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RESEARCH ARTICLE

Analysis and Correction of Inappropriate Image Duplication: the *Molecular and Cellular Biology* Experience

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ABSTRACT We analyzed 960 papers published in *Molecular and Cellular Biology* (MCB) from 2009 to 2016 and found 59 (6.1%) to contain inappropriately duplicated images. The 59 instances of inappropriate image duplication led to 41 corrections, 5 retractions, and 13 instances in which no action was taken. Our experience suggests that the majority of inappropriate image duplications result from errors during figure preparation that can be remedied by correction. Nevertheless, ~10% of papers with inappropriate image duplications in MCB were retracted (~0.5% of total). If this proportion is representative, then as many as 35,000 papers in the literature are candidates for retraction due to inappropriate image duplication. The resolution of inappropriate image duplication concerns after publication required an average of 6 h of journal staff time per published paper. MCB instituted a pilot program to screen images of accepted papers prior to publication that identified 12 manuscripts (14.5% out of 83) with image concerns in 2 months. The screening and correction of papers before publication required an average of 30 min of staff time per problematic paper. Image screening can identify papers with problematic images prior to publication, reduces postpublication problems, and requires less staff time than the correction of problems after publication.

KEYWORDS duplications, image, publication

Recently we reported an analysis of 20,000 papers from 40 biomedical journals, published over a period of 20 years, in which approximately 1 in 25 papers contained at least one inappropriately duplicated image (1). The frequent occurrence of inappropriate image duplication in published papers is a major concern, because it reduces the integrity and credibility of the biomedical literature. At one end of the spectrum, inappropriate image duplications caused by simple errors in constructing figures raise concerns about the attention given to the preparation and analysis of data, while at the other end of the spectrum, problems resulting from deliberate image manipulation and fabrication indicate misconduct. Increased awareness of such image duplications has resulted from postpublication peer review websites such as PubPeer and discussions on social media (2). Whereas simple errors found in published studies can be addressed by a correction, deliberate image manipulation or fabrication can lead to retraction of a paper (3).

Inappropriate image duplications undermine the quality of the literature and can necessitate a considerable investment of time and resources by authors and journals when discovered after publication of a scientific paper. However, we presently lack

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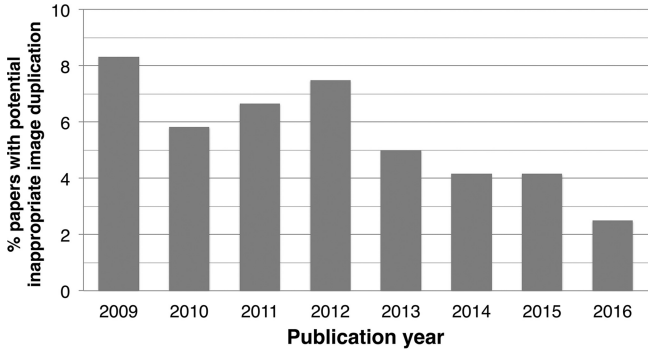

FIG 1 Percentage of papers published in ASM's *Molecular and Cellular Biology* containing potential inappropriate image duplication. Inspection of manuscripts prepublication started in 2013.

information on the causes for the inappropriate image duplications, since neither cause nor intent can be reliably inferred from inspecting images in published articles. We categorized inappropriate image duplications as simple duplications (category 1), shifted duplications (category 2), or duplications with alterations (category 3), with category 1 most likely to result from honest error, while categories 2 and 3 have an increased likelihood of resulting from outright falsification or fabrication (1). A follow-up analysis of a subset of these papers found that several variables, including academic culture, peer control, cash-based publication incentives, and national misconduct policies, were significantly associated with duplications in categories 2 and 3, suggesting that these variables might affect scientific integrity (4). In the present study, we sought to determine whether an investment by a journal to scan images in accepted manuscripts prior to publication could resolve image concerns in less time than is required to address these issues after publication.

The mission of the journals published by the American Society for Microbiology (ASM) is to publish high-quality scientific articles that have been rigorously peer reviewed by experts and evaluated by academic editors (5). In 2013, the ASM journal *Molecular and Cellular Biology* (MCB) instituted a program to analyze the figures in all accepted manuscripts before publication (6), modeled after a similar program used by the *Journal of Cell Biology* (7, 8). In this study, we applied the approach used previously (1) to published papers in the journal MCB and followed up the findings with a process that included contacting the authors of the papers. Consequently, we are now able to provide information as to how inappropriate image duplications occur. In addition, a set of manuscripts accepted for publication in MCB was inspected prior to publication for spliced, beautified, or duplicated images. For both sets of papers, the time and effort spent on following up on these papers were recorded. The results provide new insights into the prevalence, scope, and seriousness of the problem of inappropriate image duplication in the biomedical literature.

RESULTS

Inappropriate duplications in MCB published papers. A set of 960 papers published in MCB between 2009 and 2016, including 120 randomly selected papers per year, was screened for inappropriate image duplication. Of these, 59 (6.1%) papers were found to contain inappropriately duplicated images. The distribution of these showed a decline since 2013, when the screening of accepted manuscripts was introduced (Fig. 1). From 2009 to 2012, the average percentage of inappropriate image duplication was 7.08%, while after the introduction of screening accepted manuscripts in 2013, the percentage was 3.96%, a significant decrease (*t* test; $P < 0.01$).

Investigation by ASM staff into published papers with inappropriate image duplication. The 59 papers with inappropriate image duplications in MCB were investigated by contacting the corresponding authors and requesting an explanation for the apparent problem. The 59 instances of inappropriate image duplications led to 41

TABLE 1 Summary of results and comparison of inappropriate image duplication problems in published MCB papers and accepted MCB manuscripts

Action	Explanation	No. (%) for papers with inappropriate image duplication	
		Postpublication (n = 59 [6.1%])[a]	Prepublication (n = 12 [14.5%])[b]
None	Duplication could not be confirmed or not a strong case	3 (5.1)	0
	Duplication was legitimate	1 (1.7)	0 (0)
	Lab had closed after submission of paper, not pursued	2 (3.3)	0 (0)
	Older than 6 yrs[c]	4 (6.8)	0 (0)
	Authors did not reply	2 (3.3)	0 (0)
	Authors provided original blot showing no duplication	1 (1.7)	0 (0)
Correction	Simple duplication during figure assembly	40 (67.8)	11
	Error in figure assembly	1 (1.7)	1[d]
Retraction (or rejection of manuscript)	Too many errors for simple correction	3 (5.1)	0
	Intention to mislead suspected	2 (3.3)	0
Staff effort	Emails sent to resolve problems (no.)	1,400–1,600[e]	NA[f]
	Avg time spent per paper	6 h	1.5 h

[a]Published papers (n = 960 total), 2009 to 2016.
[b]Accepted papers (n = 83 total), 2 months in 2013.
[c]Although MCB has in the past retracted papers older than 6 years, we limited our investigation to papers published in the prior 6 years to be consistent with ASM policy and federal regulations established in 42 CFR 93.105 (9) for pursuing allegations of misconduct involving HHS-supported research, which specify this time limitation.
[d]Analysis revealed a potential case of nonuniform enhancements.
[e]Email estimate includes EIC correspondence.
[f]NA, not available.

corrections, 5 retractions, and 13 instances in which no action was taken (Table 1). The reasons for not taking action included origin from laboratories that had closed (2 papers), resolution of the issue in correspondence (4 papers), and occurrence of the event more than 6 years earlier (6 papers), consistent with ASM policy and federal regulations established in 42 CFR 93.105 (9) for pursuing allegations of research misconduct. Of the retracted papers, one contained multiple image issues for which correction was not an appropriate remedy, and for another retracted paper, the original and underlying data were not available, but the study was sufficiently sound to allow submission of a new paper for consideration, which was subsequently published.

Analysis of inappropriate image duplications. Authors who were contacted about image irregularities most frequently reported errors during assembly of the figures. The most commonly reported error was the accidental inclusion of the same blot or image twice. Other commonly reported mistakes were the selection of the wrong photograph, the assembly of figure panels with mock photographs that were not properly replaced, etc.

Time expenditure for published papers. For the 59 papers published with potential inappropriate image duplication concerns, the ASM publication staff members recorded ~580 emails pertaining to these cases, or an average of ~10 emails per case (range, 4 to 103). In addition, at least two phone conversations with authors took place, each approximately 1 h. The production editor and assistant production editor handled ~800 emails in their folders regarding these corrections. In addition, for 20 papers the editor in chief (EIC) was involved in communications with the authors, which involved a total of 244 emails (range per paper, 4 to 29), or an average of 12.2 messages per paper. Including the EIC time would add another 61 h (~15 min × 244 emails). The exact content of these emails was not disclosed to any individuals outside of the MCB ethics panel. The breakdown of the production staff emails was as follows: correspondences with staff members to keep them apprised of what had been received and discussions about wording (since each item needed individual assessment of the appropriate approach) or logistical details regarding retracted or republished papers. Correspondences with authors comprised the next largest category (less than half the

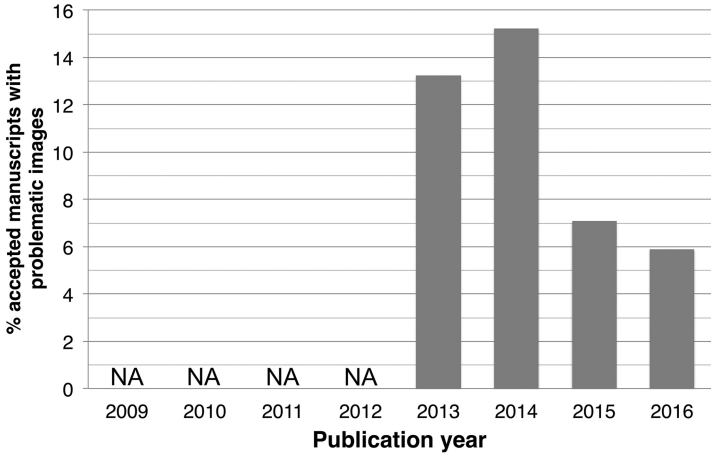

FIG 2 Percentage of accepted MCB manuscripts that were found to have problematic images, 2013 to 2016. No screening for problematic images was done before 2013. NA, not applicable.

amount of staff correspondence), followed by correspondences with the EIC. Correspondence with the printer was the smallest category. Hence, the problem of inappropriate image duplication after publication imposed a large time burden on the journal, with an average of 6 h of combined staff time (1,400 emails, estimated to take 15 min each to write and follow up, for the 59 papers) spent to investigate and follow up each paper.

Screening of manuscripts prior to publication. Analyzing the papers with inappropriately duplicated images as a function of time revealed a decline in incidence beginning in 2013, which coincided with a change in the editorial process to include prepublication screening for image problems (Fig. 1). During a period of 2 months in the beginning of 2013, 83 papers were accepted, with 452 images inspected. In this recording period, 12 papers (14.5%) were detected in which an image concern (duplication or undisclosed cuts) was identified. The percentage of papers flagged during prepublication screening was higher than the frequency of duplicated images detected in published papers, because beautification or undisclosed cuts were flagged as well. Prior to this time, no manuscript was flagged by MCB because of inappropriate image duplication, but starting in 2013, after the introduction of prepublication screening, the percentage of manuscripts flagged for image problems increased initially and then declined (Fig. 2).

Outcome of prepublication screening of manuscripts. During the recording period in 2013, 83 manuscripts were screened, and 12 manuscripts were flagged for containing duplications or other irregularities. The authors of each manuscript were contacted for follow-up by the handling editor. In 11 cases, the problem could be corrected by the submission of a new version of the figure, while in 1 instance, the authors provided the original data to show that the figure did not misrepresent the original data.

Time cost for manuscripts. When image screening was first instituted by MCB in 2013, time records were maintained for approximately 2 months to ascertain the time cost of this procedure. The total time required to inspect all images in the 83 manuscripts screened during this period was 687 min (8.3 min per screened paper). The total time required for reporting and following up of ethical concerns found in 12 papers was 375 min of ASM staff time, not counting the time devoted by the EIC to addressing these problems. Thus, the time expenditure of ASM staff/editors translated into 31.3 min per manuscript.

DISCUSSION

Here we report a detailed investigation of inappropriate image duplications in biomedical research papers and a systematic process for their correction. By focusing

on one journal within the portfolio of ASM journals, we were able to determine the outcome of image concerns. The most reassuring outcome of our findings is that the majority of inappropriate image duplications resulted from errors during figure construction that could be easily corrected by the authors. To discern whether an apparently duplicated image warranted correction, retraction, or no action required consultation with the authors and review of the primary data. The finding that 5.5% of MCB articles had inappropriate image duplications is a percentage consistent with prior findings involving over 40 journals (1). This confirmation is noteworthy because the approach used in the current study differs from prior work in that it focused on a single journal, with a 120-paper sample for each of six publication years. Of concern is that approximately 10% of the papers containing problematic images required retractions after the adjudication process, due to apparent misconduct, an inadequate author response, or errors too numerous for an author correction. Other efforts to investigate causes of inappropriate image duplication for papers published in two other American Society for Microbiology journals, *Journal of Virology* and *Infection and Immunity*, including some from a prior study (1), produced retraction rates ranging from 2.9% (1 of 35) to 21% (4 of 19), respectively, which yields an average of 10.6% ± 8.1% for the three journals.

Research misconduct has always existed, but this topic has been of increasing concern in recent years in view of several high-profile scandals, a perceived reproducibility crisis, and an epidemic of retracted papers, most of which are due to misconduct (10). The actual number of compromised papers in the extant literature is unknown, but our observations permit some estimates. Although extrapolation from three American Society for Microbiology journals to the general biomedical literature must be made with caution, our study allows a rough estimate of the number of seriously compromised papers in print. Based on the average percent retraction from the three journals, the 95% confidence interval (CI) ranges from 1.5 to 19.8%. If 3.8% of the 8,778,928 biomedical publications indexed in PubMed from 2009 to 2016 (http://dan.corlan.net/medline-trend.html) contain a problematic image (1), and 10.6% (CI, 1.5 to 19.8%) of that group contain images of sufficient concern to warrant retraction, then we can estimate that approximately 35,000 (CI, 6,584 to 86,911) papers are candidates for retraction due to inappropriate image duplication. These numbers are almost certainly an overestimate, since not all papers in the literature have images of the type studied here and MCB publishes many articles with figures involving photographic images. On the other hand, we screened only for visible duplications, and papers might contain additional problems in graphs, tables, or other data sets that are less easy to find, suggesting that this could also be an underestimate. Whatever the actual number, it is clear that the number of compromised papers in the literature is large. The continued presence of compromised papers in the literature could exert pernicious effects on the progress of science by misleading investigators in their fields. Nevertheless, even the most liberal estimates of the total number of papers that are candidates for retraction represent a very small percentage of the literature. Our findings are consistent with other studies reporting that a sizable number of papers in the literature have problems associated with misconduct (11, 12).

Our study also documents the potential value of increased journal vigilance for reducing inappropriate image duplications in published papers. A reduction in the number of inappropriate images identified in MCB papers was observed after initiation of dedicated image inspections by the journal in 2013 (6). Increased vigilance reduces problematic images by identifying and correcting errors before publication and by heightening awareness among authors to prevent such problems. However, such efforts come at considerable time and financial costs to the journal. The time invested in inspecting manuscripts prepublication was approximately 8.3 min per paper, and the identification of a problematic image resulted in additional time investment in communicating with authors and deciding if a problem raised an ethical concern. Additional costs to science include the time taken by the authors to correct figures and the delays in publication. However, these costs are likely lower than the overall cost

associated with discovery of inappropriate image duplication after publication, which triggers an investigation by the journal that consumes considerable time, as is evident from the average of 10 emails per case, and outcomes including publication of corrections and retractions. In our analysis, we found that following up on problematic images before publication costs about 30 min per problematic paper, whereas the time spent to follow up similar issues after publication, not including EIC time, was 6 h per paper, which is 12 times greater. Hence, even though the majority of inappropriate image duplications result from simple errors in assembling figures, their occurrence once identified imposes considerable costs to journals and authors and, by extension, to the scientific enterprise. Identifying image problems before publication, even though this requires additional time for journal staff, might save journals time in the end by preventing problematic images from appearing in published papers. These time estimates do not include the time required when instances of inappropriate image are referred to the author institutions and trigger an ethics investigation. Identifying potential problems before publication protects authors' reputations and prevents the collateral damage to the reputations of all authors of a retracted paper (13).

Peer review is a cornerstone of science (14, 15) and is primarily designed to look for fundamental errors in experimental setup and data analysis. Most peer reviewers do not have the expertise to analyze papers for scientific misconduct. Consequently, the responsibility of screening for plagiarism, falsification, fabrication, and other forms of scientific misconduct often lies with editors (16). This underscores the critically important roles and responsibilities of journals in maintaining the integrity of the scientific record, which include both the detection and correction of problematic data (17). Although carelessness and misconduct have always existed in science, the problem may be becoming more acute because of advances associated with the availability of programs that allow authors to prepare figures easily. The ability to cut and paste text or images combined with availability of software to manipulate and generate photographic images gives authors powerful tools that can be misused. Our prior study noted that the problem of inappropriate image duplications was largely a 21st-century phenomenon temporally associated with the proliferation of software for image construction (1). However, software advances have also provided tools to reduce error and abuse. Some publishers, including ASM, already perform routine screening of manuscripts using plagiarism detection software. Combined with manual curation and supervision, these tools work reasonably well (12, 17). However, identifying image duplication of the types reported here and in our prior study (1) is more challenging and dependent on individuals capable of spotting suspicious patterns. We noted that the prescreening process for MCB is quite good at picking up spliced images but poor at finding image duplications of the type reported in this study. Hence, without routine screening by individuals who are gifted at identifying image duplications and modifications, it is likely that the type of image problems identified in this study will continue (1). Although detecting image problems is difficult, the recent development of improved software tools appears promising (18).

The finding that most inappropriate image duplications result from carelessness and error during figure construction but impose large costs to authors and journals for their correction indicates that greater efforts to prevent such errors should be instituted by research laboratories. Given that most figures are currently constructed by authors themselves, it may be possible to reduce the prevalence of image problems by asking others in the laboratory who are not directly involved with the current research to participate in figure construction or review. Prior to the availability of image editing software, figures for research papers were usually made by individuals who specialized in this activity and were not involved in data collection. We note that in our previous study we found no instances of inappropriate image duplication prior to 1997 (1). We hypothesize that prior to the availability of software that allowed authors to construct their own figures, the discussions between photographers or illustrators and authors combined with the separation of data generation from figure preparation reduced the likelihood of these types of problems.

In addition, providing clear guidelines for the preparation of photographic images as part of a journal's instructions for authors is helpful. For example, instructions might include rules about how to disclose cuts in Western blots, the requirement of each experiment to have its own control (e.g., β-actin or globin) protein control blots (no reuse of these blots allowed), etc. Examples of such guidelines currently exist (19). ASM maintains an ethics portal in its website with information that may be helpful to authors (http://journals.asm.org/site/misc/ethicsportal.xhtml).

In summary, we confirmed our prior results by inspecting a single journal using a systematic approach and provide insights into the causes of inappropriate image duplication in research papers. The results provide both reassurance and concern regarding the state of the biomedical literature. We are reassured that the majority of duplication events result from errors that do not compromise validity of the scientific publication and are amenable to correction, notwithstanding the cost of considerable time investment on the part of the journal staff, editors, and authors. Also reassuring is the fact that only 0.5% of the papers screened had image problems of sufficient severity to require retraction. However, even this low percentage suggests that the current biomedical research literature contains many such publications that may warrant retraction. At the very least, our findings suggest the need for both authors and journals to redouble their efforts to prevent inappropriate image duplications.

MATERIALS AND METHODS

Published paper set. Papers published in 2009 to 2016 in MCB were inspected visually for inappropriate image duplication. For each year, issues 1 to 12 (January to June) were selected, and the first 10 papers in each issue containing photographic images were screened. Thus, 120 papers were inspected per publication year, resulting in a total of 960 papers screened. Since almost all MCB papers contain photographic images, no specific search term was used, but papers were counted only if they contained photographic images.

Image inspection. Published papers were scanned using the same procedure as used in our prior study (1). Briefly, one person (E. M. Bik) scanned published papers by eye for inappropriate image duplications in any photographic images or fluorescence-activated cell sorting (FACS) plots. Problematic images were also inspected by two additional authors (A. Casadevall and F. C. Fang). Such duplicated images fell into three general categories: simple duplications, duplications with repositioning, and duplications with alterations (1). As in the previous study (1), cuts and beautifications were not scored as problematic. E. M. Bik was not aware of the year in which MCB started increased screening (see below) for image problems while she screened journals. The image allegations were confirmed using Office of Research Integrity (ORI) forensic software and/or Adobe Photoshop Difference function by MCB production personnel. Decisions as to whether to pursue the allegations by contacting authors were based on this analysis. Each published paper containing suspected inappropriate image duplication problems was reported to the editor in chief of MCB. The EIC then requested clarification from the corresponding author(s) regarding concerns with the figure using the category classification described above. The EIC followed up on all concerns from 2010 and on potential concerns in categories 2 and 3. Category 1 concerns were handled by ASM staff.

Prospective screening of manuscripts before publication. Starting in January 2013, all MCB manuscripts accepted for publication were screened for inappropriate image duplications and other problems, including undisclosed cuts and beautifications (which were not counted in the screen of the published papers described above). For this study, the time to inspect these figures in manuscripts accepted from 14 January 2013 to 21 March 2013 was recorded. In the case of image problems, the authors were contacted and asked to explain and/or remake the figure. Corrections and retractions followed Committee on Publication Ethics (COPE) guidelines (https://publicationethics.org/resources/guidelines).

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This paper reports on an effort by ASM journals to review the integrity of figures in a subset of published manuscripts. That effort was not initially intended as a study but rather as due diligence in maintaining the integrity of the scientific record. However, since the results of this effort provided important information that could inform future efforts at improving the reliability of the literature, a decision was made to present the

data in a publication. The views expressed in this article do not necessarily reflect the views of this journal or the ASM.

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