatric systems.

2.5. Digital morphometry as a component of multimodal analysis

Digital morphometry refers to quantitative measurement of anatomical structures using digital images. In liver trauma, potential parameters include total liver volume, affected volume, lesion length, lesion depth, lesion area, lesion-to-liver ratio, hematoma volume, anatomical segment involvement, and changes in liver morphology.

The advantage of digital morphometry is that it can transform descriptive radiological observations into standardized numerical variables. For example, instead of describing a lesion simply as "large," an automated system could calculate the proportion of hepatic tissue affected by the lesion.

A multimodal model could combine these morphometric indicators with clinical and laboratory parameters such as age, heart rate, blood pressure, hemoglobin concentration, liver enzyme levels, and indicators of blood loss. Imaging modalities could also be integrated, including ultrasound and CT.

Such integration could potentially improve the characterization of injury severity and assist clinicians in monitoring recovery. However, these applications should be investigated prospectively rather than assumed to improve outcomes solely on the basis of technical accuracy.

2.6. Radiomics and quantitative characterization

Radiomics extends digital image analysis beyond simple anatomical measurements. It involves extraction of quantitative characteristics related to image intensity, texture, shape, and spatial relationships.

In traumatic liver injury, radiomic features could theoretically help differentiate normal parenchyma from contusion, hematoma, or lacerated tissue. When combined with morphometric measurements, these features may provide a richer representation of injury patterns.

The study by Dehbaghi et al. illustrates the potential of combining radiomics with machine learning for traumatic liver injury. However, radiomic models are sensitive to acquisition parameters, reconstruction algorithms, contrast phases, segmentation methods, and population characteristics. Consequently, models trained using one dataset may not perform similarly in another hospital or patient population.

This issue is particularly important for children because pediatric datasets are usually smaller than adult datasets. A robust pediatric AI system would require multi-center datasets representing different ages, sexes, body sizes, scanners, imaging protocols, and injury patterns.

3. Prospects for a Multimodal AI-Based System

A clinically meaningful system for pediatric liver trauma should not simply classify CT images. A more comprehensive architecture could contain four interconnected components.

First, image segmentation could automatically identify the liver and surrounding anatomical structures.

Second, digital morphometry could quantify liver volume and the size, location, depth, and distribution of traumatic lesions.

Third, radiomics and machine learning could analyze quantitative imaging characteristics and estimate injury severity.

Fourth, multimodal integration could combine imaging-derived variables with clinical and laboratory information.

The resulting system could generate an objective assessment that supports, rather than replaces, the radiologist and trauma team.

Such a system should also be explainable. Clinicians need to know why an algorithm considers an injury potentially severe. Heat maps, lesion segmentation masks, quantitative measurements, and confidence scores could make AI outputs easier to interpret.

The FUTURE-AI international consensus framework recommends that healthcare AI be developed according to

principles including fairness, universality, traceability, usability, robustness, and explainability. These principles are particularly relevant to pediatric trauma because children represent a vulnerable population and because errors may have substantial clinical consequences.

Another important issue is radiation exposure. AI should not encourage unnecessary CT examinations in children. Instead, it should be incorporated into clinically justified imaging pathways and should ideally extract maximum diagnostic value from examinations that have already been appropriately performed.

4. Discussion

The integration of AI and digital morphometry may address several limitations of conventional assessment of pediatric liver trauma. First, automated segmentation could reduce the time required for manual delineation. Second, quantitative measurements could improve reproducibility. Third, machine-learning models could assist with prioritization of potentially severe cases in busy emergency departments.

However, several limitations should be acknowledged. Most importantly, evidence specifically involving children with road traffic-related liver trauma remains limited. Many existing AI studies involve adults, mixed populations, or non-traumatic liver disease. Therefore, high performance in an adult dataset cannot be interpreted as evidence of clinical effectiveness in pediatric trauma.

Data imbalance is another challenge. Severe liver injuries may be less frequent than minor injuries, and individual pediatric centers may have insufficient numbers of cases for robust model development. Multi-center collaboration and standardized data annotation could help address this problem.

External validation is equally important. An algorithm should be evaluated on data obtained from institutions that were not involved in its training. Performance should be assessed using clinically meaningful measures such as sensitivity, specificity, area under the receiver operating characteristic curve, calibration, segmentation accuracy, and time saved during interpretation.

Finally, AI should remain a decision-support technology. The current evidence supports the concept that AI can assist radiologists, but it does not justify replacing clinical judgment. The recent international consensus on trustworthy AI emphasizes continuous monitoring, risk assessment, transparency, and appropriate human oversight

throughout the AI lifecycle.

5. Conclusion

Liver injury is an important component of pediatric abdominal trauma associated with road traffic accidents. Accurate assessment of injury severity is essential for selecting appropriate management and monitoring patients during recovery. Conventional ultrasound and CT remain fundamental diagnostic modalities, but their interpretation can be demanding in emergency settings.

Artificial intelligence, digital morphometry, automated segmentation, and radiomics provide promising opportunities for improving the quantitative assessment of traumatic liver injuries. A multimodal approach could integrate anatomical imaging characteristics with clinical and laboratory parameters, potentially providing a more comprehensive representation of injury severity than any individual data source.

Existing research has already demonstrated the feasibility of machine-learning approaches for detecting traumatic liver injury on CT. However, there remains a substantial gap in pediatric-specific evidence. Future studies should therefore focus on large, multi-center pediatric datasets, standardized digital morphometric parameters, robust external validation, explainable AI, and clinically meaningful outcome measures.

The ultimate objective should not be to replace radiologists or trauma specialists but to provide them with reliable quantitative information that can improve the speed, consistency, and objectivity of pediatric trauma assessment. If adequately validated, AI-assisted multimodal analysis may become a valuable component of precision trauma medicine.

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