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Journal of Clinical Epidemiology 65 (2012) 511−519

Journal of Clinical Epidemiology

Graphical augmentations to the funnel plot assess the impact of additional evidence on a meta-analysis

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Accepted 25 October 2011; Published online 18 February 2012

Abstract

Objective: We aim to illustrate the potential impact of a new study on a meta-analysis, which gives an indication of the robustness of the meta-analysis.

Study Design and Setting: A number of augmentations are proposed to one of the most widely used of graphical displays, the funnel plot. Namely, 1) statistical significance contours, which define regions of the funnel plot in which a new study would have to be located to change the statistical significance of the meta-analysis; and 2) heterogeneity contours, which show how a new study would affect the extent of heterogeneity in a given meta-analysis. Several other features are also described, and the use of multiple features simultaneously is considered.

Results: The statistical significance contours suggest that one additional study, no matter how large, may have a very limited impact on the statistical significance of a meta-analysis. The heterogeneity contours illustrate that one outlying study can increase the level of heterogeneity dramatically.

Conclusion: The additional features of the funnel plot have applications including 1) informing sample size calculations for the design of future studies eligible for inclusion in the meta-analysis; and 2) informing the updating prioritization of a portfolio of meta-analyses such as those prepared by the Cochrane Collaboration.

Keywords: Study design; Meta-analysis; Graphical display; Evidence-based medicine; Funnel plot; Clinical trial

1. Introduction

Graphical displays have become an integral part of reporting in meta-analysis and can facilitate the communication of important features and results of the associated statistical analysis. For example, the variability of results between studies, often referred to as heterogeneity, or the influence of individual studies on the analysis can be conveyed effectively using graphical means. The reader is referred elsewhere for recent comprehensive reviews and critiques of graphical displays used in meta-analysis [1,2].

This article proposes augmentations to one of the most widely used of graphical displays, the funnel plot [3]. In particular, we describe several novel overlays to the funnel plot, which provide a visual illustration of the impact that new studies would have on a given meta-analysis. We argue that the additional features may help to 1) establish the current robustness of a meta-analysis; 2) inform sample size calculations for the design of future studies that might be added to the meta-analysis [4]; and 3) help decide from of a portfolio of meta-analyses (such as those managed by Review Groups within the Cochrane Collaboration) which should be prioritized for updating [5].

A funnel plot is simply a scatter plot of each study's effect estimate (usually on the *x*-axis) against some measure of the precision of the effect (usually on the *y*-axis). They were first used by Light and Pillemer [3] to detect publication bias. Because larger studies typically have a more precise estimate of effect, theoretically there should be less variability between such estimates than those from less precise estimates from smaller studies, which are located lower down the plot. In the absence of bias and heterogeneity, the plot should therefore appear funnel shaped with greatest variability at the bottom and least variability at the top.

If publication bias is present, the plot can appear asymmetric because it is often assumed that small studies with

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0895-4356/$ - see front matter
doi: 10.1016/j.jclinepi.2011.10.009

What is new?

- Augmentations to the funnel plot can illustrate and help to assess the potential impact of a new study on a meta-analysis.
- The funnel plot was previously only considered for illustrating bias and between-study heterogeneity.
- The presented funnel plot augmentations will help:
  i. Meta-analysts considering how robust current conclusions are to the inclusion of future evidence from a further study;
  ii. Primary researchers to assess the impact studies they design could have on an existing meta-analysis; and
  iii. Inform the update prioritization of portfolios of systematic reviews, as required by organizations such as the Cochrane Collaboration.
- Implementation of the funnel plot augmentations is made available via downloadable code for the "R" statistics package.

negative effects are suppressed by such mechanisms (e.g., see Fig. 1A). However, several factors other than publication bias can lead to a funnel plot appearing asymmetrical [6]. If within-study biases are more likely in smaller studies than in larger studies, then asymmetry can occur, for example, if points lower down the plot are shifted in a particular direction. Furthermore, if heterogeneity is present, and is caused by factors that are correlated with precision, then asymmetry will occur in the funnel plot. In practice, it is difficult to distinguish between these potential reasons for funnel plot asymmetry, or indeed to distinguish any of them from chance. A discussion of the most appropriate scales for both axes of a funnel plot is available elsewhere [7]; we will plot the standard error (SE) on the vertical scale, with SE = 0 at the top. For a fuller history of the origins of funnel plots, see Sterne et al. [8].

In Section 2, we review previous augmentations to the funnel plot and their uses to assess publication biases and heterogeneity. Then, in Section 3, we present our novel overlays and apply them to illustrative examples from the perspective of the meta-analyst assessing the robustness of the conclusions to further evidence. In Section 4, we consider the application of the overlays from the perspective of someone designing a study to assess the impact of that study on the existing evidence base. Section 5, the discussion, concludes the paper.

2. Existing augmentations to funnel plots

Some general features have been proposed to be added to the funnel plot. We illustrate some in Fig. 1A, B using a data set derived from a fixed-effect meta-analysis of studies looking at whether rapid smoking is effective for quitting smoking in terms of abstinence at long-term follow-up [9]. Commonly included are the line of no effect (the thin vertical line in Fig. 1A), and the summary effect from the meta-analysis (the bold vertical line in Fig. 1A). Additionally, a pseudo confidence interval can be used to indicate the region within which we would expect 95% of studies to lie if the studies are all estimating the same underlying effect [10] (the dotted sloping lines in Fig. 1A). Such boundaries are useful for assessing the presence of heterogeneity in a meta-analysis data set because in the presence of heterogeneity less than 95% of the studies

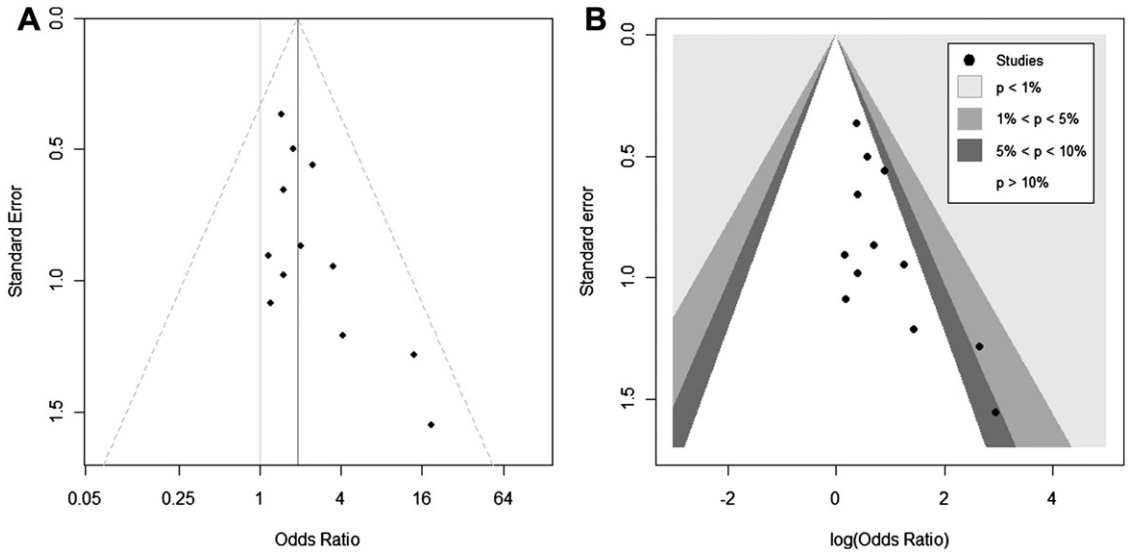

Fig. 1. A. Funnel plot including line of no effect, summary effect and pseudo 95% confidence interval derived from a review of rapid smoking for quitting smoking [9]. B. Contour enhanced funnel plot derived from a review of rapid smoking for quitting smoking [9].