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Use of artificial intelligence in total mesorectal excision in rectal cancer surgery: State of the art and perspectives

AI in TME surgery

Abstract

BACKGROUND

Image-guided surgery in Total Mesorectal Excision (TME) is crucial to prevent local recurrence of rectal cancer, which can occur due to inadequate surgical technique. An inadequate TME due to improper dissection outside the correct avascular embryological plane can lead to early recurrence.

AIM

This study aims to review the literature on the use of Artificial Intelligence (AI) and Machine Learning (ML) in rectal surgery and potential future developments.

METHODS

Online scientific databases will be searched for articles on the use of artificial intelligence in rectal cancer surgery, between 2020 and 2023.

RESULTS

The literature search yielded 876 results and only 13 studies were selected for review.

CONCLUSION

AI has the potential to revolutionize TME surgery by providing real-time surgical guidance, preventing complications, and improving training, but more research is needed to fully understand the benefits and risks of AI in TME surgery.

Key Words: Artificial Intelligence; Machine Learning; Rectal Cancer; Total Mesorectal Excision; Colorectal Surgery

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Core Tip: This review provides an overview of the current use of AI methods in surgery and the latest findings on their use during TME dissection in rectal cancer procedures. It also discusses the major limitations that AI still has in surgery and the fact that it is still not used in clinical settings. A novel approach to devising a more powerful algorithm in TME dissection is proposed.

INTRODUCTION

Colorectal cancer (CRC) is a significant public health concern, with a 1.9 million new cases and 953,000 deaths worldwide in 2020. It is the third most common cancer and the second leading cause of cancer-related deaths globally, according to GLOBOCAN data[1]. Despite advances in the non-surgical treatment of CRC, oncological radical surgical excision of the primary tumour and locoregional lymph nodes represents the predominant aspect of curative treatment. Total Mesorectal Excision (TME) is a surgical technique that has become the standard of care for the treatment of rectal cancer and involves the complete removal of the rectum and surrounding tissues, including the mesorectum, the fatty tissue that surrounds the rectum. The technique was first introduced in the 1980s and has since been shown to improve local control of the disease and reduce the risk of recurrence, leading to better long-term outcomes for patients[2]. This operation requires skill and expertise to achieve both oncological radicality and the preservation of the presacral nerves responsible for continence and sexual function.

Incomplete TME is directly linked to local tumour recurrence and decreased overall survival. Curtis *et al* demonstrated that surgeons in the top skill quartile consistently achieved superior-quality histopathological TME specimens, resulting in improved patient outcomes[3]. With many countries considering centralising rectal cancer treatment for this reason. The application of adjunctive measures such as Artificial Intelligence (AI) could aid surgeons in performing an adequate TME. The effect is likely to be more pronounced with surgeons early in their learning curve but may be useful to orientate more experienced in more challenging cases, such as cases of recurrent rectal cancer and for those patients who had previously had neoadjuvant treatment.

This paper will provide an overview of the current state of knowledge regarding the use of artificial intelligence specifically in the performance of a TME dissection, with a focus on the scientific evidence supporting its use in the management of rectal cancer.

MATERIALS AND METHODS

A comprehensive literature search was conducted to identify relevant studies for this review. The search was performed using PubMed electronic databases, using the following search terms: “TME” OR “Total Mesorectal Excision” OR “Rectal Cancer Surgery” AND “Artificial Intelligence” OR “Machine Learning” OR “Deep Learning”. The search was limited to studies published between 2020 and 2023. Only articles published in English were included. Only studies addressing the use of AI in rectal cancer surgery and specifically in TME were selected.

RESULTS

The literature search yielded 876 results. Thirteen studies met our inclusion criteria. The selection flowchart is illustrated in **Figure 1**. In an initial screening, only the title and abstract of the papers were analysed until we obtained 26 results. After reading the full text, only 13 studies were selected for review.

OVERVIEW OF AI IN MEDICINE

AI is a technology that encompasses today several approaches as Machine Learning (ML), a complex set of mathematical algorithms that allow computers to learn through experience[4], Deep Learning (DL), or Computer Vision (CV). The concept of ML is to identify patterns and optimize their parameters to better solve a specific problem through analysis of large-scale datasets [5]. ML has shown encouraging results in analysing data, such as text, images and videos. DL is a subfield of ML that uses multilayer artificial neural networks (ANNs) to draw pattern-based conclusions from input data[6]. In medicine, a large amount of data is visual, in the form of images and CV is another subfield of ML that trains machines to extract valuable information from images (e.g., radiological and histopathological) and, therefore, videos (e.g., endoscopic and surgical videos)[8]. Several groups have developed radiological image processing algorithms to enable faster diagnoses, improve visualisation of pathologies, and recognise emergency situations[8][9][11][12]. Recent examples include; DL-based algorithms to achieve accurate carotid artery stenosis detection and plaque classification using CT angiography [11], 3D convolutional neural network (CNN) to automate tumour volumes using PET/CT and MRI images[12], automatic detection of lymph node metastasis in colon and head-and-neck cancer [13][14] and DL models to automatically classifying of thyroid biopsies based on microscope images taken with a smartphone [15].

AI in Surgery

Surgical Data Science (SDS) describes an emerging field of research concerned with the collection and analysis of data produced by surgery[16]. The application of AI technology in the field of surgery was first studied by Gunn in 1976, when he explored the possibility of diagnosing acute abdominal pain with computer analysis[17]. The last two decades have seen a rise in its application in general and in colorectal surgery. AI methods have been applied in multiple areas of colorectal surgery, both preoperatively, intraoperatively, and postoperatively[18]. Preoperatively, AI can help diagnose and clinically classify patients as precisely as possible and offer a personalised treatment plan. Postoperatively, it can integrate the pathway of improved recovery after surgery (ERAS), automate pathology assessment and support research. All these elements contribute to improved patient outcomes and provide promising results.

Intraoperatively, it could help improve the surgeon's skills in laparoscopic and robotic procedures. The development of AI-based systems could support anatomy detection and trigger alerts providing surgical guidance on dangerous actions at crucial stages, improving surgeons' decision-making. ML algorithms have been so far used to identify surgical instruments as they enter the surgical field and the identification of anatomical landmarks such as vascular and nerve structures, and organs[19]. This is achieved using methods to first assess the presence and second to analyse the movement pattern of surgical instruments and/or by automatically assessing the surgical phases[20]. Mascagni *et al*'s work in 2022 developed a deep-learning model that automatically segmented the hepatocystic triangle and automatically determine compliance with the critical view of safety criteria during laparoscopic cholecystectomy, with the aim of improving of reducing bile duct injury[21].

Whilst an evolving field it is important to point out that AI-based assistance during surgery is still in an embryonic stage, and its developments, such as video segmentation and automatic detection of instruments, have so far shown little benefit with no AI algorithm having yet been approved for clinical use.

AI in TME Surgery

Artificial intelligence (AI) in total mesorectal excision (TME) surgery involves centres on training neural networks. This process starts by splitting the data into two main parts: the training data and the test data.

The training data is a pre-specified part of the overall data, and it's where the network learns most of its information.

The test data is used to see how well the network can apply what it learned to new, unseen data.

Following which the neural network is fine-tuned through a validation dataset, whereby one assesses various hyperparameters, to allow the network to appreciate the spectrum of the data which is may receive.

The task of deep learning can be divided into three categories based on the type of output expected from the network: classification, detection, and segmentation.

Classification is the task of categorising a given input into two or more possible classes. For example, a classification model could be used to identify the type of tissue in a medical image.

Detection is the task of identifying and localizing an object of interest in an image. For example, a detection model could be used to identify and track the surgical tools in a video.

Segmentation is the task of assigning a label to each pixel in an image. For example, a segmentation model could be used to identify the different organs in a medical image.

Surgical phase and tool detection models are two early examples of deep learning for surgical applications[20]. These models have been used to improve the accuracy and efficiency of surgical procedures.

The machine learning (ML) process used in surgical applications can be generally outlined with the following steps:

Obtaining an appropriate dataset. The dataset should include operative images linked to clinical outcomes. In some cases, a simple and effective way to check whether the data is sufficiently informative is to ask an expert to look at it and perform the same task proposed for the model. People with no medical education could correctly annotate the presence or absence of tools in images, but the same cannot be said for annotating surgical phases, as this requires surgical understanding and a shared definition of what exactly defines and delineates phases.

Preprocessing the data. This may involve cleaning the data, removing outliers, and normalizing the data.

Splitting the dataset. The database is split into training, test, and validation sets. It is good scientific practice to keep these sets as independent from each other as possible since the network may develop biases.

Annotation. Labeling the data is a crucial step in the ML pipeline, as it enables supervised training for ML models. The labels can be temporal or spatial. Temporal annotations are useful when we need to determine surgical phases during an operation. Spatial annotations are used to identify surgical instruments in the surgical scene or anatomical structures (e.g., tool detection).

Training the model. This involves feeding the data to the model and allowing it to learn the patterns in the data. The training process can be computationally expensive, depending on the size of the dataset and the complexity of the model.

Evaluating the model. This involves testing the model on a held-out dataset and evaluating its performance. This is done to ensure that the model is not overfitting to the training data.

Deploying the model. This involves making the model available for use in real-world applications.

As said in describing annotation, phase recognition is the process of classifying frames in a video or sequence of images according to a predetermined surgical phase. It is a computer vision (CV) task that involves analysing the visual data to identify and understand different phases or actions. The goal is to recognise the sequence of frames in a video or image sequence to identify specific actions or events happening at different time points. This can be done by observing characteristic visual cues, such as movement, shape changes, or object interactions, to differentiate between different phases. By observing patterns and correlations in the training data, the algorithm can generalize its understanding to recognise and classify new, unseen sequences.

Semantic segmentation is when an image is divided into meaningful regions or segments, and each segment is assigned a semantic label. The goal is to understand what the different parts of an image represent. To accomplish this task, an algorithm analyses the image at the pixel level and assigns each pixel a label indicating which object or category it belongs to. By observing patterns and features in the training data, the algorithm can generalize its understanding to segment new unseen images.

In the context of surgical applications, semantic segmentation can be used to identify different anatomical structures, such as organs, tissues, and blood vessels. This information can be used to guide surgeons during surgery and to improve the accuracy and safety of the procedure.

Examples of semantic segmentation in surgical applications

Identifying the tumour and surrounding tissue in cancer surgery

Locating the surgical target in minimally invasive surgery

Tracking the movement of organs and tissues during surgery

Detecting and removing blood clots

Preventing accidental injury to surrounding tissues

One of the challenges in semantic segmentation for surgical applications is the complexity of the images. Surgical images are often cluttered with noise and artefacts, which can make it difficult for the algorithm to accurately segment the different objects. Another challenge is the variability of surgical procedures. Each procedure is unique, and the objects and tissues involved can vary from patient to patient. This makes it difficult to train a single algorithm that can be used for all surgical procedures. Recent advances in deep learning have made it possible to develop more accurate and robust semantic segmentation algorithms for surgical applications. These algorithms are able to learn the complex patterns in surgical images and to generalize their understanding to new datasets [22].

In anterior rectal resection and TME, previous studies have focused on the development of DL-based phase, act, and tool recognition[22], as well as DL-based image-guided navigation systems for areolar tissue at the level of TME[23].

As mentioned before, TME is a complex surgical procedure for rectal cancer surgery that consists of the complete resection of the mesorectal envelope and requires the resection to be along the appropriate plane and to preserve vulnerable anatomical structures, such as the autonomic nerve plexus, whose injury could cause major issues such as postoperative incontinence and sexual dysfunction. Robotic surgery particular useful in TME surgery though the authors recognize that no substantial clinical benefit over laparoscopic surgery has been demonstrated[24]. However, it offers advantages in terms of the acquisition of high quality image data owing to the benefits of 3D vision and a more stable camera platform. The additional benefit is the system recognizes when a new instrument has been attached to the console thereby one can cross reference algorithms designed to detect tools easily.

The role of AI

In this context, AI could provide surgical guidance by identifying anatomical structures and helping to improve surgical quality, diminish differences between surgeons, and provide better clinical results. To this point, efforts have been made to develop image recognition algorithms using minimally invasive video data, especially focused on automated instrument detection, which only has indirect surgical benefit [25][20]. Significant results have also been obtained to identify relevant anatomical structures during less complex surgical procedures such as cholecystectomy[26][21].

The 2022 work by Kolbinger *et al* is based on 57 robot-assisted rectal resections and focuses on developing an algorithm to automatically detect surgical phases and provide identification of determined anatomical structures. In particular, the algorithm had the best results on the recognition of the mesocolon, mesorectum, Gerota's fascia, abdominal wall, and dissection planes during mesorectal excision.

In 2022 Igaki *et al* relied on the idea of the “holy plane”, first proposed by Heald in the 1980s describing TME dissection[27]. The holy plane lies between the mesorectal fascia and the parietal pelvic fascia through fibroareolar tissue and is an important landmark to follow an avascular pathway, so that TME can be performed safely and effectively. Igaki *et al* developed a DL algorithm to automatically detect areolar tissue using the open-source software DeepLabv3plus.

Limitations

One limitation of the studies is the uncertainty of detection. According to the experience of Kolbinger *et al* the automatic recognition of thin and small structures is more difficult, *e.g.* the recognition of the exact position of the dissection line in mesorectal excision. In addition, in TME, patient-related aspects such as individual anatomical variations and especially the history of neoadjuvant (radio) therapy can lead to the dissection lines being very different throughout the dataset and therefore difficult to detect automatically. These limitations could be overcome by technical improvements, *e.g.* by displaying the detection uncertainty of the target structures, *e.g.* using Bayesian calculation methods. This would also increase acceptance among surgeons. Another improvement could be real-time display by minimising the computational delay, which is currently four seconds.

The essential point for the integration of the above improvements and in general for the development of better algorithms for automatic recognition is the availability of data and thus the creation of publicly available datasets for complex surgical interventions and the creation of multicentre studies for these applications.

DISCUSSION

In TME, identification of embryonic tissue planes and the closely associated dissection line at the mesorectal fascia can be challenging because of significant variation due to neoadjuvant (radio)therapy and individual factors such as body composition. The ability to identify and highlight the fibroareolar tissue plane, vascular or nerve structures, are all key bits of anatomy which AI algorithms can augment intraoperative identification.

In robotic surgery, the use of visual aids could be considered more important than in laparoscopic surgery because of the loss of haptic feedback, that is the sense of touch and force feedback that surgeons rely on in traditional open or laparoscopic surgery. To compensate for the lack of haptic feedback, visual augmentation plays a crucial role. In addition, advanced technologies such as fluorescence and near-infrared imaging are frequently used in robotic surgery. These techniques allow visualization of blood flow, tissue perfusion, and identification of vital structures that are not readily visible under normal lighting conditions. Combined with AI-assisted visual enhancements, the surgeon's ability to make critical decisions and perform delicate manoeuvres such as TME with the required precision is improved.

Studies on AI-powered surgical guidance, which uses machine learning (ML) algorithms to automatically identify context-aware anatomical structures, surgical instruments, and surgical phases in complex abdominal surgery, require the creation of publicly available datasets and multi-centre studies. This is because the datasets need to be large and diverse enough to train AI algorithms that can generalize to new patients. Additionally, multi-centre studies are necessary to ensure that the results are valid and reproducible.

CONCLUSION

The use of AI in TME is still in its early stages, but it has the potential to revolutionize the procedure. For example, AI algorithms can be used to identify and highlight key anatomical structures, such as the mesorectal fascia, the vascular bundle, and the autonomic nervous structure. This could provide real-time surgical structures, thus helping surgeons to perform complex procedures more accurately and safely, even in cases where the anatomy is challenging.

AI algorithms can also be used to track the movement of tissues and organs during the procedure. This can help to prevent complications, such as accidental injury to surrounding tissues. For example, AI algorithms can be used to track the movement of the rectum during the dissection, which can help to prevent accidental perforation.

AI algorithms can also be used to improve the training of surgeons, helping them to be confident with the complex anatomy of the pelvis and the techniques of TME.

The use of AI in TME is still being investigated, and the results so far are promising, but while studies have shown that DL-based algorithms are able to identify fibroareolar tissue and several other anatomical structures, these models have not related these results to postoperative outcomes. It is possible this is reflective of being assessed with already expert surgeons and the true effect be most demonstrable in those surgeons earlier in their learning curve.

The use of AI in TME is a promising area of research with the potential to improve the safety and efficacy of this important surgical procedure. However, more research is needed to fully understand the benefits and risks of this technology.

ARTICLE HIGHLIGHTS

Research background

Colorectal cancer is a major public health problem, with 1.9 million new cases and 953,000 deaths worldwide in 2020. Total mesorectal excision (TME) is the standard of care for the treatment of rectal cancer, but it is a technically challenging surgery. Artificial intelligence (AI) has the potential to improve the performance of TME surgery, especially for surgeons early in their learning curve.

Research motivation

AI in surgery is a rapidly evolving field with applications in preoperative, intraoperative, and postoperative settings. In colorectal surgery, AI has been used to automate tasks such as instrument detection and anatomical structure identification. AI has also been used to develop image-guided navigation systems for TME surgery. One of the challenges of AI in surgery is the complexity of the images. Another challenge is the variability of surgical procedures. Recent advances in deep learning have made it possible to develop more accurate and robust AI algorithms for surgical applications.

Research objectives

Investigate the potential of AI in surgery, especially in colorectal surgery, and current state-of-the-art technology. Describe AI algorithms for surgical applications, such as instrument detection, anatomical structure identification, and image-guided navigation systems. Describe their limitations and their future developments, like AI algorithms that can be used in real-time. Suggest the evaluation of the safety and efficacy of AI in surgery through clinical trials.

Research methods

A literature search was conducted to identify relevant studies on the use of AI in rectal cancer surgery and specifically in TME. The search was performed using PubMed electronic databases and limited to studies published between 2020 and 2023.Only articles published in English were included.

Research results

The use of AI in rectal cancer surgery and specifically in TME is a rapidly evolving field. There are a number of different AI algorithms that have been developed for use in TME, including algorithms for instrument detection, anatomical structure identification, and image-guided navigation systems.

Research conclusions

The results of these studies are promising, but more research is needed to fully evaluate the safety and efficacy of AI in TME. Some of the challenges that need to be addressed before AI can be widely adopted in TME include the need for large datasets of labeled images to train AI algorithms, the need to develop AI algorithms that can be used in real-time, and the need to address the ethical concerns raised by the use of AI in surgery.

Research perspectives

AI has the potential to revolutionize TME by providing real-time surgical guidance, preventing complications, and improving training. However, more research is needed to fully understand the benefits and risks of AI in TME.

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