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Do Physicians Make Their Articles Readable for Their Blind or Low-Vision Patients? An Analysis of Current Image Processing Practices in Biomedical Journals from the Point of View of Accessibility

Bruno Splendiani · Mireia Ribera · Roberto Garcia · Miquel Termens

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Abstract Visual content in biomedical academic papers is a growing source of critical information, but it is not always fully readable for people with visual impairments. We aimed to assess current image processing practices, accessibility policies, and submission policies in a sample of 12 highly cited biomedical journals. We manually checked the application of text-based alternative image descriptions for every image in 12 articles (one for each journal). We determined whether the journals claimed to follow an accessibility policy and we reviewed their submission policy and their guidelines related to the visual content. We identified important features concerning the processing of images and the characteristics of the visual and the retrieval options of visual content offered by the publishers. The evaluation shows that the actual practices of textual image description in highly cited biomedical journals do not follow general guidelines on accessibility. The images within the articles analyzed lack alternative descriptions or have uninformative descriptions, even in the case of journals claiming to follow an accessibility policy. Consequently, the visual information of scientific articles is not accessible to people with severe visual disabilities. Instructions on image submission are heterogeneous and a declaration of accessibility guidelines was only found in two thirds of the sample of journals, with one third not explicitly following any accessibility policy, although they are required to by law.

Keywords Medical images · Publishing · Biomedical journals · Accessibility policies · Image description · Alternative text · Visual impairment · Disabilities · Publications

B. Splendiani · M. Ribera · M. Termens (✉)
Library and Information Science Department, University of Barcelona, Melcior de Palau, 140, 08014 Barcelona, Spain
e-mail: termens@ub.edu

B. Splendiani
e-mail: splendiani@ub.edu

M. Ribera
e-mail: ribera@ub.edu

R. Garcia
Computer Science and Industrial Engineering Department, University of Lleida, Campus Cappont, C. de Jaume II, 69, 25001 Lleida, Spain
e-mail: roberto.garcia@udl.cat

Introduction

Medical journals, intended primarily for specialists, have widened their audience with the advent of the World Wide Web. According to the Pew Internet Project estimations, between 75 and 80 % of American Internet users have searched for health-related information in online resources, including medical journals [1]. In line with the development of Medicine 2.0, defined as "The use of a specific set of web tools […] by actors in health care including doctors, patients, and scientists […] to personalize health care, collaborate, and promote health education" [2], currently, there is evidence that doctors and patients take decisions together [3, 4]. Many authors have highlighted the importance of patients accessing medical information through the web [5], and more specifically using online medical journals [3], since it enhances their insight and control over their health and health care. The access to medical information by blind people, partially sighted people, or other people with disabilities is an issue that has been stressed by previous authors. Lezzoni et al. noted the impact of information technologies "to enhance the knowledge, understanding and interpersonal connections of persons with disabilities on

multiple levels: from providing information in more accessible formats to facilitating access to reports about new treatments and assistive technologies for fostering 'virtual' peer support groups" [5]. There is evidence that users with disabilities regularly engage in searching for online health information [6, 7] and, compared with other e-patients, their medical treatment decisions have been influenced more significantly by the information they retrieve online [8]. As "limited attention has been paid to people with disabilities by health informatics researchers" [7], authors such as Purcell [9] and Marschollek et al. [10] emphasized the urgent need for the development of health information services usable by individuals with disabilities. However "this has not been widely adopted in practice" [11] and "very little scientific literature is fully understandable because mathematical formulas and critical graphical information is presently not directly accessible by any non-visual means" [12]. Disability associations such as Blind Citizens Australia [13] and the Royal National Institute of Blind People emphasize the great deal of information generated by major health care institutions that is not made accessible to people with print disabilities, namely people with a diagnosed learning disability, visual impairment, or physical disability who cannot access print in the standard way. They also suggest that health organizations should "have internal policies, procedures or technical solutions that ensure access to printed materials […] to blind and partially sighted people in preferred or alternative formats" [14]. Official guidelines concerning the treatment of health information for visually impaired people have been proposed by the Social Services of England [15]. The guidelines proposed by the Liverpool Central Primary Care Trust [16] suggest that all images related to health information should be accompanied by alternative text descriptions and be connected to the text to enable people to make sense of the information provided by figures.

Previous research on the accessibility of top medical journal websites [17, 18] focused on the evaluation of the website interface but excluded the content of the journals. During our research, we were unable to locate any other study referring to article content accessibility, except for one mention of the absence of such studies: "no previous work has analyzed accessibility to biomedical papers" [19]. To our knowledge, the accessibility to the content of biomedical papers has not yet been analyzed specifically in relation to the accessibility of the visual content.

In the context of our research, accessibility to the visual content conveyed by images in scientific articles must be guaranteed by providing text alternatives to them. A growing number of clinicians, educators, researchers, and other professionals use digital images in their work [20]; biomedical images are often referenced for clinical decision support, educational purposes, and research [21], and specialized collections of biomedical images are considered of value for research and training purposes [22]. Health care professionals regularly search for images published in medical journals to find specialized information [23]. Their effective retrieval of images "can be useful in the clinical care of patients, educations, and research" [24] and to complement the text-based search as a decision support technique [25].

People with visual disabilities often access information through assistive technologies, such as screen readers, in order to read aloud the digital textual content. The Web Content Accessibility Guidelines version 2 (WCAG 2.0) [26] and its equivalent ISO standard [27], the most widely adopted guidelines for web content, make the recommendation "Provide text alternatives for any non-text content so that it can be changed into other forms people need, such as large print, Braille, speech, symbols or simpler language." A text alternative is defined as "a text that is used in place of non-text content for those who cannot view the non-text content" [28].

When an image is embedded in a scientific paper, the function of the text alternative of the image content is usually solved by specific markup such as the alt attribute in the img element of HyperText Markup Language (HTML), which provides a short and essential description of the image (Fig. 1).

If the article is provided in PDF, the function of the text alternative is solved by the *alternate text* attribute. PDF also allows the inclusion of another attribute named *actual text* to replicate the text included as image in textual form (Fig. 2).

However, the function of the text alternative can be accomplished by any textual description presented within the context of the paper, such as an image caption, surrounding/adjacent text, and other mentions of the image (Fig. 1). Alternative text or textual descriptions may allow the image to be located, read, and understood by readers with visual disabilities under the following conditions:

- The text description is accessible by assistive technologies.
- The text describes properly the content of the image, at least providing essential information.
- The text openly refers to the image.
- The information conveyed by different descriptions is not redundant.

General recommendations and guidelines concerning textual description of images have been proposed by national associations for people with vision impairment. Guidelines from the Organización Nacional de Ciegos Españoles for DAISY Books [30] include general recommendations on textual descriptions for charts, diagrams, maps, illustrations, and photographs and focus on the function of these visual materials. Curiously, for photographs, these guidelines recommend not including any alternative text in order to avoid disturbing the flow of reading. Recommendations on how to create alt text depending on the image function in e-books

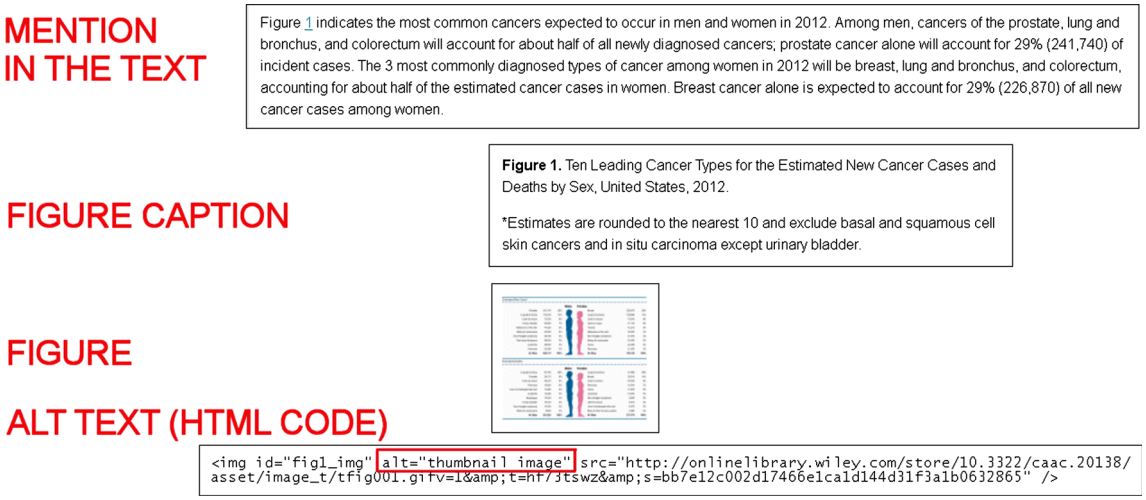

Fig. 1 Textual descriptions related to a figure in the HTML version of a medical paper. Source: [29]

have been suggested by the Royal National Institute of Blind People [31], and also general recommendations for alternative text in [32], but they are not very detailed. A very useful resource targeting general public books is the image repository of Load2Learn, a consortium created by RNIB and Dyslexia Action (https://load2learn.org.uk/hierarchy/browse/2/139/Images), which contains about 2,500 images already described as examples, but only two images are addressed to students in the higher education level.

The investigation on the application of proper text-based alternative descriptions to images in biomedical articles could also provide additional benefits. Previous research has demonstrated that many popular Internet search engines make use of alternative texts for image indexation and in particular "give higher importance to the terms present in Alt text" [33]. Besides improving image retrieval, the description of images also allows visual information to be adapted to different access modes, such as listening to an audio version of the article or reading it on the small screen of mobile devices, a media rapidly expanding in patient education material, medical education, and research projects [34]. A text-based alternative description of images could be especially useful in a mobile context of access, as "many users can be billed for download volume so images might be turned off to save costs" [35].

Clearly written and detailed descriptions benefit not only readers with disabilities, but also sighted readers [36]. Finally, alternative descriptions of images could have a positive impact on everyday working life of physicians, for example when an HTML version of a paper is sent by email and email clients block image content due to privacy concerns: unless users give explicit permission, they can only see the textual alternatives.

According to the described context, the description and retrieval of the information embedded in images in general, and in biomedical images in particular, will probably be an issue of primary importance in the next few years. A correctly applied image alternative text will provide the following results:

1. The availability of academic articles will be extended to a wider audience. People with visual disabilities will be able to access the content of the articles and people with learning disorders such as dyslexia or attention deficit hyperactivity disorder will also benefit from the image description as a multimodal support for its understanding. These people include doctoral students and researchers. A better adaptation of the content to different contexts of access adds convenience and flexibility to the conditions of work and research for every reader.
2. The publishers will fulfill the accessibility regulations (included in legislation in many countries, such as Section 508 in USA [37]) and comply with its social responsibility.
3. The authors will benefit from better findability of their articles and greater citability. The textual description of

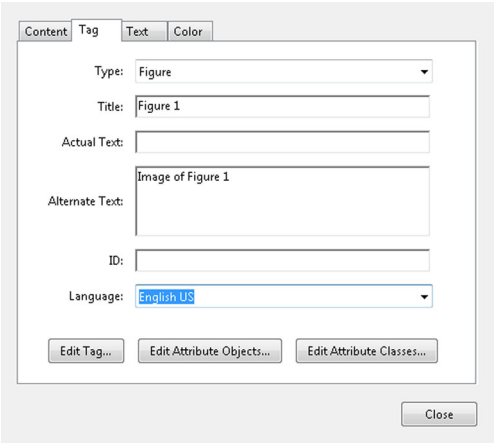

Fig. 2 Adobe Acrobat options for inserting text alternatives to images in a PDF document

images improves the retrieval of the article using search engines, fosters retrieval of academic articles, and makes it easier to share academic research.

4. Researchers publishing work in accessible formats respect the principles of emancipatory research recommended by some editors, "which require researchers to make their findings available for the benefit of the disabled people's civil rights movement" [16].

Objective

Our aim is to assess the current image processing practices in highly cited biomedical journals and the correspondence between the accessibility policy and the submission guidelines in the application of textual image descriptions.

Methods

Twelve journals in the field of biomedicine with the highest impact factor according to the ranking of the Journal Citation Report (Science Edition 2011, 26 September 2012) were identified. Apart from these journals, we included in the selection two multidisciplinary journals that publish articles in the field of biomedicine (*Nature* and *Science*) because of their high impact factor and their standing in the research community. The full list of journals selected in our research is provided in Table 1. The journals are ordered according to the impact factor as it was found in the Journal Citation Report (Science Edition 2011).

Each journal was analyzed and documented as follows:

1. We assessed the application of alternative text to images in the first research article published in 2012. The full list of the articles selected is provided in Table 2.

We did not consider tables, as they can be made accessible by other ways, nor did we consider mathematical formula. The only exception to this condition was that of tables defined as "images" in the article, which were analyzed as the rest of figures (Fig. 3).

We also analyzed supplementary material, which we define as any complementary content attached to a paper in order to support it that can be downloaded independently from the article and may consist of text, tables, figures, and/or references.

Articles are provided in (X)HTML and PDF formats, and some journals offer an enhanced version of PDF, called "interactive PDF," which is encapsulated in a Flash application. This visualization of PDF hinders accessibility features and was therefore excluded from our analysis.

In the future, with the increasing use of e-readers and e-books, articles could possibly move to other formats such as EPUB, MOBI, or IBook. We did not analyze these formats because this article focuses on current practices which involve mainly PDF and HTML. However, the current EPUB version, EPUB3, has adopted the best practices of the DAISY Consortium, an organization supporting inclusive publishing for people with print disabilities, and is "increasingly seen as the format that is most suitable for both commercial exploitation and meeting accessibility needs" [38]. This current version of the standard (EPUB3) supports features for improving accessibility, including the ability to integrate prerecorded speech synchronized with the text and other media overlays and images in scalable vector graphics (SVG) format with fallbacks to other formats. Furthermore, EPUB3 provides several mechanisms for including textual alternative descriptions to images: the alt text attribute, the figure and the figcaption elements, and the aria-describedby attribute. EPUB3 also supports MathML. However, currently, not all devices or reading software support all the accessibility features, in particular SVG or video [39], nor do all devices make user personalization available [40].

For each article, we manually checked the application of text-based alternative descriptions to the images in the body of the article and, if applicable, in supplementary content. We checked the accessibility of the images (graphs, visualizations, pictures, etc.) for compliance with guideline 1.1 of the Web Content Accessibility Guidelines 2.0 [26]. We primarily considered images that illustrate, explain, or complete the text content of the article but also included other types of images, such as the photograph of the author, that appeared within the PDF document. We excluded noncontent images such as the logo of the journal, image links to related content, advertisements, and icons.

The accessibility of the images in PDF documents was manually verified by detecting the presence of the alternate text or actual text attributes in the image tag. In both cases, the content was reviewed manually to check its suitability.

2. We reviewed the accessibility policy of the journal, as stated in the journal policies on the publisher's website, where available.
3. We reviewed the submission policy of the journal, as stated in the journal policies on the publisher's website, to see whether it made specific recommendations related to the accessibility of images.

    a. We studied the guidelines for authors regarding image submission in the articles, as stated on the journal's website. We examined the instructions concerning the submission of figures as they appeared in the general submission guidelines for authors and other instructions provided by the publisher (if available), such as

Table 1 List of medicine-related high impact factor journals selected

Journal title	ISI JCR subject(s)	Impact factor (ISI JCR)
CA: A Cancer Journal For Clinicians	Oncology	101.78
New England Journal Of Medicine	Medicine, general and internal	53.298
Annual Review of Immunology	Immunology	52.761
Nature Reviews Molecular Cell Biology	Cell biology	39.123
Lancet	Medicine, general and internal	38.278
Nature Reviews Genetics	Genetics and heredity	38.075
Nature Reviews Cancer	Oncology	37.545
Nature	Multidisciplinary science	36.28
Nature Genetics	Genetics and heredity	35.532
Nature Reviews Immunology	Immunology	33.287
Cell	Biochemistry, cell biology	32.403
Science	Multidisciplinary science	31.201

specific documents on how to prepare artwork for submission. The documentation examined included instructions concerning technical guidelines for image submission and in some cases tips or "frequently asked questions" related to them.

b. In the submission instructions, we also looked for references about the specific treatment of figures targeted to users with special needs (for example, use of specific colors for color-blind readers or high contrast for low-vision readers).

c. Together with technical requirements of the visual content (type, resolution, size, etc.), we reviewed the instructions concerning other aspects of images such as title, caption, and mentions in the text and options on how to present them on the web (thumbnail with pop-up, contextual navigation, and others).

4. We reviewed the retrieval options for visual information on the journal's website. We checked whether the online journals offered a specific retrieval system for images and whether it used image descriptions.

Results and Discussion

Analysis of Use of Alternative Text in 12 Articles

The images contained in the 12 articles selected were analyzed in detail to review the actual implementation of textual alternatives to the figures. Specifically, in the analysis of articles, we focused on the proper application of the alt text attribute of the image (in the HTML version of the paper) and alternate text or actual text attributes of the image tags (in the PDF version). When assessing the need for these attributes, we took into consideration the content of the image captions and the text surrounding the image.

The Alt Text Tag in HTML

In the HTML and PDF versions of the papers reviewed, we detected a general incorrect use and even the absence of the alt text tag for images (Table 3).

In nine papers, the alt text was redundant (five of them used the title of the figure as alt text) or uninformative (e.g., "thumbnail image," "full-size image," "20 K," "Fig. 1," etc.). In the *New England Journal of Medicine* article, the alt text attribute was empty, and in the papers of the *Annual Review of Immunology* and *Cell*, there was no alt text attribute in the img tag. In the papers of *Nature Reviews Molecular Cell Biology* and *Nature Reviews Genetics*, the alt text included apologies for the lack of application of a suitable alt text, accompanied by the invitation for users to contact the publisher if they are unable to access the image ("Unfortunately, we are unable to provide accessible alternative text for this. If you require assistance to access this image or to obtain a text description, please contact npg@nature.com"). We also checked the application of alt text in the full versions of the images (Fig. 4), offered by all the articles reviewed. The results of this analysis were very similar to the alt text application in images inside the text version of the journal: four did not have alt text and seven had redundant or uninformative alt text (they used the title of the paper or the title of the figure). In one case, the image was in Flash with missing alt text, according to the rendering of Jaws v.11 screen reader.

Alternative Descriptions in PDF

The analysis of the PDF version of the articles showed that the alternate text for images in PDF is absent in 11 journals (Table 3). The PDF versions in these journals were untagged, meaning that they lacked the elements defining the logical structure of the document that enable their correct use by

Table 2 List of papers selected from the journals for the evaluation of alt text application

Selected articles
R. Siegel, D. Naishadham, A. Jemal cancer statistics, 2012. *CA: A Cancer Journal For Clinicians*, 62(1) (2012), pp. 10–29.
J. L. Mega, E. Braunwald, S. D. Wiviott, J-P.Bassand, D. L. Bhatt, C. Bode et al. Rivaroxaban in patients with a recent acute coronary syndrome. *New England Journal of Medicine*, 366(1) (2012), pp. 9–19.
R. M. Steinman. Decisions about dendritic cells: past, present, and future. *Annual Review of Immunology*, 30(1) (2012), pp. 1–22.
P. Codogno, M. Mehrpour, T. Proikas-Cezanne. Canonical and non-canonical autophagy: variations on a common theme of self-eating? *Nature Reviews Molecular Cell Biology*, 13(1) (2012), pp. 7–12.
T. Enden, Y. Haig, N. E. Kløw, C. E. Slagsvold, L. Sandvik, W. Ghanima et al. Long-term outcome after additional catheter-directed thrombolysis versus standard treatment for acute iliofemoral deep vein thrombosis (the CaVenT study): a randomised controlled trial. *The Lancet*, 379(9810) (2012), pp. 31–38.
M. R. Branco, G. Ficz, W. Reik. Uncovering the role of 5-hydroxymethylcytosine in the epigenome. *Nature Reviews Genetics*, 13(1) (2012), pp. 7–13.
B. Keith, R. S. Johnson, M. C. Simon. HIF1α and HIF2α: sibling rivalry in hypoxic tumour growth and progression. *Nature Reviews Cancer*, 12(1) (2012), pp. 9–22.
A. Prindle, P. Samayoa, I. Razinkov, T. Danino, L. S. Tsimring, J. Hasty. A sensing array of radically coupled genetic /'biopixels/'. *Nature*, 481(7379) (2012), pp. 39–44.
G. A. Challen, D. Sun, M. Jeong, M. Luo, J. Jelinek, J. S. Berg et al. Dnmt3a is essential for hematopoietic stem cell differentiation. *Nature Genetics*, 44(1) (2012), pp. 23–31.
H. Renz, P. Brandtzaeg, M. Hornef. The impact of perinatal immune development on mucosal homeostasis and chronic inflammation. *Nature Reviews* Immunology, 12(1) (2012), pp. 9–23.
T. Rausch, D. T. W. Jones, M. Zapatka, A. M. Stütz, T. Zichner, J. Weischenfeldt, N. Jäger, et al. Genome sequencing of pediatric medulloblastoma links catastrophic DNA rearrangements with TP53 mutations. *Cell*, 148(1–2) (2012), pp. 59–71.
B. B. Aldridge, M. Fernandez-Suarez, D. Heller, V. Ambravaneswaran, D. Irimia, M. Toner, S. M. Fortune. Asymmetry and aging of mycobacterial cells lead to variable growth and antibiotic susceptibility. *Science*, 335(6064) (2012), pp. 100–104.

assistive technologies and show the meaning of elements inside it (images, tables, etc.) [42].

The *Cell* paper was only one in which the PDF version was tagged and the images had an alternative text, although the alternative descriptions were uninformative: for the first figure, the description (alternate text attribute) was "image of Fig. 1"; for the second figure, "image of Fig. 2"; and so on. Apart from the *alternative text* attribute, PDF format allows the inclusion of the actual text attribute to write in textual form the text included as image. We did not detect the presence of the actual text attribute for any image.

Alternative Description for Images in Supplementary Content

We found that four journals had images in the supplementary content file; all of them without alternative descriptions of images.

Journal Accessibility Policy

Having detected the incorrect application of alternative descriptions in HTML and PDF attributes, we checked whether the publishers claimed to follow accessibility guidelines for the journals analyzed.

Of the 12 journals analyzed, 8 have an accessibility policy statement on their website. In all of them, accessibility statements are presented as a publisher statement and they are not mentioned in the submission guidelines for authors. The subscription of an accessibility policy statement implies a commitment to make the content of the journal accessible to people with disabilities. Even journals that do not make such a statement should bear in mind that they are used in government-funded organizations such as hospitals, universities, and libraries, which are subject to national accessibility laws.

In the accessibility statement of *CA: A Cancer Journal For Clinicians* and *The Lancet*, we found a reference to compliance with official accessibility legislation in the USA (508 guidelines) and references to WCAG2. As WCAG are the

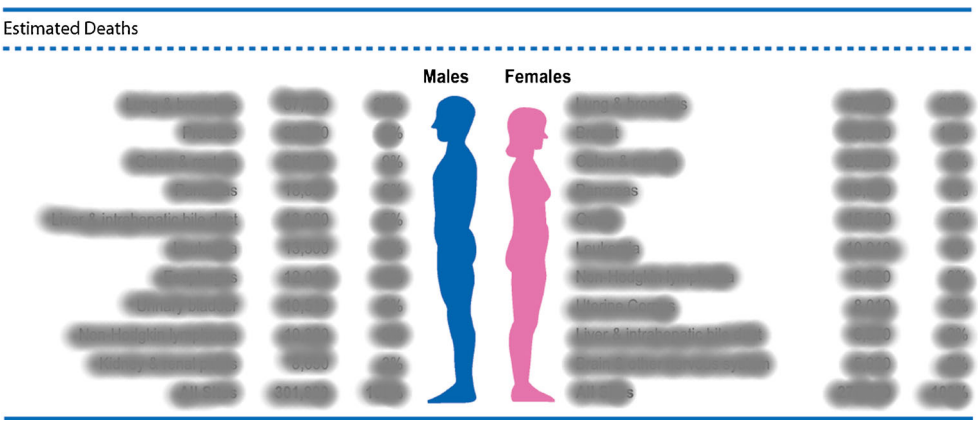

Fig. 3 Example of a table with decorative elements defined as a figure in an article. Image edited by the authors. Source: [29]

Table 3 Application of alternative text for the images in the HTML version of the paper, the full-size version of the image, and the PDF version of the paper

Journal	Alternative text of images in article page (HTML)	Alternative text of full-size version images (HTML)	Alternative text of images in PDF format
CA-Cancer J Clin	Incorrect	Absent	Absent
New Engl J Med	Absent	Absent	Absent
Annu Rev Immunol	Absent	Absent	Absent
Nat Rev Mol Cell Bio	Incorrect	Incorrect	Absent
Lancet	Incorrect	Incorrect	Absent
Nat Rev Genet	Incorrect	Incorrect	Absent
Nat Rev Cancer	Incorrect	Incorrect	Absent
Nature	Incorrect	Incorrect	Absent
Nat Genet	Incorrect	Incorrect	Absent
Nat Rev Immunol	Incorrect	Incorrect	Absent
Cell	Absent	Absent	Absent
Science	Incorrect	Incorrect	Incorrect

most widespread and standardized guidelines, we will refer to them throughout the article.

In relation to the use of alternative content for images, the accessibility statement of six journals (all of them published by the Nature Publishing Group) provided an explicit reference to it (Fig. 5). We also found an invitation to request help to access images without suitable alternative text in the alt text tag of the images (Fig. 6).

We contrasted the policy guidelines with the actual application of alt attributes in the articles (Table 4), taking into account that as the timespan from article submission to article publication is long, we were unable to determine whether this policy was already stated at the time of submission of the analyzed articles.

Apart from the application of textual alternatives to the visual content of the image, other accessibility issues related to images and text inside images should be taken into account in order to ensure the best image "readability" and interpretation from all types of readers, including readers with vision impairments.

On the use of color, WCAG 2.0 recommends not using color as the only visual means of conveying important information ("color coding"). For example, if an image of a chemical compound identifies the chemical elements present only through the colors and numbers used in the diagram, color-blind readers do not receive the same information as other readers.

The contrast between the background and foreground is another important issue to take into account in creating images and text. To guarantee optimal visualization and reading to low-vision and color-blind readers, WCAG 2.0 suggests following a luminosity ratio standard of 1 to 4.5 for the main text and 1 to 3 for large-scale text. In general, a minimum contrast should ensure that a black and white printout can be read. This guideline benefits sighted readers as well as vision-impaired ones, as it is common to read papers printed on black and white or in e-ink readers with no colors.

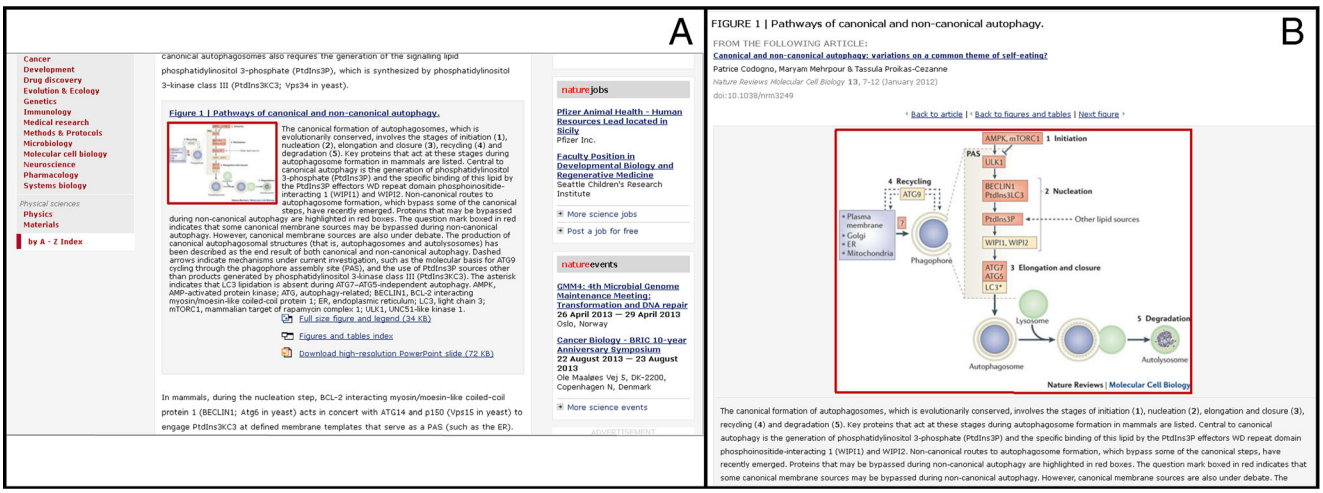

Fig. 4 Example of different presentations of the image in a journal: **a** presentation inside the html version of the article; **b**, full (enlarged) version of the image in another HTML page. Source: [41]

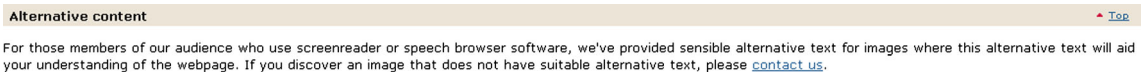

Fig. 5 Example of reference to the application of alternative content in *Nature's* accessibility policy. The paragraph says: "For those members of our audience who use screen reader or speech browser software, we've provided sensible alternative text for images where this alternative text will aid your understanding of the webpage. If you discover an image that does not have suitable alternative text, please contact us." Source: [41]

An optimal contrast ratio can be obtained by specific color combinations such as black/white, navy/white, cream/dark brown, yellow/black, and similar schemes. Combinations using red and green can create barriers to viewers with protanopia and deuteranopia (the most common types of partial color blindness) because they are unable to distinguish these two colors. For example, in figures of fluorescence staining and DNA chips, each channel is usually marked in red and green. Biologists with color blindness cannot distinguish which part is labeled with green and which part with red. We found specific guidelines referencing the proper use of color and contrast in images in two journals that will be analyzed in a later section of this article.

Font size is another central accessibility issue for people with low vision. The WCAG 2.0 guidelines encourage the use of a minimum 12 pt size for body text or text in images. To ensure best readability for readers with low vision and cognitive impairments and readers using small screens, the sans-serif font family and especially the font faces Verdana, Helvetica, and Arial are generally considered more legible than serif fonts such as Times New Roman. This recommendation is a common best practice for readability, even for sighted users, when screen resolution is not very good [43].

Other relevant issues related to images are file format, dimensions, and resolution, though WCAG 2.0 does not recommend any specific format or dimensions and just calls for high-resolution images without giving any specific number of pixels.

The Submission Policy of the Journal

All the journal websites offer a section specifying their submission policy for papers, including a subsection explaining how to submit images in papers.

As stated in the previous section, the accessibility issues related to images are image alternative descriptions, color and contrast, font type and size of text (and other labels in images), file format, dimensions, and resolution of the image. These aspects were hardly mentioned explicitly in the image submission guidelines for authors, with the exception of occasional references to specific reader barriers and the legibility of the image. In this section, the submission policies of the journals will be analyzed according to the technical requirements for image submission, the textual information related to the image, and the possible consequences of these policies regarding accessibility/readability for readers with special needs.

We found that *CA: Cancer Journal For The Clinicians*, the *New England Journal of Medicine*, and *The Lancet* were listed as following the "Uniform Requirements for Manuscripts Submitted to Biomedical Journals" (URM) [44]. The URM are a set of guidelines issued by the International Committee of Medical Journal Editors that standardize the ethical code and the preparation and formatting of manuscripts. They include specific requirements for figure submission, such as image quality and size, use of symbols and colors in specific illustrations, and general guidelines concerning the legends (the descriptive text of the image) for figures.

The analysis of the image submission instructions for authors given by the journals showed a general lack of common policies in requirements but fairly similar instructions on procedures. All journals accepted submission of images in a separate file not embedded in the manuscript text file, which was in fact the preferred option in all but one. The majority of the journals recommended sending the legend within the text file. Eight journals reserved their right to modify or redraw the image if it does not meet the specification for publication or the house style. Usually, the possible in-house manipulation of the image concerned a change of size to fit the journal's format

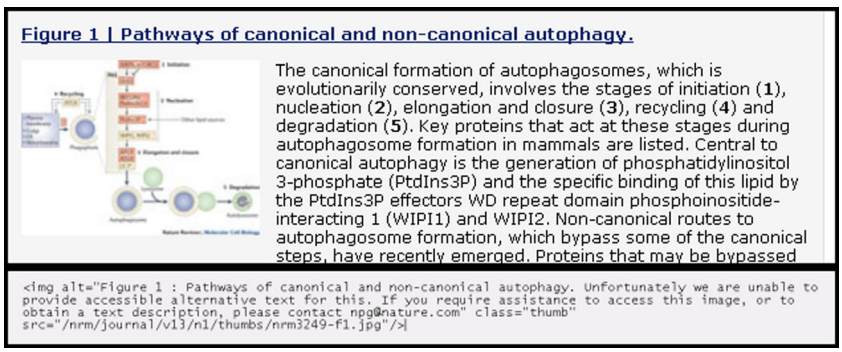

Fig. 6 Example of alt text including an invitation to request an accessible description for an image in a paper published by the *Nature* journal. The alt text says: "Unfortunately we are unable to provide accessible alternative text for this. If you require assistance to access this image, or to obtain a text description, please contact npg@nature.com." Source: [41]

Table 4 Comparison between the subscription to accessibility policies and the actual application of alternative text to images

Journal	Accessibility policy	Reference to the use of alternative text for images	Alternative text of images in article page (HTML)	Alternative text of full-size version images (HTML)	Alternative text of images in PDF format
CA-Cancer J Clin	✓		Incorrect		
New Engl J Med					
Annu Rev Immunol					
Nat Rev Mol Cell Bio	✓	✓	Incorrect	Incorrect	
Lancet	✓		Incorrect	Incorrect	
Nat Rev Genet	✓	✓	Incorrect	Incorrect	
Nat Rev Cancer	✓	✓	Incorrect	Incorrect	
Nature	✓	✓	Incorrect	Incorrect	
Nat Genet	✓	✓	Incorrect	Incorrect	
Nat Rev Immunol	✓	✓	Incorrect	Incorrect	
Cell					
Science			Incorrect	Incorrect	Incorrect

and a general image polishing and enhancement of legibility and color style. In most cases, the enhancement referred to schematic figures (Fig. 7) or medical illustrations.

Technical Requirements in Image Submission

The first aspect we analyzed in image submission was the technical requirements such as format, dimensions, color, and resolution that can affect their accessibility. For each topic, we highlight possible references to the specific treatment of figures targeting users with special needs.

Format of the Image

All journals accept images in *PostScript* (PS) and/or *Encapsulated PostScript* (EPS) format and in *Tagged Image File format* (TIFF) (Table 5). The high acceptance of TIFF and EPS as preferred figure file formats shows a great affinity with the findings of Jackson et al. [46] in radiology journals. This finding suggests that the image file formats most accepted by health science journals have remained generally the same for over a decade. It seems that the high acceptance of PostScript is due to the fact that it allows vector graphics (graphs, chart, etc.) and text to be resized irrespective of resolution and preserves the editability of the figure from the original version. TIFF, Joint Photographic Experts Group (JPEG), and Photoshop format (PSD) are generally preferred for photographic images and illustrations (raster graphics). Six journals accept PDF, eight accept Power Point (PPT), and seven accept the Adobe Illustrator format (AI). Other accepted formats are GIF, BMP, XLS, CRD, and DOC(X), although the submission of these formats is restricted by specific conditions, such as for specific types of images, and they are not considered as preferred formats for final submission. *The Lancet* accepts SVG as a submission format for figures. SVG is one of the few image formats that support accessibility features [47]. The inclusion of images in a PDF file is accepted for submission by six journals.

Generally speaking, the formats most suitable for image publication are those which do not lose quality due to compression and retain all information that was created by the capture device, including the color management information. In the case of authors obtaining images from Picture Archiving and Communication System, it is recommended to save the image in uncompressed TIFF format (if the option is available) [48]. Although PSD, AI, and EPS are also considered a good choice for publication, TIFF is preferred because it uses lossless compression, is an open standard format, and is widely adopted. Though the most commonly used version of JPEG allows a smaller image file size than TIFF, it applies a compression process that causes the loss of some visual quality and cannot be restored. The inclusion of images in PPT, XLT, and DOC is not recommended either because it causes a loss of quality.

From the point of view of accessibility, vector images are preferred to raster images because they maintain their resolution despite zooming and resizing. EPS and PDF formats can contain scalable vector images and are usually recommended for line art and combinations of photos and labeling. They also support the inclusion of information in the form of metadata and possibly allow searches in the content of the image, including text. SVG format, for example, allows the inclusion of text descriptions for each logical component of the image and for the image as a whole, which may be rendered on screen as speech or as Braille using assistive technologies. However, SVG and other vector graphics are best suited to diagrams and maps than photographic images, as SVG does not have an option for gradient meshes, which are helpful for creating photographic images.

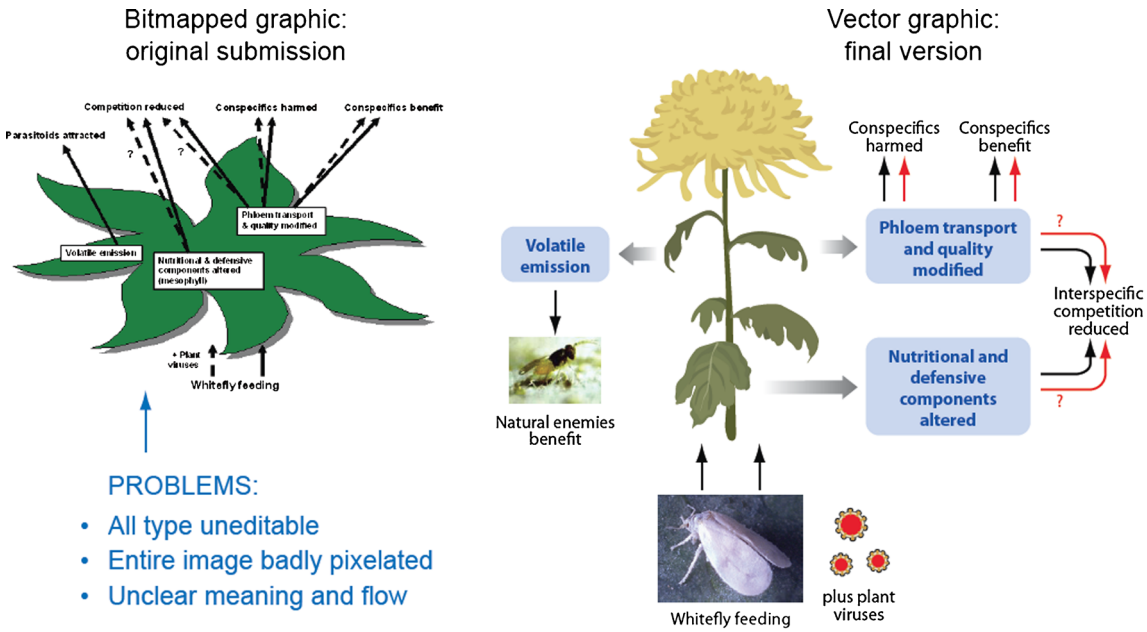

Fig. 7 Example of before and after an in-house graphic enhancement of a schematic illustration. Source: [45]

A better resolution of the image and the ability to explore the figure at increased magnification levels would benefit many readers and allow them to focus on small details of the image, as in the case of *detailed* anatomic *images*.

Image Dimensions

Generally, the guidelines concerning the image dimensions were related to the standard PDF format used in the publication of the manuscript, in order to fit the image in the width of one or two columns. The majority of the guidelines required a minimum size for image submission, starting from a minimum final width of approximately 3.5 in. for half-page figures and 8.5 in. for full-page figures. The stated image height ranged from 7.9 to 11 in. (Table 6).

Small dimensions could negatively affect the ability of low-vision readers in particular, and of all readers in general, to properly understand the content of the image, especially in

Table 5 Digital image formats accepted by the journals, categorized according to the format type: raster images, vector images, and other formats that can embed images

Journal	Digital image formats accepted														
	Raster image					Vector image				Other formats					
	TIFF	JPEG	PSD	GIF[a]	BMP[a]	EPS	PS	SVG	AI	PPT	PDF	XSL[a]	CRD[a]	DOC(X)[a]	Not specified
CA-Cancer J Clin	✓					✓									
New Engl J Med	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	
Annu Rev Immunol	✓		✓		✓	✓		✓	✓	✓	✓	✓	✓		
Nat Rev Mol Cell Bio	✓	✓	✓			✓			✓	✓		✓	✓		
Lancet	✓	✓	✓			✓	✓	✓	✓	✓	✓				
Nat Rev Genet	✓	✓	✓			✓			✓	✓		✓	✓		
Nat Rev Cancer	✓	✓	✓			✓			✓	✓	✓	✓	✓		
Nature	✓	✓		✓		✓	✓			✓	✓				✓
Nat Genet	✓					✓	✓		✓						✓
Nat Rev Immunol	✓	✓	✓			✓			✓	✓		✓	✓		
Cell	✓	✓				✓					✓				
Science	✓					✓	✓				✓			✓	

[a] Limited support

the printed version of the paper. Authors are therefore asked to submit images of a size that makes them accessible to all readers.

Color of the Image

The journals generally expressed the preference for figures to be submitted in color, especially if colors were useful to identify specific parts of the image (Table 7).

In relation to accessibility, the guidelines of *Nature Genetics* suggest providing optimal contrast with the use of color. In particular, their recommendation of the colors blue and yellow rather than red and green is based on the most common color blindness: deuteranopia. The guidelines of *Nature Genetics* also make a specific reference to readers with color blindness ("Authors are encouraged to consider the needs of color-blind readers" and suggested that primary data should be recolored using "color-safe combinations such as green and magenta, turquoise and red, yellow and blue or other accessible color palettes" [49]).

The proper use of color and contrast in images allows users with colorblindness to correctly perceive images and improves access to images for every user in poor lightning conditions and on mobile devices with a limited color palette and ones that use gray scales (such as some types of e-reader devices).

Resolution of the Image

In most journals, the minimum resolution required was 300 dots per inch (in *Nature*, the minimum was 150 dpi, and in *Science*, it was 50 dpi for the initial submission) (Table 8). In ten journals, the resolution requirements depend on the type of images; in the others, it depends on the submission step, as higher resolution is requested for revised figures submitted after peer review. The preferred resolution ranged from 266 to 600 dpi for color images, from 266 to 600 dpi for grayscale images, and from 600 to 1,200 dpi for line art images.

A low resolution could negatively affect access to the image by low-vision readers. Especially at high levels of magnification, raster images can lose their readability due to pixilation. As explained in the section dedicated to formats, vector formats could be a solution for avoiding the loss of resolution when images are displayed at high magnification levels. In the publishing industry, a resolution of 300 dpi is commonly considered the minimum acceptable standard for ensuring quality for the print reproduction of figures [50].

Size and Name of the Image File

The size of image files was specified in the guidelines of six journals (Table 9). For the submission, small files of less than 2–3 MB were generally recommended. *Cell* indicated 20 MB as the maximum size for the image file.

Five guidelines required figure numbers, based on the order of appearance in the text, to be included in the name of the image file. *Nature* and *Science* recommended including the author surname in the file name, as for example "smithfig1." *The Lancet, Nature*, and *Science* recommended including the file extension. *Science* did not accept figures broken into parts and suggested not dividing files into parts such as "smithfig1a.ps" (Table 9).

This can be relevant to accessibility because file name is the simplest textual data associated with the image for its description and can be read aloud by screen readers for blind people. In addition, the image file name is an information used by search engines (such as Google and Bing) to identify the content of a figure and establish its relevance for retrieval.

File size is directly proportional to image quality and the balance between the two factors depends on the intended use of the image. If the figure is for publication, limitations on file size could force the author to compress high-quality images, causing a loss of resolution.

Textual Information Related to the Image

Text is the preferred alternative to visual content for visual disabilities as it can be perceived as audio with the help of a text-to-speech engine or rendered in preferred presentations for low-vision readers. We therefore recollected guidelines concerning the textual information related to the images.

Image Title and Legend

The title and the legend (also known as the caption, the brief explanation usually appearing immediately above, beneath, or adjacent to an image) are the most common texts for the content definition and description of a figure. They convey visual information in a textual way and can help blind people to locate the image and access its content. They can also be useful for interpreting the figures for readers with cognitive impairments or even readers with low visual literacy (people who have limited skills in making meaningful interpretations of visual stimuli). In general, the information provided by the caption completes the visual information, gives instructions on how to read it properly, and enriches the experience of all readers with a complementary way to understand the figure. When the legend describes properly the content of the image and provides extensive information on the image, the use of the alt text attribute could be redundant.

Six out of 12 journals recommended the inclusion of a concise title for the images; for example, the *New England Journal of Medicine* suggested a title of eight words maximum (Table 10). The guidelines of *Nature* and *Cell* suggest

Table 6 Image dimensions recommended by the journals

Journal	Image dimensions		
	Minimum width	Maximum width	Maximum height
CA-Cancer J Clin	6.75 in. (17.14 cm)		
New Engl J Med	4 in. (10.26 cm)	6.5 in. (16.51 cm)	
Annu Rev Immunol		6.33 in. (16.07 cm)	7.9 in. (20.06 cm)
Nat Rev Mol Cell Bio	3.93 in. (10 cm)		
Lancet	3.93 in. (10.7 cm)		
Nat Rev Genet	3.93 in. (10 cm)		
Nat Rev Cancer	3.93 in. (10 cm)		
Nature	3.5 in. (8.9 cm)	7.2 in. (18.3 cm)	9.72 in. (24.7 cm)
Nat Genet			
Nat Rev Immunol	3.93 in. (10 cm)		
Cell		8.5 in. (21.59 cm)	11 in. (27.94 cm)
Science		8.5 in. (21.59 cm)	11 in. (27.94 cm)

Table 7 The table shows whether the journal specifies any preference on the submission of color images and recommendations on the use of color and contrast

Journal	Color and contrast			
	Color image preferred	Recommendations on the use of color	Accessibility related recommendation	Specific recommendations on color and contrast
CA-Cancer J Clin	✓	✓	✓	Gray shading in figures may not reproduce well for publication and should be avoided. Do not use overall background shading in figures. Do not use gray-shaded bars in graphs—use bars with solid, open, or hatched fill.
New Engl J Med				
Annu Rev Immunol	✓	✓	✓	For plots with multiple lines/symbols, use color to distinguish elements. Also apply a consistent color scheme across multiple illustrations.
Nat Rev Mol Cell Bio				
Lancet	✓	✓	✓	Use different colors to improve legibility. Use solid contrasting colored lines wherever possible.
Nat Rev Genet	✓	✓	✓	
Nat Rev Cancer	✓	✓	✓	
Nature	✓	✓	✓	Color, when used as an identifying tool, should be distinct. Layering type directly over shaded or textured areas and using reversed type (white lettering on a colored background) should be avoided where possible.
Nat Genet	✓	✓	✓	Where possible use blue and yellow rather than red and green to provide optimal contrast for the color vision of all readers. Authors are encouraged to consider the needs of color-blind readers. Figures should be on a white background and should avoid excessive boxing, unnecessary color, spurious decorative effects (such as three-dimensional "skyscraper" histograms) and highly pixelated computer drawings.
Cell		✓	✓	Use bold, solid colors that will reproduce well. Avoid similar shades of gray.
Science		✓	✓	Linear adjustment of contrast, brightness, or color must be applied to an entire image or plate equally.

Table 8 Recommended resolutions for the submission of different image types: color, grayscale images, and line art

Journal	Recommended Image resolution			
	Color (dpi)	Grayscale (dpi)	Line art (dpi)	Specific minimum resolution for initial submission (dpi)
CA-Cancer J Clin	300–600	300–600	1,200	
New Engl J Med	266	266	1,200	
Annu Rev Immunol	300	30	300	
Nat Rev Mol Cell Bio	300	600	1,200	
Lancet	300	300	300	
Nat Rev Genet	300	600	1,200	
Nat Rev Cancer	30	600	1,200	
Nature	300	600	1,200	150
Nat Genet	300	600	1,200	
Nat Rev Immunol	300	600	1,200	
Cell	300	500	1,000	
Science	400	400	600–1,200	50–300

including the image title at the beginning of the legend. We found in 11 journals that the image title was included at the beginning of the legend. Only in the figures of the *Annual Review of Immunology* article did we find the title not at the beginning of the caption, but included as a title tag inside the figures themselves (Fig. 8).

All guidelines encourage authors to apply a more descriptive legend of the image, complementing its title. This text should be included in the manuscript text file, though *The Lancet* also offers the possibility of submitting it in a separate MS Word file. The guidelines of *Nature* and *Cell* suggest making the legend brief.

The specification for the length of the legend varies greatly, ranging from the general recommendation to keep it succinct (and give more detail discussion for the text) to a maximum of 200 words (Table 10). *Nature* recommends a different number of words depending on whether the papers include details of methods (in which case the legend could use up to 100 words and must not relate to methods) or not (in which case the legend could use up to 300 words).

Table 9 Preferences of the journals about the size and the name of the image file to be submitted

Journal	Preferred image file size	Image file name
CA-Cancer J Clin		Figure # (i.e., Figs. 1 and 2, etc.), numbered consecutively according to the order in which they are cited in the text
New Engl J Med		
Annu Rev Immunol		Ensure the file name includes the correct figure number
Nat Rev Mol Cell Bio	Less than 2–3 MB	
Lancet		Examples: FIG1.TIF = figure 1 in TIFF format; SC4.EPS = scheme 4 in EPS format; PL2.TIF = plate 2 in TIFF format
Nat Rev Genet	Less than 2–3 MB	
Nat Rev Cancer	Less than 2–3 MB	
Nature		CorrespondingAuthorSurname_fig1.jpg
Nat Genet	Submission file: less than 1 MB Publication file: high-resolution file	
Nat Rev Immunol	Less than 2–3 MB	
Cell	1–2 MB 20 MB (maximum size)	
Science		Examples of acceptable file names: smithtext.doc. smithtextfigs.prn, smithfig1.eps, smithtextfigs.ps, smithms.ps, smithsupp.pdf

Table 10 Recommendations related to title and legend requirements and their suggested length

Journal	Image title		Image legend	
	Required	Length	Required	Length
CA-Cancer J Clin	Not specified	Not specified	✓	Succinct
New Engl J Med	✓	8 words maximum	✓	150 words maximum
Annu Rev Immunol	✓	Concise	✓	Not specified
Nat Rev Mol Cell Bio	Not specified	Not specified	✓	200 words maximum
Lancet	Not specified	Not specified	✓	Not specified
Nat Rev Genet	✓	Concise	✓	200 words maximum
Nat Rev Cancer	✓	Concise	✓	200 words maximum
Nature	Not specified	Brief	✓	Each legend, 100–300 words maximum; total legends, 500–800 maximum
Nat Genet	Not specified	Not specified	✓	Not specified
Nat Rev Immunol	✓	Concise	✓	200 words maximum
Cell	✓	Brief	✓	Not specified
Science	✓	Not specified	✓	200 words maximum

Some guidelines offer advice about the content of the legend (Table 11): for example, the *New England Journal of Medicine* suggests including "relevant clinical information, including a short description of the patient's history, relevant physical and laboratory findings, clinical course, response to treatment (if any), and condition at last follow-up" [52]. This journal also asks authors to "describe and clearly indicate all modifications, selective digital adjustments or electronic enhancements in all digital images" [53], in order to ensure veracity of submitted images. If the image includes any labeled structure, four guidelines recommend describing and explaining them in the legend. If the images consist of a multi-panel, the same four guidelines recommend including callouts corresponding to each panel (A, B, C, etc.), *Cell* specifies that "each figure legend should have a brief title that describes the entire figure without citing specific panels followed by a description of each panel" (see the section "Multi-Panel images"). Four guidelines specify that keys

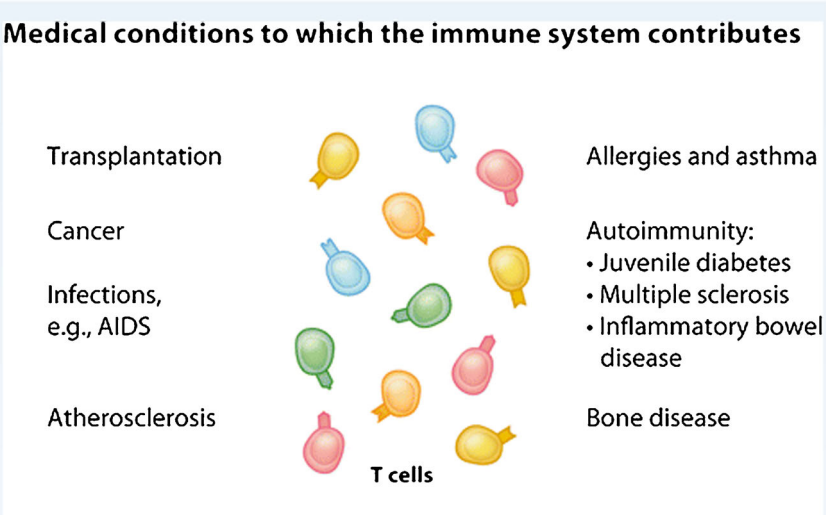

Fig. 8 Example of a figure with the title tag included in the figures and not in the caption. Source: [51]

Figure 1 The immune system contributes to various medical conditions, either to protect against disease, including with vaccination and immune therapies, or to contribute to pathology and symptoms. At the bottom of the figure are areas being studied more recently for their immune involvements: atherosclerosis and bone disease. All these conditions either are becoming more frequent or, in the case of a disease such as cancer, are decreasing very little. Also, new infections always evolve, most notably AIDS, which was not known when I began my career.

Table 11 Specific information requested in legends of images: references to labeled structures; references to nomenclature, abbreviations, arrows, and other symbols and letters; specifications of particular data types; and specification of supporting items in supplementary information

Journal	Specific information requested in legend			
	Labeled structures	Nomenclature, abbreviations, arrows, symbols, letters, and units	Specific data types	Supporting items to supplementary information
CA-Cancer J Clin	✓	✓		
New Engl J Med	✓	✓		
Annu Rev Immunol			✓	
Nat Rev Mol Cell Bio				
Lancet				
Nat Rev Genet				
Nat Rev Cancer				
Nature		✓		
Nat Genet		✓		
Nat Rev Immunol				
Cell	✓	✓		✓
Science	✓	✓	✓	

and additional explanations should be added in the legend for the nomenclature, abbreviations, arrows, symbols, letters, and units used in a figure.

Two guidelines offer advice on legends about images presenting specific data types, such as pooled data, schemes, and structural chemical formulas. The *Annual Review of Immunology* and *Science* refer to specific types of image such as schemes (e.g., structural chemical formulas) or complex equations. For example, the *Annual Review of Immunology* specifies that "equations and chemical structures that cannot be typeset in one or two lines are considered art. If possible, such equations should be submitted in math-friendly software applications such as LaTeX or MathType" [54]. *Cell* also suggests mentioning any supporting items in the Supplemental Information in the legend "(i.e., 'see also Figure S1')".

Labeling

Labels such as text, arrows, and symbols are features of an image that are directly related to its content. Their function is to tag, point to, or indicate a specific part of the figure as the focus of attention.

We found that an important recommendation about image labels is to maintain the labels separated from the figure, in order to make them easier to edit. Three guidelines explicitly recommend ensuring that text and other elements in the figures remain editable (Table 12). The guidelines of the *New England Journal of Medicine,* the *Annual Review of Immunology*, and *The Lancet* suggest providing two versions of the figure, one with the appropriate labels (text, arrows, etc.) and one without them, or alternatively creating the figure with layers, one with visuals and one with labels. The visual would be used as it is, while the publisher would make label adjustments to adapt to house style or sizing changes. The *New England Journal of Medicine* asks for the inclusion of an arrow indicating the top of the image in each original figure. *Science* recommends avoiding labels that are "not absolutely necessary for understanding the figure" and explaining them in the legend. In the case of labels with very small typography (e.g., units for scale bars) or data presented in small tables or histograms, *Nature* and *Nature Genetics* recommend presenting the information briefly in the text of the legend. For letters and labels, a sans-serif font (Arial or Helvetica) and font sizes between 7 and 9 pt were recommended by four guidelines (Table 12). The guidelines of the *Annual Review of Immunology* and *Nature* recommend a font size no smaller than 5–6 pt in order to ensure readability in print. Three journals express preferences to capitalize the first label letter (in particular for the labeling of panels). Six journals refer to the use of standard abbreviations and units in the image.

Some journals illustrate the attributes that should be taken into account in the creation of a figure (Fig. 9). *Science* refers to some general principles of information visualization for creating figures ("In laying out information in a figure, the objective is to maximize the space given to presentation of the data" and "Avoid wasted white space and clutter") [55].

From the point of view of accessibility, labels are a source of extra information related to images, so they can be used as a support for interpreting the images. The possibility of storing semantic annotations in image formats such as SVG could allow machines to interpret them not only for efficiently searching [57] and visualization [58], but also for richer description by assistive technologies.

Table 12 The table shows whether the journal specifies the preference for labels separated from the figure submitted, the recommended font size, and the font family of the image's labels

Journal	Image labeling		
	Editable labels (separated from the figure)	Font size	Font family
CA-Cancer J Clin		6–9 pt	Arial or Helvetica
New Engl J Med	✓		
Annu Rev Immunol	✓	7–9 pt (6 pt min)	Sans-serif font (Helvetica, Arial, Myriad Pro)
Nat Rev Mol Cell Bio			
Lancet	✓		
Nat Rev Genet			
Nat Rev Cancer			
Nature		7–8 pt (5 pt min)	
Nat Genet			Helvetica or Arial
Nat Rev Immunol			
Cell			Helvetica
Science		7–9 pt (5 pt min)	Sans-serif font (Helvetica preferred)

Multi-Panel Images

Multi-panel images create additional barriers to access and interpretation by people with visual or cognitive impairments because of the complexity of visual representation of different images grouped in the same figure (Fig. 10).

Multi-panel images usually require specific treatment for tagging and referencing them in the legend (see the section "Image Title and Legend") in order to make clear the localization, order, and relations between different images in the same figure. A good accessibility recommendation would be to minimize their use to clearly defined cases.

Seven of the reviewed guidelines offer specifications concerning multi-panel figures (Table 13). Generally, they suggest not submitting single panels as individual files. Many journals suggest marking the sequence of the panels with a capital letter, avoiding if possible the use of subpart letters (e.g., A, B, C, D, and E instead of A, B, C(a), C(b), and C(c)).

Some journals recommend organizing panels so that the different parts are clearly recognizable and the essential details of the figure are visible on the printed page at the smallest size.

References in the Text

As mentioned in the "Introduction," section, callouts to the image from the article text could include relevant information related to the image content, which may be useful for all kinds of readers to locate, read, and understand the content.

We found that the guidelines of two journals (*A Cancer Journal for Clinicians* and the *Annual Review of Immunology*) require authors to call out the figures in the article text (Table 14). However, with the exception of those of *The Lancet* and *Nature Reviews Cancer,* all the papers reviewed referred to all the images in the text, suggesting that this is now a common practice adopted by authors of scientific articles.

Supplementary Material

Five journals have specific guidelines for images in supplementary material. All of them demand a different file for the submission of supplementary material, including images. In many cases, the guidelines state that images in supplementary material will not be edited (and in one case even not even revised) by the publisher, so they ask the author to submit images "clearly and succinctly presented." In a few cases, the journal offers some advice about the content of supplementary material: for example, the *Annual Review of Immunology* talks about "Article-relevant material that is costly, difficult, or impossible to include in the printed volume, including figures that will not reproduce well in print." However, the article should "does not depend for comprehensibility on the online supplement" [60]. The main differences between guidelines for images in supplementary material compared with the guidelines for images in the article concern are as follows:

- The numeration of images, which should be independent from the numeration used in the print version of the paper
- The legend, which should be written directly beneath the figure
- The file size, which should be smaller than that of images in the body of the article because of limitations of space

In *Nature* [61], authors are required to submit a text summary (no more than 50 words) that describes the contents of

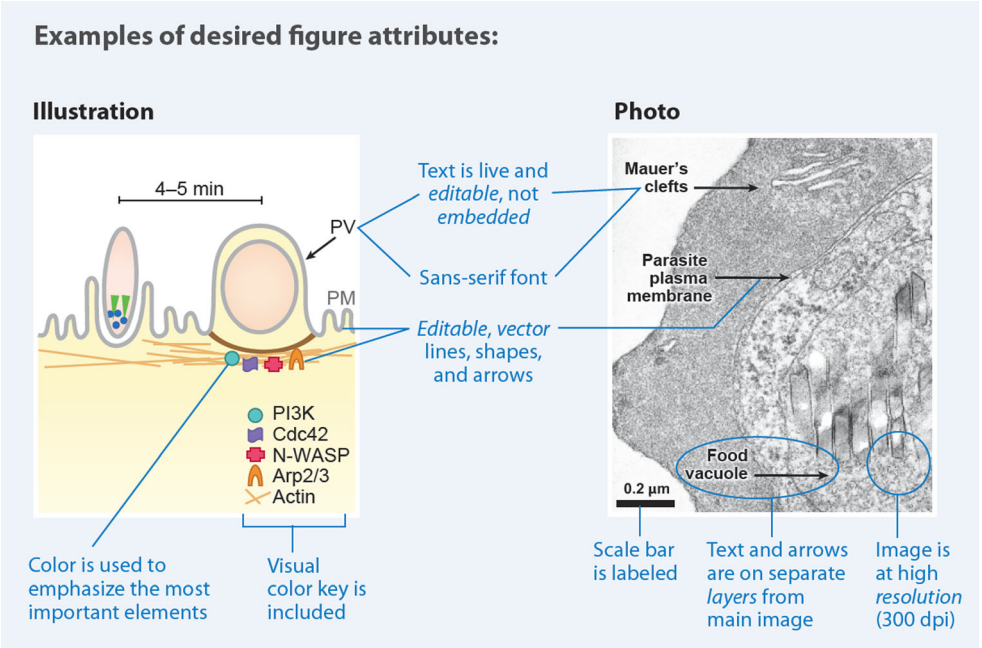

Fig. 9 Example of desired figure attributes. Source: [56]

the supplementary files. If more than one image is submitted together in one PDF, "the description should indicate how many figures and what type of text are contained within the file, and provide a general description of what the figures collectively show."

Image Presentation

In all of the journals' websites, images are presented in the article to which they belong. The images are offered to readers in HTML and PDF version in all the papers analyzed. While images in the PDF version are always presented without options for visualization, variations were identified in the options of presentation of images in the HTML versions (Table 15).

Five journals offered an enlarged version of the images in a pop-up window. In one case (*New England Journal of Medicine*), the pop-up was written in Flash: this technology introduces specific accessibility barriers and requires several techniques that are not easy to implement for making image content readable by assistive technologies. All journals showed the enlarged version including the caption of the image and two journals had a zoom option to enlarge the images, but not always reaching the 200 % recommended zoom on accessibility guidelines. The *Annual Review of Immunology* presented a contextual menu showing a summary of images in the article (Fig. 11). *Cell* and *The Lancet* accessed through the ScienceDirect interface also offered a similar menu for images (Fig. 12).

Eleven journals offer the option to download the image directly in a Power Point slide (Table 15). Different image

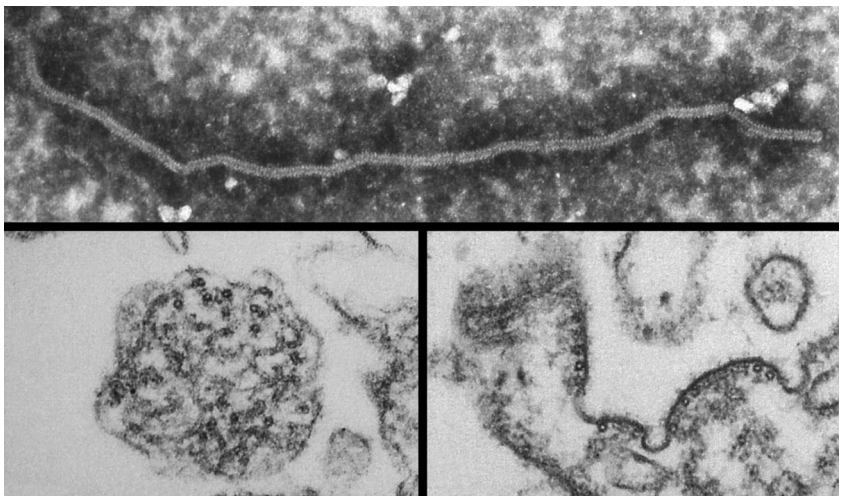

Fig. 10 Example of a multi-panel image. Source: [59]

Table 13 Specifications on the submission of multi-panel images

Journal	Multi-panel image
CA-Cancer J Clin	Files with individual panels not accepted. Figures with multiple parts should be labeled and referred to as (a), (b), (c), etc. If there are several parts to a figure, label them as 3.4(a), 3.4(b), 3.4(c), etc.
New Engl J Med	Multi-panel ICMs labeled as panel A, panel B, etc.
Annu Rev Immunol	Refer to parts of the figure as (a), (b), (c), etc. If further distinction is needed, subparts can be described as (left), (right), (top), (middle), and (bottom). In addition to individual figure files, provide a PDF file containing all figures.
Nat Rev Mol Cell Bio	Not specified
Lancet	Not specified
Nat Rev Genet	Not specified
Nat Rev Cancer	Not specified
Nature	Unnecessary figures and parts (panels) of figures should be avoided: data presented in small tables or histograms, for instance, can generally be stated briefly in the text instead. Avoid unnecessary complexity, colouring, and excessive detail.
	Figures should not contain more than one panel unless the parts are logically connected; each panel of a multipart figure should be sized so that the whole figure can be reduced by the same amount and reproduced on the printed page at the smallest size at which essential details are visible.
	For figures with more than one part, label parts "a," "b," etc. and create a PDF scan of the whole figure to show preferred layout. On each composite, include the corresponding author's name, *Nature* reference number, when known, and the figure number.
Nat Genet	Figures should not contain more than one panel unless the parts are logically connected; each panel of a multipart figure should be sized so that the whole figure can be reduced by the same amount and reproduced on the printed page at the smallest size at which essential details are visible.
Nat Rev Immunol	Not specified
Cell	Do not send figure panels as individual files. Each figure legend should have a brief title that describes the entire figure without citing specific panels followed by a description of each panel.
Science	Avoid subpart labels within a figure part; instead, maintain the established sequence of part labels [e.g., use A, B, C, D, and E instead of A, B, C(a), C(b), and C(c)].

presentation options have consequences on different kinds of readers accessing the content of the image. Blind people or people with low vision may find it difficult to recognize a visual context change, such as a new window popping up. The zoom option is a useful tool for low-vision readers.

Image Retrieval

Image retrieval can benefit from the application of proper text-based alternative descriptions of images in biomedical articles. The words used in the legend, for example, are used in some cases by the system retrieval as descriptors of image content to match the user request.

The analysis of the retrieval system of the journals' website showed that only the *Annual Review of Immunology* explicitly offers the search option using words in figure legends. This option is integrated in the advanced search interface (Fig. 13).

The *New England Journal of Medicine* search interface looks for keywords in the whole article (legends included) and offers the option of restricting the results to images (Fig. 14).

An alternative to the retrieval system of each journal is provided by ScienceDirect, which allows searches for images (and video) by legend text and whole article text in *The Lancet* and *Cell* (Fig. 15).

SpringerImages [63] offers more advanced options such as searching by image type or color. Outside the publishing world, the Google image interface allows queries to be made using images as examples [64], but this option was not offered by any of the retrieval systems considered.

In addition to the explicit options for retrieval offered in the search interface, we performed tests to detect the actual ability to retrieve the information included in legends, image labels, and alternative texts through global searches (i.e., in article text or keywords). The results showed (Table 16) that while all the journals retrieved words in legends, none retrieved words in either alternative text or labels of figures.

Conclusions

This study provides a general overview of the current status of the image submission process and the accessibility/readability of images in highly cited biomedical (and biomedical-related) journals. The results highlight three main issues in the policies and practices of the journals analyzed.

First, a third of the journals reviewed have no accessibility policy to ensure that images are accessible to all types of readers. Regarding the accessibility of images, we found that half the papers adopting an accessibility policy do not make explicit reference to the use of alternative descriptions for images on their website.

Second, even when papers are published in journals with a specific accessibility policy, alternative descriptions for images are not used properly (uninformative, redundant or empty alt text) or are not applied at all (lack of alt text or lack of alternative descriptions for images in PDF tags).

Third, the requirements for image submission are not standardized. Our analysis shows moderate variations in the

Table 14 Recommendations in journal guideline to call out figures in the article text and images referred to in the text of the articles analyzed

Journal	Recommendation to call out all figures in article text	Images called out in the text of the articles analyzed
CA: A Cancer Journal for Clinicians	✓	8 out of 8
New England Journal of Medicine	Not specified	3 out of 3
Annual Review of Immunology	✓	3 out of 3
Nature Reviews Molecular Cell Biology	Not specified	2 out of 2
Lancet	Not specified	0 out of 1
Nature Reviews Genetics	Not specified	2 out of 2
Nature Reviews Cancer	Not specified	3 out of 4
Nature	Not specified	4 out of 4
Nature Genetics	Not specified	8 out of 8
Nature Reviews Immunology	Not specified	3 out of 3
Cell	Not specified	7 out of 7
Science	Not specified	4 out of 4

submission instructions concerning the technical requirements of the visual features of images (dimensions, color, resolution, etc.), the image format, the image labeling, and the requirements for the textual information related to the image. Only a quarter of the journals reviewed follow guidelines for manuscript submission proposed by the "Uniform Requirements for Manuscripts Submitted to Biomedical Journals" and no other reference to the adoption of a standard/common/general policy for paper submission was found. Only a few journals offered tips in their guidelines on how to describe the content of images in their captions, consisting of general references to the length of the caption, the inclusion of relevant clinical information, and the inclusion of key referencing arrows, abbreviations, symbols, and letters used in the image. Only very few guidelines made reference to the use of requirements related to accessibility, such as color contrast, font size, and image format, in order to ensure the best accessibility to the visual information by readers with special needs.

As a secondary issue, we detected that the presentation of images on the web is not particularly conceived for access by readers with special needs. For example, only two journals offer a zoom presentation mode with a much enlarged version of the images. Five journals show enlarged images in pop-up windows, which might be annoying and confusing for readers using assistive technology. In one journal, the pop-up window was created in Flash, with an incorrect implementation of accessibility features.

Table 15 Alternative image presentations in HTML articles

Journal	Alternative image presentations in HTML articles					
	Enlarged version		Visualization options		Download options	
	Pop-up with caption	On another page with caption	Contextual menu for image navigation	Zoom	Download as PPT	Download in PDF file
CA-Cancer J Clin	✓	✓			✓	✓
New Engl J Med	✓	✓		✓	✓	✓
Annu Rev Immunol	✓	✓	✓	✓	✓	✓
Nat Rev Mol Cell Bio	✓	✓	✓		✓	✓
Lancet	✓	✓	✓		✓	✓
Nat Rev Genet		✓			✓	✓
Nat Rev Cancer		✓			✓	✓
Nature		✓			✓	✓
Nat Genet		✓			✓	✓
Nat Rev Immunol		✓			✓	✓
Cell	✓		✓			✓
Science		✓			✓	✓

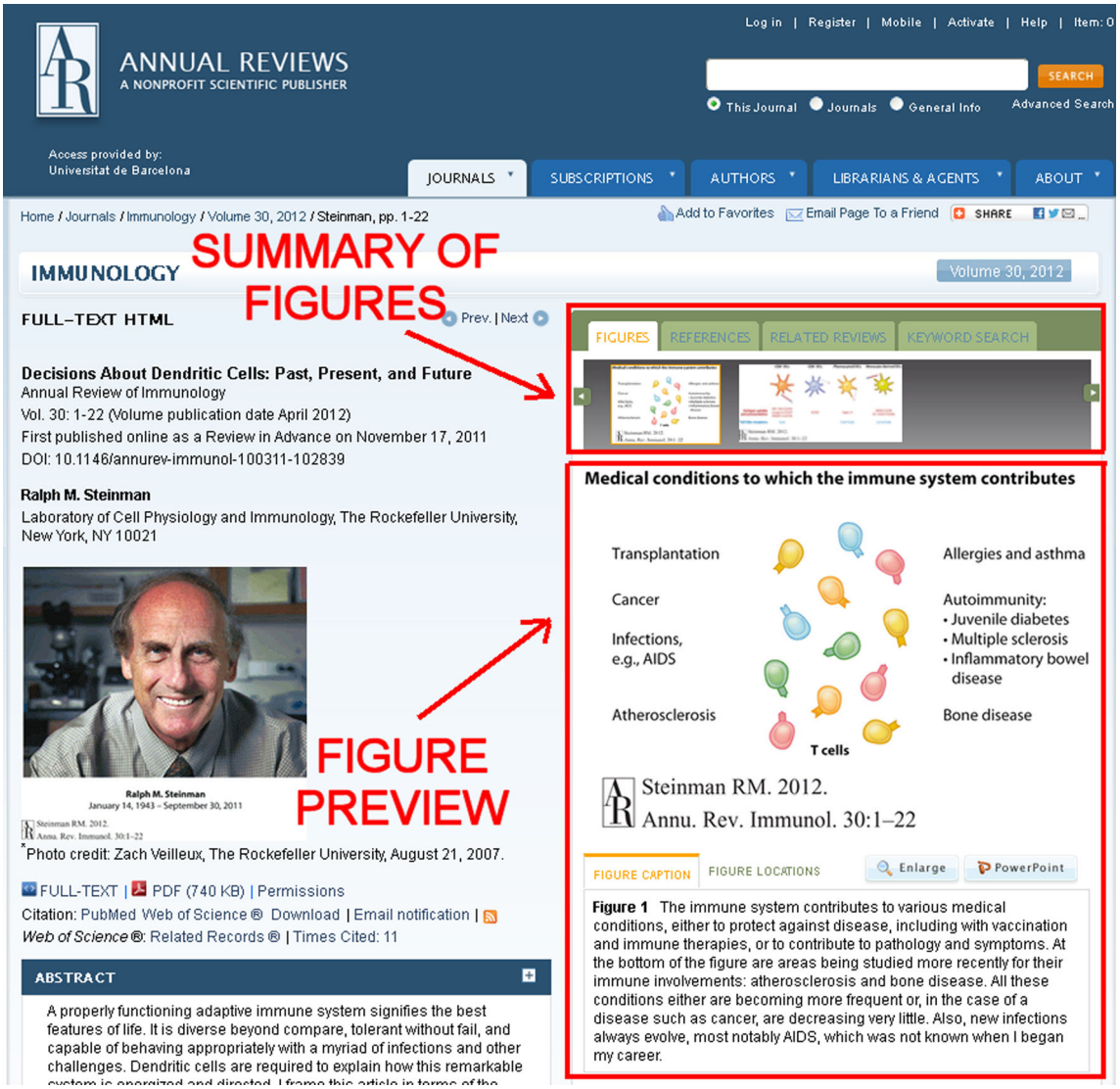

Fig. 11 Example of an image menu and image preview on the same page as the article. Source: [51]

Fig. 12 Example of an image menu on the same page as the article. Source: [62]

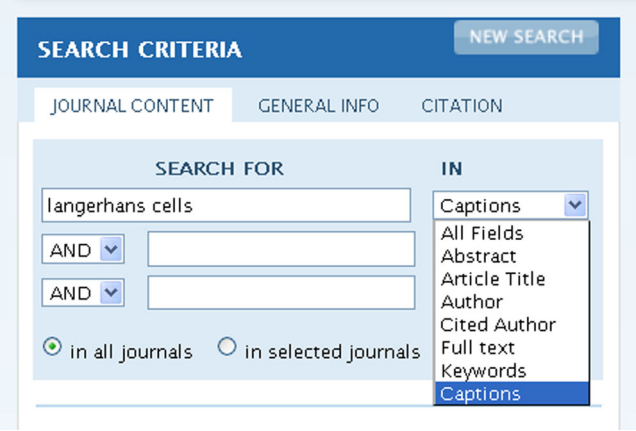

Fig. 13 Example of a search page showing the search option for keywords inside the image captions. Source: http://www.annualreviews.org/search/advanced

Finally, the information in the images only partially benefits the whole article, as alt text and labels are not exploited in the retrieval systems of the journals.

Limitations of the Study

The objective of our study was to provide a general overview of the practices and policies in the process of image submission and the application of accessibility policies concerning the description of images in biomedical scientific publications. Due to long time spans between article submission and article publication, there may be a minor mismatch between active policies applicable to the analyzed articles and the policies analyzed. Our conclusions are also extracted from a limited sample of biomedical journals and articles which were selected for their high impact factor and therefore their prominent position in scientific research. These journals should be exemplary not only in their content, but also in their respect for the medical ethos and users' rights, disability rights included. It is essential that the outstanding research they provide should be accessible to all researchers, without regard to limitations due to physical impairment, mobile access, and slow connections. Although the sample is limited, the study shows a general tendency that we consider reasonable to extend to other scientific journals in the field. Further research is needed.

Future Work and Opportunities

We do not wish to limit this study to a description, but also to suggest opportunities for improvement. We therefore present a set of general suggestions for publishers as a starting point for further work in the improvement of accessibility of images in biomedical scientific papers. We are currently working on observing clinicians in their use of images during research in order to better understand the filing and the tagging process

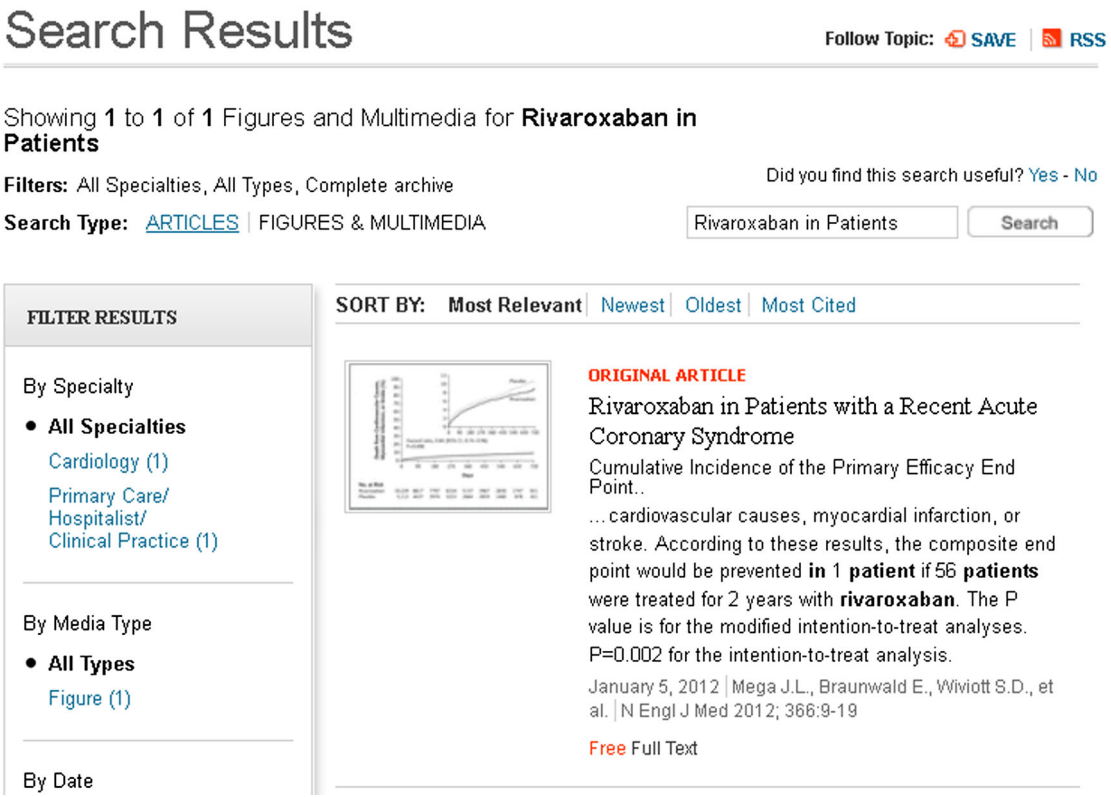

Fig. 14 Example of a search results page only showing retrieved images (*New England Journal of Medicine*)

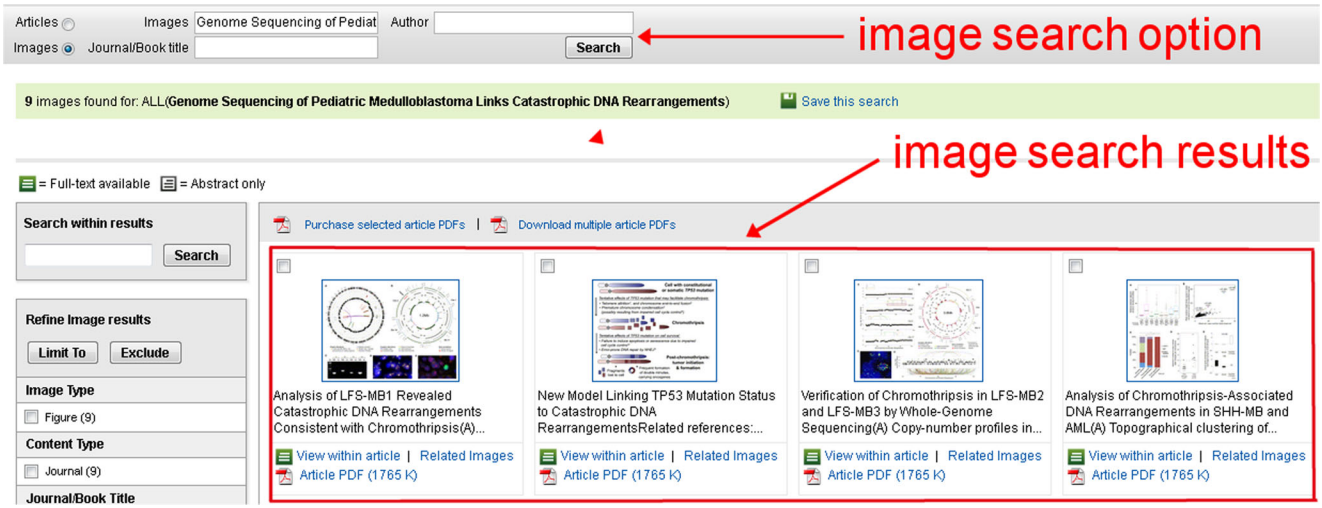

Fig. 15 Search option and results for images in ScienceDirect

during the whole workflow from image creation to dissemination and to make practical recommendations for improving accessibility.

Suggestions on Policy

The adoption of accessibility policies could be a starting point to guarantee access to content for people with disabilities, including access to visual content in scientific articles.

These policies could be standardized by journals and written as common policies for image submission, leading to better rules and facilitating the work of authors and editors. The Uniform Requirements for Manuscripts Submitted to Biomedical Journals [44] currently include requirements for figure submission and could be a good framework for new and improved rules. These requirements are intended, among others, to aid authors to meet high-quality standards in image resolution and legibility and consistency in style by effective use of contrast and symbols in figures (letters, numbers, scale markers, metric units, abbreviations, etc.), but could be easily extended to cover features such as scalability, recommendations for alternative text, and descriptions.

The incorporation in the submission guidelines of references, tips, and examples on how to make the images accessible and how to provide alternative descriptions for images could encourage authors to meet these requirements. These references could be accompanied by the explanation of the aspects to highlight to ensure the best access to visual information (such as color contrast, font size and image file name) and could perhaps be complemented with an explanation of the barriers that prevent readers with special needs from accessing the content of images.

Table 16 Search options of the retrieval systems offered by the online version of the journals analyzed. None of the journals offers the search by figure labels or by example image

Journal	Explicit scope of searches offered by search interfaces							
	In article title	In article text	In abstract	In keywords	In legend	In image labels	By image type/color	By example image
CA-Cancer J Clin	✓	✓	✓	✓				
New Engl J Med	✓	✓	✓		✓			
Annu Rev Immunol	✓	✓	✓	✓	✓			
Nat Rev Mol Cell Bio	✓	✓			✓			
Lancet	✓	✓	✓	✓	✓			
Nat Rev Genet	✓	✓			✓			
Nat Rev Cancer	✓	✓			✓			
Nature	✓	✓			✓			
Nat Genet	✓	✓			✓			
Nat Rev Immunol	✓	✓			✓			
Cell	✓	✓	✓		✓			
Science	✓	✓	✓		✓			

To raise awareness among authors of the importance of an appropriate textual description of an image, journals should promote a retrieval system explicitly covering keywords in legends, alt text tags, and semantic labels.

Suggestions on Practices

Actions aimed at ensuring a good implementation of accessibility policies could include the limitation of accessible formats for image submission and the integration of the insertion of alt text for images in the workflow of manuscript submission, with automatic validation steps. Publishers would be responsible for the correct application of alternative descriptions of images and collaborate with authors to make the images accessible.

Regarding the presentation of the images in the papers, a better zoom option (200 % minimum) and high quality at high magnification rates should be offered for readers with low vision. Good legibility on small screens is also a must for mobile applications.

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