THE JOURNAL OF PROSTHETIC DENTISTRY

SYSTEMATIC REVIEW

Digital versus conventional impressions for fixed prosthodontics: A systematic review and meta-analysis

Konstantinos M. Chochlidakis, DDS,[a] Panos Papaspyridakos, DDS, MS, PhD,[b] Alessandro Geminiani, DDS, MS,[c] Chun-Jung Chen, DDS, MS,[d] I. Jung Feng, MS,[e] and Carlo Ercoli, DDS[f]

ABSTRACT

Statement of problem. Limited evidence is available for the marginal and internal fit of fixed dental restorations fabricated with digital impressions compared with those fabricated with conventional impressions.

Purpose. The purpose of this systematic review was to compare marginal and internal fit of fixed dental restorations fabricated with digital techniques to those fabricated using conventional impression techniques and to determine the effect of different variables on the accuracy of fit.

Material and methods. Medline, Cochrane, and EMBASE databases were electronically searched and enriched by hand searches. Studies evaluating the fit of fixed dental restorations fabricated with digital and conventional impression techniques were identified. Pooled data were statistically analyzed, and factors affecting the accuracy of fit were identified, and their impact on accuracy of fit outcomes were assessed.

Results. Dental restorations fabricated with digital impression techniques exhibited similar marginal misfit to those fabricated with conventional impression techniques (P>.05). Both marginal and internal discrepancies were greater for stone die casts, whereas digital dies produced restorations with the smallest discrepancies (*P*<.05). When a digital impression was used to generate stereolithographic (SLA)/polyurethane dies, misfit values were intermediate. The fabrication technique, the type of restoration, and the impression material had no effect on misfit values (*P*>.05), whereas die and restoration materials were statistically associated (*P*<.05).

Conclusions. Although conclusions were based mainly on in vitro studies, the digital impression technique provided better marginal and internal fit of fixed restorations than conventional techniques did. (J Prosthet Dent 2016;116:184-190)

To fabricate a single crown (SC) or multiunit fixed dental prosthesis (FDP), an accurate cast is required and can be achieved with either digital or conventional impression techniques. Internal and marginal fit are 2 main clinical factors used for quality assessment of fixed restorations.[1-3] Clinical studies have shown the importance of accuracy of fit for clinical success[1,4]; however, previous investigations limited their assessment of single crown fit mostly to marginal accuracy. Studies investigating internal fit of crowns and FDPs were generally based on measurements of distinct points of sectioned tooth-crown assemblies.[5,6]

Marginal fit is considered an important criterion for clinical quality and success of fixed restorations,[1,4,7] even though marginal discrepancy alone has not been correlated with marginal microleakage.[7] In previous studies, an acceptable crown margin-tooth finishing line discrepancy ranged from 34 to 119 μm,[8] and fixed restorations with marginal discrepancies of less than 120 μm were considered more likely to be successful.[9] The internal fit is also an important criterion and has had an effect on the seating of the crown and consequently the marginal fit. Indeed, a

[a]Assistant Professor, Department of Prosthodontics, Eastman Institute for Oral Health, University of Rochester, Rochester, NY.
[b]Assistant Professor, Division of Postgraduate Prosthodontics, Tufts University School of Dental Medicine, Boston, Mass.
[c]Private practice, Rochester, NY.
[d]Instructor, Department of Dentistry, Chi Mei Medical Center, Tainan, Taiwan.
[e]Assistant Research Fellow, Department of Medical Research, Chi Mei Medical Center, Tainan, Taiwan.
[f]Professor, Department of Prosthodontics, Eastman Institute for Oral Health, University of Rochester, Rochester, NY.

Clinical Implications

Intraoral digital impressions are widely available and currently provide similar accuracy to conventional elastomeric impressions. They have several advantages, including archiving and the ability to digitally merge sectional impressions. However, digital technology requires frequent updates and will be surpassed by even newer technology.

25-μm-thick die spacer has been shown to improve the seating of a crown and increase the retention of the restoration by 25%.[10] In another study, increasing cement thickness was shown to decrease the fracture resistance of the ceramic restorations because of the greater deformation of the porcelain into the cement layer and also the decreased thickness of the restorations.[11]

The most common conventional impression materials used for definitive impressions in fixed prosthodontics are polyether (PE), and polyvinyl siloxane (PVS). These materials exhibit excellent dimensional stability and precision and have been successfully used in fixed prosthodontics for many decades.[12-16] Factors such as variation in temperature, length of time between impression making and pouring, surface wettability of the gypsum product, and disinfection procedures may result in material distortion and affect accuracy.[16,17] Also, the application of die hardener and die spacer, as well as laboratory steps for prosthesis fabrication such as waxing, investing, casting, or pressing process, may introduce dimensional error and affect the fit of the definitive restoration.[18,19]

Recent advances in technology have introduced digital impression and crown fabrication procedures, and their in clinical practice is steadily increasing.[20,21] Advances in computer-aided design and computer-aided manufacturing (CAD-CAM) technology have led to the production of more accurately fitted milled restorations[20,21] and more widespread use of a digital workflow for prosthesis fabrication.

Digital impressions in implant and fixed prosthodontics have several advantages compared with conventional techniques such as elimination of laboratory production steps that may cause misfit, lessened transport time between clinic and dental laboratory, and reduced patient discomfort.[22-26] However, conventional impressions have shown high detail accuracy and are currently routinely and successfully used. Clinical studies comparing these 2 different techniques in vivo are lacking, although there are in vitro studies measuring the marginal and internal fit of dental restorations fabricated with conventional and digital techniques. The purpose of this systematic review was to compare marginal and internal fit of fixed dental restorations fabricated with digital techniques to those fabricated using conventional impression techniques and to determine the effects of different variables on the accuracy of fit.

MATERIAL AND METHODS

This systematic review was conducted in accordance with guidelines of Transparent Reporting of Systematic Reviews and Meta-analyses (PRISMA-statement).[27] The Population, Intervention, Comparison, Outcome (PICO) frame[28] was formulated to answer 1 primary question and 5 secondary questions for a systematic review of published reports. The primary question was: in patients in need of fixed dental restorations, does the digital impression technique, compared with the conventional technique, provide better marginal and internal fit of the restoration? The 5 secondary questions were as follows: (1) in patients in need of fixed dental restorations, does a stone die, compared with a polyurethane or digital die, provide better marginal and internal fit in control and experimental groups? (2) In patients in need of fixed dental restorations, does the casting technique, compared with pressing or CAD-CAM fabrication technique, provide better marginal and internal fit in control and experimental groups? (3) In patients in need of fixed dental restorations, does a metal alloy, compared with glass ceramic or other ceramic restorative material, provide better marginal and internal fit in control and experimental groups? (4) In patients in need of fixed dental restorations, does the fabrication of SC, compared with FDP, result in better marginal and internal fit in control and experimental groups? (5) In patients in need of fixed dental restorations, does PE, compared with PVS, impression material provide better marginal and internal fit when the conventional impression technique is used?

The inclusion and exclusion criteria used in this meta-analysis are described in Table 1. Three Internet sources were used to search for eligible articles (published and early view online) in English. These databases included MEDLINE-PubMed, EMBASE (Excerpta Medical Database [Elsevier]), and Cochrane Central Register of Controlled Trials (CENTRAL). Additionally, the following journals were hand searched for potentially relevant articles: *International Journal of Prosthodontics*, *Journal of Prosthetic Dentistry*, *Journal of Esthetic and Restorative Dentistry*, *International Journal of Periodontics and Restorative Dentistry*, *European Journal of Esthetic Dentistry*, and *Journal of Prosthodontics*. The time period was from January 1, 1980, to March 1, 2015.

The search strategy included the following keyword combinations (medical subject headings [MeSH] and free-text terms): "digital impression" AND "marginal fit"; "digital impression" AND "internal fit"; "digital impression" AND "dimensional accuracy";

Table 1. Inclusion and exclusion criteria

Inclusion Criteria
1. Study in vitro or in vivo
2. Title is related to question. Studies should report on marginal and internal fit
3. Experimental and control group
4. Quantitative results provided
5. Articles should be in English language
Exclusion Criteria
1. No experimental and control group
2. Expert opinions or literature reviews
3. Studies based on charts and questionnaires only
4. Animal studies
5. No author response to inquiry for data clarification

"conventional impression" AND "marginal fit"; "conventional impression" AND "dimensional accuracy"; "digital impression" AND "single crown"; "digital impression" AND "fixed dental prosthesis"; "conventional impression" AND "single crown"; "conventional impression" AND "fixed dental prosthesis"; and "digital impression" AND "accuracy." Articles were collected in reference manager software (Endnotes; Thomson Reuters), and duplicates were discarded electronically.

To ensure reliability, a calibration exercise with two reviewers (K.C., A.G.) was conducted prior to commencing screening. Using the inclusion criteria, a random sample of 10% of citations from the search were screened independently by both reviewers. Screening only began when percent agreement was >90% across the two reviewers. A similar calibration exercise was completed prior to screening full-text articles for inclusion.

Two calibrated reviewers (K.C., A.G.) initially screened titles and abstracts for potential inclusion. If no abstract was available in the database, the abstract of the printed article was used. If the title and abstract did not provide sufficient information regarding inclusion criteria, the full article was obtained. All titles and abstracts were selected by the 2 reviewers and were discussed individually for full-text reading inclusion. Selected articles were then obtained in full text, and the 2 reviewers independently carried out full-text reading of related publications. The electronic search was supplemented by a manual search of the bibliographies of all the full-text articles selected from the initial search. Interreviewer agreement was determined using Cohen kappa statistics (k-score), and in cases where information was not clear, the authors of the pertinent study were contacted by email to elucidate the issue. Data collection was done using a standardized electronic spreadsheet. An assessment of study quality was performed for the included in vivo studies. The Cochrane Collaboration tool for assessing risk of bias was used in the case of randomized controlled clinical trials and controlled clinical trials, and the assessment result is shown in Table 2. Two calibrated reviewers (K.C., A.G.) independently extracted data and created a table from articles that met the inclusion criteria. The type of study, number of patients, number of restorations, dropout number, mean and standard deviation values of marginal and internal discrepancy, die fabrication technique, restoration fabrication technique, type of restorative material, type of conventional material, and type of prosthesis were recorded for each included article.

Quantitative and qualitative analyses was performed for the in vitro studies, but only qualitative analysis was performed for the in vivo studies because of the small number of included studies. Individual effect sizes for each study as the standardized mean difference (SMD) were computed with the following formula: [mean of marginal discrepancy or internal space in conventional impression – mean of marginal discrepancy or internal space in digital impression/pooled standard deviation]. Then, effect size estimates were corrected by the Hedges method to remove the bias caused by the small number of studies. If the effect size of a study was reported for more than 1 subgroup, the calculation of the mean and standard deviation was performed to combine the subgroup effect sizes. A 95% confidence interval for each effect size was also computed. Because effect sizes varied among studies according to population, techniques, materials, and measuring instrument, a considerable heterogeneity between studies was expected. Thus, an a priori random-effects model was chosen for meta-analysis. The overall estimate of SMDs was computed by the inverse-variance-weighted method in which the individual study was weighted by the reciprocal of the sum of the within-study variance of the study and the between-studies variance component. The test for summary effect size was performed using a z-test, dividing the summary SMD by the estimated standard deviation. Furthermore, the 95% confidence interval of the summary effect size was also computed. The homogeneity of effect sizes was accessed by the Q test, in which we compared the Q statistic and its expected value, degrees of freedom (*df*) to test the null hypothesis that all studies share the same effect size. The I^2 statistic, a ratio of true heterogeneity to observed total variation, was also calculated. In this study, a *P* value of <.05 was considered statistically significant, and I^2 >50% was considered substantial or considerable heterogeneity. To further determine the influence of different variables on the accuracy outcome, metaregression analysis was performed. Within conventional and digital impression techniques, the influence on marginal discrepancy or internal space caused by study moderators was separately explored. Because all the explored moderators were categorical variables, dummy variables were used for coding in the metaregression model. Overall subgroup summary mean values were also calculated. Because the number of studies in each subgroup was

Table 2. Cochrane collaboration tool for assessing risk of bias

Study Design	Syrek et al[36] Randomized Controlled Clinical Trial	Pradies et al[33] Prospective Controlled Clinical Trial
Adequate sequence generation	Unclear	Unclear
Remarks	"20 subjects gave informed consent and were enrolled in the study"	"Thirty participants were enrolled into the study and were fitted with 34 zirconia-ceramic single crowns"
Allocation concealment	Yes	Yes
Remarks	The sequence of … was randomized using randomization envelopes	"One operator randomized the sequence … phone application"
Blinding	Yes	Yes
Remarks	"two calibrated and blinded examiners" and "two blinded examiners"	Not blinded but as stated "Two trained investigators, who were previously calibrated…calculated"
Incomplete outcome data addressed	Yes	Yes
Remarks	"Two patients dropped out; reasons for drop out were: pulp exposure … was a protocol violation"	"Of the 34 teeth, one tooth was dropped out … Table 1."
Free of selective reporting	Yes	Yes
Remarks	"At the study, the inter-examiner agreement was 78% for marginal contours, 92% for marginal gap, 89% for interproximal contact, and 86% for occlusion. Any disagreement between the examiners was resolved by forced consensus."	"The average of the two measurements was calculated. The measurements were performed without cementing the crowns, so the increase in marginal gap width caused by cementation was not included."
Free of other sources of bias	No	No
Remarks	"[F]inancial support from 3M ESPE in Germany for this study"	"[T]his work has been partially supported by 3M ESPE"
Overall risk of bias	Medium	Medium

small, we assumed that the τ^2 value within each subgroup was the same. Then, the estimation of τ^2 was based on a larger sample size of studies. R software (R Core Team) and user-contributed R software "metafor" were used for all statistical analyses.

RESULTS

Initial electronic and manual searches identified 315 articles after discarding duplicate references. After the subsequent search at the title, abstract, and full-text reading level, 11 studies[29-39] were finally selected for inclusion (Fig. 1). The full-text reading yielded 2 clinical studies[35,38] and 9 in vitro studies[29-34,36,37,39] which satisfied inclusion criteria and were used for statistical analysis. The parameters recorded for all included studies are described in Supplemental Tables 1 and 2.

In regard to the primary PICO question, the restorations fabricated in the digital impression groups showed a nominally smaller yet not statistically significant marginal discrepancy than those fabricated in the conventional impression groups. Overall SMDs for the marginal discrepancy and internal space are shown in Table 3. A statistically significant heterogeneity was found in SMD in both analyses (Supplemental Fig. 1). In regard to the secondary PICO questions, statistically significant heterogeneity was found in overall weighted mean values in 3 of 4 analyses (Supplemental Fig. 2). In regard to the first secondary PICO question, a digital die led to a smaller discrepancy than SLA/polyurethane die (P=.009) (Supplemental Figs. 3, 4). In regard to the second secondary PICO question, in conventional groups, cast restorations provided the smallest weighted subgroup internal space compared with CAD-CAM restorations and restorations fabricated with the pressing technique (Supplemental Fig. 5). In digital groups, restorations fabricated with CAD-CAM technology showed smaller marginal and internal discrepancies than restorations fabricated with the pressing technique (Supplemental Figs. 3B, 4B). In regard to the third secondary PICO question, glass-ceramic restorations showed the largest internal space in digital and conventional groups separately compared with zirconia restorations and metal alloy (Supplemental Figs. 4C, 5C). Furthermore, the marginal discrepancy in digital groups showed that metal alloy restorations produced the smallest discrepancy, followed by that of glass-ceramics, whereas zirconia restorations showed the largest marginal discrepancy (Supplemental Fig. 3C). In regard to the fourth secondary PICO question, in the digital groups, FDPs provided smaller marginal and internal discrepancies than SCs (Supplemental Figs. 3D, 4D). In conventional groups, SCs provided smaller internal space than FDPs (Supplemental Fig. 5D). In regard to the fifth secondary PICO question, in the conventional impression groups, the PVS impression material provided a nominal smaller internal space value than PE material (Supplemental Fig. 5E).

Using appropriate assessment tools, a medium risk of bias was assigned to the 2 in vivo trials (Table 2).[35,38] The analysis showed that zirconia crowns fabricated from intraoral digital impressions demonstrated significantly less marginal discrepancy than zirconia crowns fabricated with the conventional impression technique.[38] Similar results were obtained from the other in vivo study,[35] showing that zirconia-based ceramic crowns fabricated using digital impression exhibited better marginal and internal fit than crowns fabricated from conventional impressions.

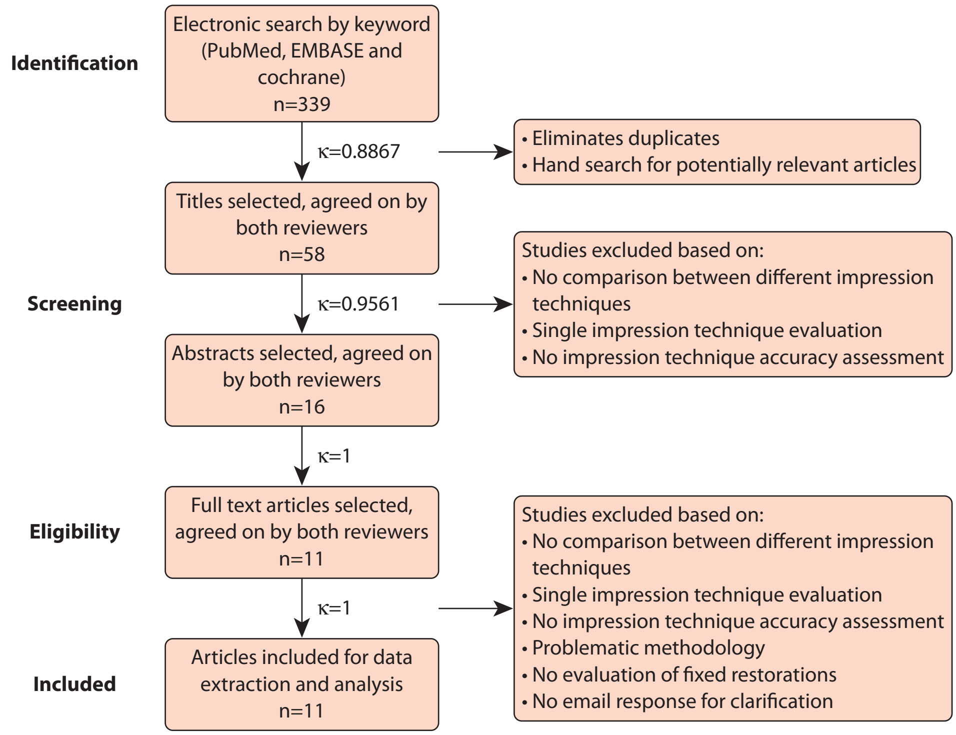


Figure 1. Search strategy.

DISCUSSION

The purpose of the present systematic review was to compare the marginal and internal fit of fixed dental restorations fabricated with digital and conventional impression techniques and to determine the effect of different variables on the accuracy outcome. Dental restorations fabricated with the digital impression technique presented with nominally smaller but not statistically significant marginal and internal discrepancies than those fabricated with the conventional impression technique. Digital dies led to restorations with nominally smaller marginal discrepancies and significantly smaller internal spaces than SLA/polyurethane dies. The above-described findings highlight the potential advantages of so-called complete digital workflow. In fact, Syrek et al[38] concluded that both of the impression techniques resulted in clinically acceptable fit but that zirconia single crowns fabricated from a digital impression had a better fit than those from conventional impressions. Additionally, interproximal contacts and marginal discrepancies were better for the digital group than the conventional group.

In regard to the effect of the restoration fabrication technique, no statistically significant differences were found in either marginal or internal discrepancy comparison in conventional and digital groups. This is in agreement with findings in previous studies[21] and clinical experience.

In regard to the effect of restoration material in the digital groups, metal alloy restorations showed the smallest marginal discrepancy compared that in glass ceramics and zirconia restorations. Glass ceramic restorations showed the largest internal space in digital and conventional groups compared with zirconia and metal alloy restorations. The internal space differences between zirconia and metal alloy and those between zirconia and glass ceramics were found to be not statistically significant. In regard to the effect of restoration type in the digital groups, FDPs provided the smallest internal and marginal discrepancies compared with SCs. In conventional groups, the opposite result was observed; SCs provided a smaller internal space than FDPs. However, no statistical significance was found for internal and marginal discrepancies between FDPs and SCs in either the conventional or the digital group. In regard to the effect of impression material, the PVS impression material provided a smaller internal space than PE material, but no statistical significance was found, in agreement with previously published studies.

The advantage of the present systematic review may include the strict selection criteria for studies with both experimental and control groups for comparative analysis. In regard to comparison with the findings of other systematic reviews, no data were available. This is the first systematic review that compared digital and conventional impression techniques for the fabrication of tooth-supported fixed restorations. However, the findings of this review must be interpreted with caution because only 2 clinical studies satisfied the inclusion criteria for meta-analysis, and the results are primarily

Table 3. Results of random-effect, meta-regression model analysis

Marginal Discrepancy, Digital Groups			Internal Space, Digital Groups			Internal Space, Conventional Groups		
	β coefficient (95% CI)	*P*		β coefficient (95% CI)	*P*		β coefficient (95% CI)	*P*
Die Fabrication Technique			**Die Fabrication Technique**			**Restoration Fabrication Technique**		
SLA/polyurethane die	85.99 (58.17-113.82)	<.001*	SLA/polyurethane die	169.69 (106.86-232.52)	<.001*	**Model 1**		
(Digital die)(SLA/polyurethane die)	-28.33 (601.12-4.46)	.090	(Digital die)-(SLA/polyurethane die)	-92.84 (-162.51 to −23.17)	.009*	Cast	49.19 (-26.35 to 124.74)	.202
						(CAD-CAM)-(cast)	47.50 (-37.36 to 132.36)	.273
Type of Restorative Material			**Type of Restorative Material**			(Press)-(cast)	84.03 (-47.73 to 215.80)	.211
Model 1			**Model 1**			**Model 2**		
Metal alloy	47.67 (12.46-82.89)	.007*	Metal alloy	80.97 (22.98-138.97)	.006*	CAD-CAM	96.70 (58.03-135.36)	<.001*
(Glass ceramic)-(metal alloy)	8.65 (-36.06 to 53.35)	.697	(Glass ceramic)-(metal alloy)	43.09 (-51.05 to 137.24)	.370	(Press)-(CAD-CAM)	36.53 (-78.14 to 151.21)	.532
(Zirconia)-(metal alloy)	33.02 (-9.11-75.16)	.124	(Zirconia)-(metal alloy)	4.02 (-72.02 to 80.05)	.918	(Cast)-(CAD-CAM)	-47.50 (-132.36 to 37.36)	.273
Model 2			**Model 2**					
Glass ceramic	80.70 (57.56-103.84)	<.001*	Zirconia	84.99 (35.82-134.16)	<.001*	**Type of Restorative Material**		
(Zirconia)-(glass ceramic)	-24.38 (-60.36 to 11.60)	.184	(Glass ceramic)-(zirconia)	39.08 (-49.90 to 128.06)	.389	**Model 1**		
(Metal alloy)-(glass ceramic)	-33.02 (-75.16 to 9.11)	.124	(Metal alloy)-(zirconia)	-4.02 (-80.05 to 72.02)	.918	Metal alloy	99.40 (13.71-185.09)	.023*
						(Glass ceramic)-(metal alloy)	40.59 (-64.85 to 146.04)	.450
Type of Prosthesis			**Type of Prosthesis**			(Zirconia)-(metal alloy)	-22.43 (-121.52 to 76.66)	.657
Single crown	69.96 (50.99-88.92)	<.001*	Single crown	110.56 (62.02-159.11)	<.001*	**Model 2**		
(FDP)-(single crown)	-15.09 (-52.91 to 22.74)	.434	(FDP)-(single crown)	-18.49 (-108.96 to 71.98)	.689	Zirconia	76.97 (27.26-126.73)	.002*
						(Glass ceramic)-(zirconia)	63.02 (-16.05 to 142.09)	.118
						(Metal alloy)-(zirconia)	22.43 (-76.66 to 121.52)	.657
						Type of Prosthesis		
						Single crown	85.56 (48.72-122.40)	<.001*
						(FDP)-(single crown)	21.84 (-54.16 to 97.84)	.573
						Type of Conventional Material		
						PE	95.06 (1.83-188.30)	.046*
						(PVS)-(PE)	-14.04 (-112.82 to 84.73)	.780

CAD-CAM, computer-aided design and computer-aided manufacture; FDP, fixed dental prosthesis; PE, polyether; PVS, polyvinyl siloxane; SLA, stereolithographic.*Statistically significant.

based on in vitro studies. The number of the included in-vitro studies was small, which may lead to heterogeneity among them. A greater number of clinical studies would be needed in order to have a more definitive conclusion. However, well-executed in vitro studies may still provide valuable insight into accuracy assessments. Moreover, a direct comparison of accuracy between the different digital impression systems could not be performed because of the limited research available.

The clinical use of digital impressions is steadily increasing. The advantages offered by this technology include the elimination of tray selection and impression materials, electronic transfer and storage of the digital file, and in-office milling of the definitive restorations. Limitations pertain to the additional cost of purchasing an intraoral scanner and the learning curve for adjusting to the new technology. Although technological improvements, enhanced user digital familiarity and education, and workflow optimization might lower the threshold for clinician acceptance of this technology, the practitioner should carefully evaluate the specific situation of the working environment. In fact, such technology requires frequent updates and/or upgrades and could be easily surpassed by an even newer technology.

CONCLUSIONS

Within the limitations of the present systematic review and meta-analysis, the following conclusions were drawn:

1. Dental restorations fabricated with the digital impression technique presented statistically similar marginal discrepancies compared with those obtained with the conventional impression technique.
2. In digital impression groups, digital dies led to restorations with smaller marginal and internal discrepancy compared with SLA/polyurethane dies.
3. In regard to "pressing" and CAD-CAM fabrication techniques, similar results were found for both the marginal and the internal discrepancy in conventional and digital groups.
4. Glass-ceramics showed the largest internal space compared with zirconia and metal alloy restorations in digital and conventional groups. In digital groups, metal alloy restorations showed the smallest marginal discrepancy compared with glass-ceramics and zirconia restorations.
5. Internal and marginal discrepancies between FDPs and SCs in both conventional and digital groups were similar.
6. When polyether and PVS were used as the conventional impression materials, similar discrepancy measurements were found for the restorations.

REFERENCES

1. Karlsson S. The fit of Procera titanium crowns. An in vitro and clinical study. Acta Odontol Scand 1993;51:129-34.
2. Oden A, Andersson M, Krystek-Ondracek I, Magnusson D. Five-year clinical evaluation of Procera AllCeram crowns. J Prosthet Dent 1998;80:450-6.
3. Besimo C, Jeger C, Guggenheim R. Marginal adaptation of titanium frameworks produced by CAD/CAM techniques. Int J Prosthodont 1997;10:541-6.
4. May KB, Russell MM, Razzoog ME, Lang BR. Precision of fit: the Procera AllCeram crown. J Prosthet Dent 1998;80:394-404.
5. Martin N, Jedynakiewicz NM. Interface dimensions of CEREC-2 MOD inlays. Dent Mater 2000;16:68-74.
6. Sjogren G. Marginal and internal fit of four different types of ceramic inlays after luting. An in vitro study. Acta Odontol Scand 1995;53:24-8.
7. White SN, Ingles S, Kipnis V. Influence of marginal opening on microleakage of cemented artificial crowns. J Prosthet Dent 1994;71:257-64.
8. Christensen GJ. Marginal fit of gold inlay castings. J Prosthet Dent 1966;16:297-305.
9. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. Br Dent J 1971;131:107-11.
10. Eames WB, O'Neal SJ, Monteiro J, Miller C, Roan JD Jr, Cohen KS. Techniques to improve the seating of castings. J Am Dent Assoc 1978;96:432-7.
11. Tuntiprawon M, Wilson PR. The effect of cement thickness on the fracture strength of all-ceramic crowns. Aust Dent J 1995;40:17-21.
12. Christensen GJ. Will digital impressions eliminate the current problems with conventional impressions? J Am Dent Assoc 2008;139:761-3.
13. Clancy JM, Scandrett FR, Ettinger RL. Long-term dimensional stability of three current elastomers. J Oral Rehabil 1983;10:325-33.
14. Endo T, Finger WJ. Dimensional accuracy of a new polyether impression material. Quintessence Int 2006;37:47-51.
15. Hondrum SO. Changes in properties of nonaqueous elastomeric impression materials after storage of components. J Prosthet Dent 2001;85:73-81.
16. Thongthammachat S, Moore BK, Barco MT 2nd, Hovijitra S, Brown DT, Andres CJ. Dimensional accuracy of dental casts: influence of tray material, impression material, and time. J Prosthodont 2002;11:98-108.
17. Rodriguez JM, Bartlett DW. The dimensional stability of impression materials and its effect on in vitro tooth wear studies. Dent Mater 2011;27:253-8.
18. Campagni WV, Preston JD, Reisbick MH. Measurement of paint-on die spacers used for casting relief. J Prosthet Dent 1982;47:606-11.
19. Gorman CM, McDevitt WE, Hill RG. Comparison of two heat-pressed all-ceramic dental materials. Dent Mater 2000;16:389-95.
20. Strub JR, Rekow ED, Witkowski S. Computer-aided design and fabrication of dental restorations: current systems and future possibilities. J Am Dent Assoc 2006;137:1289-96.
21. Kapos T, Evans C. CAD/CAM technology for implant abutments, crowns, and superstructures. Int J Oral Maxillofac Implants 2014;29S:117-36.
22. Joda T, Bragger U. Digital vs. conventional implant prosthetic workflows: a cost/time analysis. Clin Oral Implants Res 2015;26:1430-5.
23. Lee SJ, Betensky RA, Gianneschi GE, Gallucci GO. Accuracy of digital versus conventional implant impressions. Clin Oral Implants Res 2015;26:715-9.
24. Papaspyridakos P, Gallucci GO, Chen CJ, Hanssen S, Naert I, Vandenberghe B. Digital versus conventional implant impressions for edentulous patients: accuracy outcomes. Clin Oral Implants Res 2016;27:465-72.
25. Lin WS, Harris BT, Elathamna EN, Abdel-Azim T, Morton D. Effect of implant divergence on the accuracy of definitive casts created from traditional and digital implant-level impressions: an in vitro comparative study. Int J Oral Maxillofac Implants 2015;30:102-9.
26. Ting-Shu S, Jian S. Intraoral digital impression technique: a review. J Prosthodont 2015;24:313-21.
27. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 2009;6:e1000097.
28. Xiaoli Huang ML, Lin J, Demner-Fushman D. Evaluation of PICO as a Knowledge Representation for Clinical Questions. AMIA Annu Symp Proc 2006:359-63.
29. Almeida e Silva JS, Erdelt K, Edelhoff D, Araujo E, Stimmelmayr M, Vieira LC, et al. Marginal and internal fit of four-unit zirconia fixed dental prostheses based on digital and conventional impression techniques. Clin Oral Investig 2014;18:515-23.
30. An S, Kim S, Choi H, Lee JH, Moon HS. Evaluating the marginal fit of zirconia copings with digital impressions with an intraoral digital scanner. J Prosthet Dent 2014;112:1171-5.
31. Anadioti E, Aquilino SA, Gratton DG, Holloway JA, Denry I, Thomas GW, et al. 3D and 2D marginal fit of pressed and CAD/CAM lithium disilicate crowns made from digital and conventional impressions. J Prosthodont 2014;23:610-7.
32. Anadioti E, Aquilino SA, Gratton DG, Holloway JA, Denry IL, Thomas GW, et al. Internal fit of pressed and computer-aided design/computer-aided manufacturing ceramic crowns made from digital and conventional impressions. J Prosthet Dent 2015;113:304-9.
33. Keul C, Stawarczyk B, Erdelt KJ, Beuer F, Edelhoff D, Guth JF. Fit of 4-unit FDPs made of zirconia and CoCr-alloy after chairside and labside digitalization-a laboratory study. Dent Mater 2014;30:400-7.
34. Ng J, Ruse D, Wyatt C. A comparison of the marginal fit of crowns fabricated with digital and conventional methods. J Prosthet Dent 2014;112:555-60.
35. Pradies G, Zarauz C, Valverde A, Ferreiroa A, Martinez-Rus F. Clinical evaluation comparing the fit of all-ceramic crowns obtained from silicone and digital intraoral impressions based on wavefront sampling technology. J Dent 2015;43:201-8.
36. Seelbach P, Brueckel C, Wostmann B. Accuracy of digital and conventional impression techniques and workflow. Clinical Oral Investig 2013;17:1759-64.
37. Svanborg P, Skjerven H, Carlsson P, Eliasson A, Karlsson S, Ortorp A. Marginal and internal fit of cobalt-chromium fixed dental prostheses generated from digital and conventional impressions. Int J Dent 2014;53.438-2.
38. Syrek A, Reich G, Ranftl D, Klein C, Cerny B, Brodesser J. Clinical evaluation of all-ceramic crowns fabricated from intraoral digital impressions based on the principle of active wavefront sampling. J Dent 2010;38:553-9.
39. Tidehag P, Ottosson K, Sjogren G. Accuracy of ceramic restorations made using an in-office optical scanning technique: an in vitro study. Oper Dent 2014;39:308-16.

Corresponding author:
Dr Konstantinos Chochlidakis
625 Elmwood Avenue
Rochester, NY 14620
Email: kchochlidakis@URMC.Rochester.edu

Supplemental Table 1. Data extraction table for in vitro studies-Marginal discrepancy

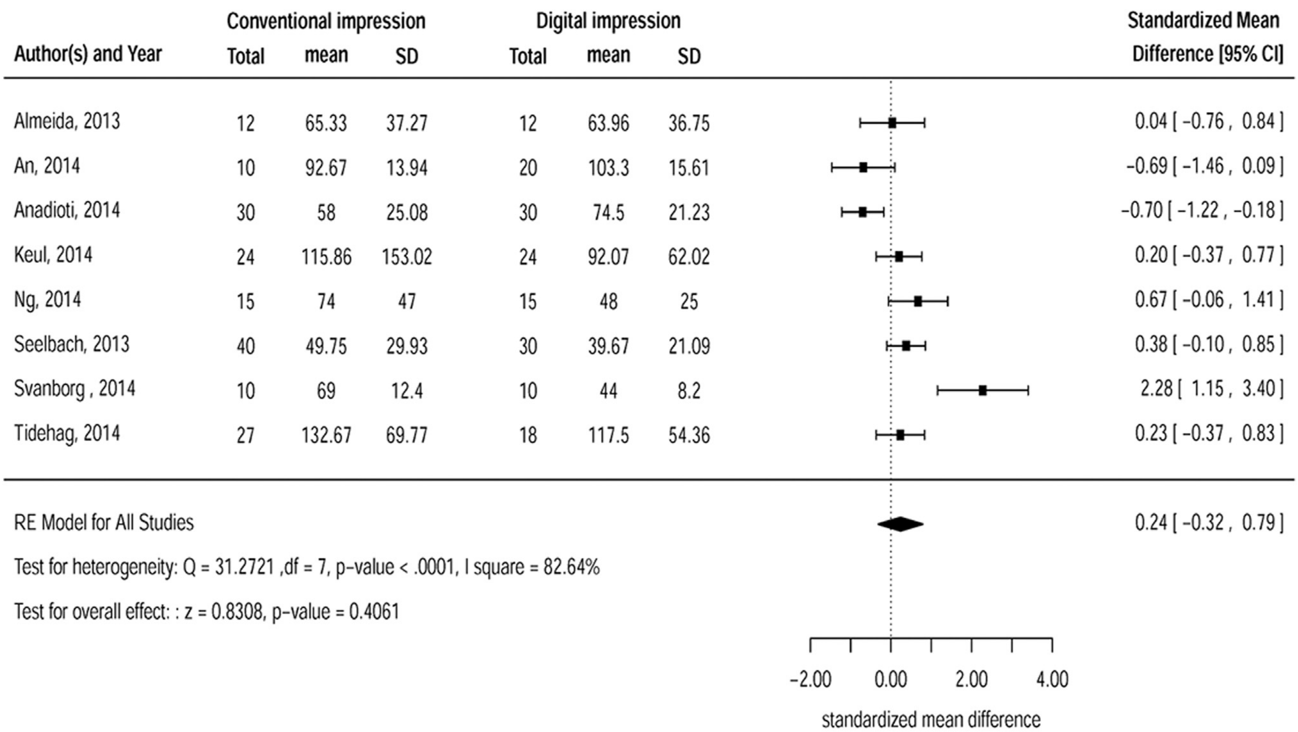
Study/Group	Sample Size	Drop Out	Marginal Discrepancy ±Standard Deviation (μm)	Die Technique	Fabrication Technique	Restorative Material	Conventional Impression	Single Crown/ Fixed Dental Prosthesis
Almeida et al[27]/ Control	12	0	65.33 ±37.27	Stone Die	CAD-CAM	Zirconia	Polyether	Fixed Dental Prosthesis
Almeida et al[27]/ Experimental	12	0	63.96 ±36.75	Digital Die	CAD-CAM	Zirconia		Fixed Dental Prosthesis
An et al[28]/ Control	10	0	92.67 ±13.94	Stone Die	CAD-CAM	Zirconia	Polyvinyl siloxane	Single Crown
An et al[28]/ Experimental (iP)	10	0	103.05 ±14.67	SLA Die	CAD-CAM	Zirconia		Single Crown
An et al[28]/ Experimental (iNo)	10	0	103.55 ±15.50	Digital Die	CAD-CAM	Zirconia		Single Crown
Anadioti et al[29]/ Control (Press)	15	0	40.00 ±9.00	Stone Die	Press	Glass-Ceramic	Polyvinyl siloxane	Single Crown
Anadioti et al[29]/ Control (CAD)	15	0	76.00 ±23.00	Stone Die	CAD-CAM	Glass-Ceramic	Polyvinyl siloxane	Single Crown
Anadioti et al[29]/ Experimental (Press)	15	0	75.00 ±15.00	SLA Die	Press	Glass-Ceramic		Single Crown
Anadioti et al[29]/ Experimental (CAD)	15	0	74.00 ±26.00	SLA Die	CAD-CAM	Glass-Ceramic		Single Crown
Keul et al[31]/ Control (ID-C)	12	0	90.64 ±90.81	Stone Die	CAD-CAM	Metal Alloy	Polyether	Fixed Dental Prosthesis
Keul et al[31]/ Control (ID-Z)	12	0	141.08 ±193.17	Stone Die	CAD-CAM	Zirconia	Polyether	Fixed Dental Prosthesis
Keul et al[31]/ Experimental (DD-C)	12	0	56.90 ±27.37	Digital Die	CAD-CAM	Metal Alloy		Fixed Dental Prosthesis
Keul et al[31]/ Experimental (DD-Z)	12	0	127.23 ±66.87	Digital Die	CAD-CAM	Zirconia		Fixed Dental Prosthesis
Ng et al[32]/ Control	15	0	74.00 ±47.00	Stone Die	Press	Glass-Ceramic	Polyvinyl siloxane	Single Crown
Ng et al[32]/ Experimental	15	0	48.00 ±25.00	Digital Die	CAD-CAM	Glass-Ceramic		Single Crown
Seelbach et al[34]/ Control (1s-cera)	10	0	38.00 ±25.00	Stone Die	Cast	Metal Alloy	Polyvinyl siloxane	Single Crown
Seelbach et al[34]/ Control (1s-Lava)	10	0	33.00 ±19.00	Stone Die	CAD-CAM	Zirconia	Polyvinyl siloxane	Single Crown
Seelbach et al[34]/ Control (2s-cera)	10	0	68.00 ±29.00	Stone Die	Cast	Metal Alloy	Polyvinyl siloxane	Single Crown
Seelbach et al[34]/ Control (2s-Lava)	10	0	60.00 ±30.00	Stone Die	CAD-CAM	Zirconia	Polyvinyl siloxane	Single Crown
Seelbach et al[34]/ Experimental (Cerec)	10	0	30.00 ±17.00	Digital Die	CAD-CAM	Glass-Ceramic		Single Crown
Seelbach et al[34]/ Experimental (Lava)	10	0	48.00 ±25.00	Digital Die	CAD-CAM	Zirconia		Single Crown
Seelbach et al[34]/ Experimental (iTero)	10	0	41.00 ±16.00	Digital Die	CAD-CAM	Zirconia		Single Crown
Svanborg et al[35]/ Control	10	0	69.00 ±12.40	Stone Die	CAD-CAM	Metal Alloy	Polyvinyl siloxane	Fixed Dental Prosthesis
Svanborg et al[35]/ Experimental	10	0	44.00 ±8.20	Digital Die	CAD-CAM	Metal Alloy		Fixed Dental Prosthesis
Tidehag et al[37]/ Control	9	0	170.00 ±94.00	Stone Die	Press	Glass-Ceramic	Polyvinyl siloxane	Single Crown
Tidehag et al[37]/ Experimental (iTero Oral)	9	0	128.00 ±59.00	Digital Die	CAD-CAM	Zirconia		Single Crown
Tidehag et al[37]/ Experimental (LAVA Oral)	9	0	107.00 ±47.00	Digital Die	CAD-CAM	Zirconia		Single Crown
Tidehag et al[37]/ Control (iTero Die Stone)	9	0	115.00 ±37.00	Stone Die	CAD-CAM	Zirconia	Polyvinyl siloxane	Single Crown
Tidehag et al[37]/ Control (LAVA die Stone)	9	0	113.00 ±48.00	Stone Die	CAD-CAM	Zirconia	Polyvinyl siloxane	Single Crown

SLA=Stereolithographic, iP=iTero-polyurethane, iNo=iTero-no die, 1s=1 step technique, 2s=2 step technique, ID-C=Indirect digitization-Base metal, ID-Z= Indirect digitization-Zirconia, DD-C= Direct digitization-Base metal, DD-Z=Direct digitization-Zirconia.

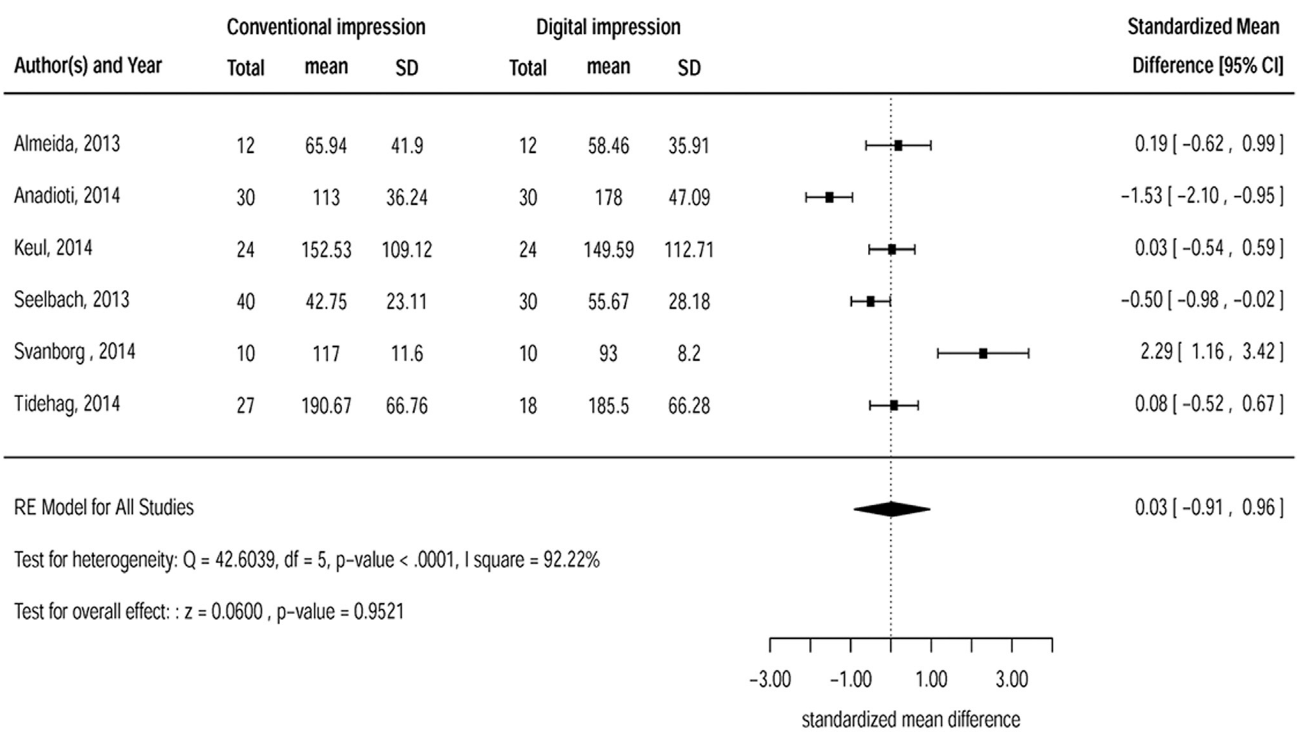
Supplemental Table 2. Data extraction table for in vitro studies-Internal space

Study/Groups	Sample Size	Drop Out	Marginal Discrepancy ± Standard Deviation (μm)	Die Technique	Fabrication Technique	Restorative Material	Conventional Impression	Single crown/ Fixed Dental Prosthesis
Almeida et al[27]/ Control	12	0	65.94 ±41.90	Stone Die	CAD-CAM	Zirconia	Polyether	Fixed Dental Prosthesis
Almeida et al[27]/ Experimental	12	0	58.46 ±35.91	Digital Die	CAD-CAM	Zirconia		Fixed Dental Prosthesis
Anadioti et al[30]/ Control (Press)	15	0	110.00 ±47.00	Stone Die	Press	Glass-Ceramic	Polyvinyl siloxane	Single Crown
Anadioti et al[30]/ Control (CAD)	15	0	116.00 ±20.00	Stone Die	CAD-CAM	Glass-Ceramic	Polyvinyl siloxane	Single Crown
Anadioti et al[30]/ Experimental (Press)	15	0	211.00 ±41.00	SLA Die	Press	Glass-Ceramic		Single Crown
Anadioti et al[30]/ Experimental (CAD)	15	0	145.00 ±24.00	SLA Die	CAD-CAM	Glass-Ceramic		Single Crown
Keul et al[31]/ Control (ID-C)	12	0	151.00 ±102.89	Stone Die	CAD-CAM	Metal Alloy	Polyether	Fixed Dental Prosthesis
Keul et al[31]/ Control (ID-Z)	12	0	154.06 ±115.00	Stone Die	CAD-CAM	Zirconia	Polyether	Fixed Dental Prosthesis
Keul et al[31]/ Experimental (DD-C)	12	0	138.43 ±106.83	Digital Die	CAD-CAM	Metal Alloy		Fixed Dental Prosthesis
Keul et al[31]/ Experimental (DD-Z)	12	0	160.75 ±117.24	Digital Die	CAD-CAM	Zirconia		Fixed Dental Prosthesis
Seelbach et al[34]/ Control (1s-cera)	10	0	44.00 ±22.00	Stone Die	Cast	Metal Alloy	Polyvinyl siloxane	Single Crown
Seelbach et al[34]/ Control (1s-Lava)	10	0	36.00 ±5.00	Stone Die	CAD-CAM	Zirconia	Polyvinyl siloxane	Single Crown
Seelbach et al[34]/ Control (2s-cera)	10	0	56.00 ±36.00	Stone Die	Cast	Metal Alloy	Polyvinyl siloxane	Single Crown
Seelbach et al[34]/ Control (2s-Lava)	10	0	35.00 ±7.00	Stone Die	CAD-CAM	Zirconia	Polyvinyl siloxane	Single Crown
Seelbach et al[34]/ Experimental (Cerec)	10	0	88.00 ±20.00	Digital Die	CAD-CAM	Glass-Ceramic		Single Crown
Seelbach et al[34]/ Experimental (Lava)	10	0	29.00 ±7.00	Digital Die	CAD-CAM	Zirconia		Single Crown
Seelbach et al[34]/ Experimental (iTero)	10	0	50.00 ±12.00	Digital Die	CAD-CAM	Zirconia		Single Crown
Svanborg et al[35]/ Control	10	0	117.00 ±11.60	Stone Die	CAD-CAM	Metal Alloy	Polyvinyl siloxane	Fixed Dental Prosthesis
Svanborg et al[35]/ Experimental	10	0	93.00 ±8.20	Digital Die	CAD-CAM	Metal Alloy		Fixed Dental Prosthesis
Tidehag et al[37]/ Control	9	0	187.00 ±89.00	Stone Die	Press	Glass-Ceramic	Polyvinyl siloxane	Single Crown
Tidehag et al[37]/ Experimental (iTero Oral)	9	0	195.00 ±69.00	Digital Die	CAD-CAM	Zirconia		Single Crown
Tidehag et al[37]/ Experimental (LAVA Oral)	9	0	176.00 ±62.00	Digital Die	CAD-CAM	Zirconia		Single Crown
Tidehag et al[37]/ Control (iTero Die Stone)	9	0	190.00 ±54.00	Stone Die	CAD-CAM	Zirconia	Polyvinyl siloxane	Single Crown
Tidehag et al[37]/ Control (LAVA die Stone)	9	0	195.00 ±50.00	Stone Die	CAD-CAM	Zirconia	Polyvinyl siloxane	Single Crown

SLA=stereolithographic, iP=iTero-polyurethane, iNo=iTero-no die, 1s=1 step technique, 2s=2 step technique, ID-C=Indirect digitization-Base metal, ID-Z=Indirect digitization-Zirconia, DD-C=Direct digitization-Base metal, DD-Z=Direct digitization-Zirconia.

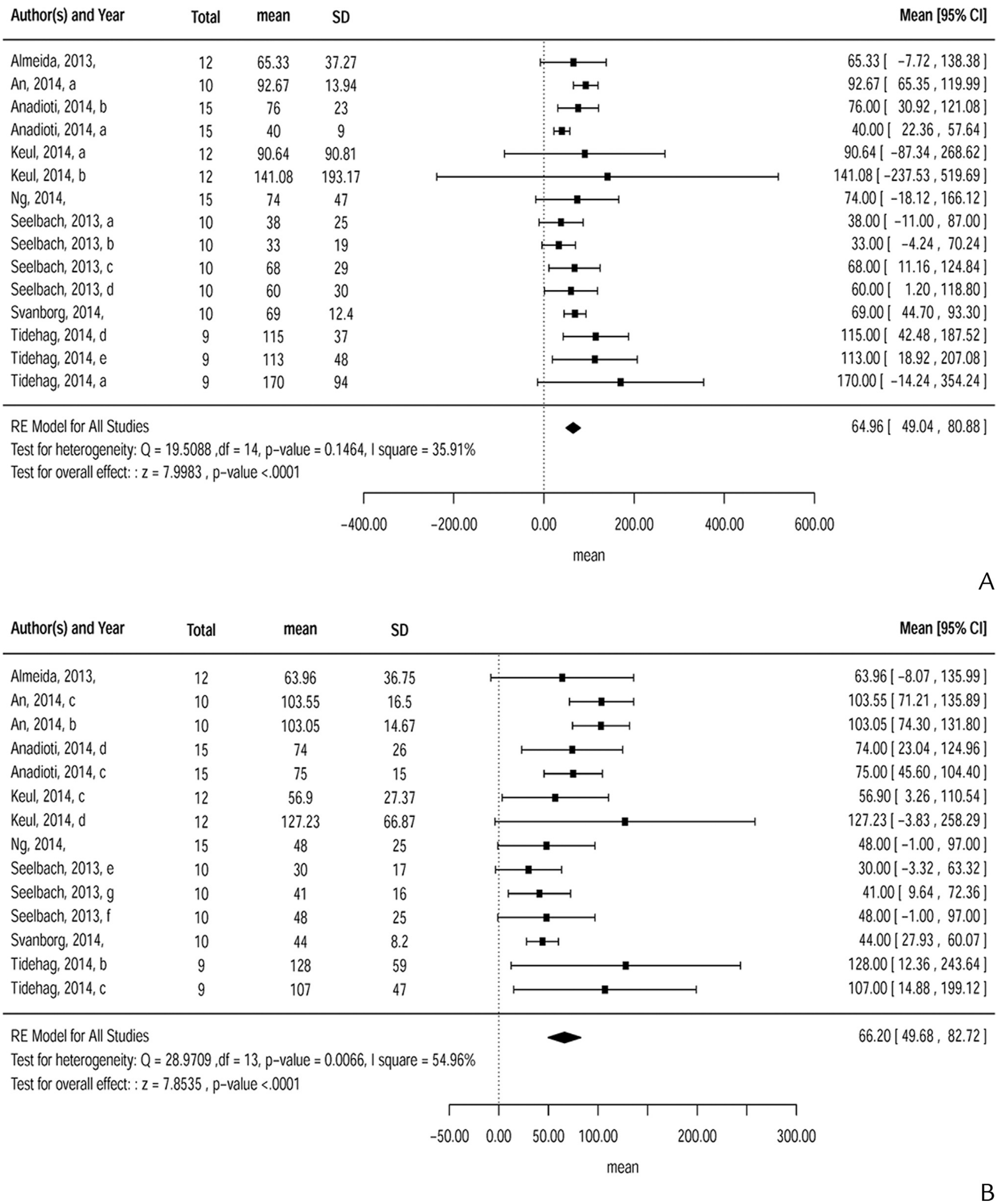


A

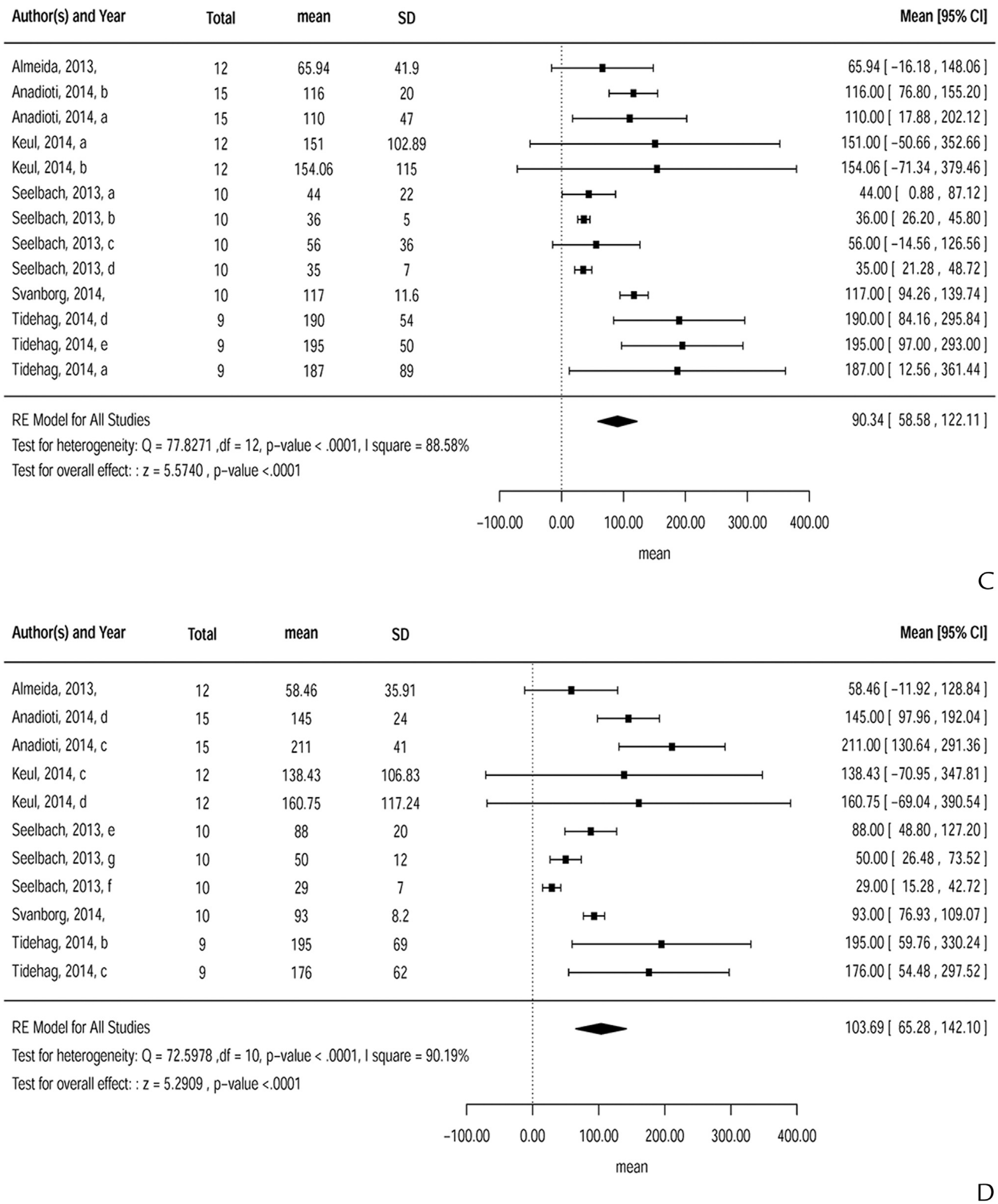


B

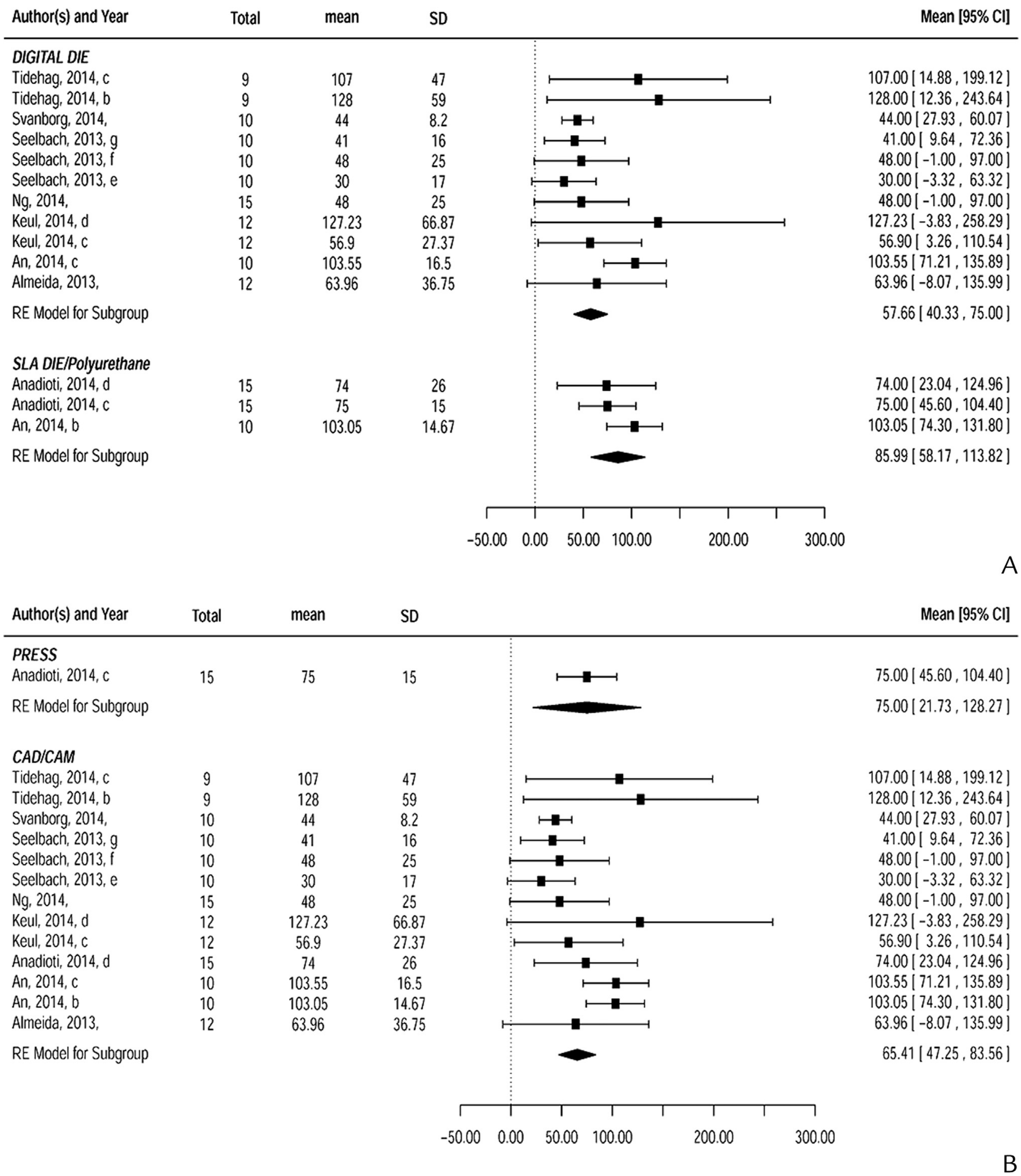
Supplemental Figure 1. Forest plots for differences in marginal and internal discrepancies between control and experimental groups.



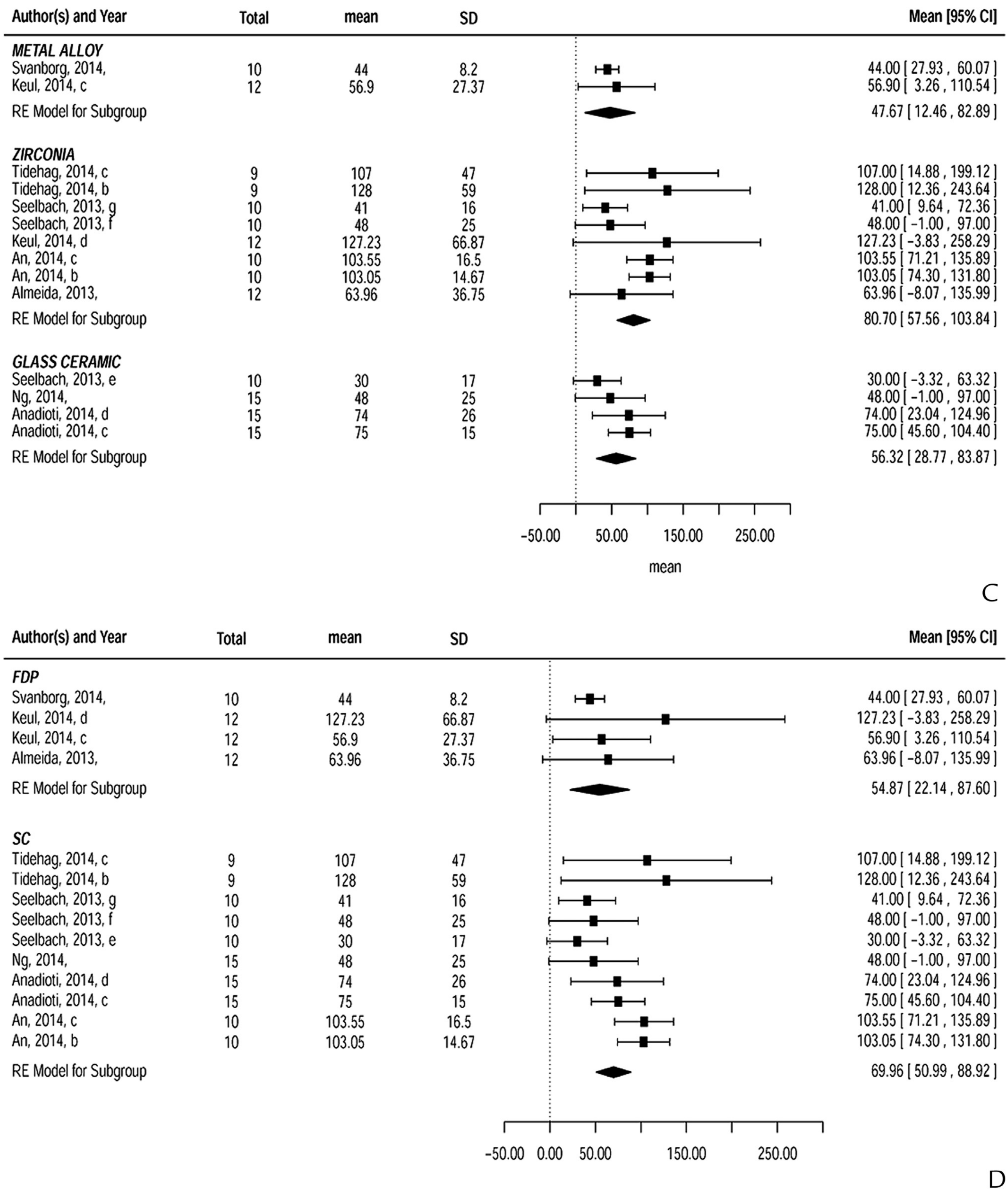
Supplemental Figure 2. Forest plots for marginal discrepancies and internal spaces in experimental and control groups.



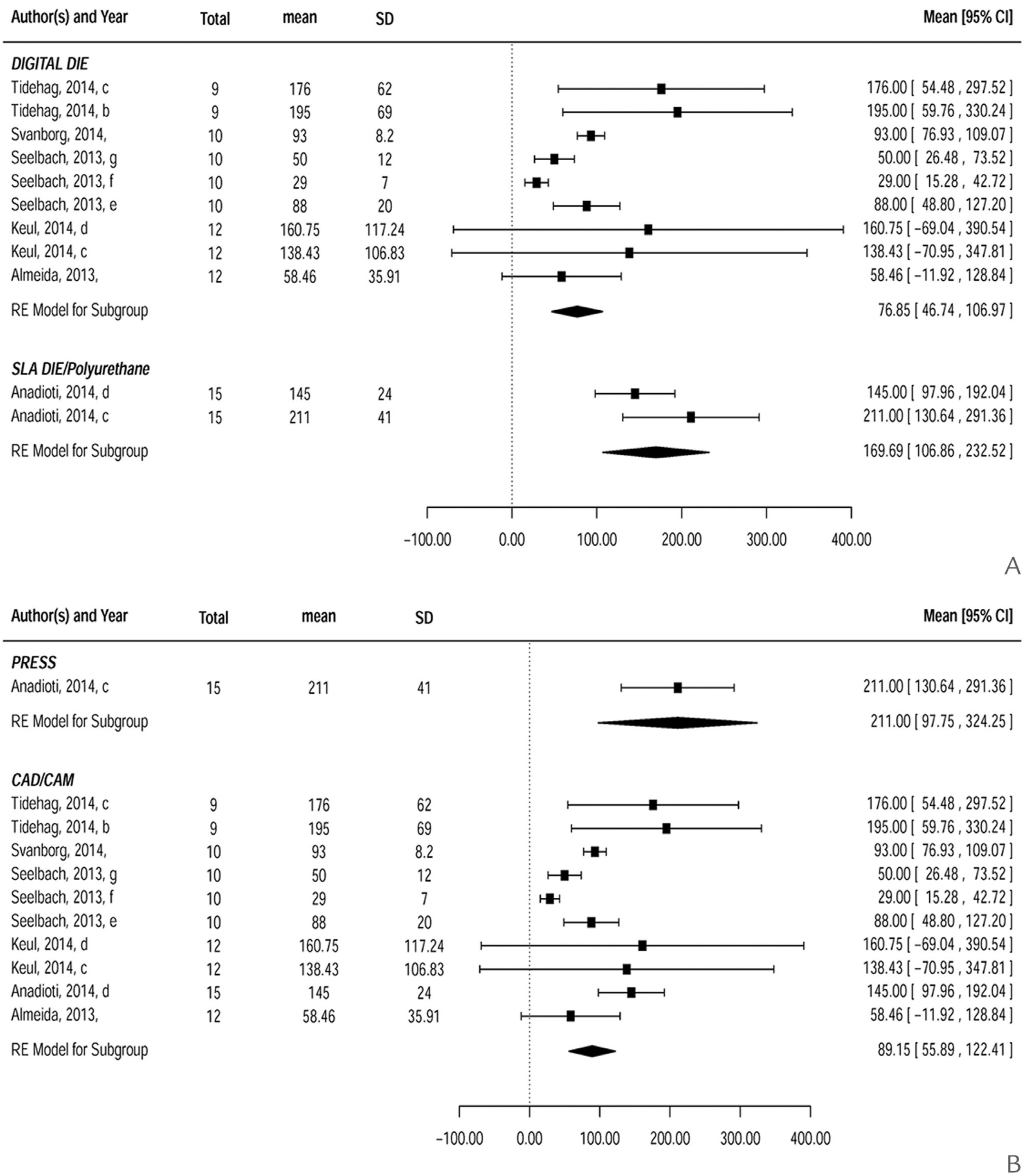
Supplemental Figure 2. (*continued*). Forest plots for marginal discrepancies and internal spaces in experimental and control groups.



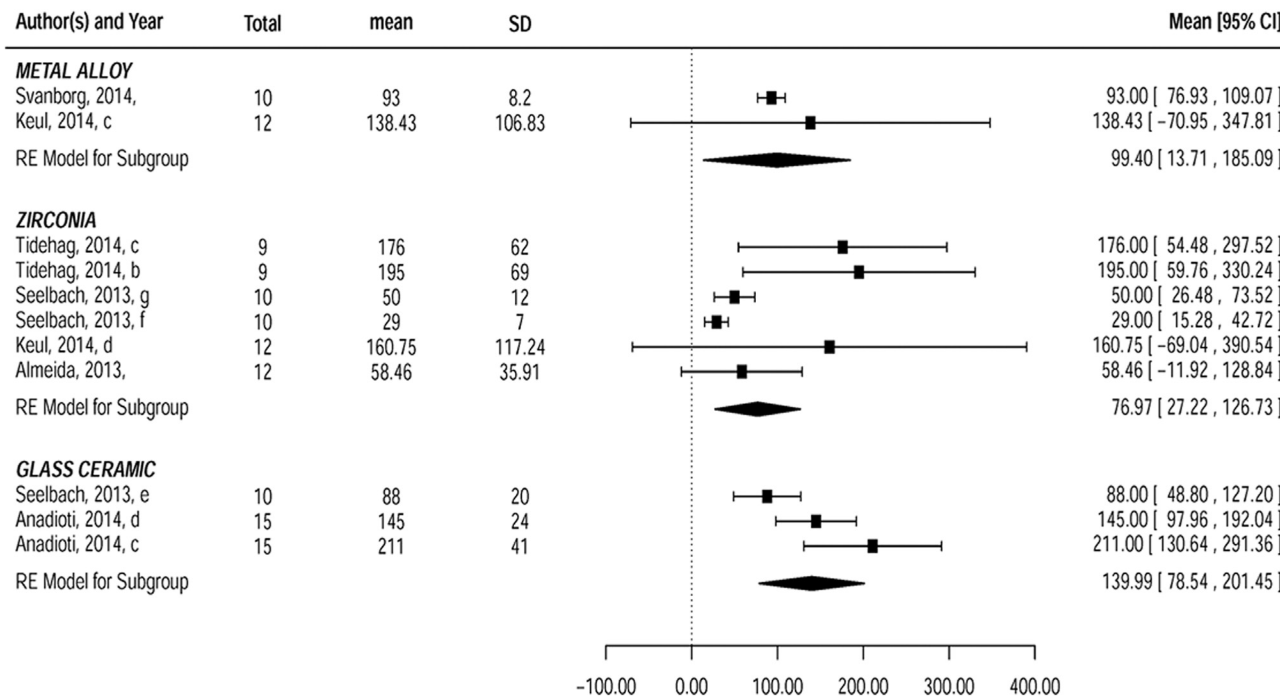
Supplemental Figure 3. Forest plot of marginal discrepancy in experimental groups (subgroup analysis).



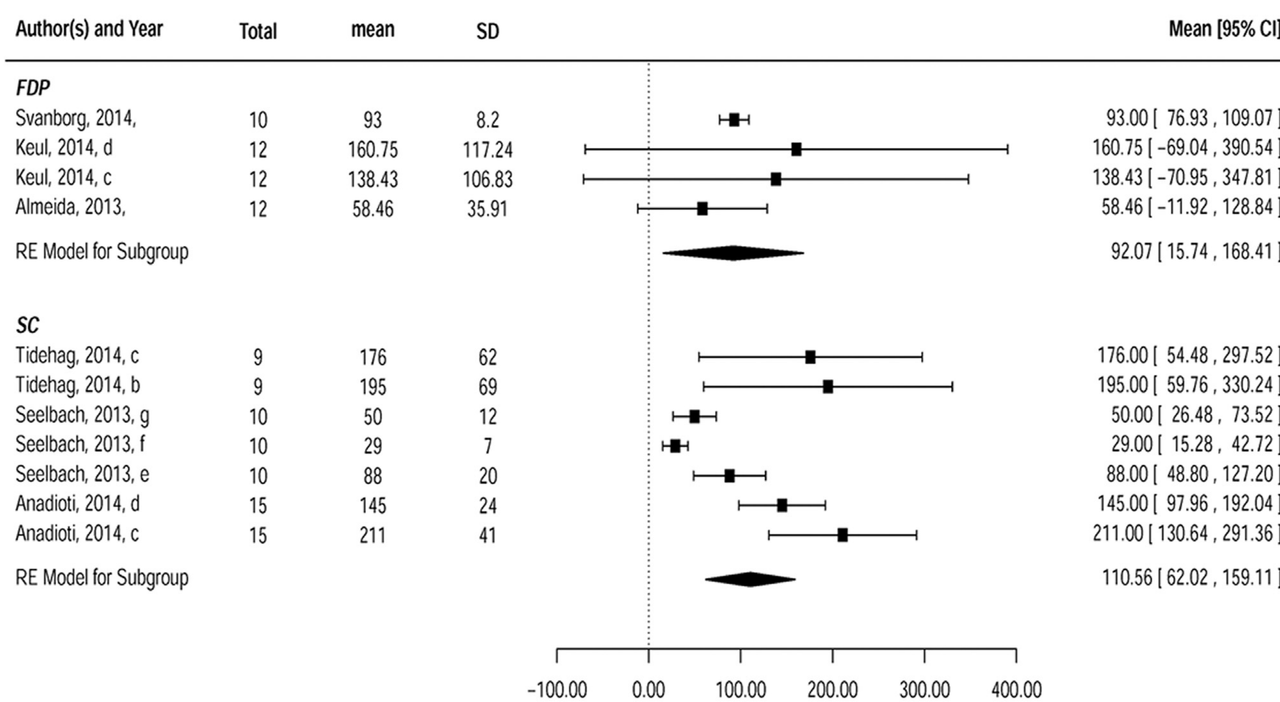
Supplemental Figure 3. (*continued*). Forest plot of marginal discrepancy in experimental groups (subgroup analysis).



Supplemental Figure 4. Forest plot of internal space in experimental groups (subgroup analysis).

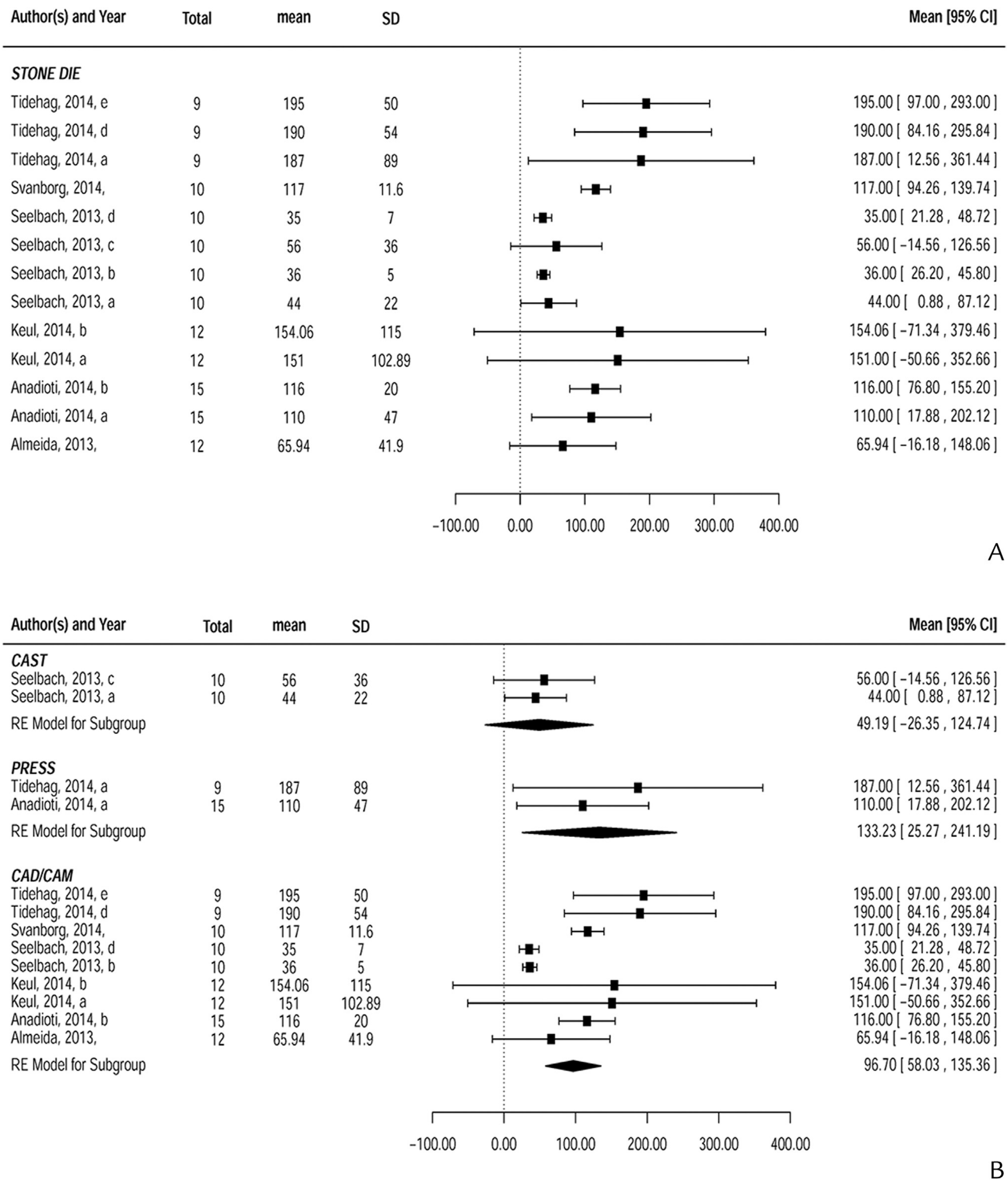


C

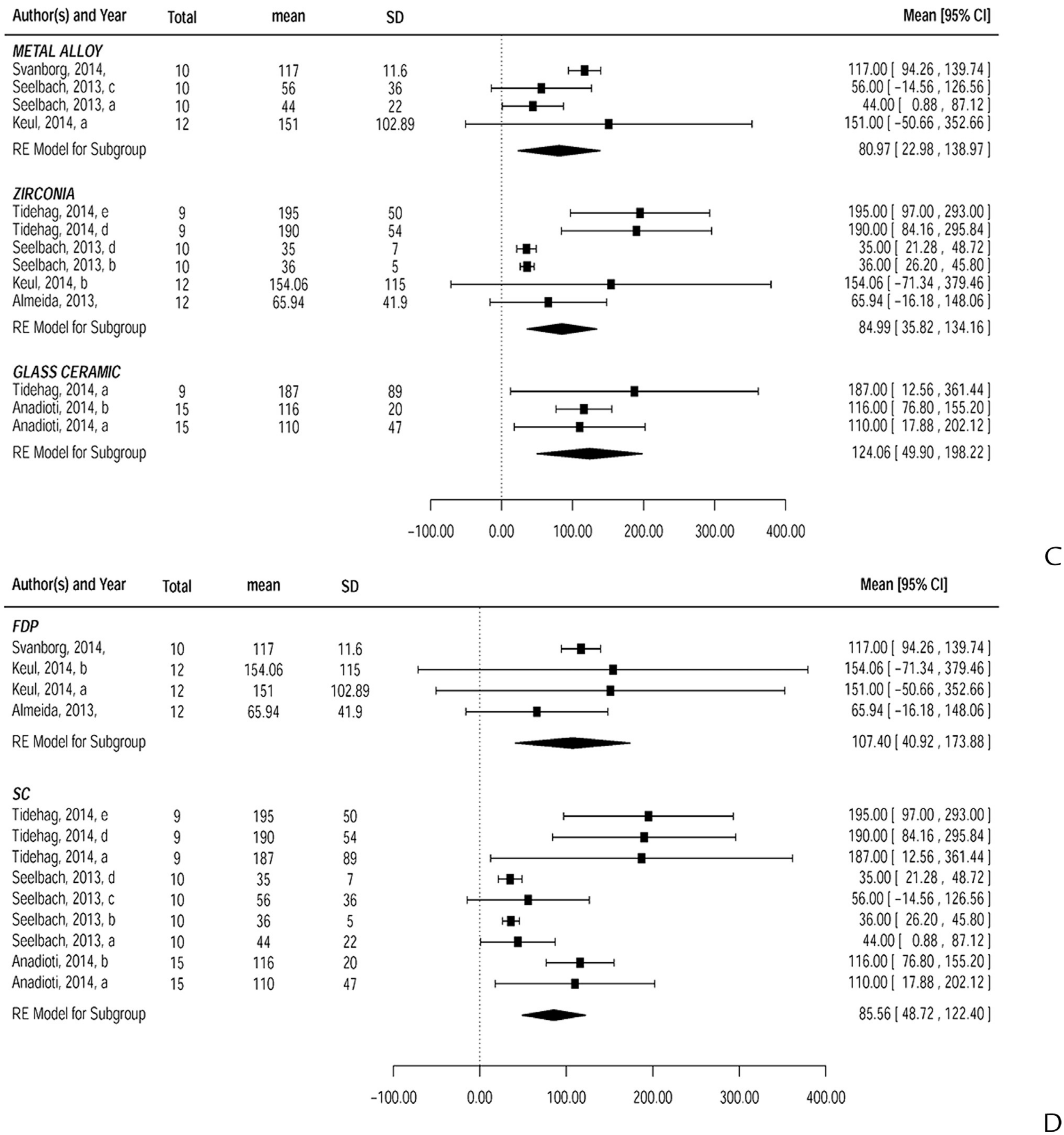


D

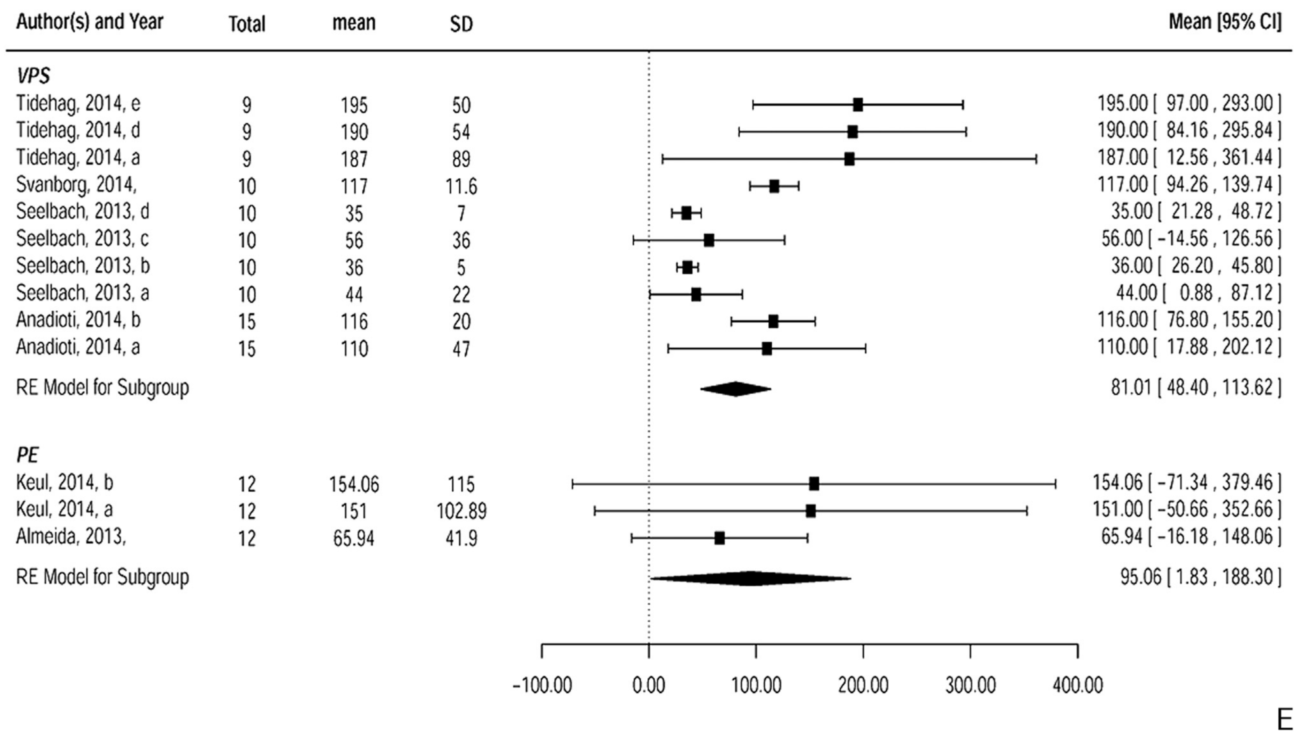
Supplemental Figure 4. (*continued*). Forest plot of internal space in experimental groups (subgroup analysis).



Supplemental Figure 5. Forest plot of internal space in control groups (subgroup analysis).



Supplemental Figure 5. (*continued*). Forest plot of internal space in control groups (subgroup analysis).



Supplemental Figure 5. (*continued*). Forest plot of internal space in control groups (subgroup analysis).