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How to Write an Original Radiological Research Manuscript

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Abstract

Many scientific manuscripts submitted for publication are limited by fundamental mistakes in their preparation, leading to rejection. We describe how to write a well-organized radiological research manuscript containing all of the important ingredients for effective communication of a hypothesis driven scientific study in the context of medical imaging.

Keywords

Manuscripts; Medical Writing; Publication Components; Radiology; Diagnostic Imaging

Introduction

Scientific manuscripts should be well organized, presenting methods, data, analysis, and interpretation in a clear and comprehensible manner [1; 2]. A well-written scientific manuscript will answer an important scientific research question in the briefest and most concise possible way. For these reasons, guidelines and structured organizational approaches have been established for reporting of imaging studies [3–5].

Unfortunately, novice authors in particular are often unaware of established scientific writing principles [6–8]. However, following these principles is key to produce a well-structured manuscript [9]. A poorly organized structure may lead to repeated manuscript submissions, or even rejection [10; 11]. An upfront investment of time on layout, structure and style is therefore essential for successful publication [12–14].

We aim to describe a structured approach on how to write an original research article in the context of medical imaging. Like many review papers, occasional updates on relevant topics like this are important for the readership, not only to reintroduce important ideas, but also to provide fresh perspectives based on diverse experience. We believe that our experience

brings a fresh look at this important topic that we hope will be impactful to the readership. While this paper is aimed at guiding radiologists to write for *European Radiology*, these principles are applicable to a broad spectrum of scientific writing.

Structure of a scientific manuscript

All research manuscripts have a similar structure, consisting of seven main components:

1. Title
2. Abstract
3. Introduction
4. Material and Methods
5. Results
6. Discussion
7. References

The *Introduction*, *Methods*, *Results*, and *Discussion* are the four main sections, each serving to a very specific purpose [15]:

- *Introduction* → Why you did what you did
- *Methods* → What you did
- *Results* → What you found
- *Discussion* → What it means

How to start?

The first step with any manuscript is to articulate your “purpose” of the study. The purpose of your study should be captured in a single sentence, and should be included at the beginning of the *Abstract* and at the end of the *Introduction*. Also, reiterate the purpose of your manuscript in the first paragraph of the *Discussion*. Without a well-defined purpose, the remainder of the manuscript will be difficult to organize.

After articulating the overall purpose of the study, give the paper a temporary title. Start by drafting a title that is succinct, and captures the “big picture” message of the study. This helps define the paper as a tangible object [16].

Next, decide which figures and tables should be included. Generate a preliminary set of figures and tables. Remember that “a picture tells a thousand words”, the same applies to figures and tables. The figures and tables must support the overall purpose of your paper. For each figure write a declarative summary statement. This summary statement will serve as the first sentence of the final caption and should capture the “*take-home message*” of that figure. The content of the paper should be evident by simply looking at the figures and summary statements in the figure captions [17].

Which part of the manuscript should be written first?

We recommend writing the *Materials & Methods* section first (*what you did*) followed by the *Results* (*what you found*). These sections are relatively easy to write, as they focus only the study itself and do not require interpretation or integration within the context of previous studies.

Next, write the *Introduction* (*why you did what you did*). Cite the most relevant and recent literature, thereby undermining the need and relevance of the own study. Last, write the *Discussion* (*what it means*). The *Discussion* is the most difficult section to write and requires integrating the previous knowledge referenced in the *Introduction* with the new insights from the *Results*.

Finally, revise your *Title* and write the *Abstract*. Both are comprehensive summaries of the four main manuscript sections. We recommend writing these two components last, thus using the already composed main manuscript for extraction.

Drafting of the manuscript components

Below we outline the purpose and structure of each section of a scientific radiological manuscript (see also Table 1).

1. Title

A well-chosen *Title* will improve the chances that potential readers will find the manuscript using standard search engines such as *PubMed*, and influence readers to open the paper once found. Overall, ‘readability’ is very important and should be considered when choosing the *Title*. It should be succinct, direct and strong. The *Title* must rapidly convey your idea so that it will capture the immediate attention [16]. Do not use acronyms or abbreviations in the *Title*. Also avoid the use of many different or uncommon acronym and abbreviations throughout the entire manuscript as this may confuse readers.

The *Title* should cover relevant characteristics of the study, such as patient population, animal model, disease, and imaging technique. Combining two sentences with a colon enhances the message and facilitates succinct wording: “*Quantitative magnetic resonance imaging of hepatic steatosis: Validation in ex vivo human livers.*” [18]. Alternatively, the main finding of the study can be phrased as a positive statement: “*Severe aortic arch calcification depicted on chest radiography strongly suggests coronary artery calcification.*” [19]. Such wording is easily remembered and catches the attention of potential readers.

2. Abstract

The *Abstract* is a brief summary of the manuscript and serves key functions. First, the *Abstract* may be the only thing editors read before deciding whether or not a manuscript should proceed with the review process. Second, the *Abstract* is critical for potential readers to decide whether or not to read the article [14]. Therefore, clearly articulate the relevance of the study in the *Abstract*. Third, the *Abstract* also impacts the ability of search engines to

find the manuscript. Also the choice of *Keywords* that are provided along with the *Abstract* is important, as it will affect the chances of people finding the article on search engines.

Generally the *Abstract* is limited to 150 to 250 words. The *Abstract* contains all major elements of the manuscript including i) *Purpose*, ii) *Methods*, iii) *Results*, and iv) *Conclusion*.

First, clearly present the *Purpose* of the study. The purpose should be reflected in the *Title* and be the same as provided later in the *Introduction*. It is important to provide a single (primary) *Purpose*, and at most, one additional (secondary) *Purpose*. Define the *Purpose* concisely in a single sentence.

In the *Methods* section, briefly describe the study population, imaging techniques, measured variables, way of data analyses, and statistics. State whether the study was retrospective or prospective. For diagnostic performance studies, describe the standard of reference. Provide the reader with enough details to be able to understand how the findings in the following results section were obtained.

In the *Results* section state only the most important findings that reflect the purpose of the study while providing significance levels.

Lastly, in the *Conclusion*, provide a clear conclusion containing the core message of the paper. This *Conclusion* must address the *Purpose* and must be substantiated by the data described in the *Results* section of the *Abstract*.

3. Introduction: Why you did what you did

The purpose of the *Introduction* is to provide the rationale for the study and explain its relevance. The *Introduction* is a means to pose important unanswered questions [17]. Generally, the *Introduction* is subdivided into three sections, that i) explain the broad relevance of your area of interest, ii) explain the originality and need for your specific study, and iii) define the purpose of your study [2].

3.1. Relevance: Statement of the issue—The first section of the *Introduction* makes the case for the importance of your broad research topic. This is the section for the “*who cares?*” question. If the question being asked is not significant, the study will have a hard time being published. Therefore, provide enough background information about a certain disease, and explain why imaging is relevant to the disease. Next, present the clinical/technical dilemma or unmet need.

3.2. Originality: Need for the study—The second section provides a short and pertinent overview of the imaging techniques that are currently used to address the clinical condition and should reference major published findings. This section is akin to a “gap analysis” and provides the *rationale* for your study by articulating the shortcomings of previous studies or current techniques. Your study should come across as the logical next step to build upon previous studies. Be sure to indicate how your study may broaden the scientific horizon and potentially improve clinical treatment.

3.3. Purpose: Hypothesis to be tested—The third section of the *Introduction* should summarize from the two previous sections the rationale for the study. This section should clearly provide the hypothesis to be tested. Remember that the lack of a clearly stated research question is the most common reason for rejection of manuscripts [2; 20]. Lastly, state the *Purpose* of the study in a single sentence, which should be the same as that in the *Abstract*.

4. Materials and Methods: What you did

The purpose of the *Materials and Methods* section is to explain, in detail, all procedures that were performed. The details should be unambiguous and easily read, like a cookbook, such that other experts in the field could reproduce the experiments. Divide this section into subsections with subheadings to provide a clear organization.

4.1. Study design and subjects—First, state that the institutional review board approved the study and whether subjects provided informed consent.

Next, provide the type of study: “*prospective*” or “*retrospective*”. State the method of sampling: “*consecutive*” or “*random*”. It is paramount to list explicitly the inclusion and exclusion criteria of the study. The results of your study may only be valid in this subject population. Therefore readers need a clear understanding of the subject population, since extrapolation of results from one subject group to another can lead to selection bias [21]. It may be helpful to provide a flow chart as the first figure in the paper explaining how subjects were recruited according to the inclusion criteria, reasons for exclusion, and final outcomes.

4.2. Imaging techniques—Provide sufficient details of how imaging data were acquired allowing readers to reproduce the study. Be sure to state the type of imaging device (e.g. MRI scanner), device manufacturer, imaging parameters, and finally, the type, amount and rate of administration of contrast agent. In some cases, a table may be the most succinct means to communicate details of the imaging acquisition.

4.3. Image analyses—Explain how the data were analyzed. First, state who (e.g. radiologist) and with which level of experience (e.g. 5 years of experience) performed the analysis. State whether readers were blinded or not. If there was more than one reader, state whether the analysis was performed in consensus or independently. Generally, it is recommended having at least two independent readers. Individual analysis more closely reflects clinical reality and comparison of the individual analysis provides insight into the variability between readers and the reliability of the data analysis method.

Define clear criteria, thresholds, and ranking systems for the applied measurement and analysis methods. For example, the severity of metastatic disease in the liver should not be graded as “minor, moderate or severe” but perhaps as “0, 1–5, 6–10 and >10 lesions”. The more clear the criteria are defined, the more objective, valid, reproducible, and comparable the data will be.

Lastly, describe how the quality of the results was evaluated. If applicable, determine both the *reliability (precision)* and *validity (accuracy)* of the acquired data. *Reliability* can be

tested in a variety ways, e.g. by assessing the intra- and interobserver variability. The *validity* of the results has to be determined by diagnostic performance tests with an appropriate reference standard. Clearly and explicitly explain the standard of reference, as it is a key component that contributes to the overall quality of the study.

4.4 Statistical analyses—Interpreting diagnostic test results requires an understanding of key statistical concepts [22]. Moreover, we recommend to consult a professional statistician *before* starting data acquisition [16]. Describe the applied statistical tests in the order of the image analyses methods. State the level of significance for p-values and correction for multiple comparisons, if necessary. This allows the reader to assess and gauge the value and significance of the reported results. Report the version and company name of the applied statistical software.

5. Results: What you found

The purpose of the *Results* section is to present your experimental data that prove or disprove the hypothesis of your study. Limit the provided results only to those that support the overall aim of the study. The organization of the *Results* section should parallel the order of the *Methods* section. Report the data in the *Results* section objectively - all interpretation of the results is reserved for the *Discussion*.

Use your figures and tables as a guide to write the *Results*. First, provide the demographic data of the patients, if the study is prospective. A table is a useful way to present comprehensive demographic data and allows comparing groups of subjects with respect to any variables that might affect the results. Next we recommend providing a figure with representative imaging examples from *individual* subjects with varying degrees of pathology or other relevant findings. *Individual* imaging examples at the beginning of the *Results* are helpful to orient the reader to the subsequent *collective* data analysis of all subjects.

The subsequent figures and tables should summarize the results from *all* subjects in a comprehensive manner. Results from the statistical analysis should be included with these results. For example, such data may demonstrate the *validity* of a new imaging technique using an independent reference standard. Finally, an assessment of the *reliability* (e.g. inter- and intraobserver variability) should be presented.

Each table and figure, with a caption, must be able to stand on its own. Results may be presented as statements in the text, as imaging examples, graphs, line diagrams, or tables. The text in the body of the paper may provide precise and detailed information, but its immediate impact is low. Imaging examples may have significant impact but unless they are compelling examples, they may not be able to convey a clear message. Data presented as graphs have the advantage of clarity and impact, and can bring out relationships between various parameters. Keep graphs simple, and eliminate all extraneous material. Tables are helpful to organize extensive data into a accessible form, providing greater impact than text, while maintaining precision [16]. The advantages and disadvantages of the various ways of presenting results are summarized in Table 2.

All figures should have an excellent image quality. Check the journal requirements for digital resolution of figures and file format. Crop images closely to emphasize the key component, and window/level images to best depict the key findings. Arrows may be helpful to draw attention to more subtle findings. Remove all identifying information about the patient from radiological images while stating age, sex, and medical condition in the figure legend.

All tables and figures must be “called out” in numerical order from the text of the manuscript. When a table or figure is called out, provide a brief explanation and the significance of the table or figure. Augment the information presented in each figure and be sure to give sufficient detail in the text to present each result in the context of the other study findings [16]. Do not repeat in detail the entire content of the figure captions, but rather highlight the most relevant findings.

Strictly avoid discrepancies and ambiguities in the *Results*. Small, unintentional errors, may lead to an overcritical review of the manuscript. Provide all data as precisely and succinctly as possible. Omit vague terms such as “most”, “some”, and “few” as they are imprecise and impart subjective judgment.

6. Discussion: What the study means

The purpose of the *Discussion* is to provide your interpretation of the data, by synthesizing what your data mean to the field. Remember to focus the *Discussion* on the interpretation of your own results. Avoid long-winded interpretations of previous studies. Also, refrain from explanations of the rationale for the study that belong in the *Introduction*. You may state new ideas based on the results of your study in the *Discussion*, but be sure to label any new idea as such. This avoids misinterpretation of new ideas as conclusions and prevents criticism of reviewers and readers.

We recommend to follow the suggestion of M.A. Kliever who proposed to divide the *Discussion* into six paragraphs [2].

6.1. Synopsis of the most relevant results—The first sentence should reiterate the overall purpose of the study. This should be followed by a concise and broad version of the evidence that supports this conclusion. This section should be concluded with the answer to the initial research purpose or hypothesis of the study.

6.2. Interpretation of own results—The second paragraph of the *Discussion* synthesizes the meaning of *your* results. Emphasize the particular significance or originality of each finding. State and stress any scientific advancement provided by these results. However, do not overstate the significance of your results. All conclusions must be supported by your data. Avoid self-promoting terms such as “*unique*”, “*highly-innovative*”, “*we are the first*”, and “*extremely valuable*”.

6.3. Interpretation of your data in the context of previous studies—In this section, describe how *your* results relate to those from *previous* studies. Provide a succinct description and appropriate references for past studies. Discuss how your results integrate

collectively or build upon past results. State if your study was larger or better powered than previous studies, as this adds strength to the argument. Similarly, if your study is more generalizable than previous studies or used more up to date technology, these points are worth making as they add strength to any claims you may make. Refer specifically to those studies that you provide in the *Introduction* of the manuscript. Also state and present negative results. Negative findings are a valuable component of the scientific literature because they force us to critically evaluate our current thinking, and fundamentally move us towards unabridged science [23]. Also note any discrepancies with previous studies. However, argue politely and try to elucidate the underlying reason. Results that are discordant with previous studies may be your most interesting findings.

6.4. Clinical or pathophysiological significance of the study—Discuss the clinical and/or scientific implications of your study. How will the results of your study impact patient care? Has your institution adopted your method as standard of care? How will the results impact on future technical developments or our understanding of fundamental biological processes?

6.5. Limitations—Clearly state the limitations of your study. Reviewers, who are experts in the field, will be aware of these drawbacks of your study, and a proactive description of these limitations will strengthen your manuscript. An open and clear description of all reasonable limitations of your study demonstrates that you, the author, are objective and unbiased [2].

You may wish to include a description of future studies that build on the results of the current study. Succinct description of future studies can demonstrate to the reviewer that you have thought carefully about the next steps.

6.6. Summary, conclusion and future directions—Summarize the most relevant finding of the study in this last sub-section. This paragraph should be no more than 2–3 sentences. One sentence should state the main conclusion, which should be the same as the *Conclusion* of the *Abstract*. If intriguing new scientific questions arose as a result of the study, an outlook for future studies can also be stated here.

7. References

Evaluate critically every scientific paper in the field for citation but select and provide only the most relevant references. Citing recent references highlights the relevance of your study. Format the citations and bibliography according to the journal's instructions. Do not exceed the maximum allowed number of citations.

Summary

The purpose of scientific writing is to communicate new knowledge in the form of a coherent, concise and logical document. Key to constructing a well-organized manuscript is defining the aim of the study very early in the writing process. If the remaining manuscript centers on this aim, a clear focus and common thread will be established throughout the manuscript.

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Key Points:

1. Mistakes in the preparation of scientific manuscripts lead to rejection
2. Scientific writing, like any important skill, can be learned
3. A well-developed approach will improve the quality of scientific writing
4. High-quality scientific writing is essential to communicate research results
5. A well-organized manuscript effectively communicates a hypothesis driven scientific study

Table 1:**Order and Content of a scientific radiological manuscript**

1.	Title
2.	Abstract
3.	Introduction
	3.1 Relevance: Statement of the issue
	3.2 Originality: Need for the study
	3.3 Purpose: Hypothesis to be tested
4.	Materials and Methods
	4.1 Study design and subjects
	4.2 Imaging techniques
	4.3 Image analyses
	4.4 Statistical analyses
5.	Results
	5.1 Descriptive statistics
	5.2 Procedural results
	5.3 Measures of data validity and reliability
6.	Discussion
	6.1 Synopsis of main findings
	6.2 Interpretation of your results
	6.3 Interpretation of your data in the context of the literature
	6.4 Clinical or pathophysiological implications
	6.5 Limitations
	6.6 Summary and future directions
7.	References

Adapted from M.A. Kliewer. [2].

Table 2:

Characteristics of various modes of data presentation

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

Adapted from F.L. Rosenfeldt et al. [16].

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