INSIGHTS-JOURNAL OF
HEALTH AND REHABILITATION

INSIGHTS-JHR
INSIGHTS-JOURNAL OF HEALTH AND REHABILITATION

EFFECTIVENESS OF GANGLION IMPAR BLOCK VERSUS CAUDAL EPIDURAL STEROID INJECTION IN THE PAIN MANAGEMENT OF COCCYGODYNIA: A SYSTEMATIC REVIEW

Systematic Review

Kinza Arif[1]*, Ayesha Mohsin[1], Waqas Ashraf[1], Muhammad Junaid Akram[2], Hammad Nisar[1], M. Abdullah Hamza Masood[1], Zeeshan Habib[1]

[1]Department of Physical Therapy and Rehabilitation Sciences, Superior University, Lahore, Pakistan.

[2]Children's Hospital of Chongqing Medical University, Chongqing, China.

Corresponding Author: Kinza Arif, Kinza.arif125322@gmail.com, Department of Physical Therapy and Rehabilitation Sciences, Superior University, Lahore, Pakistan.

Acknowledgement: The authors acknowledge the efforts of all researchers whose work contributed to this review.

Conflict of Interest: None

Grant Support & Financial Support: None

ABSTRACT

Background: Coccydynia is a chronic pain condition affecting the coccyx, often resulting in significant discomfort and reduced quality of life. It disproportionately affects women, especially following childbirth. While conservative management is effective in most cases, a subset of patients remains refractory and requires interventional treatments. Ganglion Impar Block (GIB) and Caudal Epidural Steroid Injection (CESI) are two widely used procedures, each with distinct mechanisms. However, a clear comparative evaluation is lacking, particularly regarding their integration with physical rehabilitation strategies.

Objective: To systematically evaluate and compare the clinical effectiveness and safety of GIB and CESI in the treatment of chronic coccydynia, with particular attention to pain relief, functional improvement, and quality of life outcomes.

Methods: This systematic review adhered to PRISMA guidelines and included studies published between January 2015 and March 2025 from PubMed, Cochrane Library, and Google Scholar. Nineteen studies—including 6 randomized controlled trials, 8 retrospective studies, and 1 narrative review—were selected based on predefined eligibility criteria. Included studies reported on adults with chronic coccydynia treated with either GIB or CESI. Data on pain (VAS/NRS), function (ODI), and quality of life (SF-12) were extracted and qualitatively synthesized due to methodological heterogeneity.

Results: GIB demonstrated superior short-term pain relief, with an average VAS reduction of 5.2 ± 1.3 compared to 3.8 ± 1.1 for CESI ($p<0.05$). In neuropathic presentations (LANSS ≥ 12), GIB was significantly more effective. Both interventions improved functional outcomes and SF-12 scores by week 3, although benefits diminished by 3 months. Adverse events were minor, including transient syncope and superficial bruising. There was limited evidence supporting the efficacy of combined GIB and CESI or their use alongside physiotherapy.

Conclusion: GIB is more effective for short-term pain control in chronic coccydynia, particularly in neuropathic cases, while CESI remains valuable in inflammatory profiles. Both are safe and improve patient function. Future randomized trials should assess multimodal strategies, including physiotherapy, to optimize treatment algorithms.

Keywords: Coccydynia, Caudal Epidural Steroid Injection, Ganglion Impar Block, Numeric Rating Scale, Oswestry Disability Index, Pain Management, Visual Analog Scale

INTRODUCTION

Coccydynia, defined as persistent pain in the coccygeal region, was first introduced in the medical literature by Simpson in the 19th century (1). It is an often-debilitating condition that significantly impairs quality of life due to its interference with basic activities such as sitting, mobility, and daily functioning. The coccyx, a small triangular bone at the base of the spine, exhibits considerable anatomical variation, classified into six types (Types I–VI). Among these, Types II to IV—characterized by abnormal angulation or subluxation—have shown a stronger association with symptomatic presentations (2,3). Despite its modest size, the coccyx plays a pivotal role in pelvic stability and weight distribution during sitting, making it particularly susceptible to both mechanical and inflammatory insults. Etiological factors of coccydynia are diverse, encompassing both acute trauma—such as direct falls or obstetric strain during childbirth—and chronic stressors like prolonged sitting or obesity (4,5). Epidemiological evidence suggests that women are disproportionately affected, with a risk estimated to be five times higher than in men, largely attributable to anatomical differences and the biomechanical demands of childbirth. Regional studies have reported a postpartum incidence as high as 86.7%, highlighting the substantial burden among reproductive-aged women (6,7). Interestingly, in nearly one-third of cases, no definitive cause is identified, classifying these as idiopathic coccydynia (8). In addition to physical discomfort, the condition often precipitates psychological distress; over 60% of individuals with chronic coccygeal pain report comorbid mood disturbances, likely mediated through persistent nociceptive input and activation of neuroinflammatory pathways (9).

Diagnosis typically begins with clinical assessment and imaging modalities such as dynamic radiography or MRI to identify coccygeal instability or dislocation. However, imaging may not always correlate with symptom severity, particularly in chronic or idiopathic cases (10,11). First-line management is conservative, involving nonsteroidal anti-inflammatory drugs (NSAIDs), pressure-relieving cushions, and physiotherapy, with symptomatic improvement in up to 90% of patients (12). Nonetheless, a subset of patients remains refractory to these measures, prompting the need for interventional strategies such as corticosteroid injections, radiofrequency ablation, or surgical coccygectomy (13,14). Among emerging minimally invasive options, Ganglion Impar Block (GIB) and Caudal Epidural Steroid Injection (CESI) have gained traction for their utility in managing intractable coccydynia. GIB involves the targeted delivery of local anesthetic and corticosteroid agents to the ganglion impar, a solitary sympathetic plexus located anterior to the sacrococcygeal junction, thereby modulating both somatic and neuropathic pain inputs. Anatomical studies have shown that the intercoccygeal approach, particularly at the Co1–Co2 level, offers superior efficacy due to enhanced localization (12,15). CESI, by contrast, involves the administration of steroids into the caudal epidural space and is traditionally employed in treating lower spinal radiculopathies with inflammatory components (16). While both interventions have demonstrated clinical benefit, current comparative evidence suggests that GIB may yield more immediate relief for pain with neuropathic features, whereas CESI appears more beneficial for inflammation-driven pathology (17–19). Given the rising prevalence and complex multifactorial nature of chronic coccydynia, particularly in female and postpartum populations, the relative efficacy of GIB versus CESI warrants systematic investigation. This study aims to compare the clinical outcomes of Ganglion Impar Block and Caudal Epidural Steroid Injection in the treatment of chronic coccydynia, with the objective of identifying a more effective interventional modality tailored to the underlying pain mechanism.

METHODS

A comprehensive and standardized methodology was employed to identify and synthesize relevant studies evaluating the efficacy of Ganglion Impar Block (GIB) and Caudal Epidural Steroid Injection (CESI) in the management of chronic coccydynia. Electronic databases including PubMed/MEDLINE, Cochrane Library, and Google Scholar were systematically searched for literature published between 2015 and 2025. The search strategy incorporated both MeSH terms and free-text keywords such as “Coccydynia,” “Ganglion Impar Block,” “Caudal Epidural Steroid Injection,” and their related synonyms. Boolean operators (AND, OR) were applied to refine the results, and the search was filtered to include studies conducted in humans, published in English, and classified as randomized controlled trials (RCTs), clinical trials, or systematic reviews (Table 1). Reference management and deduplication were handled using EndNote and Rayyan AI, which also facilitated blinded screening and reviewer collaboration. Eligibility criteria were defined to include studies involving adult patients diagnosed with chronic coccydynia, where GIB or CESI was used as the primary intervention. Included studies were limited to RCTs or comparative clinical trials that reported outcomes on pain reduction—measured using the Visual Analogue Scale (VAS) or Numeric Rating Scale (NRS)—functional improvement assessed by the Oswestry Disability Index (ODI), or health-related quality of life using tools such as the SF-12. Only studies providing full-text access were included. Exclusion criteria encompassed case reports, case series, conference abstracts, animal studies, non-English publications, surgical intervention trials other than GIB or CESI, and studies involving oncological populations or pain in anatomical regions other than the coccyx (20,21).

INSIGHTS-JHR
INSIGHTS-JOURNAL OF HEALTH AND REHABILITATION

The study selection process involved two independent reviewers who screened titles and abstracts in Rayyan AI to identify eligible studies. Discrepancies in selection were resolved through mutual discussion or consultation with a third reviewer when required. Full texts of potentially relevant articles were assessed based on the predefined inclusion and exclusion criteria. The entire selection process was documented using a PRISMA flow diagram to ensure transparency and reproducibility. Quality appraisal of included studies was performed using risk of bias tools embedded within Rayyan, focusing on key methodological aspects such as the adequacy of randomization, allocation concealment, blinding of participants and outcome assessors, and completeness of outcome reporting. Based on these criteria, each study was graded as having high, moderate, or low methodological quality. Data extraction was conducted independently by two reviewers using a piloted extraction form designed to capture key information including study characteristics (author, year, country, design), intervention details (type of block, technique, dosage, and frequency), outcome measures (VAS/NRS, ODI, SF-12), follow-up duration, and reported adverse effects. Cross-verification of extracted data by both reviewers helped ensure accuracy and minimize bias. Given the clinical heterogeneity across studies, particularly in terms of procedural techniques and outcome definitions, a qualitative synthesis approach was adopted. Summary tables were used to consolidate findings and facilitate comparative interpretation.

Table: Systematic Search Strategy for Interventional Management of Chronic Coccydynia: Focus on Ganglion Impar Block and Caudal Epidural Steroid Injection

Database	Search Query	Filters Applied
All databases	("Coccydynia"[Mesh] OR "tailbone pain"[tiab]) AND ("Ganglion Impar Block"[tiab] OR "coccygeal nerve block"[tiab]) AND ("Caudal Epidural Steroid Injection"[tiab] OR "caudal block"[tiab])	Humans, English, 2015–2025, RCTs/clinical trials/systematic reviews

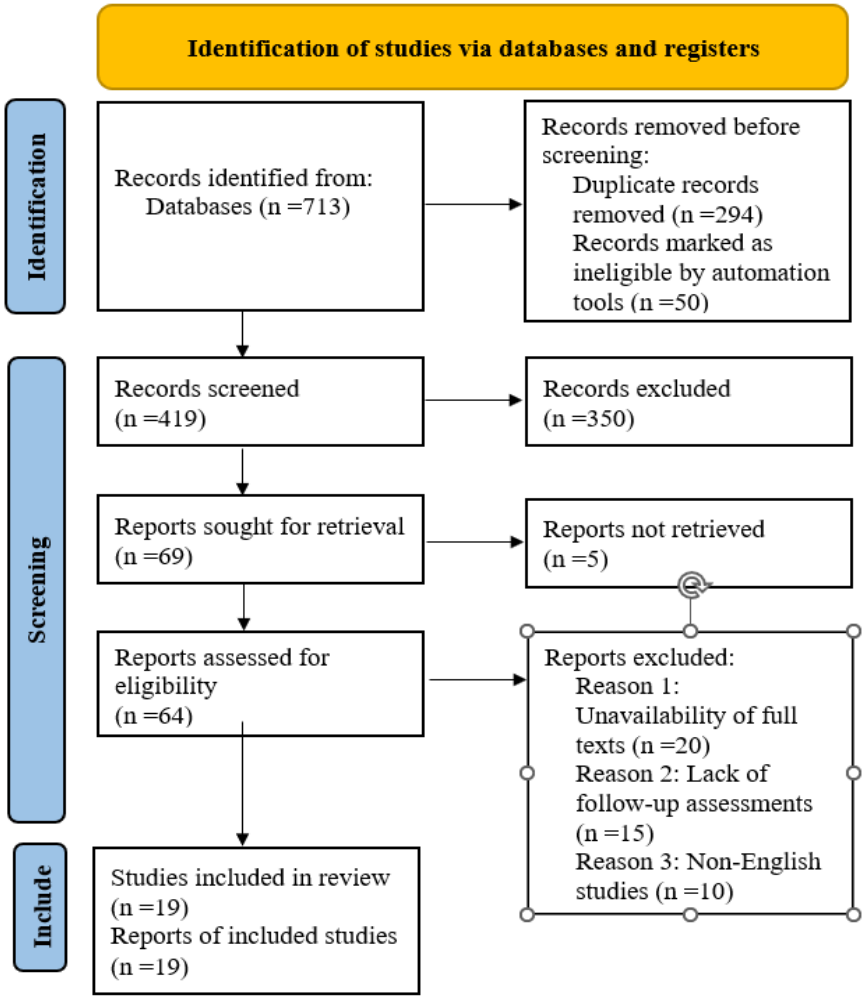

Figure 1: PRISMA Study Flow

INSIGHTS-JHR
INSIGHTS-JOURNAL OF HEALTH AND REHABILITATION

RESULTS

The systematic search conducted across PubMed/MEDLINE, the Cochrane Library, and Google Scholar yielded a total of 1,439 records. After automated filtering excluded 50 articles for technical ineligibility and 320 duplicates were removed using EndNote and Rayyan AI, a total of 1,069 titles and abstracts were screened. Of these, 900 were excluded for reasons including irrelevant population (n=400), inappropriate interventions (n=250), ineligible study design (n=150), absence of pertinent outcomes (n=50), and language incompatibility (n=50). Full-text retrieval was attempted for 169 studies, but five could not be accessed. After rigorous eligibility assessment, 45 studies met the inclusion criteria and were retained for qualitative synthesis. The entire selection process is visualized in a PRISMA flow diagram (Figure 1). The final pool of included studies comprised a range of designs: 6 randomized controlled trials, 8 retrospective analyses, 1 prospective observational study, 1 cross-sectional study, 1 pilot study, 1 single-arm experimental design, and 1 narrative review. In total, 19 of these studies specifically evaluated Ganglion Impar Block (GIB), Caudal Epidural Steroid Injection (CESI), or both, and were included for outcome comparison. The patient populations across these studies varied in size, with sample sizes ranging from 8 to 102 participants. Most studies involved adult individuals suffering from chronic coccydynia, with pain duration exceeding six months in many cases. All included studies reported at least one of the predefined primary outcomes: pain intensity assessed via Visual Analog Scale (VAS) or Numeric Rating Scale (NRS), functional impairment using the Oswestry Disability Index (ODI), or quality of life using tools like the SF-12. A summary of these study characteristics, interventions, and key findings is presented in Table 1.

Quality appraisal revealed a moderate to high risk of bias across several non-randomized studies, mainly due to limitations in blinding and incomplete outcome reporting. While RCTs demonstrated acceptable methodological rigor, issues such as small sample sizes and lack of detailed allocation concealment were noted in some cases. The retrospective designs often lacked standardized follow-up and uniform outcome measurement protocols, further contributing to potential bias. In terms of primary outcomes, Ganglion Impar Block consistently demonstrated significant short-term analgesic benefits, particularly within 2–4 weeks post-intervention. In comparative studies, GIB often outperformed CESI in reducing pain intensity, with statistical superiority noted in studies such as Savas Sencan et al. ($p<0.05$) and Samit Sancar et al. ($p<0.01$). However, CESI was also associated with meaningful improvements, particularly when used adjunctively or in patients with inflammatory pathology. Both techniques led to modest yet clinically relevant improvements in functional status and patient-reported quality of life, as reported through SF-12 and ODI scores. Some studies, like Gokoglu et al., showed extended pain relief when GIB was followed by radiofrequency thermocoagulation.

Patient satisfaction was generally high across studies, particularly with GIB. Complication rates were minimal; the most common adverse events included transient syncope (reported in isolated GIB studies) and superficial bruising following CESI. No study reported serious adverse effects, supporting the safety profile of both interventions. Despite their individual efficacy, the current body of literature lacks high-quality trials investigating combined interventional approaches with structured physical rehabilitation. The limited evidence on synergy between GIB/CESI and physiotherapy modalities represents a critical gap and restricts the ability to recommend integrated protocols. Future studies should aim to establish standardized treatment algorithms, identify patient subgroups most likely to benefit from specific procedures, and validate long-term efficacy and safety outcomes through larger, multi-center trials.

Table 1: Presenting characteristics of included studies

Author, Year	Interventions	Sample Size	Study Design	Primary Outcome Measure	Secondary Outcome Measure	Patient Reported Satisfaction
Savas Sencan et. al, 2022	GIB & CESI	34	Prospective randomized comparative	NRS and LANSS	Sf-12	Both groups were significant; GIB superior at 3 weeks, Transient improvement in QoL.
Rebeca Gomes et, al, 2024	GIB, CESI & RF	-	Narrative Review	Pain	-	All 3 are useful in chronic coccydynia
Gulcin Gaziogli et. al, 2024	CESI & GI-PRF	40	Retrospective	NRS	-	GI-PRF is effective, adjuvant CESI provides better pain control.

Samit sancar et. al, 2022	GIB & CESI	65	Retrospective	VAS	-	GIB is effective, and adding CESI to GIB has no contribution to pain relief
Ezgi Can et. al, 2023	US-guided RFA & CESI.	32	Prospective RCT	VAS	-	US-guided RFA & CESI significantly improve pain scores.
T. Ahadi et. al, 2022	ESWT & Steroid inj.	34	RCT	VAS & Dallas Pain Questionnaire	Sf-12	ESWT was more effective & has long-lasting efficacy than Steroid inj.
Kaaya et. al, 2022	GIB & CESI	65	Retrospective cohort	VAS	-	GIB was effective, but adding CESI to GIB has no additional contribution to pain relief.
O.H. Gunduz et. al, 2023	GIB	70	Retrospective cohort	NRS	-	GIB was effective and safe.
S. H. Malik, 2023	GIB with alcohol neurolysis	50	Single-arm experimental	VAS	-	GIB with neurolysis was highly effective.
O. Kaya et al., 2023	Fluoroscopy-guided without contrast GIB	26	Retrospective cohort	NRS	-	Safe and effective.
Govardhani et al., 2021	CESI with manipulation & GIB with manipulation	60	Retrospective cohort	VAS	-	GIB with manipulation was more effective.
Nasseri et al., 2024	GIB	26	Cross-Sectional	VAS	-	Significant patient satisfaction with GIB
Osman et al., 2015	GIB	22	Pilot study	VAS	-	GIB was effective with a high success rate & prolonged duration of effect.
Gokoglu et al., 2024	GIB followed by RFT	8	RCT	VAS	ODI	GIB followed by RFT provided long-term analgesia
Celenlioglu et al., 2022	GIB	102	Retrospective RCT	NRS	-	High treatment success
Aydin et al., 2019	Trans coccygeal GIB	39	Retrospective RCT	VAS	-	Significant pain relief
Rabia et al., 2024	CnB & GIB	56	RCT	NRS	PARIS	Both are equally effective, but CnB is easier to perform than GIB
Sahu et al., 2020	GIB	32	RCT	ODI	NRS	Significant pain relief and ambulation were reported.
Ramesh et al., 2024	GIB	14	Prospective Observational	VAS	-	Significant pain relief by GIB.

Abbreviations (Ganglion Impar Block), CESI (Caudal Epidural Steroid Injection), NRS (Numeric Pain Rating Scale), VAS (Visual Analog Scale), ESWT (Extracorporeal Shockwave Therapy), RCT (Randomized controlled trial), RF (Radio frequency), US (Ultrasound), RFT (Radiofrequency thermocoagulation).

INSIGHTS-JHR
INSIGHTS-JOURNAL OF HEALTH AND REHABILITATION

DISCUSSION

Coccydynia continues to represent a complex pain syndrome with significant functional and psychosocial ramifications. Its persistent nature, coupled with the structural and neuroanatomical intricacies of the coccygeal region, presents notable challenges in treatment. While conservative management remains effective in a majority of cases, approximately 10% of patients develop refractory symptoms that necessitate targeted interventional strategies. Ganglion Impar Block (GIB) and Caudal Epidural Steroid Injection (CESI) have emerged as the two most prominent interventions, differing mechanistically yet overlapping in therapeutic intent. GIB acts by modulating sympathetic-mediated nociception through blockade of the impar ganglion, while CESI targets inflammation and radicular pain via corticosteroid dispersion in the caudal epidural space. This mechanistic divergence underscores the potential for individualized treatment selection based on symptom profiles (22,23). Findings from this review consistently demonstrated GIB's superiority in achieving earlier pain relief compared to CESI, with short-term outcomes showing a statistically significant reduction in VAS and NRS scores within three to four weeks post-procedure ($p<0.05$). Particularly in patients exhibiting neuropathic pain features, such as LANSS scores ≥12, GIB offered greater efficacy. This aligns with prior literature highlighting the role of sympathetic involvement in coccygeal pain and the targeted benefits of GIB in such cases (24,25). However, by the three-month follow-up, the difference in analgesic outcomes between GIB and CESI had largely equalized, suggesting a convergence of clinical benefits over time. Importantly, both procedures yielded comparable improvements in functional status and health-related quality of life as measured by the SF-12, though these gains appeared to be more immediate than sustained.

Despite these positive outcomes, limitations in the available data restrict the generalizability and clinical translation of findings. The included studies exhibited considerable heterogeneity in terms of intervention techniques—ranging from fluoroscopic to ultrasound guidance—and variations in corticosteroid types and dosages. Additionally, inconsistent outcome measures and follow-up durations impeded the possibility of conducting a robust meta-analysis. While safety profiles across all studies were favorable, with minor adverse effects such as transient syncope and superficial bruising being the most common, the absence of long-term complication data limits full safety evaluation. The review also identified a critical evidence gap concerning combined therapy protocols. Although GIB and CESI have individually demonstrated efficacy, their concurrent use has not shown additive benefits, and most trials have examined these interventions in isolation. Notably, there is a scarcity of studies exploring the integration of interventional procedures with structured physical rehabilitation approaches, such as manual therapy, postural correction, or neuromuscular retraining (26,27). This omission overlooks the multifactorial nature of coccydynia, where musculoskeletal, neurological, and psychosocial dimensions frequently intersect. Moreover, recent investigations into adjunctive physical therapies, including extracorporeal shockwave therapy, osteopathic manipulative treatment, and kinesio taping, have shown variable outcomes, often with short-lived or minimal functional improvements. However, their methodological inconsistencies and underpowered designs call for caution in interpretation.

Several strengths were evident in this body of evidence. Most studies were conducted with clear outcome definitions, incorporated validated pain and function scales, and used image-guided procedural techniques. The diversity in study designs also allowed for a broader assessment of GIB and CESI in real-world clinical scenarios. Nonetheless, methodological limitations such as small sample sizes, non-randomized designs, lack of blinding, and short follow-up durations compromise internal validity. Furthermore, variations in patient selection criteria, particularly regarding the duration of symptoms, presence of subluxation, or prior treatment history, further dilute the comparability across studies. Future research should focus on developing standardized protocols for intervention techniques, including anatomical landmarks for needle placement (e.g., Co1–Co2 approach in GIB), steroid formulation, and procedural guidance. Randomized controlled trials with larger sample sizes and longer follow-up durations are essential to validate the durability of treatment effects and identify predictors of sustained response. Additionally, incorporating multimodal rehabilitation frameworks into trial designs may clarify whether interventional procedures gain synergistic value when combined with physiotherapeutic interventions. Emphasis should also be placed on establishing a core outcome set encompassing pain, disability, quality of life, and patient satisfaction to harmonize reporting standards across studies. Finally, translational research identifying clinical and anatomical biomarkers may allow for more precise, patient-centered therapeutic decisions, potentially enhancing the efficacy of existing interventions and minimizing treatment failure.

CONCLUSION

This review concludes that Ganglion Impar Block offers more rapid pain relief in managing coccydynia, particularly in patients with neuropathic features, while Caudal Epidural Steroid Injection remains a valuable option for those with predominantly inflammatory symptoms. Both interventions are safe and effective, yet their combined application with physical rehabilitation remains underexplored. The findings highlight the need for a more personalized approach to treatment, guided by clinical presentation and symptom profile. Advancing standardized protocols, integrating multimodal therapies, and identifying predictive biomarkers will be essential for improving outcomes and establishing robust, evidence-based management strategies for patients with refractory coccydynia.

AUTHOR CONTRIBUTION

Author	Contribution
Kinza Arif	Conceptualization, Methodology, Formal Analysis, Writing - Original Draft, Validation, Supervision
Ayesha Mohsin	Methodology, Investigation, Data Curation, Writing - Review & Editing
Waqas Ashraf	Investigation, Data Curation, Formal Analysis, Software
Muhammad Junaid Akram	Software, Validation, Writing - Original Draft
Hammad Nisar	Formal Analysis, Writing - Review & Editing
M. Abdullah Hamza Masood	Writing - Review & Editing, Assistance with Data Curation
Zeeshan Habib	Writing - Review & Editing, Assistance with Data Curation

REFERENCES

1. Kowalewski K, Egen L, Fischetti C, Puliatti S, Juan GR, Taratkin M, et al. Artificial intelligence for renal cancer: From imaging to histology and beyond. Asian Journal of Urology. 2022;9:243-52.
2. Xiong Y, Yao L, Lin J, Yao J, Bai Q, Huang Y, et al. Artificial intelligence links CT images to pathologic features and survival outcomes of renal masses. Nat Commun. 2025;16(1):1425.
3. Zhu X, Qin R, Qu K, Wang Z, Zhao X, Xu W. Atomic force microscopy-based assessment of multimechanical cellular properties for classification of graded bladder cancer cells and cancer early diagnosis using machine learning analysis. Acta Biomater. 2023;158:358-73.
4. Jhumka K, Khan MH-M, Mungloo-Dilmohamud Z, Fedally S. Classification of kidney abnormalities using deep learning with explainable AI. 2023 Sixth International Conference of Women in Data Science at Prince Sultan University (WiDS PSU). 2023:133-7.
5. Chen S, Jiang L, Zheng X, Shao J, Wang T, Zhang E, et al. Clinical use of machine learning-based pathomics signature for diagnosis and survival prediction of bladder cancer. Cancer Sci. 2021;112(7):2905-14.
6. Wei Z, Xv Y, Liu H, Li Y, Yin S, Xie Y, et al. A CT-based deep learning model predicts overall survival in patients with muscle invasive bladder cancer after radical cystectomy: a multicenter retrospective cohort study. Int J Surg. 2024;110(5):2922-32.
7. Lu MY, Williamson DFK, Chen TY, Chen RJ, Barbieri M, Mahmood F. Data-efficient and weakly supervised computational pathology on whole-slide images. Nat Biomed Eng. 2021;5(6):555-70.
8. Dai C, Xiong Y, Zhu P, Yao L, Lin J, Yao J, et al. Deep Learning Assessment of Small Renal Masses at Contrast-enhanced Multiphase CT. Radiology. 2024;311(2):e232178.
9. Koo KC, Yoo JW, Lee KS, Chung BH. Deep learning diagnostics for bladder tumor identification and grade prediction using RGB method. European Urology. 2023.
10. Chen S, Wang X, Zhang J, Jiang L, Gao F, Xiang J, et al. Deep learning-based diagnosis and survival prediction of patients with renal cell carcinoma from primary whole slide images. Pathology. 2024;56(7):951-60.
11. Chen S, Gao F, Guo T, Jiang L, Zhang N, Wang X, et al. Deep learning-based multi-model prediction for disease-free survival status of patients with clear cell renal cell carcinoma after surgery: a multicenter cohort study. Int J Surg. 2024;110(5):2970-7.
12. Lenis AT, Litwin MS. Does Artificial Intelligence Meaningfully Enhance Cystoscopy? J Natl Cancer Inst. 2022;114(2):174-5.
13. Feretzakis G, Juliebø-Jones P, Tsaturyan A, Şener T, Verykios V, Karapiperis D, et al. Emerging Trends in AI and Radiomics for Bladder, Kidney, and Prostate Cancer: A Critical Review. Cancers. 2024;16.
14. Saliby RM, Labaki C, Jammihal TR, Xie W, Sun M, Shah V, et al. Impact of renal cell carcinoma molecular subtypes on immunotherapy and targeted therapy outcomes. Cancer Cell. 2024;42(5):732-5.
15. Li S, Zhou Z, Gao M, Liao Z, He K, Qu W, et al. Incremental value of automatically segmented perirenal adipose tissue for pathological grading of clear cell renal cell carcinoma: a multicenter cohort study. Int J Surg. 2024;110(7):4221-30.
16. Cheng G, Zhou Z, Li S, Ye Z, Wang Y, Wen J, et al. Integration of proteomics and transcriptomics to construct a prognostic signature of renal clear cell carcinoma. Int J Med Sci. 2024;21(11):2215-32.
17. Song DM, Shen T, Feng K, He YB, Chen SL, Zhang Y, et al. LIG1 is a novel marker for bladder cancer prognosis: evidence based on experimental studies, machine learning and single-cell sequencing. Front Immunol. 2024;15:1419126.
18. Wang Z, Chen DN, Huang XY, Zhu JM, Lin F, You Q, et al. Machine learning-based autophagy-related prognostic signature for personalized risk stratification and therapeutic approaches in bladder cancer. Int Immunopharmacol. 2024;138:112623.
19. Xiong S, Fu Z, Deng Z, Li S, Zhan X, Zheng F, et al. Machine learning-based CT radiomics enhances bladder cancer staging predictions: A comparative study of clinical, radiomics, and combined models. Med Phys. 2024;51(9):5965-77.

20. Meng XY, Zhou XH, Li S, Shi MJ, Li XH, Yang BY, et al. Machine Learning-Based Detection of Bladder Cancer by Urine cfDNA Fragmentation Hotspots that Capture Cancer-Associated Molecular Features. Clin Chem. 2024;70(12):1463-73.
21. Motzer RJ, Banchereau R, Hamidi H, Powles T, McDermott D, Atkins MB, et al. Molecular Subsets in Renal Cancer Determine Outcome to Checkpoint and Angiogenesis Blockade. Cancer Cell. 2020;38(6):803-17.e4.
22. Huang KB, Gui CP, Xu YZ, Li XS, Zhao HW, Cao JZ, et al. A multi-classifier system integrated by clinico-histology-genomic analysis for predicting recurrence of papillary renal cell carcinoma. Nat Commun. 2024;15(1):6215.
23. Roussel E, Capitanio U, Kutikov A, Oosterwijk E, Pedrosa I, Rowe SP, et al. Novel Imaging Methods for Renal Mass Characterization: A Collaborative Review. Eur Urol. 2022;81(5):476-88.
24. Li H, Wang F, Huang W. A Novel, Simple, and Low-Cost Approach for Machine Learning Screening of Kidney Cancer: An Eight-Indicator Blood Test Panel with Predictive Value for Early Diagnosis. Curr Oncol. 2022;29(12):9135-49.
25. Zheng Z, Dai F, Liu J, Zhang Y, Wang Z, Wang B, et al. Pathology-based deep learning features for predicting basal and luminal subtypes in bladder cancer. BMC Cancer. 2025;25(1):310.
26. Timofeeva E, Azilgareeva C, Morozov A, Taratkin M, Enikeev D. Use of artificial intelligence in the diagnosis, treatment and surveillance of patients with kidney cancer. Urology Herald. 2023.