Pictorial Review

Imaging of oesophageal cancer with FDG-PET/CT and MRI

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Integrated 2-\[^{18}\text{F}\]-fluoro-2-deoxy-D-glucose (FDG) PET/CT and magnetic resonance imaging (MRI) with functional features of diffusion-weighted imaging (DWI) are advancing imaging technologies that have current and future potential to overcome important limitations of conventional staging methods in the management of patients with oesophageal cancer. PET/CT has emerged as an important part of the standard work-up of patients with oesophageal cancer. Besides its important ability to detect unsuspected metastatic disease, PET/CT may be useful in the assessment of treatment response, radiation treatment planning, and detection of recurrent disease. In addition, high-resolution T2-weighted MRI and DWI have potential complementary roles. Recent improvements in MRI protocols and techniques have resulted in better imaging quality with the potential to bring improvement in staging, radiation treatment planning, and the assessment of treatment response. Optimal use and understanding of PET/CT and MRI in oesophageal cancer will contribute to the impact of these advancing technologies in tailoring treatment to the individual patient and achieving best possible outcomes. In this article, we graphically outline the current and potential future roles of PET/CT and MRI in the multidisciplinary management of oesophageal cancer.

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Introduction

Over the past decade integrated PET/CT with 2-\[^{18}\text{F}\]-fluoro-2-deoxy-D-glucose (FDG) PET/CT has emerged as an important and recommended part of routine staging of patients with oesophageal cancer in (inter)national guidelines. FDG-PET/CT imaging — followed by endoscopic ultrasonography (EUS) — has been proposed as the most cost-effective strategy for initial staging of patients with oesophageal cancer, mainly due to its ability to detect unsuspected metastatic disease. In addition, with increasing availability and body of evidence, the role of PET/CT may further expand to include assessment of treatment response, radiation treatment planning, and detection of recurrent disease.

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Besides PET/CT, another recently advancing imaging technique is high-resolution T2-weighted MRI with diffusion-weighted imaging (DWI), which might have complementary roles in staging, treatment response assessment and radiation planning. A good understanding of PET/CT and MRI results, along with their advantages and limitations in oesophageal cancer, is important for proper interpretation of images and will contribute to the impact of these advancing technologies in tailoring treatment to the individual patient and achieving best possible outcomes. Therefore, the aim of this review is to graphically outline the current and potential future roles of PET/CT and MRI in the management of oesophageal cancer.

**PET/CT**

PET/CT provides additional information when compared to PET or CT alone in different types of malignancies including oesophageal cancer. Studies in oesophageal cancer have shown that the overall accuracy for initial staging improved from 83–86% for standalone PET to 90–92% for integrated PET/CT.

**Imaging technique**

PET/CT is performed on an integrated hybrid system combining PET capabilities with multidetector CT components in two sequential gantries. As no patient repositioning is required between the two acquisitions, an accurate co-registration of PET and CT datasets can be performed. Although no general consensus on all imaging variables exists, the currently applied protocols share some common features.

Patient preparation includes fasting for at least 6 h before the PET/CT examination, with a preferred serum glucose level of <10 mmol/l, and emptying of the bladder just before examination. Sixty to 90 min after administration of FDG, PET images are acquired in a two- or three-dimensional mode. Administered activity and time per bed-position are interrelated and may be highly variable. Reconstruction of PET images is performed using standard iterative reconstruction algorithms that incorporate ordered-subset expectation maximization. Attenuation data from the CT part of the examination is used to perform attenuation correction of the PET images.

The CT examination comprises a multidetector CT scan with a tube potential of 120–140 kV and an effective tube current of 40–120 mA. CT images are usually reconstructed with section thicknesses of 3–5 mm. Administration of oral and intravenous contrast agents improves the ability to identify the anatomical location and boundaries of lesions detected on the PET images. In addition to qualitative assessment, the FDG uptake within specific lesions can be analysed quantitatively by measuring the standardized uptake value (SUV), often expressed as its maximum (SUVmax), which is derived from the activity within the region of interest (Bq/g) multiplied by grams of body weight, divided by the total injected dose of FDG (Bq).

**MRI**

MRI of the oesophagus is often considered technically challenging. Reasons for the difficult depiction of the oesophagus include organ motion due to respiratory and cardiac action, and considerable blood flow in the aorta and pulmonary vessels, which leads to motion and flow artefacts. Additionally, the central location of the mediastinum in the body is associated with a reduced receiver coil sensitivity, resulting in a degraded signal-to-noise ratio (SNR). Over the past decade, several technical innovations became available to reduce the mentioned image artefacts. For instance, effects of respiratory motion can be reduced by automatic gated imaging using navigators, and the availability of multi-channel receiver coils resulted in improved SNR in the thorax. These improvements enable proper visualization of the oesophagus using MRI. The SNR may further be increased by scanning at a higher magnetic field strength (i.e., 3 T instead of 1.5 T). However, a disadvantage of scanning at higher field strength is the larger effect of magnetic susceptibility variations on the geometrical fidelity of MRI images. As large susceptibility variations are present in the thorax and mediastinum due to the numerous air–tissue transitions, MRI of the oesophagus at higher field strengths may be less optimal despite the higher SNR.

**Imaging technique**

In previous ex-vivo and in-vivo studies the optimal anatomical contrast (i.e. T1- or T2-weighted scans), along with the most suitable combination of repetition times (TR) and echo times (TE) was determined for visualization of the oesophagus and surrounding structures. High-resolution T2-weighted scans, rather than T1-weighted scans, enable clear depiction of the different layers of the oesophageal wall (Fig 1a). In addition, optimized in-vivo high-resolution T2-weighted MRI provides excellent contrast between the oesophagus and its surrounding structures, with oesophageal wall thickening at the level of a tumour (Fig 1b–c).

Further optimization of high-resolution T2-weighted MRI includes automatic respiratory motion compensation. In our institution, a navigator that monitors the position of the diaphragm using a fast one-dimensional MRI acquisition is applied to trigger scanning exclusively during the end-exhale position of the diaphragm, as the end-exhale position was found to reflect the most stable position of oesophageal tumours during the respiratory cycle.

A functional MRI technique that clearly depicts oesophageal tumours is DWI. With DWI, variations in the diffusion of water molecules (i.e., random mobility) among tissues are visualized (Fig 1d). To achieve image contrast, the MRI signal is labelled for diffusion using spatially varying magnetic fields (diffusion gradients). This results in a lower signal in mobile water molecules compared to immobile water molecules. If DWI images with two or more diffusion-weighting strengths (expressed in s/mm²) are scanned, it is possible to calculate the apparent diffusion...
The coefficient (ADC), a quantitative measure for diffusion. Low ADC values represent restricted diffusion of water molecules in a region of interest as a result of high cell density and intact cell membranes (e.g., spinal cord, spleen, malignant tissue), whereas high ADC values represent less restricted diffusion of water molecules in tissues with low cell density or defective cell membranes (e.g., healthy gastrointestinal organs, or malignant tissues that responded well to treatment).\[^{16,17}\]

In our experience, an anticipated MRI protocol that is potentially useful for future clinical practice in oesophageal cancer consists of both T2-weighted and DWI sequences. Depending on the clinical purpose of the MRI examination, in our opinion the field-of-view should at least include the cranio-caudal extent of the posterior mediastinum and upper abdomen to be able to visualize the primary tumour along with potentially involved lymph nodes. Scanning in the transverse plane seems appropriate for the assessment of tumour depth and ingrowth into adjacent structures, whereas sagittal and coronal scans may be useful in the determination of the cranio-caudal tumour extent.

**Oesophageal cancer staging**

Oesophageal cancer is the eighth most common cancer worldwide and the incidence is rapidly increasing.\[^{18,19}\] The disease is highly lethal due to the late onset of symptoms, with poor overall 5-year survival rates ranging from 15–25%.\[^{20}\] Curative treatment of oesophageal cancer combines neoadjuvant chemoradiotherapy (CRT) with surgery, and palliative treatment options include chemotherapy and local therapies, such as radiotherapy and endoscopic...
stenting. Optimal use and understanding of staging techniques is essential to predict prognosis and tailor treatment to individuals in order to achieve the best possible outcomes.

Staging includes upper-gastrointestinal endoscopy with biopsy to confirm the diagnosis, EUS to acquire additional information on local tumour invasion and loco-regional lymph node status, and PET/CT to assess loco-regional spread and distant metastases. Although MRI plays no role in current routine staging guidelines, it has the potential to serve as an alternative or complementary non-invasive form of staging in the near future.

**Primary tumour**

**PET/CT**

Visible FDG avidity of tumours relies on sufficient tumour volume and a metabolic activity that exceeds a certain detection threshold (currently approximately 5 mm). In a recent meta-analysis, a pooled primary oesophageal tumour detection rate with PET/CT of 92.7% was reported. The limited spatial resolution of PET particularly limits visualization of early-stage carcinomas with small volumes (i.e., Tis, T1 and T2).

Conversely, false-positive results may result from benign lesions, such as leiomyoma or secondary inflammation caused by chemotheraphy, radiation treatment, Candida infection, gastro-oesophageal reflux disease, oesophageal spasm, Barrett's oesophagus, or bacterial infection with perιstrictures. However, non-malignant PET hypermetabolism is often linear in shape involving a long craniocaudal segment with relatively low intensity and, therefore, can often be easily distinguished from more focal and intense malignant lesions.

Another consequence of the poor spatial resolution of PET and the poor contrast resolution of CT, is the limited role of these techniques in evaluating the depth of invasion (e.g., T-stage) of oesophageal cancers. EUS is the preferred method for primary tumour staging, as supported by a meta-analysis that found pooled sensitivities for diagnosing T-stage of oesophageal cancers. PET/CT has a limited value in the assessment of loco-regional lymph node involvement in oesophageal cancer.

**PET/CT**

PET/CT has a limited value in the assessment of loco-regional lymph node involvement in oesophageal cancer. A meta-analysis reported a pooled sensitivity and specificity with PET of 51% and 84%, respectively. FDG uptake of the primary tumour may obscure uptake in peritumoural lymph nodes due to the limited spatial resolution of PET. In addition, lymph nodes with microscopic involvement may lack both sufficient FDG uptake and sufficient abnormal growth for detection with PET/CT. Furthermore, false-positive findings can result from inflammatory processes in lymph nodes. PET/CT, therefore, seems rather an adjunct than an alternative to conventional CT and EUS for the assessment of lymph nodes.

**MRI**

In early MRI studies, primary tumour detection rates were disappointing for early-stage oesophageal cancers (i.e., T1 and T2). A more recent study performed high-resolution T2-weighted MRI with faster sequences and cardiorespiratory motion gating in combination with DWI, and reported detection rates of 33% for T1, 58% for T2, 96% for T3, and 100% for T4 carcinomas. Using conventional T1- and T2-weighted MRI, T-stage was correctly assessed in 60% of patients only. However, high-resolution T2-weighted MRI has been shown to enable detailed imaging of the anatomical layers of the oesophageal wall and surrounding peri-oesophageal tissues. An accuracy of 81% was reported for T-staging in a recent study using this technique, with understaging in 16% and over staging in 3% of cases. As such, high-resolution T2-weighted MRI has the potential to serve as an alternative or complementary non-invasive form of local staging in oesophageal cancer.

In early studies, 1.5 T MRI with cardiac triggering was shown to be of similar value compared with CT for the assessment of surgical resectability (i.e., distinguishing ≤T4a from T4b tumours) with an accuracy of 75–87%. So far, no studies have reported the value of modern high-resolution T2-weighted MRI (standalone or fused with DWI) in the preoperative assessment of tumour invasion into adjacent non-resectable structures (Fig 2). Modern high-resolution T2-weighted MRI with faster sequences and motion gating might prove to be of superior value in future studies.

**Lymph nodes**

**PET/CT**

PET/CT has a limited value in the assessment of loco-regional lymph node involvement in oesophageal cancer. A meta-analysis reported a pooled sensitivity and specificity with PET of 51% and 84%, respectively. FDG uptake of the primary tumour may obscure uptake in peritumoural lymph nodes due to the limited spatial resolution of PET. In addition, lymph nodes with microscopic involvement may lack both sufficient FDG uptake and sufficient abnormal growth for detection with PET/CT. Furthermore, false-positive findings can result from inflammatory processes in lymph nodes. PET/CT, therefore, seems rather an adjunct than an alternative to conventional CT and EUS for the assessment of lymph nodes.

**MRI**

A recent systematic review demonstrated a moderately poor diagnostic value of conventional MRI for lymph node staging in oesophageal cancer, with a sensitivity and specificity of 25–62% and 67–88%, respectively. (Fig 3c–d). However, high-resolution MRI may prove more valuable in the near future as a recent study with modern motion gating techniques and fast fat-suppressive sequences achieved a sensitivity and specificity of 81% and 98%. Because current evidence is sparse and significant heterogeneity of reported methodology and outcomes among different studies exists, it is difficult to extract specific nodal features that may help identify malignant nodes on MRI. In most studies using conventional MRI, size criteria have been used to identify malignant lymph nodes (i.e., short-axis diameter of >5 mm or >10 mm).
Rather than using dimensional criteria, a focal or overall high signal intensity of lymph nodes on high-resolution T2-weighted MRI was considered metastatic in one study.\textsuperscript{51} Unfortunately, application of whole-body DWI with background body signal suppression (DWIBS) did not result in major diagnostic improvements for lymph node staging in one study.\textsuperscript{43} Lymph nodes with a higher signal intensity (i.e. showing more diffusion restriction) than the spinal cord on DWIBS were considered metastatic in this study. To the best of our knowledge, no studies have reported on the value of quantitative assessment of DW images of lymph nodes by means of ADC measurements so far.

\section*{Distant metastases}

\subsection*{PET/CT}

Many studies have demonstrated that the most important incremental value of PET/CT in the management of oesophageal cancer lies in its complementary ability to detect unexpected distant metastases in 5–28\% of patients at initial presentation.\textsuperscript{5,8,48,49,52–58} In this regard, PET provides additional diagnostic information over CT, leading to significant management changes in 14–40\% of patients.\textsuperscript{35,59–63} Metastatic spread from oesophageal cancer can occur in unusual and unexpected locations and whole-body PET/CT allows for detection of those metastases that are not covered with conventional strategies, that are radiologically occult, or that are difficult to diagnose prospectively.\textsuperscript{64,65} By detecting unexpected distant metastases preoperatively, PET/CT decreases the number of inappropriate attempts of surgical exploration and should therefore be performed as a routine part of initial staging (Figs 4–5).\textsuperscript{3,57,66,67} Several studies have also reported usefulness of PET/CT for detection of new interval metastases after neoadjuvant therapy, which occur in 8–17\% of patients.\textsuperscript{58–70} Some authors, therefore, advocate a restaging PET/CT as part of the standard work-up of surgical candidates.

Additionally, synchronous primary malignancies may be revealed by PET/CT in 1.5–8\% of patients with oesophageal cancer at initial staging.\textsuperscript{62,71–74} Approximately 75\% of these synchronous tumours were not detected by routine imaging in a large retrospective study.\textsuperscript{71} The most common synchronously involved sites included the colon and rectum (55\%), followed by lung, kidney, thyroid, and head and neck.

\subsection*{MRI}

To date no studies have been published on the value of MRI in detecting distant metastases from oesophageal cancer. Although specific MRI protocols may provide valuable information on distant spread to specific organs, such as the liver, in some cases, MRI is unlikely to be of additional value in the assessment of the whole body.

\section*{Treatment response assessment}

\subsection*{PET/CT}

Over the past two decades contradictory results have been published on the usefulness of PET and PET/CT for the assessment of response to neoadjuvant chemo(radio)therapy or definitive CRT.\textsuperscript{75–82} CRT-induced oesophagitis or ulceration of the oesophagus can cause increased FDG accumulation and persistently raised SUVs, which leads to false-positive results on PET/CT and precludes accurate detection of residual cancer.\textsuperscript{83–85}

Oesophagitis generally manifests after the first 2 weeks of treatment and evaluation of treatment response within the first 2 weeks has, therefore, been suggested to be the
least prone to false-positive findings.\textsuperscript{77,80,86,87} In addition, accurate prediction of early response during treatment may allow for early modifications of the treatment protocol in non-responders that suffer from ineffective toxic CRT and unnecessarily delayed surgery.\textsuperscript{88} Indeed, a meta-analysis showed that a 50% reduction in SUV\textsubscript{max} or SUV\textsubscript{mean} between pre-treatment PET and a PET performed within the first 2 weeks of neoadjuvant CRT was the optimal condition for response prediction in oesophageal cancer.\textsuperscript{89} However, this meta-analysis and another recent meta-analysis on the value of PET(CT) for response evaluation found pooled sensitivities and specificities of 67–70% only, and recommended that PET(CT) should not yet be used in routine clinical practice to guide neoadjuvant therapy decisions.\textsuperscript{89,90}

Although a clinical complete response based on PET/CT may well reflect a true pathological complete response (Fig 6a–c), it is important to note that this finding should be interpreted with caution when considering omission of surgical resection. A subsequent loco-regional recurrence rate as high as 42% has been reported in PET-based clinical complete responders that did not undergo oesophagectomy.\textsuperscript{91} In the largest series published to date ($n=284$), the specificity of combined PET and endoscopic biopsy-based clinical complete response for true pathological complete response was very low (30%).\textsuperscript{21,82,92} Therefore, until more accurate tools for response evaluation have been developed, surgery-eligible oesophageal cancer patients should be encouraged to undergo oesophagectomy following CRT despite achieving a clinical complete response based on PET/CT and endoscopic biopsies.\textsuperscript{21,82,92}

**MRI**

DWI may provide complementary information regarding tumour regression in response to CRT (Figs 6d–f and 7), besides measurements of dimensional changes in tumour diameter or volume on anatomical MRI. Encouraging pilot

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**Figure 3** A 56-year-old man was diagnosed with a biopsy-proven cT2N1M0 adenocarcinoma of the distal third of the oesophagus. (a) Diagnostic CT revealed two suspected lymph nodes in the lesser omentum with maximum diameters of 16 mm and 14 mm, respectively (arrows), and (b) a transverse PET image confirmed pathological FDG-uptake of the two nodes. (c) High-resolution T2-weighted MRI was similarly capable of identifying the two enlarged lymph nodes (arrows), and both these nodes in (d) clearly showed restricted diffusivity on the corresponding DW image ($b=800$ s/mm\textsuperscript{2}). After neoadjuvant chemoradiotherapy followed by oesophagectomy, histopathology confirmed two lymph nodes in the lesser omentum with residual disease.
studies using DWI in rectal cancer have reported sensitivities and specificities of up to 100% for the prediction of pathological complete response early during neoadjuvant CRT.\(^93\)

Initial experience with DWI in oesophageal cancer has been published in the last few years and more pilot studies are currently ongoing.\(^94-97\) The difference between pre-treatment and post-treatment median ADC values (or $\Delta$ADC) was inversely correlated with the histopathological tumour regression grade and may, therefore, be helpful to discriminate responders from non-responders.\(^96\) In another study in 27 patients with clinical T4 oesophageal carcinomas undergoing definitive CRT, the difference between pre-treatment ADC and ADC early during treatment had a predictive value of 100% for responders (suboptimally defined by RECIST criteria\(^98\) using CT and oesophagography).\(^97\)

However, before clinical consequences may be justified, further studies are required to optimize MRI protocols, timing of scans, and confirm the preliminary clinical evidence in larger populations. In a recently embarked study at our institution we aim to determine the complementary

Figure 4 A 72-year-old man was referred to our institution with a biopsy-proven “cT3N1M0” adenocarcinoma of the gastro-oesophageal junction. In addition to prior endoscopy, EUS, and diagnostic CT (a) at the referring centre, we performed a staging PET/CT (b) that revealed an oval-shaped focus of increased FDG-uptake in the right adrenal gland (arrow). CT-guided biopsy of the lesion demonstrated a metastatic poorly differentiated adenocarcinoma matching the known primary oesophageal tumour. In retrospect, with advancing knowledge from the PET/CT examination the lesion in the adrenal gland may already have been detected on the diagnostic CT (a) from the referring centre. Although this patient was referred for treatment with curative intent, the proven M1 disease precluded surgical resection and PET/CT changed the treatment plan to palliative chemotherapy. In addition, an enlarged lymph node just above the coeliac trunk was detected at CT (a; arrowhead) and showed intense FDG-uptake on PET/CT (b; arrowhead). In the most recent (seventh) edition of the TNM-classification, however, coeliac node involvement is no longer considered distant metastatic (M1) disease and forms no contraindication to treatment with curative intent.

Figure 5 A 66-year-old man presented with a cT3N2Mx adenocarcinoma of the gastro-oesophageal junction. (a) PET/CT demonstrated the FDG-avid junction tumour (arrow) along with previously unexpected distant metastatic spread to the spine (arrowheads). (b) In addition to the unexpected osseous metastases (middle arrow) two locations suspected of skeletal muscle metastases were identified by PET/CT (lateral arrow; right subscapular muscle and left pectoral muscle, respectively). After histological confirmation of the (osseous) metastases palliative chemotherapy was initiated.
value of DWI in addition to PET/CT for response evaluation by performing both optimized MRI and PET/CT before, during, and after neoadjuvant CRT for oesophageal cancer.\textsuperscript{99} In future efforts additional attention should be paid to the assessment of metastatic lymph nodes, because a complete local tumour response may be accompanied by residual malignancy in the locoregional lymph nodes in approximately 10% of local pathological complete responders (e.g., ypT0N1).\textsuperscript{100}

**Radiation treatment planning**

**PET/CT**

In order to maximize the chances of acquiring locoregional tumour control by means of radiation therapy, accurate delineation of tumour volume is crucial to optimize the dose to the target and simultaneously minimize the volume of irradiated surrounding tissues.\textsuperscript{101} CT images (together with available information from EUS) are most commonly used for this purpose in oesophageal cancer, but unfortunately CT is not able to precisely demonstrate the proximal and distal margins of oesophageal tumours in many cases. Indeed, in a recent study the assumed oesophageal tumour length based on CT was found not to reflect the histopathological tumour extent.\textsuperscript{102} In contrast, PET/CT enables delineation of the biologically active tumour volume, and its depiction of oesophageal tumours has been shown to correlate well with histopathological extent.\textsuperscript{103} PET/CT, therefore, has great potential to provide valuable information for radiation treatment planning.\textsuperscript{18,104}

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**Figure 6** A 53-year-old woman diagnosed with a biopsy-proven cT4aN2M0 squamous cell carcinoma of the mid-oesophagus. EUS showed ingrowth of the tumour into the adjacent right pleura and suspected lymph nodes in the mediastinum and at the level of the coeliac trunk (confirmed by FDG-avidity on PET/CT) and aortopulmonary window (non-FDG-avid). PET/CT and MRI examinations were performed before (a,d), during (b,e), and after (c,f) neoadjuvant chemoradiotherapy to assess response to treatment. (a) Sagittal fusion PET/CT image before the start of neoadjuvant chemoradiotherapy shows a mid-oesophageal FDG-avid tumour with a length of 9.2 cm, which in (b) showed some tumour shrinkage to 8.4 cm on a corresponding PET/CT image obtained after the first 10 days of neoadjuvant treatment, and in (c) a complete metabolic regression in both primary tumour and previously suspected lymph nodes (not shown) at 55 days after completion of chemoradiotherapy. (d) Corresponding pre-treatment fusion T2-weighted/DWI sagittal image (b = 800 s/mm\(^2\)) shows the tumour with homogeneous restricted diffusivity and a length of 9.3 cm, with an early response in (e) after 10 days of chemoradiotherapy (length 7.8 cm) and a complete regression with normalized diffusivity in (f) at 55 days post-chemoradiotherapy, similar to PET/CT. Histology after subsequent surgical resection confirmed a ypT0N0 pathological complete response (Mandard 1).
The use of PET/CT for tumour delineation results in both decreases and increases of the target volume when compared to CT and EUS in 10–63% of patients (Fig 8a–c). These changes may ultimately allow for improvement in coverage of the true malignant volume and for relevant additional sparing of normal surrounding tissues. However, there are no studies demonstrating the impact of such modifications by PET/CT in terms of improved loco-regional control or survival. One study reported that the addition of FDG-PET to CT-based planning decreased both inter- and intra-observer variability, but this finding could not be confirmed in another study. Therefore, standard implementation of PET/CT into the tumour delineation process for radiation treatment planning remains subject of debate and requires further clinical validation.

**MRI**

The usefulness of MRI in the radiation treatment planning process has already been established for...
malignancies of the head and neck, prostate, rectum, and cervix. Although current available evidence for radiation treatment planning using MRI in oesophageal cancer is scarce, recent technical improvements of both anatomical and functional MRI may allow for further target definition improvement using MRI (Fig 8d–f).

DWI scans can be fused with T2-weighted MRI or CT images in radiation treatment planning systems to delineate the target volume. Promisingly, in a recent study with 42 oesophageal squamous cell carcinoma patients the cranio-caudal tumour length was most precisely delineated according to DWI (followed by T2-weighted MRI and conventional CT) when compared to the postoperative pathological lesion length. However, more studies are required to clarify the potential role of high-resolution MRI including DWI for this purpose before any firm recommendations can be made. In addition, future clinical studies in oesophageal cancer should aim to determine the potential value of the recently developed MRI-linac system that integrates an MRI system with a radiotherapy accelerator, allowing for simultaneous irradiation and real-time MRI.

Recurrent disease

PET/CT

PET/CT allows for accurate detection of recurrent disease after initial treatment with curative intent. Sensitivities of 93–100%, specificities of 67–88%, and accuracies of 84–92% have been reported for the detection of recurrent oesophageal cancer. PET after surgical resection was of additional value to conventional surveillance methods in 27% of patients in one study. In this way, PET/CT may change clinical decision-making in palliative management and ultimately improve patient survival.

In particular, the sensitivity for the detection of loco-regional recurrence is higher with PET than with CT, because postoperative changes and scarring at CT is often difficult to differentiate from recurrent disease (Fig 9). However, the specificity of CT was found to be higher than that of PET as false-positive FDG accumulation in the gastric tube and thoracic lymph nodes may also occur. In other studies, integrated PET/CT was more accurate than CT alone for detection of nodal recurrence and distant spread.
metastases.\textsuperscript{120,125} Therefore, integrated PET/CT appears to be the most accurate technique for the detection of recurrent oesophageal cancer (Figs 9–10).

\textbf{MRI}

The current available literature on the value of MRI for the detection of recurrent oesophageal cancer is limited.\textsuperscript{126} A more recent study implemented DWI in the MRI protocol and found that recurrent lymph nodes show evident diffusion restriction with an accuracy of 81\%.\textsuperscript{127} However, due to the lack of evidence and the introduction of integrated PET/CT with its

\textbf{Figure 9} A 60-year-old man with a history of neoadjuvant chemoradiotherapy followed by transthoracic oesophagectomy for a ypT2N1M0 adenocarcinoma of the distal third of the oesophagus presented 6 months after surgery with dysphagia and a noted swelling in the cervical region. (a) Conventional CT was not able to clearly distinguish between normal postoperative changes or local recurrent disease at the cranial part of the gastric tube (arrow), but PET/CT showed intense FDG-uptake at the local site, highly suspected of local recurrence (arrow). Arrowheads in (a) and (b) indicate a surgical staple along the gastric tube. (c) CT revealed a large lymphadenopathy (arrow) in the left lower cervical region (level V), which in (d) showed high FDG-uptake on PET images. Cytological examination of a fine-needle aspiration of this node revealed recurrent metastatic adenocarcinoma.

\textbf{Figure 10} An example of a case demonstrating the incremental value of integrated PET/CT over standalone for the detection of distant recurrent disease after initial treatment with curative intent for oesophageal cancer. A 71-year-old woman with a history of a ypT3N2 microscopically irradically resected (R1) adenocarcinoma of the gastro-oesophageal junction and a pathological non-response to preoperative chemotherapy (Mandard 5) presented 18 months after surgery with pain in the right anterior chest wall. (a) Initially, conventional CT was performed that could not provide any detection of recurrent disease or another explanation for the symptoms. (b) Subsequently, PET/CT was performed revealing a pathologically increased FDG-uptake of the fourth right rib, fitting metastatic disease that could explain patient’s complaints. Note: the stretched appearance of the costal FDG-uptake typically represents malignant disease rather than healing of a (recent or old) fracture.
excellent diagnostic accuracy for the detection of both loco-regional and distant recurrent disease, MRI seems to play no important role for this purpose in current or future practice.

Conclusion

PET/CT has emerged as a useful adjunct to conventional staging methods in oesophageal cancer and is of particular importance for the detection of unexpected distant metastases and recurrent disease. Current evidence for MRI is limited, but a future complementary role is expected in staging and radiation treatment planning based on first trials. The clinical role of PET/CT and MRI in assessing response to treatment remains uncertain and will continue to evolve with ongoing research and more widespread application of these techniques.

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