Instructions for meaningful figures in radiological research publications

Leitfaden zur Gestaltung aussagekräftiger Abbildungen in wissenschaftlichen radiologischen Publikationen

Authors
Luca Julius Pape[1, 2], Julia Hambach[1, 2], Peter Bannas[1]

Affiliations
1 Department of Radiology, University Medical Center Hamburg-Eppendorf, Hamburg, Germany
2 Institute of Immunology, University Medical Center Hamburg-Eppendorf, Hamburg, Germany

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Georg Thieme Verlag KG, Oswald-Hesse-Straße 50, 70469 Stuttgart, Germany

Correspondence
Prof. Dr. Peter Bannas
Department of Radiology, University Medical Center Hamburg-Eppendorf, Martinistraße 52, 20246 Hamburg, Germany
p.bannas@uke.de

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ABSTRACT

Purpose In this paper, we explain the structure and function of different types of figures and provide guidance on how to create effective figures for radiological research publications.
Method Based on scientific literature and our own experience, we have compiled a series of instructions to support the purposeful creation of effective figures for radiological research publications.
Results Effective figures play a crucial role in radiological research publications by clearly visualizing complex content and thereby enhancing its comprehensibility. Different types of figures have distinct strengths that should be strategically employed for optimal impact. The interplay between figures weaves the *"common thread"* of a publication, facilitating reader comprehension and providing a straightforward path to the answer of the central research question. The systematic coordination *(line of evidence)* and effective design of individual figures are crucial to compellingly support the publication's central hypothesis.
Conclusion The deliberate creation and coordination of figures in radiological research publications are decisive factors for successful publishing.

Key Points

- Different types of figures have distinct strengths that should be strategically employed for optimal impact.
- The interplay between figures weaves the *"common thread"* of a publication, facilitating reader comprehension and providing a straightforward path to the answer of the central research question.
- The appropriate coordination of different types of figures enables an effective and precise presentation of the research findings.
- The systematic coordination *(line of evidence)* and effective design of individual figures are crucial to compellingly support the publication's central hypothesis.
- The deliberate creation and coordination of figures in radiological research publications are decisive factors for successful publishing.

Citation Format

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ZUSAMMENFASSUNG

Ziel Die vorliegende Arbeit erläutert die Funktion und Struktur unterschiedlicher Abbildungsformen und bietet eine Anleitung für die Gestaltung aussagekräftiger Abbildungen in wissenschaftlichen radiologischen Publikationen.
Methode Basierend auf der Fachliteratur sowie eigener Erfahrung haben wir eine Anleitung verfasst, welche die gezielte Gestaltung aussagekräftiger Abbildungen für wissenschaftliche radiologische Publikationen unterstützen soll.
Ergebnisse Aussagekräftige Abbildungen spielen eine zentrale Rolle in radiologischen Publikationen, indem sie komplexe Inhalte anschaulich vermitteln und so deren Nachvollziehbarkeit erleichtern. Die unterschiedlichen Arten von

Abbildungen haben spezifische Stärken, die gezielt eingesetzt werden müssen, um eine optimale Wirkung zu erzielen. Das Zusammenspiel der Abbildungen spinnt den *„roten Faden“* einer Publikation und führt die Leserschaft in einem konsistenten und leicht nachvollziehbaren Format durch die Beantwortung der wissenschaftlichen Fragestellung. Die sorgfältige Koordination *(Beweiskette)* und Gestaltung der einzelnen Abbildungen sind entscheidend, um die zentrale Hypothese der Publikation überzeugend zu belegen.

Schlussfolgerung Die Gestaltung aussagekräftiger Abbildungen und deren sorgfältige Koordination sind ein entscheidender Faktor für die erfolgreiche Veröffentlichung einer radiologischen Publikation.

Kernaussagen

- Unterschiedliche Arten von Abbildungen haben spezifische Stärken, die gezielt genutzt werden sollten, um eine optimale Wirkung zu erzielen.
- Das Zusammenspiel der einzelnen Abbildungen spinnt den *„roten Faden“* einer Publikation und führt die Leserschaft durch die Beantwortung der wissenschaftlichen Fragestellung.
- Die richtige Kombination der unterschiedlichen Abbildungsformen ermöglicht eine effektive und präzise Vermittlung der Forschungsergebnisse.
- Die sorgfältige Koordination *(Beweiskette)* und die effektive Gestaltung der einzelnen Abbildungen sind entscheidend, um die zentrale Hypothese der Publikation überzeugend zu belegen.
- Die sorgfältige Koordination und Gestaltung der Abbildungen einer radiologischen Publikation sind ein entscheidender Faktor für die erfolgreiche Veröffentlichung.

Introduction

Meaningful figures play an important role in radiological publications as they convey complex content in a clear manner, making it easier to understand [1, 2, 3, 4].

The interplay of the individual figures spins the “*common thread*” of a publication and guides the reader through the answer to the scientific question in a consistent and easy-to-follow format. Carefully coordinating (“*line of evidence*”) and designing each figure in a way that substantiates the publication’s central hypothesis is crucial.

Poor design and coordination of the figures can lead to scientific data being misunderstood and/or a text not being accepted for publication [5]. In addition to the abstract, figures are decisive for the reviewers when assessing a publication. They reveal at a glance whether they were designed with care or not. Carefully designed figures, which show the collected data clearly and without distortion, suggest that care was also taken when conducting the actual study. This insight influences, consciously or subconsciously, the decision-making process. Therefore, optimal coordination and design of the figures are a decisive factor for successful publication.

This paper explains the function and structure of different types of figures and provides guidance for the creation of meaningful figures in radiological publications.

Strengths and weaknesses of different forms of data presentation

The scientific results of radiological studies can be presented in various forms. The content and design of the individual figures play a central role, as they form the basis of the results section of the publication [5].

Different types of figures have specific strengths and weaknesses (▶ **Table 1**) [4]. Knowledge of these strengths and weaknesses is crucial to select the most meaningful form of data presentation and thus communicate the scientific results in the best possible way.

Results can generally be presented in the form of text statements, tables, graphs, schematic drawings, or radiological imaging findings [5].

▶ **Table 1** Strengths and limitations of different types of data presentation.

	Text	Table	Graph	Illustration	Radiological image
Content	+++	++++	++	+	+
Precision	+++	+++	++	+	++
Impact	+	++	++++	+++	+++
Interest	+	++	+++	++++	++++

‘+’ signs serve as a relative scale from ‘+’ (weak) to ‘++++’ (strong). Adapted from *F.L. Rosenfeldt et al. Heart Lung Circ 2000; 9: 82–87*

The text form allows a high degree of precision and density of content, but has the least visual impact and generates the least interest.

Tables are useful for organizing extensive data in a precise, clear way. They have a slightly stronger visual impact than pure text.

Graphs can be used to display data clearly and comprehensibly. They best illustrate connections between different parameters and arouse the reader's interest through their strong visual impact. Compared to tables, graphs are less precise because exact numerical values, for example, cannot be read from a curve diagram.

Schematic drawings and radiological imaging findings have the strongest visual impact and thus generate the greatest interest among readers [4].

The deliberate combination of different types of figures allows authors to arouse the interest of the reader (graphs, diagrams, imaging findings) and at the same time ensure the required high level of precision (text form, tables).

In summary, the targeted combination of the different types of figures contributes significantly to the effective and precise communication of the research results.

Optimal presentation of radiological imaging findings

Radiological imaging findings such as X-ray, CT or MRI images are naturally an essential component of scientific radiological publications [2, 3, 5].

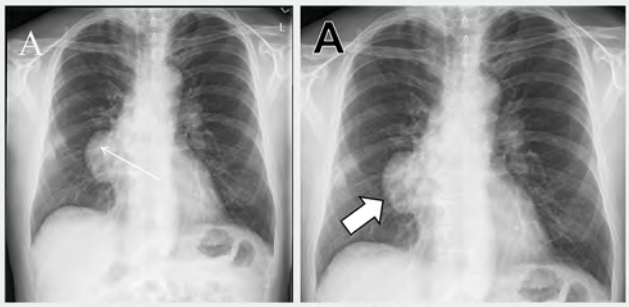
To convincingly convey the scientific results of the study, careful and representative selection of the underlying imaging findings is crucial.

In addition, excellent image quality is essential. This includes a high resolution and a good contrast ratio. Publishers generally provide precise guidelines for the minimum/maximum resolution and file format. In *Fortschr Röntgenstr*, 300 dpi is required for color and black-and-white images, and at least 600 dpi for illustrations [6]. It is advisable to choose the same resolution for all illustrations. Labels that would permit the identification of the test subjects or patients must be removed.

The brightness and contrast of the image should be adjusted before export from the PACS so that the main findings are best displayed. Editing the image afterwards should be avoided. The relevant image findings should ideally be placed in the center of the image and enlarged by cropping on all sides [7].

Annotations within the figures should be made using sans serif fonts such as Arial in bold to optimize readability [7, 8]. Make sure to choose a black font against a white background or vice versa. To further improve legibility, it is particularly advisable to chose a high contrast outline (white on black or vice versa) for letters on backgrounds with inhomogenous brightness levels [9].

Arrows are helpful to indicate specific findings [10]. So-called arrowheads should only be used when necessary. They must clearly point to the finding, which is why equilateral triangles should be avoided [11]. These markers should also be sufficiently large and contrast well with the background. Markers should extend up to the finding, but should not overlap with it.



▶ **Fig. 1 Comparison of a suboptimal and an optimal presentation of a radiological image. a** Suboptimal presentation of the main finding (bronchial carcinoma). The image has not been cropped on all sides, resulting in a small reproduction of the main finding. Panel label "A" is too small and difficult to read due to the white serif font against a white background. The white arrow is too thin and difficult to distinguish against the white background. Additionally, the arrow overlaps with the main finding, which should be avoided. **b** Optimal presentation of the same radiological finding. The image was cropped on all sides to enlarge the main finding and bring it into focus, ideally at the center of the image. The legibility of the panel label "A" has been improved by using a bold sans serif font with a high-contrast outline (white against black). Outlining letters is especially suitable for images with uneven brightness levels. The arrow is wide and similarly outlined. It extends directly up to the main finding without actually overlapping with it.

▶ **Fig. 1** illustrates these aspects by comparing a suboptimally presented radiological imaging finding with an optimized presentation.

When coordinating all the figures in the publication, it is important to use uniform labels and markers to ensure a clear visual language. Visual consistency is achieved through a uniform font and font size. It is advisable to consider in advance whether a figure will only take up one column or an entire page width in the final print.

In the main text of the manuscript, all tables and figures must be referenced in numerical order. The content and message of each table and figure are briefly explained. The main text does not repeat the entire content of the figure legends, but only highlights the most relevant results. The information visualized in the figures is intended to support the statements made in the main text [3].

In summary, careful selection of the imaging findings, high quality of the image material and consistent labeling ensure clear and effective communication of the demonstrated radiological findings.

Meaningful figure legends

Every good scientific figure needs a meaningful figure legend [3]. Each individual figure, along with its figure legend, must be self-explanatory without reading the main text [5].

The figure legend should begin with a summarizing sentence, which we refer to as the *"headline"*. By highlighting the main findings, the "headline" lets readers easily identify the figure's key message.

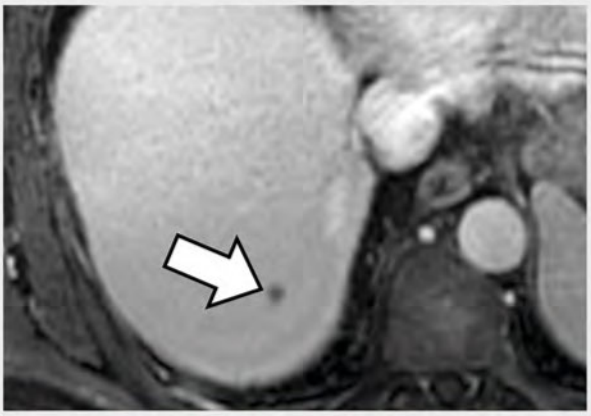


Fig. X: Improved detection of small hepatic metastases. Contrast-enhanced axial fat-saturated T1-weighted liver MRI in a 42-year-old man with colorectal cancer. Note the improved conspicuity of the metastasis *(arrow)*.

▶ **Fig. 2 Essential components of a figure legend for a radiological image**. An optimal figure legend should begin with a concise 'headline' summarizing the figure's content or key message (*red*). This enables the reader to immediately grasp the content of the figure. Clarity can be enhanced by formatting this first sentence in bold. Next, mandatory information on the patient and imaging technique is provided. This involves details on contrast enhancement (*yellow*), orientation (*blue*), and the imaging modality (*purple*). Additionally, the age and sex of the patient (*orange*) as well as their diagnosis (*green*) must also be specified. The meaning of any added elements or markers (*arrow*) is also explained. As described in ▶ **Fig. 1**, the image shown here was cropped on all sides to enlarge the main finding and bring it into focus. The arrow has a high-contrast outline and extends right up to the relevant finding without actually overlapping with it.

For radiological imaging findings, information on the imaging technique must be provided (▶ **Fig. 2**) [3]:

1. Imaging technique: conventional X-ray, CT, MRI, etc.
2. Use of contrast media: yes/no, contrast media used
3. Plane: axial/coronal/sagittal
4. MRI: Specify the sequence technique
5. CT: Specify the window setting (if necessary, specify Hounsfield units)
6. PET/CT: Specify the tracer (e. g., [^{18}F] FDG)

The following information about the patient is required:

1. Age
2. Sex
3. Diagnosis

The meaning of any inserted graphical elements (arrows etc.) is explained in the figure legend. Adding a conclusive statement such as "*Note the XY (arrow)*" at the end can enhance the impact and clarity of the figure legend.

In summary, figure legends should start with a concise *"headline"*. Radiological imaging findings should contain all information on the imaging technique as well as the relevant clinical background. Each figure, along with its figure legend, should be self-explanatory.

The "*figure storyboard*" as the common thread

Carefully coordinating the individual figures gives the entire publication a *"common thread"*. Deliberately coordinated figures form the *line of evidence* that supports the publication's central hypothesis. Care should be taken to let the figures build upon each other, thus creating a cohesive link between individual sections of the manuscript. This creates a uniform ensemble that tells the "*story*" of the entire manuscript [9, 12].

We recommend preparing what we call a "*figure storyboard*" before starting the detailed work on the figures. This serves as a concrete starting point to define the manuscript's common thread. In practice, the figure storyboard consists of a text document into which preliminary figures and tables are inserted. First, the *"headline"* of each figure legend is formulated to succinctly summarize its message (see above). The figure storyboard then forms the scientific *line of evidence* and links the initially formulated *aim* of the study with its preliminary *conclusion.*

In the course of creating the manuscript, the figure storyboard is iteratively revised until a clear central theme emerges. The figure storyboard can then help to write the results section of the manuscript [13].

We recommend working with this "*storyboard document*" as well as a "*main text document*" until the final manuscript is submitted. Viewing both documents side-by-side enables simultaneous editing of illustrations, captions and main text.

Furthermore, we recommend printing out the final figure storyboard to check how the figures will look on paper. Each figure should be scaled to the expected print size (column width or page width). Each figure has its own page in the storyboard document. The figure legend is placed below, ideally in "Times New Roman", 12pt [14]. As a rule of thumb, annotations within the figure should have approximately the same font size as the figure legend below.

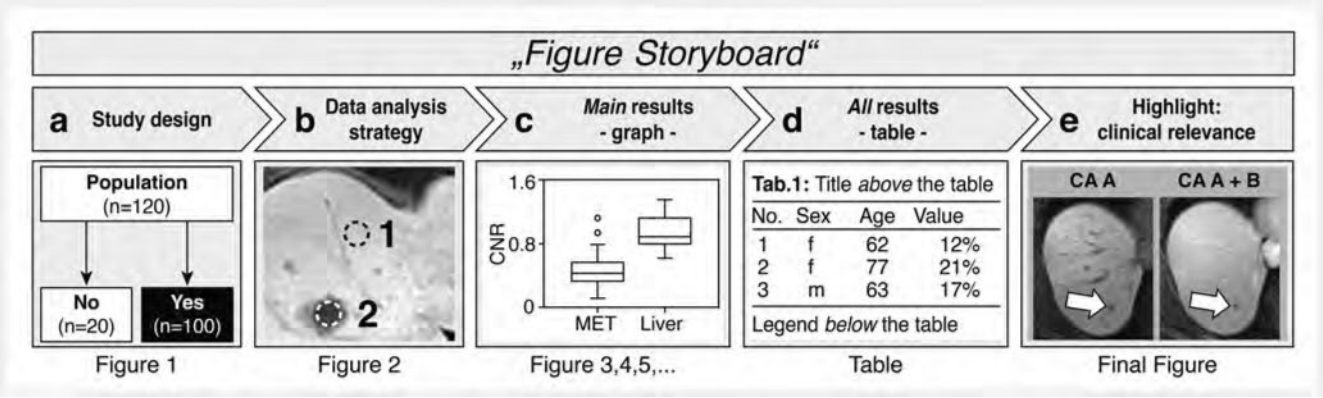
In terms of content, the figure storyboard provides the narrative for the manuscript. The different types of figures that can be used in the figure storyboard are shown in ▶ **Fig. 3.**

For original radiological research, the following system can be used:

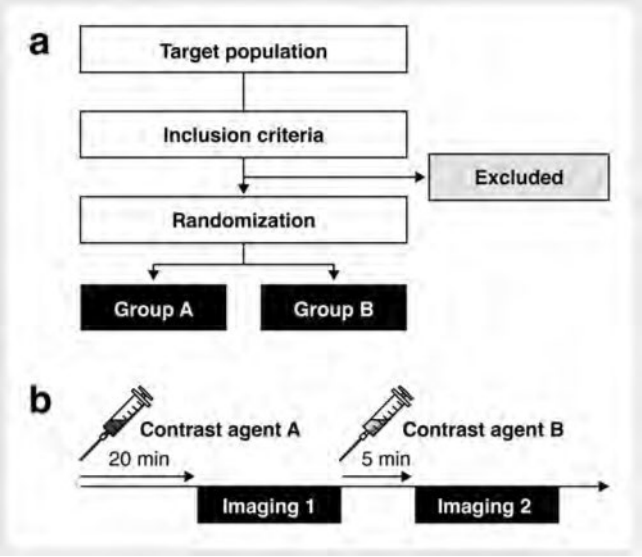
1. Schematic visualization of the study design or experimental setup
2. Illustration of measurement methods and analysis strategy
3. Graphical presentation of the *most important* results
4. Tabular presentation of *all* results
5. *"Highlight figure"* to highlight the clinical relevance of the study

This system serves as an organizational guideline and can, of course, be adapted to the individual manuscript. If necessary, points can appear multiple times or be omitted.

In summary, the *"figure storyboard"* provides the structural framework for presenting figures in scientific publications in a coordinated and harmonious way.



▶ **Fig. 3 Schematic representation of the *"figure storyboard"*.** The content and sequence of the figures in a publication convey the study's common thread, thereby forming the *"figure storyboard"*. **a** The first figure visualizes the study design, including all inclusion and exclusion criteria. **b** The second figure illustrates the imaging technique and analysis approach. **c** The third figure graphically conveys the study's key findings, effectively presenting the most important results. **d** Tables are used to present all results in a precise and well-structured manner. **e** The final figure is a *"highlight figure"* specifically emphasizing the clinical relevance of the study.



▶ **Fig. 4 Visual representation of clinical trials or experimental studies.** The first figure of a publication serves to present even complex studies or experimental setups in a comprehensible manner. **a** The study design of a clinical trial is depicted, including all inclusion and exclusion criteria, aiming to precisely characterize the study groups and ensure reproducibility of the study. **b** The setup of an experimental study is illustrated in a schematic drawing. This allows for the visual representation of the relationship between different components and complex temporal sequences.

The first figure: Visual presentation of the study design or experimental setup

Schematic drawings and illustrations are ideally suited as the *first* figure of a publication. They convey complex study designs or experimental setups in an intuitive and clear way (▶ **Fig. 4**) [15].

The advantage of schematic illustrations is that different components along with their spatial and temporal arrangement can be depicted. In addition, they can highlight crucial aspects by omitting unimportant components and showing relevant components in a larger size [9]. Ideally, a good schematic drawing requires less space compared to plain text to convey the same amount of information [15].

One of the quality features of good schematic drawings and illustrations is a consistent visual language: If, for example, a specific procedure is depicted several times, the same symbol and/or color should always be used within the same illustration as well as in subsequent figures.

In summary, schematic drawings and illustrations are used to convey complex study designs intuitively and with a high content density.

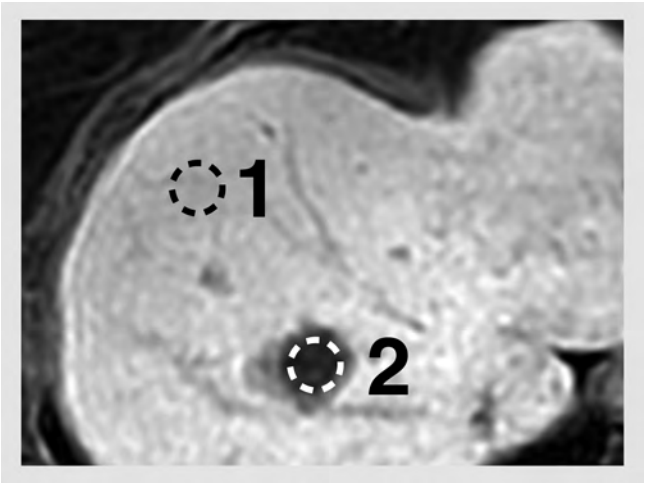
The second figure: Illustration of measurement methods and analysis strategy

The *second* figure of the publication is used to communicate the measurements and analyses performed during the study in an understandable and unambiguous way (▶ **Fig. 5**). Exemplary radiological imaging findings are particularly suitable for conveying an exact and authentic impression of the generated image material and the analysis strategy.

The analysis strategy can be illustrated, for example, by depicting the localization and size of the analyzed *regions of interest* (ROIs) within the selected exemplary images. The analysis strategy presented here is the basis of the results presented later. As these "*data sources*" form the foundation for all subsequent results and conclusions, they should be presented clearly and convincingly.

Visualization of the analysis strategy is also a central aspect of good scientific practice: It ensures future reproducibility of the study.

In summary, providing detailed depictions of the measurement methods and analysis strategy enhances comprehension and validity of the subsequent analyses.



▶ **Fig. 5 Illustration of the imaging technique and analysis strategy.** The *second* figure in a publication illustrates both the imaging technique and the analysis strategy. In our example, the placement of the *regions of interest* (ROIs) illustrates the recording of signal intensity values for healthy liver tissue (ROI: 1) and metastases (ROI: 2). All subsequent statistical analyses and, ultimately, the conclusion of the entire study are based on these values. The ROIs in the example image are distinctly labeled and have high contrast (black on white and vice versa, dashed) to enhance discrimination against the background. As an example, the ROI placement in an MRI contrast agent study for the detection of hepatic metastases is presented.

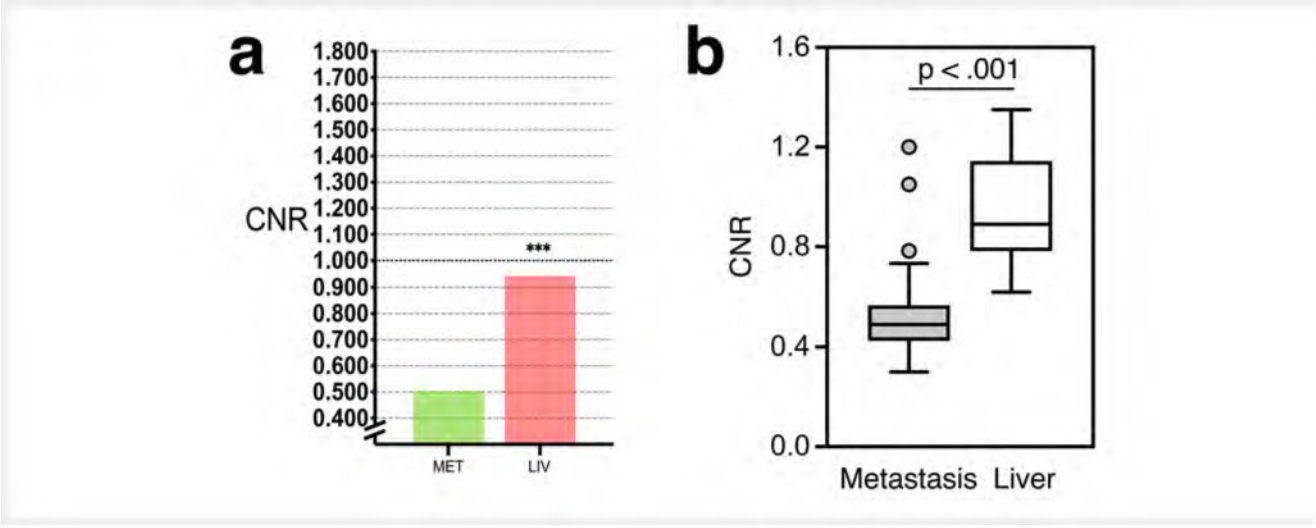
The third figure: Graphical presentation of the most important results

The *third* figure of the publication effectively conveys the study's key findings by presenting the most important data as a graph [9].

To clearly communicate the data, the amount of information depicted in the graph should be reduced to a sensible minimum [9]. Only this way is the content of the graph easy to understand and memorable. Readers can then intuitively recognize and interpret patterns and trends themselves. To ensure the required transparency and comprehensibility, data not shown in graphs should be made accessible in its entirety in the supplements or in tables.

When designing the graphs, all labels, colors, grid lines, and tick marks should be used deliberately and sparingly. Reducing the number of graphical elements to a useful minimum directs the eye to the actual data [12].

To visualize data in a comprehensible and meaningful way, care should be taken to chose an appropriate type of graph. Guidelines for the graphical presentation of scientific data call for the visual depiction of means, distribution, and any individual outlying data points [16, 17, 18]. In practice, this means that simple bar charts are insufficient for presenting continuous biomedical data. Instead, guidelines recommend using box plots and scatter plots, as they provide a comprehensive depiction of the data [17, 19].



▶ **Fig. 6 Comparison of suboptimal and optimal graphs.** The *third* figure of a publication graphically depicts the most important results to effectively communicate key findings. **a** *Suboptimal* presentation of results. Bar charts are generally considered suboptimal for many types of biomedical data, as they do not accurately depict value distributions. In our example, the Y-axis is cut off at the bottom, implying a more pronounced difference between the two study groups. In addition, the Y-axis is too long at the top, rendering the bars unnecessarily small. The Y-axis labeling includes a confusing number of decimal points, and the bold font distracts from the chart's content. The colors used here are not accessible for readers with color blindness. The indicators of statistical significance (asterisks) depicted here are misleading. To improve clarity, the horizontal lines should be removed. **b** *Optimized* visualization of the same results. Box plots allow the visual representation of relevant statistical parameters such as median (horizontal line), quartiles (box), and the confidence interval (whiskers). Outliers (circles) are clearly identified. The axes are clearly labeled. The Y-axis starts at zero. The top end is adjusted to the maximum values of the data to present the relevant graphs in an undistorted manner and as large as possible. Box plots are depicted in light and dark shades to enhance visibility for readers with poor color vision. Statistical significance is unmistakably indicated by a p-value.

The use of red and green colors to differentiate data sets should be avoided in order to make graphs accessible for people with color vision deficiencies [20, 21].

▶ **Fig. 6** shows a comparison of suboptimal and optimal graphical presentations.

In summary, graphs convey the most important study results in an engaging and effective manner. The careful selection of the data presented and a clear design of the graphs are essential. All data that is not graphically visualized should be made accessible in tables or the supplements.

Tables: Overview of all measured values

Tables are suitable for presenting all collected data in a clear and precise manner. Presenting all measured parameters comprehensively and accurately allows readers to critically analyze the results and, if necessary, make further calculations (e. g., planning case numbers for future studies).

Each table consists of three elements: the title, the actual table, and the legend. Their exact structure varies depending on the specifications of the selected journal.

As a guideline, the title should be located *above* the table (▶ **Fig. 3d**) [8, 22]. It succinctly summarizes the content of the table, similar to the "*headline*" of the figure legend (see above).

The actual table should be designed in a clear and simple format with appropriate groupings. We recommend avoiding vertical lines, as these disrupt the readability within a row [7]. Horizontal lines are used sparingly to distinguish sections of the table or highlight groups [22].

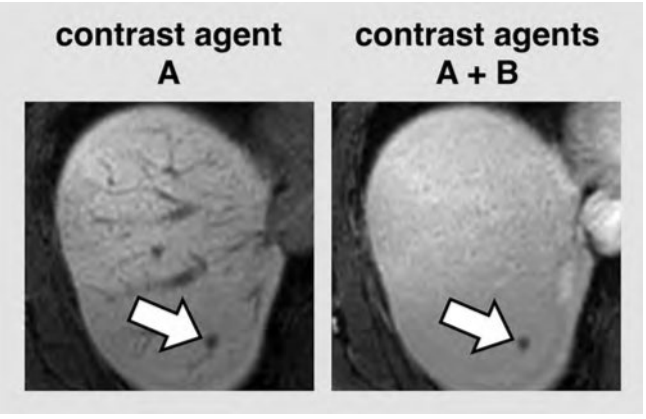
The legend is usually located *below* the table. It contains the definition of any abbreviations as well as information on statistical significance (▶ **Fig. 3d**). The legend ensures that the data is interpreted correctly without requiring readers to refer to additional information in the main text.

In summary, tables allow for the well-structured and precise presentation of large amounts of data. Clear formatting and informative legends increase comprehensibility.

The final figure: *"Highlight figure"*

The final figure of a publication is the "*highlight figure*". It is used to highlight the clinical relevance of the study by applying it to an exemplary clinical case. This includes, for example, highlighting how the newly investigated method has influenced the management or outcome of a patient compared to the standard of care. This allows for the realistic presentation of the study's potential clinical applicability. The use of a highlight figure is illustrated with a concrete example in ▶ **Fig. 7**.

In summary, the highlight figure illustrates the clinical relevance of the study. Furthermore, it rekindles the interest of the reader after a potentially exhausting reading of the results section.



▶ **Fig. 7** ***"Highlight figure"* for illustrating the clinical relevance of the study.** The last figure is a *"highlight figure"* that uses a real-world case to emphasize the clinical relevance of the study. For this purpose, a side-by-side comparison of the established method with the newly investigated method is particularly useful. This illustrates how the newly investigated method has influenced the outcome or management of the patient compared to the established method. In the MRI image example here, a small hepatic metastasis was overlooked with the established method (contrast agent A), while it was easily detected by the new method (contrast agents A + B). The detection of this metastasis has influenced the interdisciplinary management of the patient, thus illustrating the potential clinical relevance of the new method (adapted from Bannas et al., Eur Radiol 2017; 27(1):32–30).

Summary

Well-designed figures play a central role in the publication of scientific manuscripts, especially in radiology. Selecting the right types of figures based on their specific strengths contributes significantly to the effective communication of the research. High-quality images as well as carefully designed labels and markers are essential for the clear and unambiguous presentation of the results.

The "*figure storyboard*" provides the organizational framework for presenting figures and tables in a coordinated and deliberate manner. As part of the scientific *line of evidence,* each figure builds upon the previous and assumes a specific function within the manuscript. The figures thus form a clear "*common thread*" that guides readers through the answer to the research question.

The *first* figure of a manuscript is a schematic illustration used for the intuitive presentation of the study design. The *second* figure illustrates the measurement methods and analysis strategy based on exemplary radiological imaging findings. The *third* figure conveys the most important study results as a graph in an effective and convincing manner. *Tables* are used to clearly and precisely present large amounts of data. As the manuscript's *final* figure, we recommend using a "*highlight figure*" that emphasizes the clinical relevance and potential *impact* of the study.

Conclusion

Carefully and deliberately designing the figures of a radiological research publication is crucial for effectively conveying the research findings and ensuring the successful publication of the manuscript.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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