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Multidisciplinary Delphi consensus-based recommendations on the use of image-guided radiotherapy for upper gastrointestinal tumours: an AIRO–AITRO–AIFM study

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Abstract

Objectives: Upper gastrointestinal (GI) malignancies represent one of the most challenging scenarios for image-guided radiotherapy (IGRT). Despite technological advances, clinical practice remains heterogeneous among centres. This national, multidisciplinary Delphi consensus, jointly promoted by AIRO, AITRO, and AIFM, aimed to harmonise IGRT implementation in upper-GI radiotherapy (RT) and define shared recommendations.

Methods: A two-round modified Delphi process was conducted between May and August 2025 among 20 Italian experts (radiation oncologists, medical physicists, and radiation therapists) with ≥10 years of experience in upper-GI RT. 16 key questions were organised into thematic areas. Agreement was rated using a five-point Likert scale; consensus was predefined as ≥75 %. Following Round 1, the

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steering committee reviewed closed-ended responses, open-ended answers, and panel feedback, and formulated 13 statements for Round 2.
Results: All experts completed both rounds, and consensus was achieved for all final statements. Key sources of geometric uncertainty were identified as respiratory motion, rotational setup errors, and anatomical variability. The panel supported the use of dedicated immobilisation systems and advanced imaging tools, including auto-contouring for OAR delineation. Respiratory control strategies were considered the most effective approaches, while fiducial markers were recognised as valuable tools for tumour tracking in selected cases. Daily cone-beam CT was identified as the minimum standard for treatment verification.
Conclusions: This national, multidisciplinary consensus provides a structured framework for defining IGRT standards in upper-GI malignancies. The high agreement levels confirm a shared vision and practice, supporting harmonised and precision-oriented RT delivery.

Keywords: image-guided radiotherapy (IGRT); upper gastrointestinal cancers; Delphi consensus; motion management; IGRT protocols; AIRO-AITRO-AIFM

Introduction

Image-guided radiotherapy (IGRT) is an integral component of modern radiation oncology, enabling precise target localization, motion management, and adaptive treatment delivery. In the context of upper gastrointestinal (GI) malignancies – such as liver, pancreas, and gastric cancers – the clinical implementation of IGRT is particularly challenging due to the complex interplay of respiratory and peristaltic motion, organ deformation, and varying filling of abdominal structures [1, 2].

Despite technological advances with respect to on-board imaging, motion control, and treatment planning, significant heterogeneity in clinical practice still exists amongst radiotherapy (RT) centres. To address this variability, the Italian Association of Radiotherapy and Clinical Oncology – Gastrointestinal Study Group (AIRO-GI) recently conducted a nationwide survey to describe current IGRT practices for upper-GI malignancies in Italian RT centres. The questionnaire included 15 general and 45 site-specific questions for liver, pancreas, and gastroesophageal junction (GEJ), gathering responses from 44 Italian centers. The results of this survey revealed that although advanced technologies, such as four-dimensional cone-beam computed tomography (4D-CBCT) (81 %) and six degrees of freedom (6-DoF) couches (79 %), are widely available, their routine clinical implementation remains limited. The survey highlighted marked heterogeneity in fasting protocols, immobilization methods, and respiratory motion management strategies. Notably, substantial variability was observed in the methodological approaches used for margin delineation, with centres reporting the adoption of different national and international guidelines (including Italian Association of Radiotherapy and Clinical Oncology [AIRO], European Society for Radiotherapy and Oncology-Advisory Committee in Radiation Oncology Practice [ESTRO-ACROP], American Society for Radiation Oncology [ASTRO], Radiation Therapy Oncology Group [RTOG], and National Comprehensive Cancer Network [NCCN]), as well as heterogeneous in-house protocols [3]. Overall, these findings demonstrate substantial variability in immobilization methods, motion management strategies, imaging integration, and correction protocols, underscoring the need for structured, consensus-based national guidelines.

While several recommendations and guidelines addressing specific aspects of RT are available, there is currently a lack of comprehensive guidance covering the entire IGRT workflow in upper-GI malignancies. Existing documents tend to focus on individual components (e.g., motion management, target delineation, or image guidance) rather than providing an integrated, practice-oriented framework. This fragmentation likely contributes to the heterogeneity observed across centres, as also confirmed by recent national survey data [3]. Acknowledging the need for harmonisation, AIRO, in collaboration with the Italian Association of Radiation Therapy and Medical Physics Technologists (AITRO) and the Italian Association of Medical Physicists (AIFM), promoted a Delphi consensus project focused on the use of IGRT in upper-GI malignancies to harmonise clinical workflows, provide practical guidance, and define shared recommendations immediately applicable in real-world settings. The initiative aimed to identify areas of agreement/disagreement amongst radiation oncologists, medical physicists, and radiation therapists, and to define minimum technical requirements and recommended clinical practices for safe and effective IGRT implementation.

This study reports and critically discusses the results of a Delphi consensus process conducted by a multidisciplinary panel of experts, which formulated recommendations to optimise the RT management of upper-GI malignancies, with particular relevance for high-precision treatments such as stereotactic body radiotherapy (SBRT). These recommendations address comprehensive technical aspects of RT practice that are not covered by existing clinical guidelines.

Materials and methods

Study design

A two-round modified Delphi process was conducted between May and August 2025 to achieve multidisciplinary consensus on the use of IGRT for upper-GI malignancies. The aim was to harmonise national clinical practice and define minimum technical requirements for IGRT implementation, particularly in the setting of SBRT. The Delphi method was chosen for its structured and iterative approach, allowing experts to express and refine their views anonymously across successive rounds.

The study protocol was reviewed and approved by the Scientific Committee and Board of the Italian Association of Radiation Oncology (AIRO), Italian Association of Radiation Therapy and Medical Physics Technologists (AITRO), and Italian Association of Medical Physicists (AIFM). The formal endorsement number was issued by AIRO (Endorsement AIRO No. 19/2025).

Participants

The selection of experts followed predefined eligibility criteria based on professional experience, disciplinary background, and acknowledged expertise, in accordance with international guidance for the design and reporting of Delphi studies [4, 5]. Panel size was determined pragmatically in accordance with Delphi methodology, which relies on purposive expert sampling and is guided by study scope, complexity, and feasibility [6, 7].

The project's scientific committee supervised the recruitment process, ensuring balance and diversity in professional roles, areas of specialization, and geographic representation. In total, 20 professionals were invited to participate after identification through institutional referrals and scientific societies.

Eligibility criteria included at least 10 years in the relevant field and active engagement in research, clinical practice, or education in upper-GI malignancies. Experts were identified through institutional referrals and scientific societies to ensure multidisciplinary representation and recognised expertise in the field.

All participants contributed on a voluntary basis, confirming the absence of any potential conflicts of interest.

A summary of panel composition by professional roles and geographic distribution across Northern, Central, and Southern Italy (including the islands) is reported in Table 1.

Measurement and procedure

A comprehensive review of the available literature was performed to identify current evidence and clinical practices related to IGRT in upper-GI malignancies, with particular focus on SBRT. The scope and search strategy were defined by the scientific committee. The literature review was conducted independently by three members of the steering committee, who subsequently shared and compared their findings. Relevant publications were identified through searches of major international databases (PubMed/MEDLINE and Scopus), and reference lists of selected articles were also screened. The search was conducted between February and March 2025.

Following this process, the steering committee convened in an online meeting to discuss and synthesise the findings. Evidence synthesis enabled identification of 16 key questions (KQ. Specifically, the domains were defined to reflect the key areas addressed in the literature, including: sources of geometric uncertainty (setup, rotations, organ motion); immobilization systems and patient preparation; respiratory motion management; planning target volume (PTV) margin definition; tumour tracking and fiducials; IGRT protocols and frequency; target and organs at risk (OARs) delineation; planning objectives, dose conformity, and adaptive workflows. These elements are consistently highlighted in current literature and international recommendations as key determinants of accuracy and reproducibility in upper-GI malignancies, and therefore provided the conceptual framework for the development of the KQ [1, 2, 8–15].

Each question was formulated as a declarative statement and rated using a five-point Likert scale (1=strongly disagree, 5=strongly agree). Additional open-ended fields were provided for free comments, rationale, and bibliographic citations.

Table 1: Panel composition by specialty and geographic distribution.

Characteristics		n (%)
Professional roles	Radiation Oncologists	9 (45 %)
	Medical Physicists	6 (30 %)
	Radiation Therapists	5 (25 %)
Geographic distribution	Northern Italy	9 (45 %)
	Central Italy	8 (40 %)
	Southern Italy and Islands	3 (15 %)

The first Delphi round was launched in May 2025 and remained open until 20 June 2025 via a secure Google Forms link. Participants received a detailed invitation letter outlining the project goals, instructions, and confidentiality statement.

For each item, consensus was defined as ≥75 % agreement (sum of "agree" + "strongly agree"). Items reaching 60–74 % were classified as moderate consensus, and those < 60 % as no consensus. Closed-ended responses were summarized as frequencies and percentages. Open comments were independently reviewed by two investigators to extract recurring themes, technical suggestions, and references cited by participants. The steering committee subsequently reviewed these analyses both individually and collectively.

16 KQ were evaluated in the first round. The steering committee systematically evaluated the closed-ended responses, the open-ended answers, and the qualitative feedback provided by the panel after the first round. Through an integrated assessment of these elements, discrepancies were discussed and resolved, and the findings were synthesised into a shared interpretation classifying each KQ according to its consensus status and determining whether it should be retained (clear consensus reached), reformulated (borderline or mixed results), or expanded (free-text comments revealed sub-topics). Consequently, 13 definitive KQ were prepared for the second round, maintaining alignment with the original thematic domains.

The second and final round was launched on August 1, 2025, and closed on August 25, 2025. All first-round participants were re-invited by e-mail. Participants were again asked to rate their agreement on a five-point Likert scale. The objective of this round was to re-evaluate areas of uncertainty and consolidate consensus across disciplines. An overview of the Delphi consensus process is provided in Figure 1.

Statistical analysis

Quantitative data were analysed using Microsoft Excel 365. Results were expressed as frequency distributions and agreement percentages for each statement. Consensus categories were defined as: strong consensus: ≥75 % agreement; moderate consensus: 60–74 %; no consensus: <60 %. Bibliographic references cited by experts were catalogued and cross-checked to support the discussion section.

Results

The final Delphi panel included 20 experts who completed both the first and second Delphi rounds. Consensus was achieved on all the statements following the two voting sessions.

Round 1

A total of 20 experts completed the first-round questionnaire, representing a balanced distribution amongst radiation oncologists, medical physicists, and radiation therapists.

All items were addressed by 100 % of participants. The first round comprised 16 KQ covering clinical and technical domains related to IGRT for upper-GI malignancies (Table 2). Consensus was reached on 3 out of 16 KQ.

All statements related to sources of geometric uncertainty (KQ1) reached the predefined consensus threshold and were retained without modification. The panel consistently recognised the following as clinically relevant sources of treatment uncertainty: inter-fraction patient positioning (agreement 80 %), patient rotational errors (e.g., pitch and roll) (agreement 95 %), uncontrolled respiratory motion, in

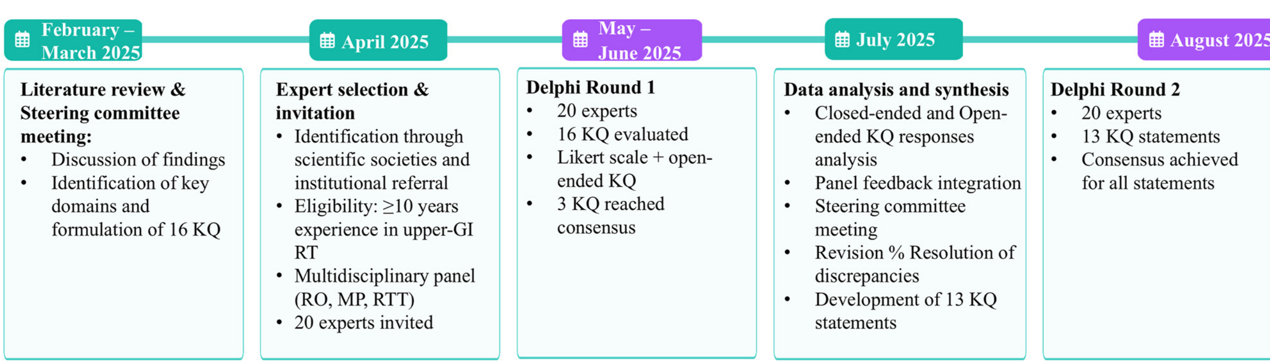

Figure 1: Overview of the Delphi consensus process. Note: KQ, key questions; GI, gastrointestinal; RT, radiotherapy; RO, radiation oncologist; MP, medical physicist; RTT, radiation therapy technologist.

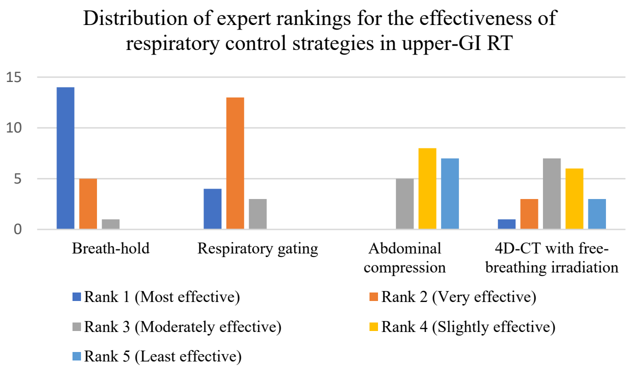

Figure 2: Distribution of expert rankings for the effectiveness of respiratory control strategies in upper-GI RT. Note: GI, gastrointestinal; RT, radiotherapy.

the absence of breath-hold (BH) or 4D-CT (agreement 95 %), spontaneous internal organ motion (agreement 85 %), and variations in gastric filling (agreement 100 %).

Consensus was also achieved for the statement "The integration of auto-contouring software into the workflow is useful for defining organs at risk" (KQ11, agreement 75 %). Similarly, the panel agreed that "a reduction of the Clinical Target Volume (CTV) – Planning Target Volume (PTV) margins is possible in SBRT treatments compared to conventional RT" (KQ13, agreement 90 %). These KQ were therefore not submitted for further evaluation in Round 2.

Responses related to Immobilization and patient setup (KQ2–3) showed partial agreement, with additional insights emerging from open-ended comments; these inputs were synthesised by the steering committee to generate a single reformulated statement for Round 2. The statement concerning the use of intravenous contrast media (IV-CM) during CT imaging (KQ4) reached consensus (agreement 80 %); however, it was reformulated based on panel feedback to improve clarity and better reflect clinical practice.

Responses addressing Motion management (KQ5–6), tumour tracking and use of fiducials (KQ7–8), Target and OARs definition (KQ9–10), Planning objectives (KQ12), and Image guidance, motion verification and Institutional standardisation (KQ14–16) did not reach full consensus. In these areas, only partial consensus was achieved. The steering committee evaluated the closed-ended responses together with the open-ended answers and the qualitative feedback provided by the panel, which had been explicitly encouraged to comment on and refine the proposed statements. Based on this integrated assessment, discrepancies were examined and resolved, resulting in the formulation of 13 revised statements for Round 2.

Table 2: Summary of round 2 Delphi consensus statements on the use of IGRT for upper-GI malignancies, including expert agreement rates and corresponding consensus levels.

KQ	Statement	Agreement n/20 (%)
1	Immobilization using vacuum-bag, body-fix, or wing-board is generally sufficient, with optimal results when combined with surface-guided SGRT	19/20 (95 %)
2	The use of IV CM in the planning CT scan should be helpful to ensure correct delineation of the OARs and target volumes of the RT treatment	20/20 (100 %)
3	Among the available respiratory control strategies for accurate treatment of the upper abdomen, BH and respiratory gating are generally considered the most effective. Abdominal compression and 4D-CT with free-breathing irradiation may be used in selected cases, depending on patient compliance, institutional protocols, and available technology	18/20 (90 %)
4	Please rank the following respiratory control strategies from most to least effective in your clinical experience: (Rank 1=most effective, rank 5=least effective). BH, respiratory gating, 4D-CT with free breathing irradiation, abdominal compression	See Table 3 and Figure 2
5	An expansion margin of 3–5 mm for the PTV may be considered in the presence of adequate organ motion management strategies and intra-fraction verification, and should be tailored according to the specific technology employed	20/20 (100 %)
6	In CT-based upper abdominal RT, fiducial marker placement, although not a minimum requirement, remains the most effective method for accurate tumour tracking	16/20 (80 %)
7	Key limitations in defining the target and OARs include respiratory and peristaltic motion, poor soft tissue contrast in CT imaging, and a lack of standardized delineation protocols. These issues may be improved through the integration of MRI and/or PET imaging, motion management, fiducials, and AI-assisted contouring	19/20 (95 %)
8	In an RT treatment of the upper abdomen, priority OARs to delineate include the duodenum, liver, kidneys (especially the contralateral one), stomach, spinal cord, and small and large bowel. Additional structures such as the pancreas (if not the target), esophagus, heart, lungs, and major vessels (e.g., aorta, portal vein) should be considered based on tumor location, proximity, and technique used (e.g., SBRT vs. conventional RT)	20/20 (100 %)

Table 2: (continued)

KQ	Statement	Agreement n/20 (%)
9	In the planning phase, the primary objective is to achieve optimal target volume coverage – with dose conformity and steep dose fall-off beyond the PTV – while strictly respecting OAR constraints. This requires careful margin selection, robust motion management, use of advanced imaging fusion, implementation of daily IGRT, and quality assurance procedures. Adaptive RT and standardized patient preparation can further enhance treatment accuracy and safety	19/20 (95 %)
10	Daily IGRT with CBCT, including BH or 4D-CBCT when BH or respiratory-gated techniques are employed, represents the minimum standard for verifying setup and internal motion in abdominal treatments	20/20 (100 %)
11	CBCT-based IGRT, including BH or 4D-CBCT when BH or respiratory-gated techniques are employed, is generally considered the minimum standard for verifying patient setup and internal organ motion in upper abdominal RT. However, alternative imaging modalities – such as MRI-guided RT, ultrasound, or planar imaging – may be considered valid and applicable in specific clinical contexts, provided they meet minimum requirements for accuracy, reproducibility, and motion assessment	16/20 (80 %)
12	In daily IGRT for upper abdominal RT, it is considered optimal to adopt soft tissue matching, bone matching, or a combination of both, with manual correction when needed. Residual motion should be assessed when respiratory control systems are used	20/20 (100 %)
13	Each center should define an internal protocol that specifies acceptable intervals for correcting both rotational and translational setup errors, to ensure consistent and safe treatment delivery	20/20 (100 %)

SGRT, Surface-Guided Radiotherapy; IGRT, image-guided radiotherapy; GI, gastrointestinal; SBRT, stereotactic body radiotherapy; RT, radiotherapy; CT, computed tomography; OARs, organs at risk; IV CM, intravenous contrast medium; BH, breath-hold; PTV, planning target volume; MRI, magnetic resonance imaging; PET, positron emission tomography; CBCT, cone-beam computed tomography.

A comprehensive overview of all Round 1 KQ and response distributions is provided in Appendix A.

Round 2

13 statements were formulated and submitted to the expert panel for the second and final Delphi round. All 20 experts who participated in the first round completed the second-round questionnaire. No statement failed to reach consensus, confirming convergence across all domains evaluated (Table 2).

Discussion

To the best of our knowledge, this Delphi consensus represents the first multidisciplinary effort in Italy to define a shared framework for IGRT in upper-GI malignancies, integrating the perspectives of radiation oncologists, medical physicists, and radiation therapists. The high level of agreement observed across most statements reflects a well-established and harmonised understanding of the key technical requirements and clinical priorities in this complex and evolving field. The collected consensus statements address critical aspects of upper-GI malignancies management, particularly scenarios requiring high geometric accuracy and motion control, such as SBRT.

Sources of geometric uncertainty

The intrinsic complexity of the upper-GI region, characterised by target mobility and organ deformation, can significantly compromise treatment delivery [1, 16–18].

The Delphi panel confirmed that geometric uncertainty in upper-GI RT is intrinsically multifactorial, arising from the combination of patient setup variation, rotational misalignments, respiratory motion, and spontaneous internal organ motion, as well as day-to-day variations in gastric and bowel filling. These findings are consistent with contemporary IGRT recommendations that highlight the need to account for both inter- and intrafraction uncertainties and organ motion in the upper abdomen [1].

From a practical standpoint, the experts identified uncontrolled respiratory motion and rotational setup errors as major contributors to residual inaccuracies during treatment delivery. This view is supported by evidence demonstrating that upper-GI targets can undergo complex three-dimensional motion and non-rigid deformation, where centre-of-mass shifts and shape changes can be substantial [16–18]. In this scenario, geometric uncertainty extends beyond simple translational displacement to include deformation and variation in the spatial relationships between target and surrounding organs at risk (OARs) [19, 20].

Table 3: Distribution of expert rankings for the effectiveness of respiratory control strategies in upper-GI RT.

Respiratory control strategy	Rank 1 + 2 (most effective + very effective)	Rank 3 (moderately effective)	Rank 4 + 5 (slightly effective + least effective)	Total answers	Consensus (%) (rank 1 + 2)
Breath-hold	19	1	0	20	95 %
Respiratory gating	17	3	0	20	85 %
Abdominal compression	0	5	15	20	0 % (100 % disagreement)
4D-CT with free-breathing irradiation	4	7	9	20	20 %

GI, gastrointestinal; RT, radiotherapy; CT, computed tomography.

Immobilization and patient setup

Experts agreed that immobilization using vacuum-bag, Body-fix, or wing-board systems ensures adequate coverage for upper-GI treatments, particularly when integrated with SGRT for setup verification and intrafraction monitoring [2, 8, 21]. In line with these findings, the literature supports the use of SGRT as a valuable adjunct, improving setup accuracy and enabling continuous positioning checks during delivery [8, 21].

Conversely, the panel expressed a cautious view on abdominal compression. Recent systematic reviews and literature have demonstrated heterogeneous results in motion reduction and patient tolerance [22, 23]. The panel, therefore, favoured immobilization strategies that ensure comfort and reproducibility.

CT-imaging and target delineation

Visualization and target delineation of upper-GI targets remains challenging due to limited soft-tissue contrast, frequent gas-related artifacts in the stomach and bowel, and motion-induced blurring during CT acquisitions [1].

Full consensus was achieved regarding the usefulness of contrast-enhanced planning CT in improving visualization of both target and OARs. This finding reflects the literature's use of IV-CM to support accurate anatomical delineation and improve the identification of adjacent critical structures [2, 9].

Despite the advantages of contrast-enhanced CT, this is not always available in RT departments as reflected in the national survey, which reported its use in 57.5 % of liver cases and 52.3 % of pancreatic cases, while remaining less frequently adopted for gastroesophageal junction tumours (20.9 %) [3].

Motion management

The choice of respiratory motion–management strategy in upper-GI RT begins with the simulation CT, in which the patient's ability to perform and maintain a given technique is assessed. In accordance with the ESTRO-ACROP recommendations, the Delphi panel expressed a preference for respiratory control, with BH as the first option whenever feasible, and respiratory gating as an appropriate alternative when a stable and reproducible breathing pattern can be achieved. These techniques are considered the most effective approaches for reducing respiratory-induced organ motion and creating conditions for CTV–PTV margin reduction in upper-GI treatments [2, 10–12, 22–27].

Conversely, strategies such as abdominal compression and free-breathing 4D-CT–based planning were regarded by the panel as less preferred options, to be reserved for patients who cannot reliably perform BH or gating. This is consistent with recent systematic reviews and ESTRO guidance, which highlight the heterogeneous and sometimes limited motion reduction achieved with compression and the potential impact on patient comfort [10, 22, 28].

Importantly, the panel acknowledged that no motion-management technique can eliminate organ motion uncertainties. The systematic review conducted in 2025 by Farrugia et al. on upper-GI RT in BH conditions clearly showed that, although BH substantially improves tumour position reproducibility compared with free breathing, a residual variability in target position persists within fractions [25].

The panel agreed that residual uncertainties associated with the chosen motion-management approach must always be considered when defining CTV–PTV margins. In practice, this implies that motion mitigation and margin design cannot be considered as separate steps: BH and gating can justify smaller margins by reducing organ motion, but the remaining intrafraction variability must still be incorporated into margin selection to maintain robust target coverage [12, 27, 29–31].

Target and OARs definition

A high level of consensus was achieved regarding the main limitations affecting the definition of targets and organs at risk in upper-GI RT. Experts identified respiratory and peristaltic motion, the limited soft-tissue contrast of CT imaging, and heterogeneity in delineation protocols as relevant contributors to contouring variability.

To mitigate visualization challenges, the panel endorsed the use of multimodal imaging workflows – particularly Magnetic Resonance Imaging (MRI) and/or Positron Emission Tomography (PET) fusion to improve visualization of tumour boundaries and reduce inter-observer variability [2, 28, 32, 33]. These findings are consistent with the results of the national survey, in which 95 % of centres reported routinely performing diagnostic image fusion with simulation CT, indicating that this approach is already a well-established standard in clinical practice [3].

The literature supports the integration of multimodal imaging to improve target and OARs delineation. MRI offers superior soft-tissue contrast compared with conventional planning CT for tumour and OAR delineation, while CT-PET may provide complementary functional information for identifying metabolically active disease sub-volumes.

Accurate image fusion requires careful workflow standardisation. Mismatches between imaging modalities (arising from geometric distortion, different immobilization systems, non-coherent patient positioning or respiratory phase) can introduce co-registration errors that can negatively affect contour accuracy [1, 13, 28, 32, 33].

In addition, experts acknowledged the emerging role of AI-assisted contouring tools in improving delineation consistency and efficiency, provided that contours are validated by experienced clinicians, especially in complex districts such as the upper abdomen.

Full consensus was reached regarding OARs that should be systematically delineated in upper-GI RT. Duodenum, stomach, liver, kidneys (particularly the contralateral), spinal cord, and small and large bowel were identified as priority structures for dose limitation. Additional OARs include: pancreas (when not the target volume), oesophagus, heart, lungs, and major vessels, which should be contoured when clinically relevant due to tumour proximity or steep dose gradients, particularly in SBRT.

Finally, according to the available literature, the use of planning risk volumes (PRVs) for mobile OARs may help improve treatment robustness by accounting for inter- and intra-fractional variations in organ position, motion, and deformation, which may still affect local dose distribution despite optimal motion-management strategies [14, 15].

Planning objectives

Full consensus was achieved in the second round regarding the fundamental objectives of the planning phase: in the planning phase, the primary objective is to achieve optimal target volume coverage, with dose conformity and steep dose fall-off beyond the PTV, while strictly respecting organ-at-risk (OAR) constraints. This requires careful margin selection, robust motion management, use of advanced imaging fusion, implementation of daily IGRT, and quality assurance procedures. Adaptive RT and standardized patient preparation can further enhance treatment accuracy and safety."

In line with this statement, margin design must follow established RT principles, where systematic and random geometric uncertainties are explicitly quantified and incorporated into the CTV–PTV expansion, as recommended by the literature [14, 15].

Routine daily volumetric IGRT, together with formal quality assurance (QA) procedures, was considered essential for ensuring that the planned dose is consistently delivered to the intended anatomy. In this regard, institutional QA programs aligned with AAPM TG-179 are recommended to guarantee geometric accuracy, imaging performance, and reproducibility over the full treatment course in CT-based IGRT workflows [13].

Overall, these recommendations ensure that dosimetric objectives remain robust despite the anatomical challenges.

Image guidance and verification

Unanimous agreement was reached, defining daily cone-beam computed tomography (CBCT) – including BH or 4D-CBCT when BH or respiratory-gated techniques are employed – as the minimum standard for IGRT in upper-GI RT. This finding reinforces the principle that volumetric verification is indispensable for safe treatment delivery in regions characterized by high motion and poor soft-tissue contrast [12, 34]. These results are consistent with the findings of the national survey, which identified daily IGRT as standard practice across the majority of centres for upper-GI RT [3].

However, the panel also recognized that alternative or complementary imaging modalities may be appropriate depending on institutional resources and patient characteristics, provided they meet defined standards of accuracy and reproducibility [12, 30, 35, 36].

In CT-based workflows where soft-tissue contrast remains sub-optimal and target visibility is limited, the panel acknowledged the potential role of fiducial markers. Evidence shows that fiducial markers are an effective solution for direct tumour localization. Marker–tumour distance is the strongest determinant of localization accuracy, and CTV-PTV margins must reflect such distance-dependent residual errors [36–40]. However, their use remains limited in current clinical practice, as highlighted by the national survey, which reported low adoption rates across upper-GI RT (<10 % for liver and <5 % for pancreas and GEJ) [3].

Other surrogate structures that may assist target localization, in accordance with ESTRO-ACROP recommendations, are liver, diaphragm, portions of liver adjacent to the tumour, Lipiodol deposits or metallic stents, or when present, calcifications or surgical clips [12].

Lipiodol or stent matching has shown in literature excellent correlation with CBCT-based position assessment ($r \approx 0.99$), supporting their use [41].

In pancreatic SBRT delivered in controlled breath-hold, PTV-based matching, using vascular structures and adjacent organs as reference, resulted in lower systematic and random errors than GTV-matching, both interfraction and intrafraction, supporting a regional soft-tissue–based verification approach when the tumour itself is poorly visible [42].

Image matching and motion verification

Full consensus was reached on soft-tissue–based registration, as the preferred daily image-matching approach in upper-GI RT, optionally combined with bone alignment and manual correction, as the preferred method for daily verification. Rigid bone matching alone was considered inadequate given the limited reliability of bony anatomy in regions characterized by high-motion and deformation.

Image matching should follow a stepwise and anatomy-driven logic: an initial bone alignment remains useful for correcting translational setup errors; residual rotational misalignments may persist and can be corrected when a 6DoF couch is available. Once setup uncertainties are addressed, soft-tissue matching enables the correction of motion-related geometric discrepancies. In contrast, clinician-guided refinement remains essential to ensure reliable tumour localization in motion-sensitive upper-GI treatments. Attention must be paid to OARs, as motion in the upper abdomen is non-rigid: targets and OARs do not move synchronously and can undergo different deformation patterns and filling variations [1, 12, 19].

In controlled-breathing workflows, image matching is performed in the same respiratory phase used during simulation. When substantial discrepancies between daily image-matching and CT-simulation are observed, despite optimal matching and motion management, treatment adaptation may be required to maintain PTV coverage while respecting OAR constraints.

Institutional standardisation

The Delphi process also highlighted the collective commitment to procedural harmonization. All participants agreed that each centre should define internal protocols specifying acceptable thresholds for translational and rotational corrections, ensuring a uniform approach to treatment accuracy. This shared recommendation supports a national effort toward standardizing IGRT workflows, aligning with the broader goals of AIRO, AITRO, and AIFM to harmonize clinical practice across Italian RT centers.

Strengths and limitations

This national Delphi consensus is specifically dedicated to image guidance and motion management in upper-GI RT in Italy, with particular focus on SBRT. The main strength of this study lies in the multidisciplinary composition of the expert panel, including radiation oncologists, medical physicists, and radiation therapists from multiple institutions with extensive clinical experience. This diversity allowed for a comprehensive evaluation of IGRT practices from clinical, medical physics, and technical perspectives.

The high agreement reached across most domains reflects a strongly shared current clinical practice. Importantly, the Delphi was intentionally focused on technologies and workflows that are realistically available across most RT departments, ensuring that the results are immediately applicable.

Nevertheless, the authors acknowledge certain limitations, including the potential for selection bias among experts, as participation was based on predefined expertise criteria and voluntary involvement, the limited panel size (20 experts), the national composition of the panel, and the reliance on self-reported practices rather than prospective clinical validation.

The findings reflect the perspectives of Italian centres with specific resource availability and may not fully represent the technological heterogeneity across Italian centres, particularly in settings with limited access to advanced respiratory motion management strategies, such as breath-hold or 4D-based approaches, across simulation and treatment workflows. However, the consensus was intentionally focused on defining minimum technical requirements for IGRT implementation in upper-GI malignancies, particularly in high-precision treatments such as SBRT, which inherently require adequate technological resources.

Moreover, the consensus process is inherently opinion-driven and may not capture the full breadth of evidence emerging in rapidly evolving fields such as CBCT-based adaptive RT, integrating rapid CBCT, AI-assisted auto-contouring, and real-time plan optimization, which now allow systematic correction of interfraction anatomical changes, enabling “a new plan every day when necessary” and MR-guided RT that offers superior soft-tissue visualization, online adaptation, and intrafraction motion tracking, representing a promising strategy for tumours undergoing complex motion and deformation.

These advanced systems have the potential to reduce target visualisation and motion-related uncertainties, improving target coverage while increasing OAR protection. However, their clinical implementation remains limited by cost, workflow duration, and the need for a dedicated multidisciplinary team. As these technologies progressively expand within the national network, future updates will need to integrate their role into standard IGRT pathways.

Conclusions

This national Delphi consensus provides a structured, evidence-based reference for the application of IGRT in upper-GI RT, outlining shared recommendations for immobilization, imaging, motion management, and quality assurance.

The consensus clearly indicates that achieving precision in this anatomical district requires the integration of multiple components. A coherent “chain” must connect simulation imaging, motion mitigation, case-specific margin design, daily soft-tissue verification, and standardized correction thresholds. When applied consistently within a harmonized workflow, these elements collectively ensure accuracy.

Moreover, this work focused on approaches already accessible to most Italian RT departments, ensuring that the recommendations are immediately implementable and capable of producing tangible improvements in current clinical practice.

The high degree of agreement achieved demonstrates a strong alignment and provides the foundation for developing standardized national guidelines to promote consistency and safety in these challenging upper-GI RT treatments.

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Informed consent: This study involved an anonymized Delphi consensus process among healthcare professionals, with voluntary participation and informed consent implied by participation.

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Appendix. Summary of round 1 Delphi Consensus KQ on the use of IGRT for upper-GI malignancies, including expert agreement rates and corresponding consensus levels

KQ	Question/statements	Agreement (n/20)	Agreement %
1	**Express your degree of agreement with the following statements regarding the main sources of uncertainty expected during radiotherapy treatment, in relation to patient setup and organ motion:**		
	Ariations in patient position between sessions represent a significant source of uncertainty	16/20	**80 %**
	Patient rotations (pitch, roll) negatively affect treatment accuracy	19/20	**95 %**
	Uncontrolled respiratory motion (no BH, no 4D-CT) is a relevant cause of uncertainty	19/20	**95 %**
	Spontaneous internal organ motion (e.g., stomach, intestine) is a clinically relevant variable	17/20	**85 %**
	Variations in gastric filling or emptying affect treatment reproducibility	20/20	**100 %**
2	**Which of the following devices do you consider sufficient for optimal patient immobilization?**		
	Vacuum-bag	19/20	**95 %**
	Body-fix	16/20	**80 %**
	Thermoplastic mask	13/20	**65 %**
	Wing-board + Prostep	15/20	**75 %**
3	**Are there any other immobilization devices you consider helpful in ensuring adequate patient immobilization? (Open question):** Integration of SGRT with vacuum-bag or body-fix; use of supports such as knee/foot rests to improve comfort and reproducibility		
4	**The use of intravenous contrast media (IV CM) in the planning CT scan is essential to ensure correct delineation of the OARs and target volumes of the radiotherapy treatment**	16/20	**80 %**
5	**Express your degree of agreement with the following statements regarding respiratory control strategies for accurate treatment of the upper abdomen**		
	The best respiratory control strategy for accurate treatment of the upper abdomen is respiratory gating	11/20	**55 %**
	The best respiratory control strategy for accurate treatment of the upper abdomen is breath-hold.	17/20	**85 %**
	The best respiratory control strategy for accurate treatment of the upper abdomen is abdominal compression	3/20	**15 %**
	The best strategy is to use 4D-CT and irradiate during free breathing	7/20	**35 %**
6	**According to your experience, what is the residual uncertainty associated with the different motion-management techniques (e.g., BH, 4D-CT, gating, tracking) and how does this influence the definition of the CTV–PTV expansion margin? (Open question):** Residual uncertainty decreases from ITV/4D-CT to abdominal compression, and is lowest with breath-hold, gating and tracking. CTV–PTV margins could typically be reduced when active motion management (BH/gating/tracking) and daily IGRT are used, whereas larger margins are required for ITV-based or less effective motion-control strategies, and are further adapted according to tumour site		
7	**Express your degree of agreement with the following statements regarding tumour tracking strategies for accurate treatment of the upper abdomen**		
	The best tumour tracking strategy is the use of fiducial markers	16/20	**80 %**
	The best tumour tracking strategy is the use of anatomical surrogates (e.g., liver dome, diaphragm, vertebrae)	6/20	**30 %**
	The best tumour tracking strategy is surface-tracking	7/20	**35 %**
	The best tumour tracking strategy is 4D-CT imaging	10/20	**50 %**
8	**The use of fiducial markers is essential in radiotherapy treatments of the upper abdomen**	10/20	**50 %**
9	**In your opinion, what are the main limitations in defining the target and organs at risk in upper-GI radiotherapy? What techniques do you consider most appropriate to overcome them? (Open question):** Major limitations include poor soft-tissue contrast on CT, respiratory and peristaltic motion, anatomical variability (including filling changes and deformation), lack of reliable surrogates on CBCT, and absence of standardized delineation guidelines.		

(continued)

KQ	Question/statements	Agreement (n/20)	Agreement %
	Suggested solutions include multimodal imaging (contrast-CT, MRI, PET fusion), motion management, fiducials or alternative surrogates, image quality enhancement techniques, patient preparation protocols, and improved training and contouring standardization		
10	**Which organs at risk do you consider a priority to delineate in a radiotherapy treatment of the upper abdomen? (Open question):** The duodenum, stomach, liver, kidneys (particularly the contralateral one), spinal cord and small and large bowel were identified as the highest-priority OARs. Additional structures such as the esophagus, heart, lungs, pancreas (if not the target), major vessels (e.g., aorta, portal vein), and biliary tract may require delineation depending on tumor location, proximity, and treatment technique		
11	**The integration of auto-contouring software into the workflow is useful for defining organs at risk**	15/20	**75 %**
12	**Which objectives do you consider essential in the planning phase to ensure adequate target coverage and sparing of organs at risk? (Open question):** The planning phase must ensure robust target coverage while respecting mandatory OAR dose constraints. Experts emphasized the importance of steep dose gradients (especially in SBRT) use of validated constraints and no hotspots in OARs. This requires: Motion management strategies, careful CTV–PTV margin selection based on residual uncertainty and the incorporation of advanced multimodal imaging (contrast-enhanced CT, MRI, PET). Daily volumetric IGRT, appropriate patient preparation and quality assurance procedures were mentioned as necessary to ensure precision and reproducibility		
13	**A reduction of the CTV-PTV margins is possible in SBRT treatments compared to conventional radiotherapy**	18/20	**90 %**
14	**Is daily IGRT with CBCT sufficient for checking setup and internal motion in abdominal treatments?**	8/20	**60 %**
15	**If you believe there is a valid alternative to daily IGRT with CBCT for verifying setup and internal motion in abdominal treatments, please specify it below. (Open question):** MRI-guided RT when available. Fiducial-based tracking using kV/fluoroscopic imaging, 4D-CBCT or breath-hold CBCT aligned with the same respiratory control used in simulation. SGRT as a supportive tool		
16	**Express your degree of agreement with the following statements regarding radiotherapy treatment, in relation to patient setup and inter- and intrafraction errors:**		
	If respiratory control systems are used, it is mandatory to adopt strategies to evaluate residual motion	16/20	**80 %**
	The best IGRT-CBCT strategy is automatic matching combined with manual correction	17/20	**85 %**
	The best IGRT-CBCT strategy is soft-tissue matching	8/20	**40 %**
	The best IGRT-CBCT strategy is soft--tissue + bone matching	9/20	**45 %**
	The best IGRT-CBCT strategy is bone matching	4/20	**20 %**
	It is mandatory that each centre uses an internal protocol that identifies acceptable intervals within which to correct rotational setup errors	19/20	**95 %**
	It is mandatory that each centre uses an internal protocol that identifies acceptable intervals within which to correct translational setup errors	18/20	**90 %**

KQ, key questions; BH, breath-hold; 4D, four-dimensional; IGRT, image-guided radiotherapy; SGRT, surface-guided radiotherapy; CBCT, cone-beam computed tomography; OAR, organ at risk; MRI, magnetic resonance imaging; PET, positron emission tomography; CTV, clinical target volume; PTV, planning target volume; ITV, internal target volume. Bold values indicate the percentage of expert agreement for each statement. The percentage values were displayed in bold only to distinguish them from the preceding column, which reports the absolute number of experts who agreed with each statement out of the 20 panel members (n/20).

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