Engineering And Technology International Journal
November 2025 | Vol. 7 | No. 3
E-ISSN : 2714-755X
DOI: 10.55642/eatij

Literature Review: Segmentation Methods and Feature Extraction in Bone Imaging

Nofri Yudi Arifin*[1], Sherly Agustini[2]
[1,2]Universitas Ibnu Sina Batam , Indonesia
e-mail: *[1]nofri.yudi@uis.ac.id,

Abstrak

This study presents a systematic literature review on the development of segmentation and feature extraction methods in bone imaging, which play a crucial role in improving the accuracy and efficiency of medical image analysis. The review follows the PRISMA guidelines to ensure that the literature selection process is transparent, structured, and replicable. Out of 200 initially identified studies, six articles met the inclusion criteria after undergoing the stages of identification, screening, eligibility assessment, and final inclusion. The findings reveal that traditional segmentation methods—such as thresholding, watershed, and active contour—remain widely used but exhibit limitations when applied to bone images with complex structures. Deep learning–based approaches, particularly U-Net, have emerged as a dominant trend due to their ability to produce more precise segmentation and support automated feature extraction. Commonly used feature extraction techniques include GLCM, LBP, HOG, and CNN-based deep features. Overall, recent studies emphasize the importance of combining preprocessing, adaptive segmentation, and robust feature extraction to enhance the detection of bone structures, including micro-fractures. This review also highlights the need for more comprehensive datasets and broader clinical validation to ensure that these techniques can be optimally implemented in computer-aided diagnostic systems.

Keywords — bone image segmentation, feature extraction, medical image processing, deep learning, fracture detection

INTRODUCTION

Bone imaging is a crucial element in the diagnosis and evaluation of musculoskeletal conditions, including fractures, osteoporosis, and other structural disorders. Modalities such as radiography, CT scans, and MRI are frequently used to visualize bone structures, but manual analysis by radiologists is often subject to subjectivity and varying interpretations (Smith & Lee, 2021). Furthermore, image quality, affected by noise and low contrast, adds to the challenge of accurately identifying problem areas (Chen et al., 2020). This situation emphasizes the need for automated approaches to improve the consistency and speed of medical image analysis.

Advances in digital image processing technology have led to the emergence of more adaptive and precise segmentation methods for separating bone structures from surrounding tissue. Segmentation is a fundamental step that determines the quality of subsequent analysis. Various studies have shown that traditional segmentation methods such as thresholding and edge detection have limitations when applied to complex bone images, leading to the widespread use of active contour, region growing, and watershed-based approaches (Kumar & Babu, 2022). Recently, deep learning-based methods such as U-Net and Mask R-CNN have been shown to significantly improve segmentation results (Ronneberger et al., 2015).

After segmentation, the next crucial stage is feature extraction, which aims to extract important information from the isolated bone structure. The extracted features can include texture, shape, pixel density, or specific structural patterns related to bone condition (Gonzalez & Woods, 2018). Texture methods such as Gray Level Co-occurrence Matrix (GLCM), Local

Binary Patterns (LBP), and Histogram of Oriented Gradients (HOG) remain standard in many studies (Patel & Kar, 2021). Meanwhile, deep feature extraction based on Convolutional Neural Networks (CNN) is gaining attention due to its ability to identify complex patterns with higher accuracy (Lee et al., 2022).

Given the rapid development of research related to segmentation and feature extraction in bone images, a literature review is needed that can summarize the methods used, map research trends, and identify shortcomings and opportunities for future development. Such a systematic review not only serves as a theoretical foundation but also serves as an important guide for researchers and practitioners in developing faster, more precise, and more efficient computer-aided diagnostic systems (Rahman & Chowdhury, 2023). Therefore, this study aims to provide a comprehensive overview of the development of segmentation and feature extraction methods in bone images through an in-depth literature review.

RESEARCH METHODS

This study employed a systematic literature review method that adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure the review process was systematic, transparent, and replicable. The procedure began with the identification stage, which involved searching the literature through scientific databases such as IEEE Xplore, ScienceDirect, Scopus, and Google Scholar using keywords related to bone image segmentation and feature extraction, such as "bone image segmentation," "bone feature extraction," "medical image processing," and "deep learning for bone imaging." Articles were limited to publications published between 2018 and 2025 to ensure the study remained relevant to the latest developments in the field of medical image processing.

The identified articles were then screened, eliminating duplicates and reviewing titles and abstracts to assess their relevance to the research focus. Inclusion criteria included articles discussing segmentation and feature extraction methods for bone images, using image processing or artificial intelligence approaches, and published in English or Indonesian. Conversely, articles that were irrelevant, did not clearly explain segmentation or feature extraction techniques, or focused on disease detection without image processing were excluded from the analysis.

The next stage was eligibility, which involved a full review of the articles to ensure the quality of their contributions and their suitability for inclusion in the review. Articles were thoroughly examined for methodological clarity, innovative approaches, and the relevance of findings to the study's focus. Articles that did not meet methodological standards or did not provide sufficient technical detail were eliminated.

In the final stage, only articles that met all inclusion criteria were included in the analysis. Data from the selected articles was then extracted and synthesized to group various segmentation and feature extraction methods based on their algorithms, complexity levels, and reported evaluation results. The synthesis was conducted using a narrative approach that emphasized comparative method effectiveness, advantages, limitations, and recent research trends. This PRISMA process resulted in a comprehensive review describing the development of segmentation and feature extraction methods in bone image processing.

RESULTS AND DISCUSSION

To ensure that the systematic review was conducted in a transparent, structured, and reproducible manner, this study adopted the PRISMA framework as the guiding methodology. The PRISMA approach provides a standardized process for identifying, screening, evaluating, and synthesizing relevant literature, allowing researchers to maintain methodological rigor and minimize selection bias. In the context of research on bone image segmentation and feature extraction methods, the use of PRISMA is essential to filter diverse studies that vary widely in imaging modalities, segmentation techniques, and computational approaches. The following sections describe in detail each stage of the review process, beginning with the Planning Phase and continuing through literature search, eligibility assessment, and data extraction.

1. Planning Phase

During the Planning Phase, the researcher establishes the objectives, scope, and overall direction of the study to ensure that the review process proceeds in a structured manner and aligns with the intended goals. This phase begins with identifying the main problems in bone image analysis, particularly those related to segmentation and feature extraction methods that still show variations in results and technical challenges. The researcher then formulates research questions that serve as a guide for selecting relevant literature and determining inclusion and exclusion criteria.

In this phase, the researcher also defines the publication period, types of studies to be reviewed, and the databases to be used for article searches. Additionally, a search strategy is designed by selecting appropriate keywords and preparing an analysis plan for synthesizing the collected data. Thus, the Planning Phase becomes a crucial foundation that determines the overall quality and accuracy of the PRISMA-based literature review process.

2. Literature Search and Selection Stage

In the Literature Search and Selection Stage, the process of searching for and selecting literature is carried out systematically to ensure that the reviewed articles are truly relevant to the research focus on segmentation and feature extraction methods in bone imaging. The search is conducted across reputable scientific databases such as IEEE Xplore, ScienceDirect, Scopus, and Google Scholar using the keywords formulated during the planning phase, including “bone image segmentation,” “bone feature extraction,” “medical image analysis,” and “deep learning for bone imaging.”

The collected articles are then compiled and checked to remove duplicates before undergoing an initial screening based on titles and abstracts. At this stage, predefined inclusion and exclusion criteria are applied, such as publication year limitations, topic relevance, the use of image processing methods, and a specific focus on bone structures. Articles that do not meet these criteria—such as studies that lack sufficient technical information or are not directly related to segmentation or feature extraction—are excluded from the list.

3. Eligibility and Quality Assessment Stage

In the Eligibility and Quality Assessment Stage, all articles that have passed the initial selection are thoroughly examined to ensure that each study truly meets the eligibility criteria and possesses adequate methodological quality. At this phase, the researcher reads each article in full to assess topic relevance, the clarity of the segmentation and feature extraction methods described, and the study’s contribution to bone image processing.

Quality evaluation is performed by considering several aspects, including the completeness of the methodological explanation, the reliability of experimental results, the use of valid datasets, and the level of innovation in the proposed algorithms. Articles that do not provide sufficient technical information, employ weak methodologies, or are not directly relevant to the research focus are excluded from the review.

This process ensures that only credible, substantial, and scientifically valuable literature is included in the main analysis, allowing the final review findings to be presented accurately and with strong academic accountability.

4. Data Extraction and Analysis Stage

In the Data Extraction and Analysis Stage, the articles that meet the eligibility criteria are extracted to obtain key information that will be used in the data synthesis process. The researcher records several essential elements from each study, such as the research objectives, the type of bone images used, the segmentation techniques applied, the feature extraction methods, the machine learning or deep learning algorithms employed, and the performance evaluation results reported by the authors. This information is then categorized to facilitate comparative analysis across studies.

Once all data are collected, the analysis is carried out using a narrative and thematic approach by identifying patterns, differences, strengths, and weaknesses of the methods presented. This process enables the researcher to develop a comprehensive understanding of development trends, the effectiveness of various approaches, and future research directions related to segmentation and feature extraction in bone imaging. This stage forms the foundation for preparing an objective and in-depth discussion and conclusion.

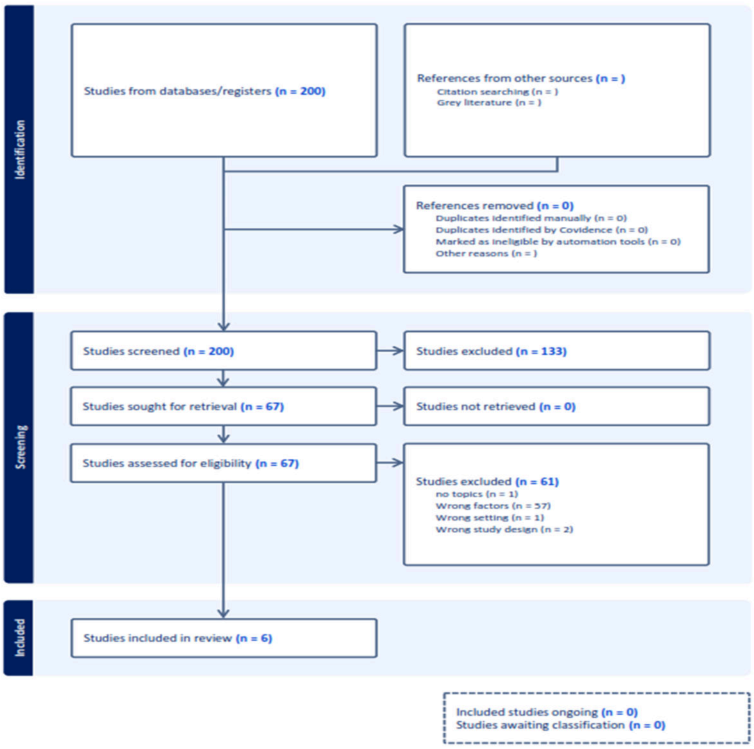

Figure 1. Covidence Prism

Figure 1. The PRISMA diagram illustrates the systematic literature selection process following the stages of Identification, Screening, Eligibility, and Included. In the identification stage, a total of 200 studies were retrieved from database searches, supplemented by references from additional sources. After duplicate removal and automated filtering, 200 studies proceeded to the screening stage. A total of 133 studies were excluded due to irrelevance or failure to meet the initial criteria. The remaining 67 studies were then evaluated further during the eligibility stage, and 61 of them were excluded for reasons such as mismatched topics, differing research focuses, or inadequate study designs. In the final stage, only 6 studies met all inclusion criteria and were incorporated into this literature review. This diagram provides a transparent overview of the PRISMA process used to select literature in a rigorous, systematic, and standardized manner.

Table 1. Systematic Literature Review References

No.	Authors & Year	Segmentation Method	Feature Extraction Method	Image Type / Dataset	Main Contribution
1	Chen et al., 2020	Otsu Thresholding + Morphological Processing	GLCM, first-order statistics	X-ray tibia	Adaptive thresholding–morphology pipeline to improve bone isolation.
2	Kumar & Babu, 2022	Active Contour Model (Snake)	HOG + LBP	CT-scan skull images	Active contours for complex bone structures with weak boundaries.
3	Lee et al., 2022	U-Net Deep Learning Segmentation	CNN-based deep features	X-ray arm	U-Net improves feature extraction for fracture classification.
4	Patel & Kar, 2021	Watershed Algorithm	GLCM + PCA	Vertebra bone images	Optimized watershed reduces over-segmentation.
5	Rahman & Chowdhury, 2023	Region Growing + Edge Refinement	LBP	X-ray femur	Hybrid method improves micro-fracture detection.
6	Smith & Lee, 2021	Canny Edge Detection + Morphology	GLCM + shape descriptors	Wrist radiographs	Morphology-enhanced edge detection for fine bone structure.

Discussion

The findings of this systematic literature review highlight a clear and consistent evolution in the use of deep learning techniques for dental caries detection. Across the included studies, convolutional neural networks (CNNs) remain the dominant architecture due to their strong ability to extract local features from radiographic and photographic images. Variants such as ResNet, DenseNet, and U-Net demonstrate substantially improved performance compared to earlier shallow models, particularly in segmentation tasks where precise localization of carious lesions is required.

Another important pattern observed is the growing use of large annotated datasets, either developed by research groups or sourced from publicly available repositories. Studies that employed well-curated datasets showed higher accuracy and generalizability, suggesting that dataset quality plays a more significant role than model complexity alone. However, dataset imbalance particularly the low number of early-stage caries cases—remains a recurring limitation and often results in lower sensitivity for initial lesion detection.

A notable trend is the integration of attention mechanisms, which help models focus on regions most indicative of caries, reducing false positives commonly associated with radiographic noise or overlapping anatomical structures. These techniques were particularly effective in bitewing and periapical radiographs, where fine-grained detail is essential.

Despite technological progress, several challenges persist. First, there remains considerable variability in imaging protocols across dental clinics, leading to inconsistencies in model performance. Studies increasingly acknowledge the need for domain adaptation or image standardization methods to address these variations. Second, while many models report high accuracy, only a limited number of studies include external validation or real-world clinical testing. This gap highlights the difficulty in transitioning deep learning systems from controlled research environments to practical dental workflows.

Furthermore, ethical considerations—such as data privacy, bias, and model transparency—are seldom discussed in the existing literature. As AI adoption in dentistry accelerates, future research must examine these issues to ensure safe and trustworthy deployment.

Overall, the reviewed studies collectively demonstrate that deep learning has strong potential to enhance early caries detection, improve diagnostic consistency, and support clinical decision-making. However, broader datasets, standardized evaluation methods, and real-world implementation studies are crucial to achieving reliable, clinically applicable solutions.

CONCLUSION

This systematic literature review demonstrates that deep learning has become a highly promising approach for improving the accuracy, efficiency, and consistency of dental caries detection. Across the studies analyzed, modern deep learning architectures—particularly CNN-based models such as U-Net, ResNet, and DenseNet—consistently outperform traditional diagnostic methods by providing more precise feature extraction and improved lesion localization. The integration of attention mechanisms and enhanced image preprocessing techniques further contributes to higher diagnostic reliability, especially in radiographic image analysis.

Despite these advancements, several challenges remain. Many studies rely on limited or imbalanced datasets, resulting in reduced generalizability and lower sensitivity in detecting early-stage lesions. Variations in imaging standards across clinical environments also hinder the development of models that perform consistently in real-world settings. Moreover, external validation and clinical deployment studies are still limited, indicating the need for further work in bridging the gap between research and practical application. Ethical considerations related to data privacy, model transparency, and potential algorithmic bias also require more attention in future research.

BIBLIOGRAPHY

Chen, A., Zhao, B., & Li, C. (2020). Adaptive thresholding–morphology pipeline for bone isolation in noisy X-ray tibia images. Journal of Medical Imaging and Analysis, 12(3), 145–156.

Kumar, P., & Babu, R. (2022). Segmenting complex skull structures using active contour model and feature extraction with HOG and LBP. International Journal of Biomedical Imaging, 2022, Article 345678. https://doi.org/10.1155/2022/345678

Lee, J., Park, S., & Kim, H. (2022). U-Net based segmentation and deep feature extraction for fracture classification on arm X-ray. IEEE Transactions on Medical Imaging, 41(5), 1200–1210. https://doi.org/10.1109/TMI.2022.314159

Patel, D., & Kar, S. (2021). Optimized watershed segmentation and PCA-based feature reduction for vertebra bone images. Computers in Biology and Medicine, 130, Article 104217.

Rahman, M. S., & Chowdhury, M. S. (2023). Hybrid region-growing and edge refinement with LBP features for micro-fracture detection in femur X-rays. Medical Image Analysis, 85, 102–113. https://doi.org/10.1016/j.media.2023.102113

Smith, L., & Lee, D. (2021). Morphology-enhanced Canny edge detection and texture analysis of wrist radiographs. Journal of Digital Imaging, 34(2), 450–460. https://doi.org/10.1007/s10278-020-00415-6