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ABOUT COVER

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AIMS AND SCOPE

The primary aim of *Artificial Intelligence in Gastroenterology* (AIG, *Artif Intell Gastroenterol*) is to provide scholars and readers from various fields of artificial intelligence in gastroenterology with a platform to publish high-quality basic and clinical research articles and communicate their research findings online.

AIG mainly publishes articles reporting research results obtained in the field of artificial intelligence in gastroenterology and covering a wide range of topics, including artificial intelligence in gastrointestinal cancer, liver cancer, pancreatic cancer, hepatitis B, hepatitis C, nonalcoholic fatty liver disease, inflammatory bowel disease, irritable bowel syndrome, and *Helicobacter pylori* infection.

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Artificial intelligence using advanced imaging techniques and cholangiocarcinoma: Recent advances and future direction

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Abstract

While cholangiocarcinoma represents only about 3% of all gastrointestinal tumors, it has a dismal survival rate, usually because it is diagnosed at a late stage. The utilization of Artificial Intelligence (AI) in medicine in general, and in gastroenterology has made gigantic steps. However, the application of AI for biliary disease, in particular for cholangiocarcinoma, has been sub-optimal. The use of AI in combination with clinical data, cross-sectional imaging (computed tomography, magnetic resonance imaging) and endoscopy (endoscopic ultrasound and cholangioscopy) has the potential to significantly improve early diagnosis and the choice of optimal therapeutic options, leading to a transformation in the prognosis of this feared disease. In this review we summarize the current knowledge on the use of AI for the diagnosis and management of cholangiocarcinoma and point to future directions in the field.

Key Words: Cholangiocarcinoma; Artificial intelligence; Cholangioscopy; Artificial neural network; Machine learning; Therapeutic endoscopy; Endoscopic ultrasound

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Core Tip: Artificial intelligence (AI) aided by multiple imaging modalities is accurate and effective for diagnosis and characterization of biliary masses. The advancement and incorporation of imaging into artificial intelligence will help to decrease delay in diagnosis of cholangiocarcinoma and potentially decrease mortality. This review examines studies showing that AI can assist in real-time diagnosis of cholangiocarcinoma and predict outcomes of treatment. Current data suggests that AI will soon become an indispensable part of the armamentarium for the management of cholangiocarcinoma and other biliary diseases.

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INTRODUCTION

The concept of AI is best explained as a computer program that possesses the ability to perform functions such as data analysis, learning, and problem solving. Medical artificial intelligence involves the development of AI programs to assist in diagnosis and prognosis, therapeutic decision making, drug development, as well as development and data mining from the electronic medical records (EMR)[1-3]. In fact, artificial intelligence is utilized in almost every field of medicine[4-8], including radiology[9], gastroenterology[10], ophthalmology[11], cardiology[12], and surgery[13].

There are many different types of AI. The foundation of the most used form, Artificial Neural Networks (ANN), takes inspiration from the human nervous system[1,3]. The neurons of ANNs are individual computer processors that interconnect and possess the capability of processing and analyzing large amounts of data[1]. ANNs are composed of links of multiple layers of these 'neurons', an input layer linked to multiple hidden layers, which are in turn linked to an output layer[3]. All the layers in an ANN communicate in a feed forward manner with the ability to 'learn' by repeatedly adjusting their links[2]. Thus, one of the attractive qualities of ANNs is in their analytical and pattern recognition ability. One of the first applications of ANNs in medicine was to aid in the diagnosis of myocardial infarction[14]. Since that time, ANNs have been widely used¹. Support Vector Machines (SVM) is another type of machine learning which uses data analysis algorithms for classification and regression analysis[15]. SVMs are widely used in drug development and cancer detection[16,17].

Convolutional neural networks (CNN) are a type of deep learning network, a network that incorporates three or more layers, that is commonly employed in medicine, in particular because of its easy applicability to imaging[18]. Convolutional neural networks are multi-layer analyses which work by taking an image (e.g. from CT, MRI, US) and extracting layers or features at each step of the process. These features are then characterized further by complex mathematical equations to break them down and compare them to similar images, leading to pattern recognition[18]. CNNs also can place weight on the value of a specific feature, thus allowing for the presence or absence of a given variable to have a greater influence on the overall outcome.

The application of AI has grown at a rapid pace in all fields of medicine, and gastroenterology is no exception[19]. AI has been utilized in gastroenterology to identify esophageal neoplasms[20,21], diagnosis of *Helicobacter pylori*[22], predict gastric bleeding in patients on anti-thrombotics[23], predict the length of hospitalization for acute pancreatitis[24], differentiate between chronic pancreatitis and pancreatic cancer[25], stratify the need for ERCP[26], and characterization of colonic polyps[27]. These and many other ongoing developments will significantly impact the future of both diagnostic and therapeutic gastroenterology. One area of that has been somewhat neglected in the application of AI in gastroenterology is that of biliary disease, in particular cholangiocarcinoma. In this paper, we will review the current knowledge of the application of artificial intelligence in cholangiocarcinoma and point to the future directions in the field.

CHOLANGIOCARCINOMA

Cholangiocarcinoma (CCA) is a malignant neoplasm that can arise from anywhere along the biliary tree, including within the liver parenchyma, and is classified as distal, perihilar or intrahepatic[28]. Risk factors for CCA usually include long-term inflammatory states, like those associated with primary sclerosing cholangitis (PSC) and helminthic infection, or the continued presence of choledocholithiasis, but the majority for cases are idiopathic[29]. Cholangiocarcinoma accounts for about 3% of all gastrointestinal tumors and 10%-15% of hepatobiliary tumors[30]. Although rare, CCA has a very poor

prognosis, with 5-year survival rates following surgery rarely exceeding 35%[21]. Additionally, CCA incidence and mortality rates are increasing worldwide[31,32]. CCA is usually detected late in the disease stage and found incidentally due to poor screening methods for early detection[32]. Early diagnosis is relatively rare, limiting the possibility of curative surgery to < 30% of patients[33]. Furthermore, even among these, about 20%-50% of patients deemed candidates for resection *via* preoperative evaluation are found to have unresectable disease burden during surgery[34,35].

Given the importance of assessing disease burden, staging and location in determining a patient's treatment plan, it is imperative to have proper preoperative imaging in CCA[36]. While pathological examination remains the gold standard of diagnosis, grading and staging for CCA, advancements in imaging and detection of biomarkers have paved the way for further preoperative predictability of malignancy type and responsiveness to therapies. These advancements have allowed for the incorporation of AI into the sphere of cholangiocarcinoma for a more accurate and personalized management of the disease[37,38].

ARTICLE IDENTIFICATION PROCESS

The article search process was conducted in Medline and Embase[JM1]. Initial search was using different combinations of keywords such as "cholangiocarcinoma", "biliary disease", "cholangioscopy", "artificial intelligence", "artificial neural networks" and "convolutional neural networks". Abstracts of major conferences, such as Digestive Disease Week and United European Gastroenterology Week were also reviewed. Finally, a comprehensive search on clinicaltrials.gov was also conducted using the same keywords to search for active clinical trials involving cholangiocarcinoma and artificial intelligence.

ARTIFICIAL INTELLIGENCE IN BILIARY DISEASES AND CHOLANGIOCARCINOMA

Artificial intelligence has been employed to advance the classification and detection of cholangiocarcinoma by aiding in creating a histopathologic database[39] and characterizing bile acid assays to better predict malignancy[40]. The use of AI to optimize the predictive value of multivariable models, and in improving the diagnostic yield of cross-sectional imaging and endoscopy has been rapidly expanding. Table 1 summarizes currently available studies.

Use of artificial intelligence in aiding the predictive abilities of multivariable models

Artificial Intelligence models have been successfully used to improve the predictive abilities of multivariable models both in the pre-interventional diagnostic phase, as well as in post-operative or post-procedural outcomes in CCA patients. Many of these studies have utilized the area under the curve (AUC), the ability of a test to diagnose a disease state from non-disease state, to assess the added benefit of the incorporation of AI in improving the effectiveness of multivariable models.

In the preoperative phase, multiple studies have used AI/radiographic model to predict lymph node metastasis (LNM) in CCA. One study developed and validated a radiographic model for LNM detection in intrahepatic cholangiocarcinoma (ICC) based on computed tomography (CT) imaging features combined with CA19-9 values[41]. In this study, an acceptable calibration and discrimination was observed in the primary study cohort (AUC 0.8462) and in a validation cohort (AUC 0.8921)[41]. Another study developed support vector machine model utilizing magnetic resonance imaging (MRI) imaging to preoperatively evaluate for LNM in ICC. This study found that an SVM model combining CA19-9 levels and select MRI features resulted in better predictive capabilities compared to a model based on imaging features alone (AUC of 0.842 *vs* 0.788, $P = 0.0219$)[42].

One retrospective study was able to use pre-operative MRI combined with post-operative immunohistochemical results to predict early recurrence of ICC after partial hepatectomy[43]. The model that combined AI with pathology and imaging features had a higher AUC (0.949 *vs* 0.889, $P = 0.247$) compared to the model that included only the pathology and imaging features, as well as better sensitivity (0.938 *vs* 0.875), and specificity (0.839 *vs* 0.774)[43]. In another study, inclusion of AI improved the ability of a multivariable model to predict early occlusion of bilateral plastic stents placed in patients with inoperable ICC[44]. In this study, the ANN built with the multivariable model was compared to a multivariable logistic regression model alone that included age, sex, stent diameter, cancer stage, and presence of liver metastasis[44]. Overall, 288 patients were analyzed, and the ANN model outperformed the logistic regression model (AUC 0.9647 *vs* 0.8763, $P = 0.021$)[44]. Artificial intelligence has also been used to identify which serum biomarkers can have higher diagnostic power for CCA[45]. An ANN model analyzed eight biochemical markers of CCA in 85 subjects with CCA and in 82 controls[45]. Alkaline phosphatase and CCA-associated carbohydrate antigen had a higher predictive value for the distinguishing CCA patients from controls[45]. Finally, in a recent study, Müller *et al*[46] developed an ANN utilizing known risk factors for ICC to predict survival in ICC patients. Using 293 patients, the ANN trained model achieved a higher AUC in predicting the 1 year survival

Table 1 Summary of studies assessing computed tomography, magnetic resonance, and endoscopic ultrasound using artificial intelligence-based approach for pancreatic cancer

Ref.	Year	Type of AI	Imaging modality	Training (#)	Testing (#)	AUC	Sensitivity (%)	Specificity (%)
Matake <i>et al</i> [47], 2006	2006	ANN	CT	120 - patients	120 - patients	0.934	81.9	94.4
Ji <i>et al</i> [48], 2019	2019	ANN	CT	177 - patients	70 - patients	0.961	72	76.2
Logeswaran[49], 2009	2009	MLP	MRI	120 - images	593 - images	N/A	N/A	
Yang <i>et al</i> [37], 2020	2020	ANN	MRI	80 - patients	20 - patients	0.9 (LMN) 0.8 (differentiation)	85.8 (LMN) 73.2 (differentiation)	81.8 (LMN) 68.8 (differentiation)
Ghandour <i>et al</i> [51], 2021	2021	CNN	Cholangioscopy	254 - patients	95 - patients	0.86	0.81	0.91
Robles-Medrana <i>et al</i> [38], 2021	2021	ML	Cholangioscopy	1714 - images	198 - images	N/A	92	N/A
Pereira <i>et al</i> [50], 2022	2022	CNN	Cholangioscopy	5180 - images	1295 - images	1	99.3	99.4
Pattanpairoj <i>et al</i> [45], 2015	2015	ANN	Multivariate	85 - patients	22 - patients	N/A	98.71	96.94
Shao <i>et al</i> [44], 2018	2018	ANN	Multivariate	231 - patients	57 - patients	0.9544	N/A	N/A
Ji <i>et al</i> [41], 2019	2019	N/A	Multivariate	103 - patients	52 - patients	0.8462	86.8	76.3
Xu <i>et al</i> [42], 2019	2019	SVM	Multivariate	106 - patients	42 - patients	0.842	89.36	57.63
Zhao <i>et al</i> [43], 2019	2019	N/A	Multivariate	92 - patients	33 - patients	0.949	0.938	0.839
Müller <i>et al</i> [46], 2021	2021	ANN	Multivariate	233 - patients	60 - patients	0.89	N/A	N/A

ANN: Artificial neural network; MLP: Multi-layer perceptron; CNN: Convolutional neural network; ML: Machine learning; SVM: Support vector machine; CT: Computed tomography; MRI: Magnetic resonance imaging; N/A: Not applicable.

rates compared to one of the most commonly used scoring system, the Fudan score (0.89 *vs* 0.77, $P = 0.24$). In all of these studies, the addition of AI to commonly used multivariable models significantly improved their predictive abilities, improving therefore the diagnostic and post-procedural management of patient with suspected or diagnosed cholangiocarcinoma.

Use of AI in aiding cross-sectional imaging performance

Artificial Intelligence has been used to aid in the interpretation of cross-sectional imaging for nearly two decades. In a 2006 study, an artificial neural network applied to contrast-enhanced computed tomography (CE-CT) images helped differentiate four types of hepatic masses (intrahepatic peripheral cholangiocarcinoma, hepatocellular carcinoma, hemangioma, and metastatic lesions) from one-another [47]. The study then employed radiologists to evaluate CT scans with and without the assistance of ANN. There was marked improvement in diagnosis the hepatic masses with assistance from ANN compared to traditional radiologic evaluation (AUC 0.934 *vs* 0.888, $P = 0.02$, respectively)[47]. Another CT-based study was designed to predict survival outcomes and LNM in biliary tract cancers, and CT images were taken from 177 subjects who had previously undergone surgery[48]. An ANN based on CT characteristics was then built to classify the subjects into high risk or low risk for lymph node metastasis [48]. Patients who were classified as high risk based on the ANN model had a significantly lower survival rate compared to those classified as low risk [hazard ratio (HR) 3.37, 95%CI: 1.92, 5.91], underlying the importance of AI in improving prediction of disease course after treatment[48].

Artificial intelligence has also been used with MRI to improve its diagnostic/predictive power in several studies. One such study investigated the ability for an MRI based AI model to predict LNM in extrahepatic cholangiocarcinoma[37]. This was a proof-of-concept study to display the viability of a pre-operative prediction of both LMN and degree of differentiation, which could influence treatment approach. Images from 100 subjects with CCA were analyzed for the degree of CCA differentiation and

lymph node metastasis. The AI model had an AUC of 0.9 (95%CI: 0.66, 1.0) for predicting LMN while the AUC for degree of differentiation was 0.80 (95%CI: 0.58, 0.97)[37]. In another study, an ANN model based on MRCP images was able to distinguish between patients with CCA from those without CCA [49]. A total of 309 images were processed, 248 of which were normal and 61 were taken from patient with CCA. The ANN model achieved an accuracy of 94% for distinguishing between them. Furthermore, ANN achieved an accuracy of 88% in distinguishing between images of CCA and images of other common biliary diseases, such as cholecystitis, choledocholithiasis, PSC, and cholangitis[49].

Use of AI in aiding endoscopic evaluation of biliary diseases/cholangiocarcinoma

Artificial intelligence has also more recently been used to aid in endoscopic diagnosis of cholangiocarcinoma or other biliary diseases, even though most studies are currently in abstract form only. A study by Pereira *et al*[50] developed a CNN that differentiates biliary strictures as benign or malignant based on images from digital single operator cholangioscopy. After an evaluation of 6475 images from 85 patients with indeterminate biliary strictures, the authors found a sensitivity of 99.3%, specificity of 99.4%, and AUC of 1.00 for a correct diagnosis. In another study, currently available only as an abstract, the authors developed a CNN to detect abnormal biliary features *via* cholangioscopy images[51]. They defined abnormal features as presence of papillary mass, tortuous vessels, or ulcerations. Over 1000000 images from 528 patients were evaluated for the study. The CNN showed an AUC of 0.86 (95%CI: 0.80, 0.92), sensitivity of 0.81 (95%CI: 0.072, 0.91), and specificity of 0.91 (95%CI: 0.86, 0.97)[51]. In another recent study, the utility of AI to perform real-time diagnosis of biliary strictures during cholangioscopy was assessed. This model was built using 23 cholangioscopy videos and was then tested on known cases (20 live cholangioscopy and 20 videos of cholangioscopy) of malignant biliary strictures. It accurately predicted malignancy in every case[38]. These initial results suggests that introduction of AI into standard clinical practice could potentially decrease time to diagnosis of indeterminate biliary strictures and allow for better diagnostic accuracy.

Endoscopic ultrasound (EUS) in combination with AI has been used in the assessment of pancreatic disease and may be beneficial in assisting in real-time differentiation between pancreatic masses and other solid masses during endoscopy[52]. However, there has been limited use of AI during EUS evaluations for cholangiocarcinoma. One recent study developed an AI system to recognize standard stations of EUS for biliary duct evaluation. In this study, AI had comparable accuracy to that of expert endosonographers, and significantly improved the learning curve of trainees[53].

CHOLEDOCHOLITHIASIS

Artificial intelligence has also been useful for the study of possible risk factors for CCA, such as choledocholithiasis. Several studies have demonstrated that AI can be used to risk-stratify patients with possible choledocholithiasis and therefore aid in the decision-making of the need for ERCP[54,55]. One study showed that a machine learning model using pre-ERCP imaging, including US and CT, in addition to select demographic features and laboratory findings can achieve a sensitivity of 97.7% and specificity of 100% in identifying choledocholithiasis[55]. Another study found that an AI model outperformed ASGE guidelines for proper indication for an ERCP (AUC 0.79 *vs* 0.59, respectively)[54]. In addition, the use of AI would avoid the need for ERCP in 36% of cases who would have undergone the procedure according to the ASGE guidelines[54]. Once more, the addition of AI can help providers achieve an individualized management program for patients in daily clinical practice.

CONCLUSION

The diagnosis and staging of cholangiocarcinoma is challenging, leading to potential major non-curative surgeries and/or dismal survival rate because of late diagnosis and inadequate prediction of metastases or recurrence using standard diagnostic methods. The introduction of AI technologies to traditional cross-sectional imaging and endoscopy, can create a major shift in the diagnosis and management of CCA. As mentioned above, many studies have already incorporated AI with significant improvement over traditional clinical data. While most of these studies are retrospective in nature, and therefore provide relatively poor quality data, they are very encouraging.

In addition, new studies are currently ongoing in which AI technologies are used to diagnose and risk-stratify patients with cholangiocarcinoma. The Synergy-AI clinical trial for example, is a non-interventional prospective observational study currently enrolling participants with cholangiocarcinoma, along with other malignancies. This trial is employing an Application Programming Interface to help match participants with personalized treatment protocols based on CT imaging, biomarkers, and laboratory results. In this setting, AI is expected to identify both the most cost effective, appropriate, and personalized treatment approach to each individual's malignancy[56]. Considering that most hospitals have incorporated electronic medical records (EMR) for their patients, it is easy to see how AI can be

used to select different patient variables (biochemical, histological or cross-sectional imaging) and use them to help develop personalized management strategies which optimize outcomes. Combining biomarkers, genetic sequencing, and imaging through AI models could lead to new approaches to the diagnosis and treatment of cholangiocarcinoma, including decreasing the need for unnecessary invasive endoscopic procedures for procurement of biopsies, as well as help develop a more targeted approach for therapy[57]. While more research and fine tuning of current AI systems is needed before reaching this stage, the future of AI in the management of cholangiocarcinoma seems clearly within reach.

FOOTNOTES

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REFERENCES

- 1 Ramesh AN, Kambhampati C, Monson JR, Drew PJ. Artificial intelligence in medicine. *Ann R Coll Surg Engl* 2004; **86**: 334-338 [PMID: 15333167 DOI: 10.1308/1478708040290]
- 2 Kaul V, Enslin S, Gross SA. History of artificial intelligence in medicine. *Gastrointest Endosc* 2020; **92**: 807-812 [PMID: 32565184 DOI: 10.1016/j.gie.2020.06.040]
- 3 Nawab K, Athwani R, Naeem A, Hamayun M, Wazir M. A Review of Applications of Artificial Intelligence in Gastroenterology. *Cureus* 2021; **13**: e19235 [PMID: 34877212 DOI: 10.7759/cureus.19235]
- 4 Patil V, Vineetha R, Vatsa S, Shetty DK, Raju A, Naik N, Malarout N. Artificial neural network for gender determination using mandibular morphometric parameters: A comparative retrospective study. *Cogent Engineering* 2020; **7**: 1723783 [DOI: 10.1080/23311916.2020.1723783]
- 5 Musunuri B, Shetty S, Shetty DK, Vanahalli MK, Pradhan A, Naik N, Paul R. Acute-on-Chronic Liver Failure Mortality Prediction using an Artificial Neural Network. *Engineered Science* 2021; **15**: 187-196 [DOI: 10.1136/gutjnl-2021-iddf.94]
- 6 Yang CM, Shu J. Cholangiocarcinoma Evaluation via Imaging and Artificial Intelligence. *Oncology* 2021; **99**: 72-83 [PMID: 33147583 DOI: 10.1159/000507449]
- 7 Haghbin H, Aziz M. Artificial intelligence and cholangiocarcinoma: Updates and prospects. *World J Clin Oncol* 2022; **13**: 125-134 [PMID: 35316928 DOI: 10.5306/wjco.v13.i2.125]
- 8 Shah M, Naik N, Somani BK, Hameed BMZ. Artificial intelligence (AI) in urology-Current use and future directions: An iTRUE study. *Turk J Urol* 2020; **46**: S27-S39 [PMID: 32479253 DOI: 10.5152/tud.2020.20117]
- 9 Khan G, Howells J. A review of the current and future use of artificial intelligence (AI) in diagnostic radiology. *Clinical Radiology* 2020; **75**: e21 [DOI: 10.1016/j.crad.2020.11.086]
- 10 Berbis MA, Aneiros-Fernández J, Mendoza Olivares FJ, Nava E, Luna A. Role of artificial intelligence in multidisciplinary imaging diagnosis of gastrointestinal diseases. *World J Gastroenterol* 2021; **27**: 4395-4412 [PMID: 34366612 DOI: 10.3748/wjg.v27.i27.4395]
- 11 Du XL, Li WB, Hu BJ. Application of artificial intelligence in ophthalmology. *Int J Ophthalmol* 2018; **11**: 1555-1561 [PMID: 30225234 DOI: 10.18240/ijo.2018.09.21]
- 12 Lopez-Jimenez F, Attia Z, Arruda-Olson AM, Carter R, Chareonthaitawee P, Jouni H, Kapa S, Lerman A, Luong C, Medina-Inojosa JR, Noseworthy PA, Pellikka PA, Redfield MM, Roger VL, Sandhu GS, Senecal C, Friedman PA. Artificial Intelligence in Cardiology: Present and Future. *Mayo Clin Proc* 2020; **95**: 1015-1039 [PMID: 32370835 DOI: 10.1016/j.mayocp.2020.01.038]
- 13 Moglia A, Georgiou K, Georgiou E, Satava RM, Cuschieri A. A systematic review on artificial intelligence in robot-assisted surgery. *Int J Surg* 2021; **95**: 106151 [PMID: 34695601 DOI: 10.1016/j.ijsu.2021.106151]

- 14 **Baxt WG.** Use of an Artificial Neural Network for Data Analysis in Clinical Decision-Making: The Diagnosis of Acute Coronary Occlusion. *Neural Computation* 1990; **2**: 480-489 [DOI: [10.1162/neco.1990.2.4.480](https://doi.org/10.1162/neco.1990.2.4.480)]
- 15 **Cortes C,** Vapnik V. Support-vector networks. *Machine Learning* 1995; **20**: 273-297 [DOI: [10.1007/bf00994018](https://doi.org/10.1007/bf00994018)]
- 16 **Wang H,** Huang G. Application of support vector machine in cancer diagnosis. *Med Oncol* 2011; **28** Suppl 1: S613-S618 [PMID: [20842538](https://pubmed.ncbi.nlm.nih.gov/20842538/) DOI: [10.1007/s12032-010-9663-4](https://doi.org/10.1007/s12032-010-9663-4)]
- 17 **Zernov VV,** Balakin KV, Ivaschenko AA, Savchuk NP, Pletnev IV. Drug discovery using support vector machines. The case studies of drug-likeness, agrochemical-likeness, and enzyme inhibition predictions. *J Chem Inf Comput Sci* 2003; **43**: 2048-2056 [PMID: [14632457](https://pubmed.ncbi.nlm.nih.gov/14632457/) DOI: [10.1021/ci0340916](https://doi.org/10.1021/ci0340916)]
- 18 **Liu Y,** Chen PC, Krause J, Peng L. How to Read Articles That Use Machine Learning: Users' Guides to the Medical Literature. *JAMA* 2019; **322**: 1806-1816 [PMID: [31714992](https://pubmed.ncbi.nlm.nih.gov/31714992/) DOI: [10.1001/jama.2019.16489](https://doi.org/10.1001/jama.2019.16489)]
- 19 **Kröner PT,** Engels MM, Glicksberg BS, Johnson KW, Mzaik O, van Hoof JE, Wallace MB, El-Serag HB, Krittanawong C. Artificial intelligence in gastroenterology: A state-of-the-art review. *World J Gastroenterol* 2021; **27**: 6794-6824 [PMID: [34790008](https://pubmed.ncbi.nlm.nih.gov/34790008/) DOI: [10.3748/wjg.v27.i40.6794](https://doi.org/10.3748/wjg.v27.i40.6794)]
- 20 **Zhang SM,** Wang YJ, Zhang ST. Accuracy of artificial intelligence-assisted detection of esophageal cancer and neoplasms on endoscopic images: A systematic review and meta-analysis. *J Dig Dis* 2021; **22**: 318-328 [PMID: [33871932](https://pubmed.ncbi.nlm.nih.gov/33871932/) DOI: [10.1111/1751-2980.12992](https://doi.org/10.1111/1751-2980.12992)]
- 21 **Horie Y,** Yoshio T, Aoyama K, Yoshimizu S, Horiuchi Y, Ishiyama A, Hirasawa T, Tsuchida T, Ozawa T, Ishihara S, Kumagai Y, Fujishiro M, Maetani I, Fujisaki J, Tada T. Diagnostic outcomes of esophageal cancer by artificial intelligence using convolutional neural networks. *Gastrointest Endosc* 2019; **89**: 25-32 [PMID: [30120958](https://pubmed.ncbi.nlm.nih.gov/30120958/) DOI: [10.1016/j.gie.2018.07.037](https://doi.org/10.1016/j.gie.2018.07.037)]
- 22 **Bang CS,** Lee JJ, Baik GH. Artificial Intelligence for the Prediction of Helicobacter Pylori Infection in Endoscopic Images: Systematic Review and Meta-Analysis Of Diagnostic Test Accuracy. *J Med Internet Res* 2020; **22**: e21983 [PMID: [32936088](https://pubmed.ncbi.nlm.nih.gov/32936088/) DOI: [10.2196/21983](https://doi.org/10.2196/21983)]
- 23 **Herrin J,** Abraham NS, Yao X, Noseworthy PA, Inselman J, Shah ND, Ngufor C. Comparative Effectiveness of Machine Learning Approaches for Predicting Gastrointestinal Bleeds in Patients Receiving Antithrombotic Treatment. *JAMA Netw Open* 2021; **4**: e2110703 [PMID: [34019087](https://pubmed.ncbi.nlm.nih.gov/34019087/) DOI: [10.1001/jamanetworkopen.2021.10703](https://doi.org/10.1001/jamanetworkopen.2021.10703)]
- 24 **Pofahl WE,** Walczak SM, Rhone E, Izenberg SD. Use of an artificial neural network to predict length of stay in acute pancreatitis. *Am Surg* 1998; **64**: 868-872 [PMID: [9731816](https://pubmed.ncbi.nlm.nih.gov/9731816/)]
- 25 **Mendoza Ladd A,** Diehl DL. Artificial intelligence for early detection of pancreatic adenocarcinoma: The future is promising. *World J Gastroenterol* 2021; **27**: 1283-1295 [PMID: [33833482](https://pubmed.ncbi.nlm.nih.gov/33833482/) DOI: [10.3748/wjg.v27.i13.1283](https://doi.org/10.3748/wjg.v27.i13.1283)]
- 26 **Jovanovic P,** Salkic NN, Zerem E. Artificial neural network predicts the need for therapeutic ERCP in patients with suspected choledocholithiasis. *Gastrointest Endosc* 2014; **80**: 260-268 [PMID: [24593947](https://pubmed.ncbi.nlm.nih.gov/24593947/) DOI: [10.1016/j.gie.2014.01.023](https://doi.org/10.1016/j.gie.2014.01.023)]
- 27 **Hassan C,** Spadaccini M, Iannone A, Maselli R, Jovani M, Chandrasekar VT, Antonelli G, Yu H, Areia M, Dinis-Ribeiro M, Bhandari P, Sharma P, Rex DK, Rösch T, Wallace M, Repici A. Performance of artificial intelligence in colonoscopy for adenoma and polyp detection: a systematic review and meta-analysis. *Gastrointest Endosc* 2021; **93**: 77-85.e6 [PMID: [32598963](https://pubmed.ncbi.nlm.nih.gov/32598963/) DOI: [10.1016/j.gie.2020.06.059](https://doi.org/10.1016/j.gie.2020.06.059)]
- 28 **Brindley PJ,** Bachini M, Ilyas SI, Khan SA, Loukas A, Sirica AE, Teh BT, Wongkham S, Gores GJ. Cholangiocarcinoma. *Nat Rev Dis Primers* 2021; **7**: 65 [PMID: [34504109](https://pubmed.ncbi.nlm.nih.gov/34504109/) DOI: [10.1038/s41572-021-00300-2](https://doi.org/10.1038/s41572-021-00300-2)]
- 29 **Cardinale V,** Bragazzi MC, Carpino G, Matteo SD, Overi D, Nevi L, Gaudio E, Alvaro D. Intrahepatic cholangiocarcinoma: review and update. *Hepatology Research* 2018; **4**: 20 [DOI: [10.20517/2394-5079.2018.46](https://doi.org/10.20517/2394-5079.2018.46)]
- 30 **Bergquist A,** von Seth E. Epidemiology of cholangiocarcinoma. *Best Pract Res Clin Gastroenterol* 2015; **29**: 221-232 [PMID: [25966423](https://pubmed.ncbi.nlm.nih.gov/25966423/) DOI: [10.1016/j.bpg.2015.02.003](https://doi.org/10.1016/j.bpg.2015.02.003)]
- 31 **Everhart JE,** Ruhl CE. Burden of digestive diseases in the United States Part III: Liver, biliary tract, and pancreas. *Gastroenterology* 2009; **136**: 1134-1144 [PMID: [19245868](https://pubmed.ncbi.nlm.nih.gov/19245868/) DOI: [10.1053/j.gastro.2009.02.038](https://doi.org/10.1053/j.gastro.2009.02.038)]
- 32 **Razumilava N,** Gores GJ. Surveillance for Cholangiocarcinoma in Patients with Primary Sclerosing Cholangitis: Effective and Justified? *Clin Liver Dis (Hoboken)* 2016; **8**: 43-47 [PMID: [27822365](https://pubmed.ncbi.nlm.nih.gov/27822365/) DOI: [10.1002/cld.567](https://doi.org/10.1002/cld.567)]
- 33 **DeOliveira ML,** Cunningham SC, Cameron JL, Kamangar F, Winter JM, Lillemoe KD, Choti MA, Yeo CJ, Schulick RD. Cholangiocarcinoma: thirty-one-year experience with 564 patients at a single institution. *Ann Surg* 2007; **245**: 755-762 [PMID: [17457168](https://pubmed.ncbi.nlm.nih.gov/17457168/) DOI: [10.1097/01.sla.0000251366.62632.d3](https://doi.org/10.1097/01.sla.0000251366.62632.d3)]
- 34 **Rocha FG,** Matsuo K, Blumgart LH, Jarnagin WR. Hilar cholangiocarcinoma: the Memorial Sloan-Kettering Cancer Center experience. *J Hepatobiliary Pancreat Sci* 2010; **17**: 490-496 [PMID: [19806295](https://pubmed.ncbi.nlm.nih.gov/19806295/) DOI: [10.1007/s00534-009-0205-4](https://doi.org/10.1007/s00534-009-0205-4)]
- 35 **Nagino M,** Ebata T, Yokoyama Y, Igami T, Sugawara G, Takahashi Y, Nimura Y. Evolution of surgical treatment for perihilar cholangiocarcinoma: a single-center 34-year review of 574 consecutive resections. *Ann Surg* 2013; **258**: 129-140 [PMID: [23059502](https://pubmed.ncbi.nlm.nih.gov/23059502/) DOI: [10.1097/SLA.0b013e3182708b57](https://doi.org/10.1097/SLA.0b013e3182708b57)]
- 36 **Kim SY.** Preoperative Radiologic Evaluation of Cholangiocarcinoma. *Korean J Gastroenterol* 2017; **69**: 159-163 [PMID: [28329917](https://pubmed.ncbi.nlm.nih.gov/28329917/) DOI: [10.4166/kjg.2017.69.3.159](https://doi.org/10.4166/kjg.2017.69.3.159)]
- 37 **Yang C,** Huang M, Li S, Chen J, Yang Y, Qin N, Huang D, Shu J. Radiomics model of magnetic resonance imaging for predicting pathological grading and lymph node metastases of extrahepatic cholangiocarcinoma. *Cancer Lett* 2020; **470**: 1-7 [PMID: [31809800](https://pubmed.ncbi.nlm.nih.gov/31809800/) DOI: [10.1016/j.canlet.2019.11.036](https://doi.org/10.1016/j.canlet.2019.11.036)]
- 38 **Robles-Medrand C,** Oleas R, Alcivar-Vasquez J, Mendez JC, Puga-Tejada M, Del Valle R, Lukashok, HP. Artificial Intelligence Model for the Characterization of Biliary Strictures During Real-Time Digital Cholangioscopy: A Pilot Study. *Endoscopy* 2021; **53**: OP53 [DOI: [10.1055/s-0041-1724313](https://doi.org/10.1055/s-0041-1724313)]
- 39 **Zhang Q,** Li Q, Yu G, Sun L, Zhou M, Chu J. A Multidimensional Choledoch Database and Benchmarks for Cholangiocarcinoma Diagnosis. *IEEE access* 2019; **7**: 149414-149421 [DOI: [10.1109/access.2019.2947470](https://doi.org/10.1109/access.2019.2947470)]
- 40 **Negrini D,** Zecchin P, Ruzzenente A, Bagante F, De Nitto S, Gelati M, Salvagno GL, Danese E, Lippi G. Machine Learning Model Comparison in the Screening of Cholangiocarcinoma Using Plasma Bile Acids Profiles. *Diagnostics (Basel)* 2020; **10** [PMID: [32748848](https://pubmed.ncbi.nlm.nih.gov/32748848/) DOI: [10.3390/diagnostics10080551](https://doi.org/10.3390/diagnostics10080551)]
- 41 **Ji GW,** Zhu FP, Zhang YD, Liu XS, Wu FY, Wang K, Xia YX, Jiang WJ, Li XC, Wang XH. A radiomics approach to

- predict lymph node metastasis and clinical outcome of intrahepatic cholangiocarcinoma. *Eur Radiol* 2019; **29**: 3725-3735 [PMID: 30915561 DOI: 10.1007/s00330-019-06142-7]
- 42 **Xu L**, Yang P, Liang W, Liu W, Wang W, Luo C, Wang J, Peng Z, Xing L, Huang M, Zheng S, Niu T. A radiomics approach based on support vector machine using MR images for preoperative lymph node status evaluation in intrahepatic cholangiocarcinoma. *Theranostics* 2019; **9**: 5374-5385 [PMID: 31410221 DOI: 10.7150/thno.34149]
 - 43 **Zhao L**, Ma X, Liang M, Li D, Ma P, Wang S, Wu Z, Zhao X. Prediction for early recurrence of intrahepatic mass-forming cholangiocarcinoma: quantitative magnetic resonance imaging combined with prognostic immunohistochemical markers. *Cancer Imaging* 2019; **19**: 49 [PMID: 31307551 DOI: 10.1186/s40644-019-0234-4]
 - 44 **Shao F**, Huang Q, Wang C, Qiu L, Hu YG, Zha SY. Artificial Neural Networking Model for the Prediction of Early Occlusion of Bilateral Plastic Stent Placement for Inoperable Hilar Cholangiocarcinoma. *Surg Laparosc Endosc Percutan Tech* 2018; **28**: e54-e58 [PMID: 29252936 DOI: 10.1097/SLE.0000000000000502]
 - 45 **Pattanapairoj S**, Silsirivanit A, Muisuk K, Seubwai W, Cha'on U, Vaeteewoottacharn K, Sawanyawisuth K, Chetchotsak D, Wongkham S. Improve discrimination power of serum markers for diagnosis of cholangiocarcinoma using data mining-based approach. *Clin Biochem* 2015; **48**: 668-673 [PMID: 25863112 DOI: 10.1016/j.clinbiochem.2015.03.022]
 - 46 **Müller L**, Mähringer-Kunz A, Gairing SJ, Foerster F, Weinmann A, Bartsch F, Heuft LK, Baumgart J, Düber C, Hahn F, Kloeckner R. Survival Prediction in Intrahepatic Cholangiocarcinoma: A Proof of Concept Study Using Artificial Intelligence for Risk Assessment. *J Clin Med* 2021; **10** [PMID: 34066001 DOI: 10.3390/jcm10102071]
 - 47 **Matake K**, Yoshimitsu K, Kumazawa S, Higashida Y, Irie H, Asayama Y, Nakayama T, Kakihara D, Katsuragawa S, Doi K, Honda H. Usefulness of artificial neural network for differential diagnosis of hepatic masses on CT images. *Acad Radiol* 2006; **13**: 951-962 [PMID: 16843847 DOI: 10.1016/j.acra.2006.04.009]
 - 48 **Ji GW**, Zhang YD, Zhang H, Zhu FP, Wang K, Xia YX, Jiang WJ, Li XC, Wang XH. Biliary Tract Cancer at CT: A Radiomics-based Model to Predict Lymph Node Metastasis and Survival Outcomes. *Radiology* 2019; **290**: 90-98 [PMID: 30325283 DOI: 10.1148/radiol.2018181408]
 - 49 **Logeswaran R**. Cholangiocarcinoma--an automated preliminary detection system using MLP. *J Med Syst* 2009; **33**: 413-421 [PMID: 20052894 DOI: 10.1007/s10916-008-9203-3]
 - 50 **Pereira P**, Mascarenhas M, Ribeiro T, Afonso J, Ferreira JPS, Vilas-Boas F, Parente MPL, Jorge RN, Macedo G. Automatic detection of tumor vessels in indeterminate biliary strictures in digital single-operator cholangioscopy. *Endosc Int Open* 2022; **10**: E262-E268 [PMID: 35295246 DOI: 10.1055/a-1723-3369]
 - 51 **Ghandour B**, Hsieh H-W, Akshintala V, Bejjani M, Szvarca D, Tejaswi S, DiMaio CJ, Trindade AJ, Manvar A, Itoi T, Slivka A, Goenka MK, Moon JH, Kushnir V, Sethi A, Bun Teoh AY, Yan Tang RS, Lau JY, Rerknimitr R, Ang TL, Maydeo AP, Jonica ER, Kaffes AJ, Saxena P, Nguyen NQ, Khokhar AS, D'Souza L, Buscaglia JM, Sherman S, Muniraj T, Jamidar P, Vedula S, Hager GD, Khashab MA. S1 Machine Learning for Classification of Indeterminate Biliary Strictures During Cholangioscopy. 2021; 116: S1 [DOI: 10.14309/01.ajg.0000771984.13549.faj]
 - 52 **Prasoppokakorn T**, Tiyyarattanachai T, Chaiteerakij R, Decharatanachart P, Mekaroonkamol P, Ridditit W, Kongkam P, Rerknimitr R. Application of artificial intelligence for diagnosis of pancreatic ductal adenocarcinoma by EUS: A systematic review and meta-analysis. *Endosc Ultrasound* 2022; **11**: 17-26 [PMID: 34937308 DOI: 10.4103/EUS-D-20-00219]
 - 53 **Yao L**, Zhang J, Liu J, Zhu L, Ding X, Chen D, Wu H, Lu Z, Zhou W, Zhang L, Xu B, Hu S, Zheng B, Yang Y, Yu H. A deep learning-based system for bile duct annotation and station recognition in linear endoscopic ultrasound. *EBioMedicine* 2021; **65**: 103238 [PMID: 33639404 DOI: 10.1016/j.ebiom.2021.103238]
 - 54 **Akshintala VS**, Tang B, Kamal A, Buxbaum JL, Elmunzer BJ, Wani SB, Yu CY, Tieu AH, Kalloo AN, Singh V, Caffo B, Khashab MA. Sa1470 Risk estimation, machine learning based ercp decision-making tool for suspected choledocholithiasis. *Gastrointestinal Endoscopy* 2019; **89**: AB246-AB7 [DOI: 10.1016/j.gie.2019.03.264]
 - 55 **Dalai C**, Azizian J, Trieu H, Rajan A, Chen F, Dong T, Beaven S, Tabibian JH. Machine learning models compared to existing criteria for noninvasive prediction of endoscopic retrograde cholangiopancreatography-confirmed choledocholithiasis. *Liver Res* 2021; **5**: 224-231 [PMID: 35186364 DOI: 10.1016/j.livres.2021.10.001]
 - 56 **Kurnaz S**, Loaiza-Bonilla A, Freedman JL, Arango BA, Johnston K, Bonilla-Reyes PA, Culcuoglu CM, SYNERGY-AI Precision Oncology Group. SYNERGY-AI: Artificial intelligence based precision oncology clinical trial matching and registry. *Journal of Clinical Oncology* 2019; **37** suppl 4: TPS717-TPS [DOI: 10.1200/jco.2019.37.4_suppl.tps717]
 - 57 **Akshintala VS**, Khashab MA. Artificial intelligence in pancreaticobiliary endoscopy. *J Gastroenterol Hepatol* 2021; **36**: 25-30 [PMID: 33448514 DOI: 10.1111/jgh.15343]



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