# The Use of Quality Improvement Interventions in Reducing Rarely Appropriate Echocardiograms: A Systematic Review and Meta-Analysis

Michael Tao[1], Mohammed Al-Sadawi[1], Navid Ahmed[1], Neda Dianati-Maleki[1], Noelle Mann[1], and Smadar Kort[1]

[1]Stony Brook University Hospital

February 23, 2023

## Abstract

**Background**: As the volume of cardiac imaging continues to increase, so is the number of tests performed for rarely appropriate indications. Appropriate use criteria (AUC) documents were published by professional societies with quality improvement (QI) interventions developed in various institutions. However, the effectiveness of these interventions has not been assessed in a systematic fashion. **Methods:** We performed a database search for studies reporting the association between cardiac imaging, AUC and QI. We selected studies assessing the effect of QI interventions on performance of rarely appropriate echocardiograms. The primary endpoint was reduction of rarely appropriate testing. **Results:** Nine studies with 22,070 patients met inclusion criteria. QI interventions resulted in statistically significant reduction in rarely appropriate tests (OR 0.52, 95% CI 0.41-0.66; $p<0.01$). The effects of QI interventions were analyzed over both the short (< 3 months) and long-term (> 3 months) post intervention (OR 0.62, 95% CI: 0.49-0.79; $p<0.01$ in the short term, and OR 0.47, 95% CI: 0.35-0.62; $p<0.01$ in the long term). Subgroup analysis of the type of intervention, classified as education tools or decision support tools showed both significantly reduced rarely appropriate testing (OR 0.54, 95% CI: 0.41-0.73; $p<0.01$; OR 0.47, 95% CI: 0.36-0.61; $p<0.01$). Adding a feedback tool did not change the effect compared to not using a feedback tool (OR 0.49 vs. 0.57, 95% CI: 0.36-0.68 vs. 0.39-0.84; $p>0.05$). **Conclusion:** QI interventions are associated with a significant reduction in performance of rarely appropriate echocardiography testing, the effects of which persist over time.

### The Use of Quality Improvement Interventions in Reducing Rarely Appropriate Echocardiograms: A Systematic Review and Meta-Analysis

Michael Tao[a] MD, Mohammed Al-Sadawi[a]MBBch, Navid Ahmed[a] MD, Neda Dianati-Maleki[a] MD, Noelle Mann[a] MD, Smadar Kort[a] MD

a - Stony Brook University Hospital, 101 Nicolls Rd, Stony Brook, New York 11794

**Corresponding Author:** Smadar Kort MD

**Email: Smadar.Kort@stonybrookmedicine.edu**

**Address:** Department of Medicine, Division of Cardiology, Stony Brook University Hospital

101 Nicolls Rd, Stony Brook, NY 11794, USA

**Word Count:** 4202

**Running Title:** QI to reduce rarely appropriate echocardiography

**Key Words:** Quality Improvement, Echocardiography, Appropriate Use Criteria, Rarely Appropriate

**Guidelines Statement:** The systematic review was conducted with a protocol in accordance with the Preferred Reporting of Items for Systematic reviews and Meta-Analyses (PRISMA) statement.

**Data Availability Statement:** The data that support the findings of this study are available from the corresponding author upon reasonable request.

**Sources of Funding:** None

**Disclosures:** None

**Conflicts of Interest:** The authors report no relevant conflicts of interest.

**Ethics Approval Statement:** This manuscript complies with ethical standards.

**Patient Consent Statement:** This manuscript does not utilize patient data in a form requiring patient consent.

**Abstract:**

**Background** : As the volume of cardiac imaging continues to increase, so is the number of tests performed for rarely appropriate indications. Appropriate use criteria (AUC) documents were published by professional societies with quality improvement (QI) interventions developed in various institutions. However, the effectiveness of these interventions has not been assessed in a systematic fashion.

**Methods:** We performed a database search for studies reporting the association between cardiac imaging, AUC and QI. We selected studies assessing the effect of QI interventions on performance of rarely appropriate echocardiograms. The primary endpoint was reduction of rarely appropriate testing.

**Results:** Nine studies with 22,070 patients met inclusion criteria. QI interventions resulted in statistically significant reduction in rarely appropriate tests (OR 0.52, 95% CI 0.41-0.66; $p<0.01$). The effects of QI interventions were analyzed over both the short ($<3$ months) and long-term ($>3$ months) post intervention (OR 0.62, 95% CI: 0.49-0.79; $p<0.01$ in the short term, and OR 0.47, 95% CI: 0.35-0.62; $p<0.01$ in the long term). Subgroup analysis of the type of intervention, classified as education tools or decision support tools showed both significantly reduced rarely appropriate testing (OR 0.54, 95% CI: 0.41-0.73; $p<0.01$; OR 0.47, 95% CI: 0.36-0.61; $p<0.01$). Adding a feedback tool did not change the effect compared to not using a feedback tool (OR 0.49 vs. 0.57, 95% CI: 0.36-0.68 vs. 0.39-0.84; $p>0.05$).

**Conclusion:** QI interventions are associated with a significant reduction in performance of rarely appropriate echocardiography testing, the effects of which persist over time.

## Background

Over the past several decades, the use of non-invasive cardiac imaging has increased faster than any other form of healthcare. The utilization of transthoracic echocardiography has been estimated to grow at a rate of approximately 6-8% per year.[1,2] While this drastic rise has helped to accelerate patient care and diagnose a broad spectrum of cardiac pathology, a large number of imaging studies are ordered for rarely appropriate indications. These rarely appropriate echocardiograms have been reported to range from 6% to 23% of all ordered studies for reference.[3,4]

The appropriate use criteria (AUC) for echocardiography were published by the American College of Cardiology Foundation, the American Society of Echocardiography, and other professional societies in 2007 in response to the growing demand for the use of echocardiography. This document was updated in 2011 reflecting new publications on this topic.[5] In 2013 a decision was made by the professional societies to modify the terminology to better reflect clinical practice and decision making.[4,6] While older documents used appropriate, uncertain, and inappropriate as the criteria, all documents published after 2013 included appropriate, may be appropriate, and rarely appropriate. A decision was also made to write multimodality imaging documents which includes transthoracic, transesophageal, and stress echo as well as all other modalities available for cardiac imaging (nuclear stress test, CT, MRI, and invasive angiography), instead of focusing on single modality, again, reflecting clinical practice where more than one modality is available to choose from.[7,8] Various QI interventions were developed to help incorporate the AUC guidelines into clinical practice. To date, only few studies assessing the effectiveness of these AUC-guided interventions in changing provider behavior have been published, and their ability to reduce the performance of rarely appropriate echocardiograms is not known. Most studies that are available have been limited to single-center studies with limited cohorts for comparison of QI intervention.

There have been very few systematic reviews currently looking at whether AUC-guided interventions are an effective tool for reducing rarely appropriate echocardiograms. High-quality meta-analysis is vital for substantiating evidence to show the utility of the AUC guidelines. We therefore conducted a systematic review and meta-analysis to evaluate the effect of AUC quality improvement (QI) interventions aimed at reducing rarely appropriate echocardiography testing. To capture older publications and yet be consistent with the most updated AUC terminology, both "inappropriate" and "rarely appropriate" echocardiograms were included in our meta-analysis and were referred to as "rarely appropriate".

## Methods

*Data Search*

This systematic review was performed using a preplanned protocol. The results were reported in adherence to the guidelines of the PRISMA statement (Preferred Reporting Items for Systematic Reviews and Meta-analyses). An experienced librarian created a search strategy utilized to systematically find relevant publications. The search was conducted in February 2022. The question addressed in this meta-analysis was whether QI interventions are associated with a reduction in inappropriate or rarely appropriate echocardiography testing and whether the effect persisted over time. A systematic search was conducted using Ovid MEDLINE, EMBASE, Scopus, Web of Science, Google Scholar, and EBSCO CINAHL for relevant literature that reported an association between cardiac imaging, AUC, and QI. The search was not restricted to time or publication status (Figure 1).

*Data sources*

Two independent reviewers performed an electronic search using the following keywords: "total quality management", "quality improvement", "guidelines adherence", "appropriateness criteria", "appropriate use", "exercise test", "stress test", "cardiac imaging", "echocardiogram", and "echocardiography". The references of the included studies, other systematic reviews, and meta-analyses were also manually reviewed to obtain a comprehensive list of studies. After identifying relevant studies, the full texts of the selected articles were examined by both reviewers based on inclusion criteria. Disagreements were resolved by consensus.

*Study Selection*

Studies were selected using the PICO format to include those that assessed patients undergoing echocardiography (Population), comparing the effect of AUC guided QI interventions (Intervention) to pre intervention or study groups not receiving the intervention (Comparison), assessing for a reduction in performance of rarely appropriate echocardiograms (Outcomes).

*Data Extraction*

Two reviewers independently extracted the study data using a predefined data extraction sheet. Variables that were extracted from the studies included: Lead author, year of publication, study design, QI tool, the timing of follow-up, total echocardiography testing before and after QI, and rarely appropriate echocardiography testing before and after QI.

*Data synthesis and statistical analysis*

Meta-analysis was carried out comparing the effect of all QI interventions on the performance of rarely appropriate echocardiography testing and also analyzed based on short-term ($<$ 3 months) and long-term ($>$3 months) effects. Subgroup analysis was performed for specific QI interventions, including Feedback

Tool, Education Tool, or Decision Support Tool. Statistical analysis was performed using comprehensive meta-analysis software.[9]The extent of heterogeneity was determined by I2 (ranging from 0% to 100%). Due to high heterogeneity, we used a random-effects model to examine the effect and outcomes, which were presented as odds ratio (OR) with Z-value. Statistical significance was considered with a P-value $< 0.05$ and all tests were 2-sided. Funnel plot of standard error by log HR was created to qualitatively assess publication bias.

## Results

Our primary search identified 2018 potentially eligible studies. After removing duplicates, review articles, abstracts, editorials, and letters, 28 full-text articles were examined. A total of 9 studies including 22,070 subjects met eligibility criteria and were included in our meta-analysis.[3,10–17] 3 studies were randomized control trials comparing a QI intervention group to a non-intervention group while 6 were prospective studies comparing rarely appropriate echocardiography ordering behavior in a single study group before and after QI intervention. The mean follow-up was 14 months. Education Tools used in included studies were small group lectures, grand rounds, printed educational resources, electronic AUC cards, and physical pocket-sized AUC cards. Feedback Tools included feedback emails and performance reports sent to providers at different intervals. Decision Support Tools were electronic medical record pop-ups when echocardiograms are ordered.

*Effects of QI Interventions*

QI interventions resulted in a statistically significant reduction in rarely appropriate tests compared to the control group (OR 0.52, 95% CI 0.41-0.66; p<0.01) (Figure 2). The effects of QI interventions were analyzed over both the short (< 3 months) and long-term (> 3 months) with (OR 0.62, 95% CI: 0.49-0.79; p<0.01) in the short term and (OR 0.47, 95% CI: 0.35-0.62; p<0.01) in the long term (Figure 3). This suggests that the introduction of a QI intervention resulted in both an immediate change in provider ordering behavior to be more consistent with AUC guidelines, with increasing effect over time. When we compared the odds ratios for short-term and long-term follow-up, we found that there may be a trend towards an increase in effect on long-term follow-up.

We also performed subgroup analysis of the type of QI intervention to assess whether the effectiveness of QI intervention varied by modality. Our analysis revealed that using either education tools or decision support tools were both statistically significant in reducing rarely appropriate testing (OR 0.54, 95% CI: 0.41-0.73; p<0.01; OR 0.47, 95% CI: 0.36-0.61; p<0.01) (Figure 4). Feedback tools are often added to other QI intervention modalities due to the assumption that it may augment the effect of QI interventions. Our subgroup analysis showed that adding a feedback tool to either an education tool or a decision support tool did not change the effect compared to not using the feedback tool. The odds ratios for QI intervention with or without a feedback tool added were similar and demonstrated that QI interventions were effective at reducing rarely appropriate testing even when used as the sole QI modality without addition of a feedback tool (OR 0.49 vs. 0.57, 95% CI: 0.36-0.68 vs. 0.39-0.84; p>0.05) (Figure 5).

## Conclusions

As healthcare increasingly shifts its focus toward value-based care, echocardiography has been a prime target for refinement as it remains a frontline tool for the diagnosis and management of various cardiovascular diseases.[18] Given its wide availability in all types of clinical settings as well as its safety profile, echocardiography is at risk for being misused. Common outpatient scenarios in which rarely appropriate echocardiograms are ordered include routine surveillance for heart failure with recent imaging less than one year prior, repeat assessment of left ventricular ejection fraction in patients with coronary artery disease, monitoring trivial or small pericardial effusions, and reassessment of valvular heart disease at an interval more frequent than recommended by professional society guidelines.[10] Common inpatient scenarios resulting in rarely appropriate echocardiogram orders include fevers without bacteremia or new murmur, lightheadedness or presyncope without other evidence of cardiovascular disease, evaluation for pulmonary embolism, and surveillance of left ventricular ejection fraction in patients with coronary disease or patients with prior normal ventricular function and no change in clinical status.[11,19] It is especially important to target these rarely appropriate clinical scenarios as the volume of echocardiography testing continues to increase.

In our search through existing literature, studies evaluating the effectiveness of AUC-based QI interventions have demonstrated mixed results. However, most of these studies have been single-center studies with only the Echo WISELY trial being a multicenter trial.[12] The results of our meta-analysis help to further clarify this topic, demonstrating that AUC QI interventions are associated with a successful reduction in rarely appropriate echocardiography testing. While some small studies showed that the effects of QI interventions resulted in an initial significant change in target behavior with eventual loss of effect over time, our results suggest that the effects of AUC-based QI interventions are persistent over long-term follow-up with a trend towards further reduction in rarely appropriate testing.

It must be noted that when the initial professional societies AUC documents were published, echocardiography studies were characterized as “appropriate”, “uncertain”, or “inappropriate”. However, this was subsequently revised to the categories of “appropriate”, “may be appropriate”, and “rarely appropriate”, to acknowledge that studies previously characterized as “inappropriate” may be appropriate in certain specific, infrequently encountered clinical settings. In our review of existing literature, we included both sets of nomenclature based on time of publication. However, to be consistent with the most updated AUC recommendations, published results utilizing the outdated terminology of “inappropriate” were included as “rarely appropriate” in our analysis. It is important to emphasize that for each specific indication the inappropriate and rarely appropriate criteria are not exchangeable, however, since we didn’t look at specific indications, but rather investigated the effect of an intervention of clinicians’ behavior, including both terminologies in our analysis is perfectly reasonable.

One issue that has been called into question is whether the effectiveness of AUC QI interventions demonstrated in single-center studies, is generalizable. Of particular interest is differences in adaptation of QI interventions by physicians in training and more senior physicians. It is expected to see greater degree of behavioral changes in practice among physicians in training, who are more receptive to changes in practice behavior and feedback. Single center studies that are focused on trainees only, can therefore demonstrate greater degree of effectiveness of such AUC QI interventions.[10,11]The advantage of our meta-analysis is that it encompasses providers of different specialties as well as providers of differing levels of training, and the results are therefore more generalizable.

Another important question is whether educational QI tools are effective in changing provider behavior even when not combined with a feedback tool. Our study demonstrate that the use of a feedback tool is not necessary for educational tools to be effective and that the addition of feedback tools to educational or decision support tools did not further enhance QI intervention. Several studies have suggested that the effectiveness of educational tools when used alone stems from the fact that many providers are simply not aware of the existence of appropriate use criteria for ordering echocardiograms.[13,15] These authors suggest that by simply teaching providers about AUC indications for echocardiograms via modalities including lectures and reference cards, there is a significant change in ordering behavior.

While we demonstrated in this meta-analysis that the addition of feedback tools was not necessary when combined with other QI modalities, there is limited available data to draw conclusions regarding the effectiveness of feedback tools when used as the solitary QI intervention. It has been seen in QI studies aimed at reducing rarely appropriate testing done using other types of radiological imaging that feedback tools are effective when used alone as an intervention.[20–22] To our knowledge, there have not been any similar studies conducted for AUC-based QI interventions targeted towards rarely appropriate echocardiogram testing. Furthermore, it is possible that the format for feedback delivery is also important. In the study by Bhatia et al, it was observed that when feedback was given in both email format as well as performance reports, many providers ignored email feedback but did access their performance reports.[12] Further studies are needed to better clarify both the role of feedback tools and format for feedback in AUC-based QI intervention.

*Study Limitations*

While this meta-analysis provides robust evidence for the utility of AUC QI interventions and incorporates studies with a diverse group of providers, we believe that there is still not enough information to assess whether the results can be generalized to physicians across specialties and whether there are inter-specialty differences in the effectiveness of the interventions. Majority of the studies utilizing educational and feedback tools were targeted at three particular specialties: cardiology, internal medicine, and primary care physicians. However, in true clinical practice echocardiograms are ordered by physicians across all clinical specialties as well as by mid-level providers. Additionally, given that the majority of included studies using educational tools targeted a limited group of physicians, it is unclear how feasible it would be to implement similar QI interventions in larger, multi-provider settings.

One aspect that limits generalizability of this meta-analysis is the heterogeneity seen across studies. This is likely a result of differences in the inherent design and implementation of QI protocols across difference studies, thus the heterogeneity was expected. We addressed this via subgroup analysis by type of QI intervention and by duration of follow-up. This was effective in reducing heterogeneity in the decision-support tool subgroup. We further addressed this using a random effect model for analysis, which accounts for inherent differences in methodology and design across included studies.

Lastly, all studies included in this meta-analysis were performed at academic medical centers, making it difficult to generalize the results to the community setting where a significant portion of echocardiograms are ordered and performed.

The application of AUC-based QI interventions appears to be effective in reducing rarely appropriate echocardiography testing. This meta-analysis has shown that educational tools and decision support tools are effective QI interventions regardless of whether a feedback tool is incorporated. Further studies are needed to elucidate the effectiveness of different formats of feedback tools as well as the generalizability of AUC-based QI interventions in the community setting and across medical specialties.

**References:**

1. Blecker S, Bhatia RS, You JJ, Lee DS, Alter DA, Wang JT, Wong HJ, Tu J v. Temporal trends in the utilization of echocardiography in Ontario, 2001 to 2009. *JACC. Cardiovascular imaging* . 2013;6(4):515–522.

2. Kirkpatrick JN, Ky B, Rahmouni HW, Chirinos JA, Farmer SA, Fields A v., Ogbara J, Eberman KM, Ferrari VA, Silvestry FE, Keane MG, Opotowsky AR, Sutton MSJ, Wiegers SE. Application of appropriateness criteria in outpatient transthoracic echocardiography. *Journal of the American Society of Echocardiography : official publication of the American Society of Echocardiography* . 2009;22(1):53–59.

3. Chen W, Saxon DT, Henry MP, Herald JR, Holleman R, Zawol D, Sivils S, Kenaan MA, Kolias TJ, Gurm HS, Bhave NM. Effects of an Electronic Medical Record Intervention on Appropriateness of Transthoracic Echocardiograms: A Prospective Study. *Journal of the American Society of Echocardiography* . 2021;34(2):176–184.

4. Mansour IN, Razi RR, Bhave NM, Ward RP. Comparison of the updated 2011 appropriate use criteria for echocardiography to the original criteria for transthoracic, transesophageal, and stress echocardiography. *Journal of the American Society of Echocardiography : official publication of the American Society of Echocardiography* . 2012;25(11):1153–1161.

5. Douglas PS, Garcia MJ, Haines DE, Lai WW, Manning WJ, Patel AR, Picard MH, Polk DM, Ragosta M, Ward RP, Weiner RB. ACCF/ASE/AHA/ASNC/HFSA/HRS/SCAI/SCCM/SCCT/SCMR 2011 Appropriate Use Criteria for Echocardiography. A Report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, American Society of Echocardiography, American Heart Association, American Society of Nuclear Cardiology, Heart Failure Society of America, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, Society of Critical Care Medicine, Society of Cardiovascular Computed Tomography, Soci. *Journal of the American Society of Echocardiography : official publication of the American Society of Echocardiography* . 2011;24(3):229–267.

6. Hendel RC, Patel MR, Allen JM, Min JK, Shaw LJ, Wolk MJ, Douglas PS, Kramer CM, Stainback RF, Bailey SR, Doherty JU, Brindis RG. Appropriate Use of Cardiovascular Technology: 2013 ACCF Appropriate Use Criteria Methodology Update: A Report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force. *Journal of the American College of Cardiology* . 2013;61(12):1305–1317.

7. Doherty JU, Kort S, Mehran R, Schoenhagen P, Soman P. ACC/AATS/AHA/ASE/ASNC/HRS/SCAI/SCCT/SCMR/STS 2017 Appropriate Use Criteria for Multimodality Imaging in Valvular Heart Disease : A Report of the American College of Cardiology Appropriate Use Criteria Task Force, American Association for Thoracic Surgery, American Heart Association, American Society of Echocardiography, American Society of Nuclear Cardiology, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Computed Tomography, Society for. Journal of nuclear cardiology : official publication of the American Society of Nuclear Cardiology. 2017;24(6):2043–2063.

8. Doherty JU, Kort S, Mehran R, Schoenhagen P, Soman P, Dehmer GJ, Bashore TM, Bhave NM, Calnon DA, Carabello B, Conte J, Dickfeld T, Edmundowicz D, Ferrari VA, Hall ME, et al. ACC/AATS/AHA/ASE/ASNC/HRS/SCAI/SCCT/SCMR/STS 2019 Appropriate Use Criteria for Multimodality Imaging in the Assessment of Cardiac Structure and Function in Nonvalvular Heart Disease: A Report of the American College of Cardiology Appropriate Use Criteria Task Force, American Association for Thoracic Surgery, American Heart Association, American Society of Echocardiography, American Society of Nuclear Cardiology, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, Soci. Journal of the American College of Cardiology. 2019;73(4):488–516.

9. Borenstein M, Hedges L, Higgins J, Rothstein H. Comprehensive Meta-Analysis Software (CMA).

10. Bhatia RS, Dudzinski DM, Malhotra R, Milford CE, Sanborn DMY, Picard MH, Weiner RB. Educational Intervention to Reduce Outpatient Inappropriate Echocardiograms: A Randomized Control Trial. *JACC: Cardiovascular Imaging* . 2014;7(9):857–866.

11. Bhatia RS, Milford CE, Picard MH, Weiner RB. An educational intervention reduces the rate of inappropriate echocardiograms on an inpatient medical service. *JACC. Cardiovascular imaging* . 2013;6(5):545–555.

12. Bhatia RS, Ivers NM, Yin XC, Myers D, Nesbitt GC, Edwards J, Yared K, Wadhera RK, Wu JC, Kithcart AP, Wong BM, Hansen MS, Weinerman AS, Shadowitz S, Elman D, et al. Improving the Appropriate Use of Transthoracic Echocardiography: The Echo WISELY Trial. *Journal of the American College of Cardiology* . 2017;70(9):1135–1144.

13. Willens HJ, Nelson K, Hendel RC. Appropriate use criteria for stress echocardiography: impact of updated criteria on appropriateness ratings, correlation with pre-authorization guidelines, and effect of temporal trends and an educational initiative on utilization. *JACC. Cardiovascular imaging* . 2013;6(3):297–309.

14. Johnson T v., Rose GA, Fenner DJ, Rozario NL. Improving appropriate use of echocardiography and single-photon emission computed tomographic myocardial perfusion imaging: a continuous quality improvement initiative. *Journal of the American Society of Echocardiography : official publication of the American Society of Echocardiography* . 2014;27(7):749–757.

15. Levitt K, Edwards J, Chow CM, Bhatia RS. Development of an Educational Strategy and Decision Support Tool to Enhance Appropriate Use of Stress Echocardiography at a Large Academic Medical Center: A Prospective, Pre- and Postintervention Analysis. *Journal of the American Society of Echocardiography : official publication of the American Society of Echocardiography* . 2015;28(12):1401–1409.

16. Dudzinski DM, Bhatia RS, Mi MY, Isselbacher EM, Picard MH, Weiner RB. Effect of Educational Intervention on the Rate of Rarely Appropriate Outpatient Echocardiograms Ordered by Attending Academic Cardiologists: A Randomized Clinical Trial. *JAMA Cardiology* . 2016;1(7):805–812.

17. Gandhi S, Ho EC, Ong G, Zahrani M, Lu J, Leong-Poi H, Edwards J, Bhatia S (R S)., Levitt K, Chow CM, Connelly KA. A Physician Education Tool to Improve Appropriate Use Criteria for Stress Echocardiog-

raphy: Long-Term Follow-Up of a Single-Center Study. *Journal of the American Society of Echocardiography : official publication of the American Society of Echocardiography* . 2019;32(9):1255–1257.

18. Steeds RP. Echocardiography: frontier imaging in cardiology. *The British journal of radiology* . 2011;84 Spec No 3(Spec Iss 3).

19. Rameh V, Kossaify A. Appropriate Use Criteria in Echocardiography: An Observational Institutional Study with the Perspective of a Quality Improvement Project. *https://doi.org/10.4137/CMC.S36504* . 2016;10:23–28.

20. Eccles M, Steen N, Grimshaw J, Thomas L, McNamee P, Soutter J, Wilsdon J, Matowe L, Needham G, Gilbert F, Bond S. Effect of audit and feedback, and reminder messages on primary-care radiology referrals: a randomised trial. *Lancet (London, England)* . 2001;357(9266):1406–1409.

21. Martin AR, Wolf MA, Thibodeau LA, Dzau V, Braunwald E. A Trial of Two Strategies to Modify the Test-Ordering Behavior of Medical Residents. *http://dx.doi.org/10.1056/NEJM198012043032304* . 2009;303(23):1330–1336.

22. Thomas RE, Croal BL, Ramsay C, Eccles M, Grimshaw J. Effect of enhanced feedback and brief educational reminder messages on laboratory test requesting in primary care: a cluster randomised trial. *Lancet (London, England)* . 2006;367(9527):1990–1996.

**Figure Legend:**

**Figure 1:** Flow diagram depicts study selection for inclusion in the meta-analysis according to the PRISMA statement for reporting systematic reviews and meta-analyses.

**Figure 2** : Forest Plot Demonstrating the effect of QI intervention on reducing rarely appropriate echocardiographic studies. Heterogeneity: df= 8 (P <0.01), I2 = 73.8; Test for overall effect: Z = -5.36 (P <0.01).

**Figure 3:** (a) Forest Plot Demonstrating the effect of QI intervention on reducing rarely appropriate echocardiographic studies in short-term (<3 months). Heterogeneity: df= 4 (P <0.01), I2 = 72.1; Test for overall effect: Z = -3.89 (P <0.01). (b) Forest Plot Demonstrating the effect of QI intervention on reducing rarely appropriate echocardiographic studies in long-term (>3 months). Heterogeneity: df= 6 (P <0.01), I2 = 79.2; Test for overall effect: Z = -5.17 (P <0.01).

**Figure 4:** (a) Forest Plot Demonstrating the effect of using educational aid intervention on reducing rarely appropriate echocardiographic studies. Heterogeneity: df= 5 (P <0.01), I2 = 77.63; Test for overall effect: Z = -4.05 (P <0.01). (b) Forest Plot Demonstrating the effect of using decision support tool intervention on reducing rarely appropriate echocardiographic studies. Heterogeneity: df= 3 (P 0.47), I2 = 0; Test for overall effect: Z = -6.51 (P <0.01).

**Figure 5:** (a) Forest Plot Demonstrating the effect of using feedback tools as part of QI intervention on reducing rarely appropriate echocardiographic studies. Heterogeneity: df= 4 (P <0.01), I2 = 80; Test for overall effect: Z = -4.37 (P <0.01). (b) Forest Plot Demonstrating the effect of not using feedback tools as part of QI intervention on reducing rarely appropriate echocardiographic studies. Heterogeneity: df= 3 (P 0.05), I2 = 60.89; Test for overall effect: Z = -2.83 (P <0.01).

**Figure 1**

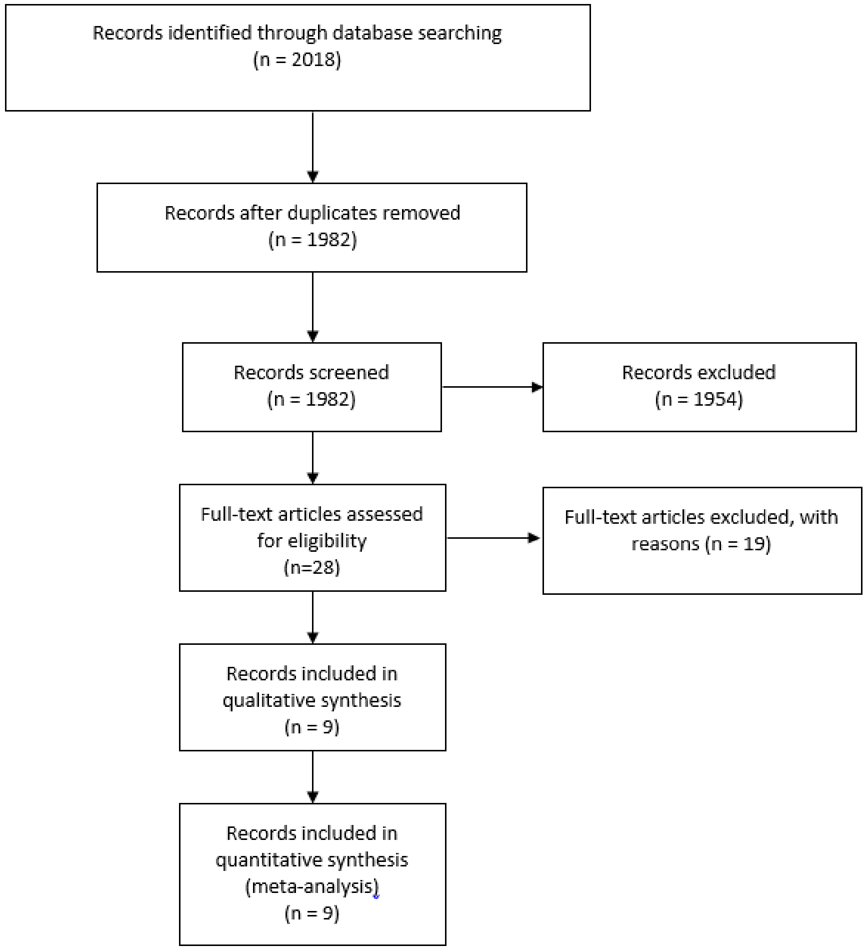



**Figure 2**

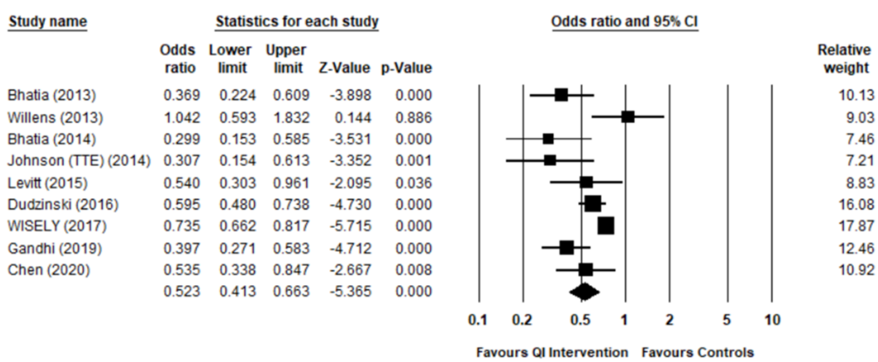
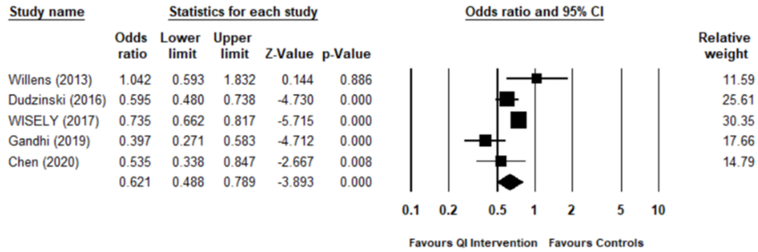



**Figure 3**

(a)




(b)

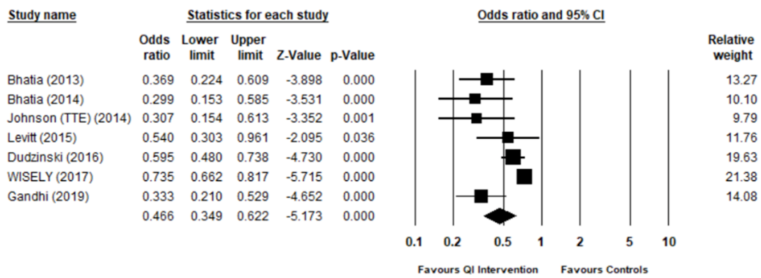
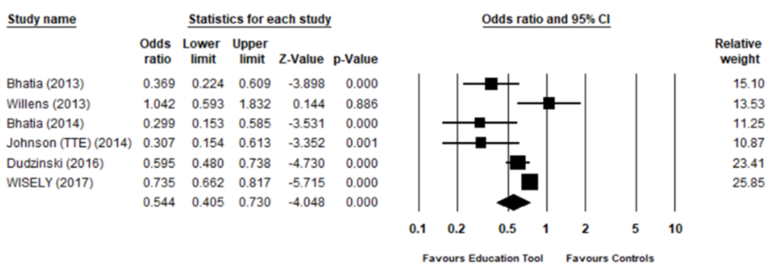



**Figure 4**

(a)




(b)

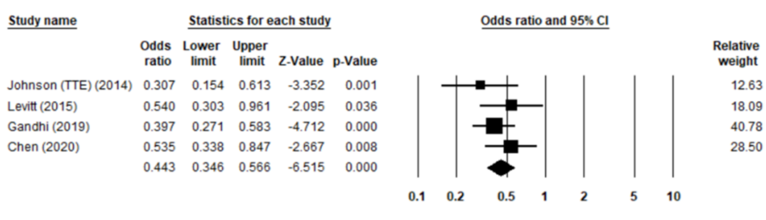
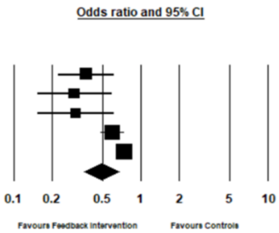



**Figure 5**

**(a)**

| Study name | Odds ratio | Lower limit | Upper limit | Z-Value | p-Value | Relative weight |
|---|---|---|---|---|---|---|
| Bhatia (2013) | 0.369 | 0.224 | 0.609 | -3.898 | 0.000 | 17.52 |
| Bhatia (2014) | 0.299 | 0.153 | 0.585 | -3.531 | 0.000 | 13.08 |
| Johnson (TTE) (2014) | 0.307 | 0.154 | 0.613 | -3.352 | 0.001 | 12.65 |
| Dudzinski (2016) | 0.595 | 0.480 | 0.738 | -4.730 | 0.000 | 27.00 |
| WISELY (2017) | 0.735 | 0.662 | 0.817 | -5.715 | 0.000 | 29.76 |
| | 0.490 | 0.356 | 0.675 | -4.372 | 0.000 | |

Statistics for each study




**(b)**

| Study name | Odds ratio | Lower limit | Upper limit | Z-Value | p-Value | Relative weight |
|---|---|---|---|---|---|---|
| Willens (2013) | 1.042 | 0.593 | 1.832 | 0.144 | 0.886 | 22.23 |
| Levitt (2015) | 0.540 | 0.303 | 0.961 | -2.095 | 0.036 | 21.79 |
| Gandhi (2019) | 0.397 | 0.271 | 0.583 | -4.712 | 0.000 | 29.62 |
| Chen (2020) | 0.535 | 0.338 | 0.847 | -2.667 | 0.008 | 26.37 |
| | 0.569 | 0.385 | 0.841 | -2.828 | 0.005 | |

Statistics for each study