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Original Article

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A Pragmatic Approach to Derogate Dialysate-Induced Body Composition Bias in Peritoneal Dialysis Patients: Insight from a Single-Center Study*

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ABSTRACT

Objective: Dialysate in peritoneal cavity is expected to affect multifrequency bioimpedance analysis measurement in peritoneal dialysis patients. Nevertheless, the extent of dialysate influence on multifrequency bioimpedance analysis measurement appears to be varied with the weight used in the calculation. Thus, this study aimed to evaluate the impact of dialysate on body composition when different weights were used in the multifrequency bioimpedance analysis measurement.
Methods: This single-center study was conducted among 30 peritoneal dialysis patients in a tertiary referral hospital. Multifrequency bioimpedance analysis parameters were evaluated under 3 different conditions: (i) actual body weight without dialysate instilled (reference method); (ii) dialysate-included body weight with dialysate instilled (DIBW), and (iii) actual body weight with dialysate instilled (ABW). Differences, reproducibility, and agreements between the reference method with dialysate-included body weight and actual body weight methods were examined using repeated measure analysis of variance, intraclass correlation coefficients, and Bland–Altman analysis, respectively.
Results: Pairwise comparisons showed significant differences ($P < .05$) between reference and DIBW in most multifrequency bioimpedance analysis parameters (10/14) except on intracellular water ($P = .286$), skeletal muscle mass ($P = .518$), skeletal muscle index ($P = .079$), and body cell mass ($P = .357$). Meanwhile, only extracellular water ($P < .001$), extracellular/total body water ($P < .001$), and bone mineral content ($P < .001$) were significantly different for ABW when compared to the reference. Compared to DIBW, ABW showed lesser measurement bias, narrower 95% limit of agreement, and better reproducibility in most of the multifrequency bioimpedance analysis parameters with reference method.
Conclusion: We concluded that dialysate-induced multifrequency bioimpedance analysis bias can be reasonably corrected using patient's actual body weight upon body composition assessment.
Keywords: Multifrequency bioelectrical impedance analysis, dialysate, peritoneal dialysis

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INTRODUCTION

Body composition-related health issues are prevalent in the dialysis population, namely, fluid overload (45%-67%), protein–energy wasting (28%-54%), and sarcopenia (13%-34%).[1-3] These issues could jeopardize disease prognosis, quality of life, hospitalization rate, and mortality risk in this vulnerable population. Therefore, Kidney Disease Outcome Quality Initiative guidelines emphasize the need for routine nutrition assessment for early diagnosis and timely intervention of these conditions in dialysis care.[4]

Multifrequency bioelectrical impedance analysis (MFBIA) has been gaining popularity in the dialysis setting to assess and monitor patients' hydration status and body composition.[5-8] Due to its noninvasive and easy-handling properties, the use of MFBIA devices in dialysis care allows health-care professionals to make data-driven decisions on body composition-related health issues regularly and cost-effectively. MFBIA measures body composition by transmitting low and harmless electric current at multiple frequencies to estimate body compartments that exhibit a varying degree of resistance and reactance against the current flow.[9] As such, MFBIA is highly sensitive toward electrical conductors such as metallic objects and electronic devices, which would otherwise interfere the electric current flow, resulting in biased estimation.[10] Peritoneal dialysate, being an electrolyte solution, is also expected to interfere MFBIA measurement of peritoneal dialysis (PD) patients. Therefore, MFBIA measurement is recommended to be conducted on empty peritoneal cavity (i.e., without dialysate) to prevent erroneous results.[11-15] Nevertheless, removing dialysate prior to MFBIA measurement appears to be cumbersome in the clinical setting, especially when PD patients surge is expected following the implementation of PD-favored policy.[16-18] This condition could lead to the underutilization of this technology and ultimately result in late diagnosis of body composition-related health issues in PD patients.

Noteworthily, the extent to which peritoneal dialysate affects the body composition measurement, especially the nutritional parameters, remains inconclusive.

Therefore, this study aimed to evaluate the impact of dialysate on body composition parameters in PD patients when different body weights (ABW vs. DIBW) were used in the calculation of MFBIA measurement.

METHODS

Study Design and Participants Recruitment

This was a single-center cross-sectional study conducted at the PD outpatient clinic of a tertiary referral hospital located in the Klang Valley, Malaysia. A total number of 30 subjects were recruited using consecutive sampling. Sample size was estimated using G*Power software v3.1.9.2 (Franz Faul, University Kiel, Germany) for analysis of variance (ANOVA) (repeated measures, within factors), significant level = 5%, statistical power = 80%, effect size = 0.18 based on a previous study,[13] and $r = .75$ (good correlation between repeated measures). The calculated sample size was 30 after accounting for a 10% nonresponse rate. Subjects were recruited if they were at least 18 years old and undergoing continuous ambulatory PD. On the other hand, patients with amputation, cardiac pacemakers, or implanted metallic devices were excluded from the study. Prior to the data collection, a detailed explanation of the research procedure was given, and written informed consent was obtained from every subject. This study was approved by the Ethics Committee of the National Medical Research Register, Ministry of Health Malaysia (protocol number: NMRR-19-2501-50205; approval date: September 27, 2019) and the Universiti Putra Malaysia's Ethic Committee for Research Involving Human Subjects (protocol number: JKEUPM-2019-467; approval date: October 25, 2019).

MAIN POINTS

- Peritoneal dialysate results in statistically significant multi-frequency bioimpedance analysis (MFBIA) measurement bias in several parameters, and the degree of bias is influenced by applied weight in MFBIA.
- When dialysate-included body weight (DIBW method) is used in MFBIA, significant measurement biases were detected in majority of parameters (10/14), including hydration parameters, muscle parameters, fat parameters, whole-body phase angle, and bone mineral content.
- When actual body weight (ABW method) is used in MFBIA, significant measurement biases were detected only in 3 parameters (3/14), which are hydration parameters and bone mineral content. Furthermore, the biases of these parameters are within the clinically acceptable range.
- Given that lesser measurement bias, better reproducibility and agreement with reference method, ABW method can be regarded as a pragmatic approach to reasonably correct the dialysate-induced measurement bias when dialysate removal is unfeasible.

Height and Weight Measurements

Subjects' height and weight were measured using a telescopic measuring rod (SECA 220, Hambury, Germany) and a calibrated weighing scale (SECA 780, Hambury, Germany) in accordance with International Society of Advancement in Kinanthropometry (ISAK) protocol.[19] A technical error of measurement (TEM) of 1% was used to check the intra-reliability of the measurements. Third measurement was taken when the measurement discrepancy exceeded 1%. Subjects were asked to perform the dialysate exchange at the study site. Prior to the dialysate drainage, subject's body weight with dialysate instilled was measured. After the drainage, the drained dialysate was weighted. Subsequently, subject's ABW and DIBW were calculated prior to the MFBIA measurement as below:

A = Body weight with dialysate instilled before drainage

B = Weight of drained dialysate

$\text{ABW} = A - B$

$\text{DIBW} = \text{ABW} + 2\text{ kg}$ (from 2 L fresh dialysate)

Body mass index (BMI) was then calculated using ABW as below:

$\text{BMI (kg/m}^2) = \text{ABW (kg)} / \text{Height (m}^2)$

Subjects were then classified based on BMI categories, which were underweight (<18.5 kg/m^2), normal weight (18.5-24.9 kg/m^2), overweight (25.0-29.9 kg/m^2), obese class 1 (30.0-34.9 kg/m^2), obese class 2 (35.0-39.9 kg/m^2), and obese class 3 (≥40.0 kg/m^2).[20]

Multifrequency Bioimpedance Analysis Measurement

Multifrequency bioimpedance analysis was performed using a portable device—InBody S10 (InBody Co., Ltd, Seoul, Korea). This device performs direct MFBIA measurement at a wide range of frequencies (1kHz-1000kHz). Three MFBIA measurements were taken for each subject under 3 different conditions. First, MFBIA was conducted in compliance with the gold standard, whereby the dialysate was drained out, and ABW was applied (reference method). Afterward, 2 L of dialysate was instilled, and MFBIA was performed twice using different applied weights, namely ABW (ABW method) and DIBW (DIBW method). The detailed process of MFBIA measurements is depicted in Figure 1.

All measurements were taken in the sitting position using tetrapolar 8-points touch type electrodes placed on both hands (i.e., thumb and middle finger) and feet (i.e., between ankle-bone and heel) as per the manufacturer's measurement protocol.[21] The first measurement was taken after the completion of dialysate drainage. Before the first measurement, subjects were asked to rest in the sitting position for at least 15 minutes to achieve fluid equilibrium for accurate MFBIA measurement. Then, subjects were asked to remain in the same sitting position to avoid the disruption of fluid equilibrium while instilling 2 L of fresh dialysate. Subsequently, second and third measurements were taken after the dialysate instillation using ABW and DIBW, respectively. Variables of interest include (i) hydration parameters [i.e., total body water (TBW), intracellular water (ICW), extracellular water (ECW), and ECW/TBW ratio], (ii) muscle parameters [i.e., skeletal muscle mass (SMM), skeletal muscle index (SMI), fat free mass (FFM), and soft lean mass (SLM)], (iii) fat parameters [i.e., fat mass (FM), body fat percentage (BFP), and visceral fat area (VFA)], and (iv) other parameters [i.e., whole-body phase angle (PhA), body cell mass (BCM), and bone mineral contents (BMC)].

Statistical Analysis

Continuous data were reported as mean ± SD, whereas categorical data were presented as frequency (n) and percentages (%). Normality, homoscedasticity, and sphericity assumptions were checked before statistical tests. Differences in MFBIA measurements between methods were tested with repeated measures ANOVA adjusted for age, gender, ethnicity, and BMI. Subsequently, pairwise comparisons were performed using Bonferroni correction. Reproducibility of MFBIA measurements under 3 different conditions was examined by intraclass correlation coefficient (ICC). Whereas the agreement between measurements was examined using Bland–Altman analysis by which the proportional bias was checked by simple linear regression. Data were analyzed using the Statistical Package for the Social Sciences (SPSS) software version 26.0 (IBM SPSS Corp.; Armonk, NY, USA). Statistical significance was set at *P* <.05.

RESULTS

Subjects' Characteristics

A total number of 30 subjects successfully completed this study with only 1 dropout due to incomplete MFBIA measurement (response rate = 96.8%). Subjects' characteristics are presented in Table 1.

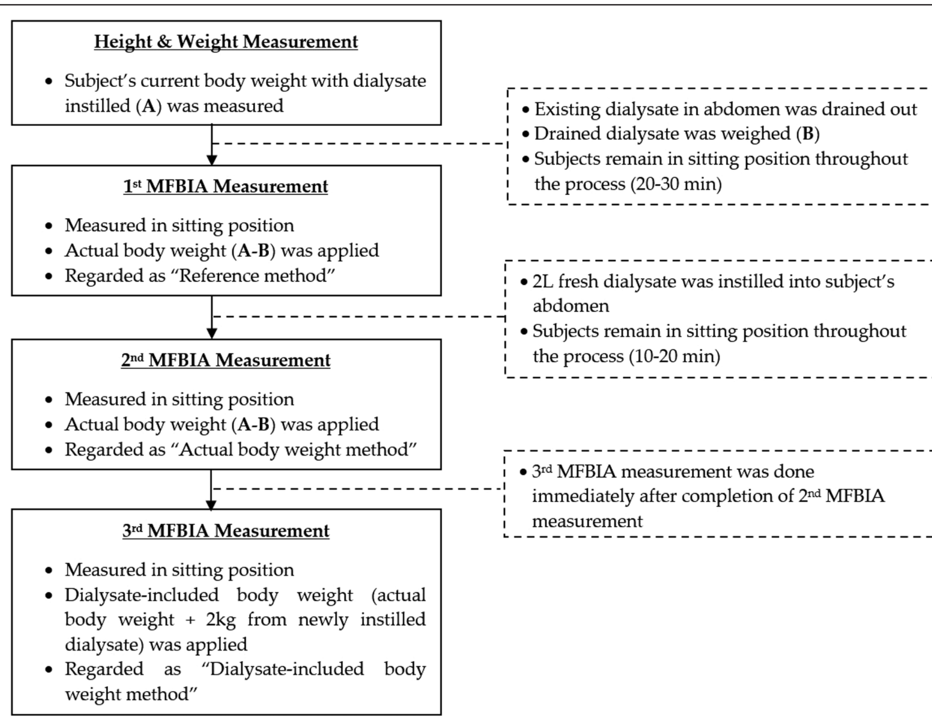

Figure 1. The Process of MFBIA Measurement.

Table 1. Subjects' Characteristics (n = 30)	
Characteristics	**n (%) or Mean ± SD**
Age (years)	51.5 ± 11.5
Gender	
Male	14 (46.7)
Female	16 (53.3)
Ethnicity	
Malay	16 (53.3)
Chinese	13 (43.3)
Indian	1 (3.3)
Actual body weight (kg)	65.0 ± 14.4
BMI (kg/m^2)	25.8 ± 4.9
Underweight (<18.5)	1 (3.3)
Normal weight (18.5-24.9)	11 (36.7)
Overweight (25.0-29.9)	15 (50.0)
Obese class 1 (30.0-34.9)	2 (6.7)
Obese class 2 (35.0-39.9)	0 (0.0)
Obese class 3 (≥40.0)	1 (3.3)
Instilled-dialysate glucose concentration g/dL	
1.5	20 (66.7)
2.3 or 2.5	6 (20.0)
4.25	4 (13.3)

Data are expressed as n (%) or mean ± SD.
BMI, body mass index.

Comparison of Multifrequency Bioimpedance Analysis Parameters Between Reference, Dialysate-Included Body Weight, and Actual Body Weight Methods

Table 2 presents the difference in MFBIA parameters generated by reference, DIBW, and ABW methods. Significant differences were detected in extracellular water (P = .032), fat-free mass (P = .048), soft lean mass (P = .049), fat percentage (P = .004), and bone mineral content (P = .015). Pairwise comparisons showed significant differences between reference and DIBW methods in most of the MFBIA parameters (10/14), including total body water (P = .004), extracellular water (P < .001), extracellular water/total body water (P <.001), fat-free mass (P = .003), soft lean mass (P = .006), fat mass (P <.001), body fat percentage (P <.001), visceral fat area (P <.001), whole-body phase angle (P = .005), and bone mineral content (P <.001), whereas no significant differences in intracellular water (P = .286), skeletal muscle mass (P = .518), skeletal muscle index (P = .079), and body cell mass (P = .357). On the other hand, only extracellular water (P <.001), extracellular water/total body water (P <.001), and bone mineral content (P <.001) showed significant differences between reference and ABW methods, whereas no significant differences were found in total body water (P = .246), intracellular water (P = 1.000), skeletal muscle mass (P = 1.000), skeletal muscle index (P = 1.000), fat-free mass (P = .194), soft lean mass (P = .406), fat mass (P = .194), body fat percentage (P = .085), visceral fat area (P = .980), whole-body phase angle (P = .079), and body cell mass (P = 1.000).

Reproducibility of Multifrequency Bioimpedance Analysis Parameters Under Different Tested Conditions

Intraclass correlation coefficient results of DIBW and ABW methods in regard to reference method are presented in Table 3. All MFBIA parameters generated by both DIBW and ABW methods showed excellent reproducibility (ICC > 0.9) with that generated by reference method. In comparison, ABW methods exhibit relatively higher ICCs with reference method in virtually all MFBIA parameters (except fat percentage) compared to DIBW method.

Agreements Between Reference Method with Dialysate-Included Body Weight and Actual Body Weight Methods

Bland–Altman plots are depicted in the supplementary material (Supplementary Figure 1). Mean differences, 95% limit of agreement (LoA), and proportional bias of MFBIA parameters between reference method with DIBW and ABW methods are presented in Table 4. Actual body weight method demonstrated smaller magnitude of mean difference compared to DIBW method in most of the parameters (except for ECW/TBW and fat percentage which showed similar magnitude of mean difference between these 2 methods). Notably, the width of 95% LoAs were relatively smaller in ABW methods in most of the MFBIA parameters compared to that of DIBW methods, indicating a better agreement between ABW and reference methods. Both DIBW and ABW methods showed significant proportional biases in ECW/TBW and FM. However, only ABW showed significant proportional bias for BFP.

DISCUSSION

In this study, we found significant individual effect of dialysate on MFBIA measurement across different spectrums of assessments even after adjusting for confounding factors (i.e., age, gender, ethnicity, and BMI). Notwithstanding the foregoing, the dialysate influences on the MFBIA parameters appeared to be fairly small as shown by the magnitude of mean differences. This could be due to the fact that peritoneal dialysate is localized in the trunk, which has limited impedance contribution to the MFBIA measurement due to its short length and large cross-sectional area compared to the limbs.[11,13]

However, the intriguing part is that the extent of dialysate influence on the MFBIA measurement varied when different weights were used in the calculation.[12] This idea was conceived from the heterogeneous findings in the literature when different weights (ABW vs. DIBW) were used in the MFBIA measurements.[11-15,22-24] Correspondingly, weight adjustment is also a ubiquitous approach in nutritional assessment to avoid under- and overestimation of dietary requirement for dialysis patients.[4] Based on

Table 2. **Comparison of MFBIA Parameters Between Reference, DIBW, and ABW Methods (n = 30)**

Parameter	Reference Method	DIBW Method	ABW Method	*P*
Hydration assessment				
Total body water (L)	34.5 ± 0.9[a]	34.9 ± 0.9[ab]	34.7 ± 0.9[b]	.078
Intracellular water (L)	20.9 ± 0.6	21.0 ± 0.6[a]	20.8 ± 30.6[a]	.186
Extracellular water (L)	13.7 ± 0.4[ab]	13.9 ± 0.4[ac]	13.8 ± 0.4[bc]	.032
Extracellular water/total body water	0.396 ± 0.003[ab]	0.400 ± 0.003[a]	0.399 ± 0.003[b]	.060
Muscle assessment				
Skeletal muscle mass (kg)	25.2 ± 0.8	25.3 ± 0.8[a]	25.2 ± 0.8[a]	.294
Skeletal muscle index (kg/m^2)	7.4 ± 0.2	7.5 ± 0.2[a]	7.4 ± 0.2[a]	.091
Fat free mass (kg)	46.9 ± 1.3[a]	47.4 ± 1.3[ab]	47.1 ± 1.3[b]	.048
Soft lean mass (kg)	44.1 ± 1.2[a]	44.5 ± 1.2[ab]	44.2 ± 1.2[b]	.049
Fat assessment				
Fat mass (kg)	19.7 ± 1.1[a]	21.1 ± 1.2[ab]	19.5± 1.2[b]	.077
Body fat percentage (%)	28.5 ± 1.5[a]	29.7 ± 1.5[ab]	28.0 ± 1.5[b]	.004
Visceral fat area (cm^2)	92.1 ± 5.0[a]	100.6± 5.3[ab]	93.1 ± 5.0[b]	.392
Other parameters				
Whole-body phase angle (°)	4.24 ± 0.24[a]	4.11 ± 0.23[a]	4.16 ± 0.24	.140
Body cell mass (kg)	29.9 ± 0.8	30.0 ± 0.8[a]	29.9 ± 0.8[a]	.251
Bone mineral content (kg)	2.76 ± 0.09[ab]	2.88 ± 0.10[ac]	2.86 ± 0.09[bc]	.015

Reference method refers to "performing MFBIA with actual body weight and without dialysate instilled"; DIBW method refers to "performing MFBIA with dialysate-included body weight and with dialysate instilled"; ABW method refers to "performing MFBIA with actual body weight and with dialysate instilled." Data are presented as estimated marginal mean ± SEM; data were analyzed using repeated measure ANOVA adjusted for age, gender, ethnicity, and BMI;
ABW, actual body weight; DIBW, dialysate-included body weight; MFBIA, multifrequency bioelectrical impedance analysis.
[a,b,c]Data sharing the same superscript indicate that they are significantly different (*P*<.05) with each other.

Table 3. Intraclass Correlation Coefficients Between Reference Method with DIBW and ABW

	DIBW and Reference		ABW and Reference	
Parameters	**ICC**	**95% CI**	**ICC**	**95% CI**
Hydration assessment				
Total body water (L)	0.994	0.877-0.998	0.997	0.982-0.999
Intracellular water (L)	0.996	0.976-0.999	0.998	0.995-0.999
Extracellular water (L)	0.989	0.516-0.997	0.994	0.806-0.999
Extracellular water/total body water	0.941	0.138-0.986	0.949	0.213-0.988
Muscle assessment				
Skeletal muscle mass (kg)	0.996	0.979-0.999	0.998	0.995-0.999
Skeletal muscle index (kg/m^2)	0.994	0.973-0.998	0.998	0.994-0.999
Fat free mass (kg)	0.993	0.848-0.998	0.996	0.976-0.999
Soft lean mass (kg)	0.994	0.896-0.999	0.997	0.986-0.999
Fat assessment				
Fat mass (kg)	0.990	0.514-0.998	0.997	0.980-0.999
Body fat percentage (%)	0.992	0.904-0.998	0.991	0.937-0.997
Visceral fat area (cm^2)	0.982	0.567-0.995	0.995	0.991-0.998
Other parameters				
Whole-body phase angle (°)	0.982	0.920-0.993	0.989	0.976-0.995
Body cell mass (kg)	0.996	0.977-0.999	0.998	0.995-0.999
Bone mineral content (kg)	0.940	0.099-0.986	0.955	0.292-0.989

Reference method refers to "performing MFBIA with actual body weight and without dialysate instilled"; DIBW method refers to "performing MFBIA with dialysate-included body weight and with dialysate instilled."
ABW, actual body weight; DIBW, dialysate-included body weight.

Table 4. Statistics of Bland–Altman Analysis

Parameters	DIBW – Reference				ABW – Reference			
	Mean difference[a]	95% LoA	Width of 95% LoA	$b^{\dagger}$	Mean difference[a]	95% LoA	Width of 95% LoA	$b^{\dagger}$
Hydration assessment								
TBW (L)	0.6 ± 0.1**	−0.184, 1384	1.568	−0.006	0.3 ± 0.1	−0.484, 1.084	1.568	−0.017
ICW (L)	0.2 ± 0.1	−0.388, 0.788	1.176	−0.010	0.1 ± 0.1	−0.292, 0.492	0.784	−0.018
ECW (L)	0.3 ± 0.1***	−0.092, 0.692	0.600	−0.001	0.2 ± 0.1***	0.004, 0.396	0.400	−0.017
ECW/TBW	0.003 ± 0.001***	−0.001, 0.007	0.008	−0.092**	0.003 ± 0.001***	-0.001, 0.007	0.008	−0.083**
Muscle assessment								
SMM (kg)	0.3 ± 0.1	−0.484, 1.084	1.568	−0.011	0.1 ± 0.1	−0.488, 0.688	1.176	−0.019
SMI (kg/m²)	0.1 ± 0.1	−0.096, 0.296	0.392	0.021	0.0 ± 0.1	−0.196, 0.196	0.392	0.004
FFM (kg)	0.8 ± 0.1**	−0.376, 1.976	2.352	−0.009	0.5 ± 0.1	−0.480, 1.480	1.960	−0.019
SLM (kg)	0.7 ± 0.1**	−0.280, 1.680	1.960	−0.005	0.4 ± 0.1	−0.580, 1.380	1.960	−0.017
Fat assessment								
FM (kg)	1.2 ± 0.1***	0.024, 2.376	2.400	0.036**	−0.5 ± 0.1	−1.480, 0.480	1.960	0.032**
BFP (%)	0.9 ± 0.2***	−0.668, 2.468	3.136	0.020	−0.9 ± 0.2	−2.860, 1.060	3.920	0.053**
VFA (cm²)	6.6 ± 0.8***	−2.024, 15.224	17.248	0.032	−0.9 ± 0.7	−8.348, 6.548	14.896	0.015
Other parameters								
PhA (°)	−0.11 ± 0.03**	−0.384, 0.164	0.549	−0.039	-0.05 ± 0.02	−0.305, 0.205	0.510	−0.005
BCM (kg)	0.3 ± 0.1	−0.484, 1.084	1.568	−0.012	0.1 ± 0.1	−0.488, 0.688	1.176	−0.020
BMC (kg)	0.15 ± 0.01***	−0.007, 0.307	0.314	−0.020	0.12 ± 0.01***	−0.037, 0.277	0.314	−0.033

95% LoA, 95% limit of agreement; ABW, actual body weight; BCM, body cell mass; BFP, body fat percentage; BMC, bone mineral content; DIBW, dialysate-included body weight; ECW, extracellular water; FFM, fat-free mass; FM, fat mass; ICW, Intracellular water; PhA, whole-body phase angle; SLM, soft lean mass; SMI, skeletal muscle index; SMM, skeletal muscle mass; TBW, total body water; VFA, visceral fat area.
[a] Data are presented as mean ± SEM.[†] Proportional bias was examined using simple linear regression. ** $P<.01$.*** $P<.001$.

our findings, the use of DIBW with dialysate instilled during the MFBIA measurement accentuated the dialysate-induced body composition bias. The dialysate effect, however, was attenuated when subject's ABW was used for the MFBIA measurement. This is in tandem with the previous study.[12] This implies that weight of dialysate instilled exerted a significant impact on MFBIA measurement apart from electrical conductivity of the dialysate itself.

Noteworthily, although statistically significant, the disparities in the MFBIA parameters when ABW was used in regard to reference method (i.e., empty abdomen) are deemed clinically acceptable. For instance, the use of ABW in the MFBIA measurement with dialysate instilled resulted in a discrepancy of only 0.003 for ECW/TBW; 0.2 L for ECW; and 0.12 kg for bone mineral content compared to referenced method. Our study also demonstrated that the use of ABW could avoid the problems of overestimating muscle and fat masses shown in previous studies,[13,15] which is likely to delay the diagnosis of nutritional problems such as protein energy wasting and sarcopenia. Therefore, weight adjustment (DIBW to ABW) should be considered during MFBIA measurement when dialysate drainage prior to the measurement if not feasible in the clinical setting.

Besides that, we acknowledge that the differences between our study findings and literature could also be attributed to the variations in BIA device and measurement protocol. For instance, we employed a different BIA device compared to previous studies.[11-15] It is important to note that different BIA devices utilize different algorithm (Cole–Cole model vs. regression model), measurement frequency (single frequency vs. multifrequency), and measurement approaches (whole-body measurement vs. segmental measurement).[25] As a result, the body composition parameters derived from different BIA devices might not be comparable.[26] In the current study, InBody S10 was used. Although it adopts the same algorithm with the BIA device (i.e., InBody 720) used in previous study,[15] inconsistent results were found despite ABW was used in the calculation. This could be explained by the difference in the measurement position inherent to the BIA device (standing vs. sitting). Compared to InBody 720, InBody S10 offers a unique advantage that allows subjects to be measured in the sitting position. This can avoid the unnecessary fluid shift due to posture change prior the MFBIA measurement as subjects can remain in the sitting position throughout the procedure from dialysate drainage to MFBIA measurement. Previous studies reported impedance change of 3%-5% owing to posture change prior BIA measurement.[27,28]

To the best of our knowledge, this is the first study that specifically investigates the impact of applied weight (ABW vs. DIBW) on dialysate-induced MFBIA measurement bias. Based on the study findings, we proposed a practical approach to correct the dialysate-induced MFBIA measurement bias by applying ABW in measurement. Despite having modest sample size, we found that our study had achieved 100% power (depicted in supplementary Table 1). This indicates an extremely high likelihood of detecting a significant effect if one exists. Achieving 100% power is a strong indicator of the robustness of our study and increases our confidence in the result. The major limitation of the current study was the lack of sample representative in the context of ethnicity distribution and BMI categories. This undermines the generalizability of our research findings. In addition, our study findings cannot be extrapolated to other BIA devices which use different algorithms to estimate body composition. Therefore, future research with a more representative sample is needed to verify the effectiveness of ABW method to correct the dialysate-induced MFBIA bias using different BIA devices.

CONCLUSION

Peritoneal dialysate induces substantial bias in MFBIA measurements, with ABW method showing less bias compared to DIBW method. Since the dialysate-induced bias in ABW method falls within the clinically acceptable range, applying ABW over DIBW in MFBIA is a pragmatic and reasonable method to correct the bias when dialysate removal is not feasible. The findings of this study provide a pragmatic and reliable approach for conducting MFBIA in PD patients. This could enhance the utility of MFBIA as a screening tools in various scenarios to combat body composition related issues in this vulnarable population.

Ethics Committee Approval: Ethics Committee of the National Medical Research Register, Ministry of Health, Malaysia (protocol number: NMRR-19-2501-50205; approval date: September 27, 2019) and the Universiti Putra Malaysia Ethic Committee for Research Involving Human Subjects (protocol number: JKEUPM-2019-467; approval date: October 25, 2019).

Informed Consent: Written informed consent was obtained from every subject.

Peer-review: Externally peer-reviewed.

Author Contributions: Conception – S.W.L., Z.A.M.D., Y.M.C., N.F.Z.; Design – S.W.L., Z.A.M.D.; Supervision – Z.A.M.D.; Fundings – Z.A.M.D.; Materials – S.W.L.; Data Collection and/or Processing – S.W.L.; Analysis and/or Interpretation – J.H.L., S.W.L., C.K.M.L., I.I., Y.M.C., N.F.Z.; Literature Review – S.W.L., J.H.L., C.K.M.L.; Writing – S.W.L., J.H.L., C.K.M.L.; Critical Review – Z.A.M.D., J.H.L., C.K.M.L., I.I., Y.M.C., N.F.Z.

Declaration of Interests: The authors have no conflict of interest to declare.

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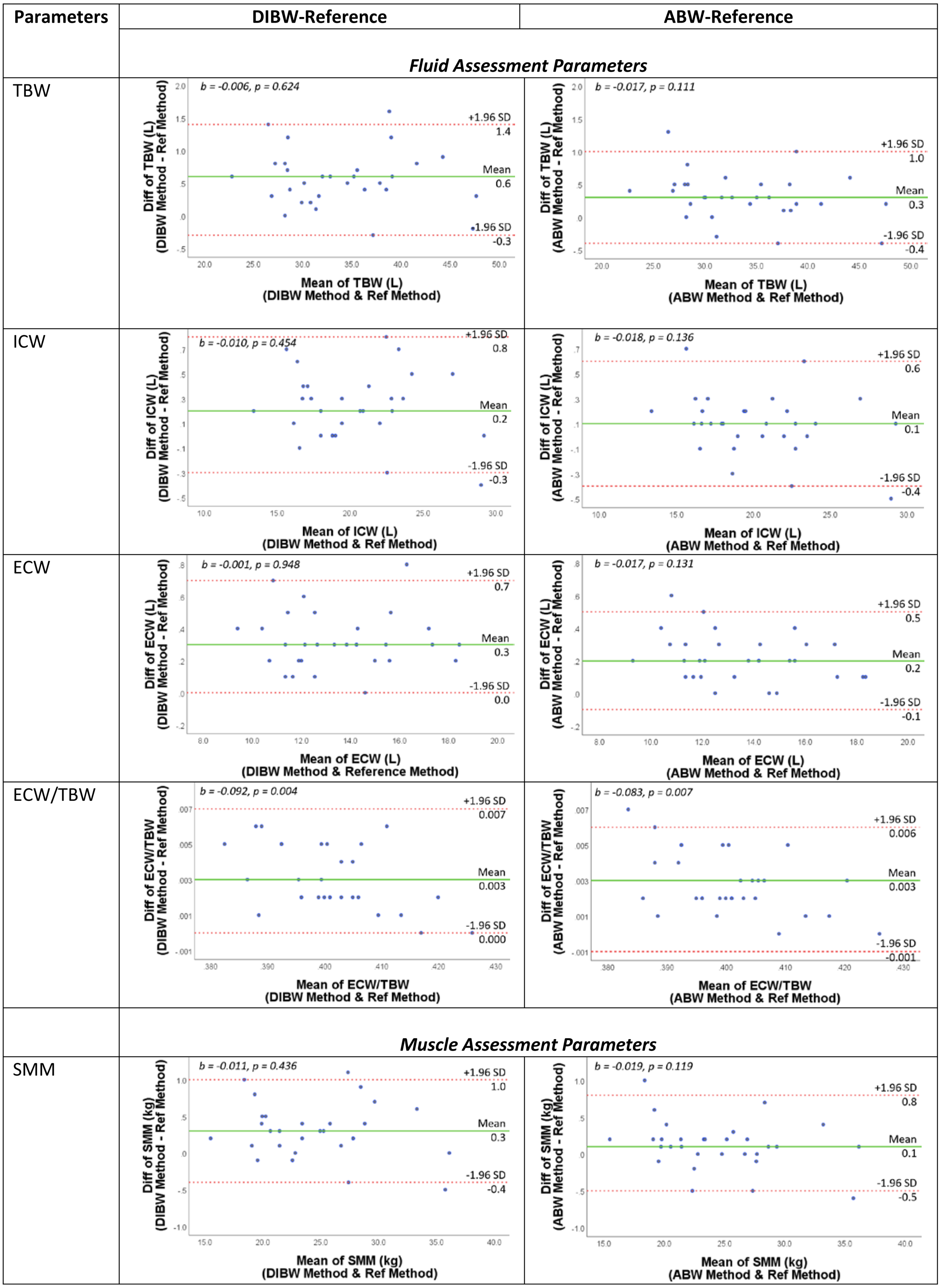
REFERENCES

1. Carrero JJ, Thomas F, Nagy K, et al. Global prevalence of protein-energy wasting in kidney disease: a meta-analysis of contemporary observational studies from the International Society of renal nutrition and metabolism. *J Ren Nutr*. 2018;28(6):380-392. [CrossRef]
2. Guo Q, Yi C, Li J, Wu X, Yang X, Yu X. Prevalence and risk factors of fluid overload in Southern Chinese continuous ambulatory peritoneal dialysis patients. *PLoS One*. 2013;8(1):e53294. [CrossRef]
3. Shimokata H, Shimada H, Satake S, et al. Epidemiology of sarcopenia. *Geriatr Gerontol Int*. 2018;18(suppl 1):13-22. [CrossRef]
4. Ikizler TA, Burrowes JD, Byham-Gray LD, et al. KDOQI clinical practice guideline for nutrition in CKD: 2020 update. *Am J Kidney Dis*. 2020;76(3):S1-S107. [CrossRef]
5. Panorchan K, Nongnuch A, El-Kateb S, Goodlad C, Davenport A. Changes in muscle and fat mass with haemodialysis detected by multi-frequency bioelectrical impedance analysis. *Eur J Clin Nutr*. 2015;69(10):1109-1112. [CrossRef]
6. Fürstenberg A, Davenport A. Comparison of multifrequency bioelectrical impedance analysis and dual-energy X-ray absorptiometry assessments in outpatient hemodialysis patients. *Am J Kidney Dis*. 2011;57(1):123-129. [CrossRef]
7. Hyun SH, Choi JY, Cho JH, Park SH, Kim CD, Kim YL. Assessment of fluid and nutritional status using multifrequency bioelectrical impedance analysis in peritoneal dialysis patients. *Blood Purif*. 2014;37(2):152-162. [CrossRef]
8. Lim CK, Lim JH, Ibrahim I, et al. Bioelectrical impedance analysis derived-phase angle as a pragmatic tool to detect protein energy wasting among multi-ethnic hemodialysis patients. *Diagnostics (Basel)*. 2021;11(10):1745. [CrossRef]
9. La Milia V, Pontoriero G, Virga G, Locatelli F. Ionic conductivity of peritoneal dialysate: a new, easy and fast method of assessing peritoneal membrane function in patients undergoing peritoneal dialysis. *Nephrol Dial Transplant*. 2015;30(10):1741-1746. [CrossRef]
10. Mialich MS, Sicchieri JMF, Junior AAJ. Analysis of body composition: a critical review of the use of bioelectrical impedance analysis. *Int J Clin Nutr*. 2014;2(1):1-10.
11. Than N, Woodrow G, Oldroyd B, Gonzalez C, Turney JH, Brownjohn AM. Short communication effect of peritoneal fluid on whole body and segmental multiple frequency bioelectrical impedence in patients on peritoneal dialysis. *Eur J Clin Nutr*. 2000;54(5):450-451. [CrossRef]
12. Arroyo D, Panizo N, Abad S, et al. Intraperitoneal fluid overestimates hydration status assessment by bioimpedance spectroscopy. *Perit Dial Int*. 2015;35(1):85-89. [CrossRef]
13. Davenport A. Does peritoneal dialysate affect body composition assessments using multi-frequency bioimpedance in peritoneal dialysis patients? *Eur J Clin Nutr*. 2013;67(2):223-225. [CrossRef]
14. Sipahi S, Hur E, Demirtas S, et al. Body composition monitor measurement technique for the detection of volume status in

peritoneal dialysis patients: the effect of abdominal fullness. *Int Urol Nephrol*. 2011;43(4):1195-1199. [CrossRef]
15. Kang SH, Cho KH, Park JW, Yoon KW, Do JY. Body composition measurements using bioimpedance analysis in peritoneal dialysis patients are affected by the presence of dialysate. *Nephrology (Carlton)*. 2014;19(11):727-731. [CrossRef]
16. Liu FX, Gao X, Inglese G, Chuengsaman P, Pecoits-Filho R, Yu A. A global overview of the impact of peritoneal dialysis first or favored policies: an opinion. *Perit Dial Int*. 2015;35(4):406-420. [CrossRef]
17. Niang A, Iyengar A, Luyckx VA. Hemodialysis versus peritoneal dialysis in resource-limited settings. *Curr Opin Nephrol Hypertens*. 2018;27(6):463-471. [CrossRef]
18. Bello AK, Levin A, Lunney M, et al. Global Kidney Health Atlas: A report by the International Society of Nephrology on the Global Burden of End-stage Kidney Disease and Capacity for Kidney Replacement Therapy and Conservative Care across World Countries and Regions. International Society of Nephrology. *Int. J. Nephrol*. 2019. Accessed 10 January, 2023. [CrossRef]
19. Stewart A, Marfell-Jones M, Olds T, De Ridder H. *International Standards for Anthropometric Assessment*, 3rd ed. International Society for the Advancement of Kinanthropometry; Lower Hutt: New Zealand; 2011.
20. World Health Organization. *A Healthy Lifestyle – WHO Recommendations*; 2010. Available at: https://www.who.int/europe/news-room/fact-sheets/item/a-healthy-lifestyle---who-recommendations. Accessed May 1, 2023.
21. InBody Co. L. *Body S10 User's Manual*; 2018. Available at: https://nl.inbody.com/wp-content/uploads/2019/01/InBodyS10_CDmanual_Eng_E.pdf. Accessed December 31, 2021.
22. Cheng CH, Chen MY, Lee YJ, et al. Assessment of nutritional status in continuous ambulatory peritoneal dialysis patients: a comparison of bioelectric impedance and conventional methods. *Zhonghua Yi Xue Za Zhi (Taipei)*. 2000;63(10):758-764.
23. Parmentier SP, Schirutschke H, Schmitt B, et al. Influence of peritoneal dialysis solution on measurements of fluid status by bioimpedance spectroscopy. *Int Urol Nephrol*. 2013;45(1):229-232. [CrossRef]
24. Davison SN, Jhangri GS, Jindal K, Pannu N. Comparison of volume overload with cycler-assisted versus continuous ambulatory peritoneal dialysis. *Clin J Am Soc Nephrol*. 2009;4(6):1044-1050. [CrossRef]
25. Kotanko P, Levin NW, Zhu F. Current state of bioimpedance technologies in dialysis. *Nephrol Dial Transplant*. 2008;23(3):808-812. [CrossRef]
26. Pajek M, Sember V, Čuk I, Šimenko J, Pajek J. Comparison of body composition monitor and InBody 720 bioimpedance devices for body composition estimation in hemodialysis patients and healthy controls. *Symmetry*. 2021;13(1):150. [CrossRef]
27. Brantlov S, Ward LC, Jødal L, Rittig S, Lange A. Critical factors and their impact on bioelectrical impedance analysis in children: a review. *J Med Eng Technol*. 2017;41(1):22-35. [CrossRef]
28. Kushner RF, Gudivaka R, Schoeller DA. Clinical characteristics influencing bioelectrical impedance analysis measurements. *Am J Clin Nutr*. 1996;64(3):423S-427S. [CrossRef]

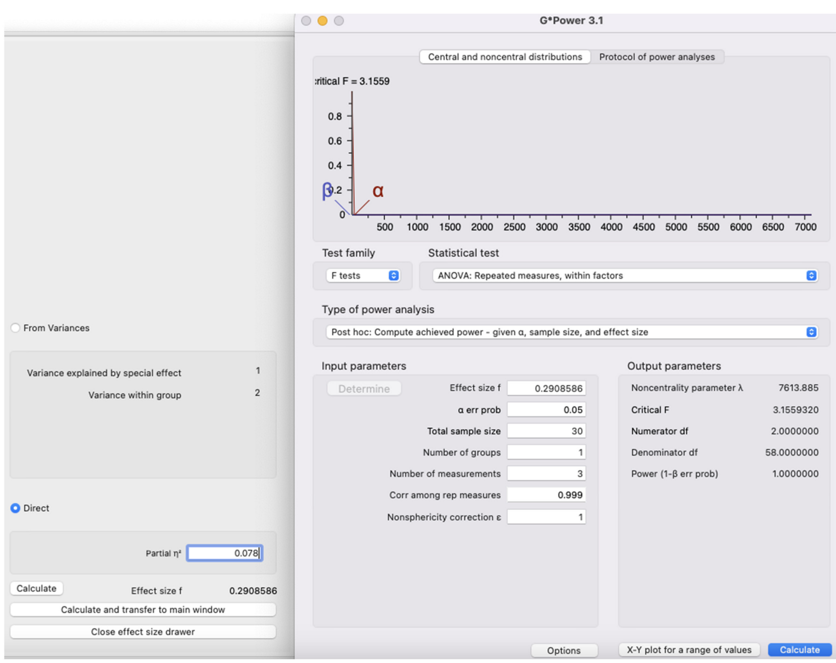


Supplementary Figure 1. Bland–Altman plot for MFBIA parameters. Reference method refers to "performing MFBIA with actual body weight & without dialysate instilled"; DIBW method refers to "performing MFBIA with dialysate-included body weight & with dialysate instilled"; ABW method refers to "performing MF-BIA with actual body weight & with dialysate instilled." Abbreviations: DIBW, dialysate-included body weight; ABW, actual body weight; Ref, reference; TBW, total body water; ICW, intracellular water; ECW, extracellular water; SMM, skeletal muscle mass; SMI, skeletal muscle index; FFM, fat-free mass; SLM, soft lean mass; FM, fat mass; BFP, body fat percentage; VFA, visceral fat area; PhA, phase angle; BCM, body cell mass; BMC, bone mineral content.

Supplementary Table 1. Post-hoc power analysis.			
Parameter	**Partial Eta Squared, η_p^2**	**Effect Size**	**Power (%)**
Hydration assessment			
Total body water (L)	0.078	0.291	100
Intracellular water (L)	0.074	0.283	100
Extracellular water (L)	0.144	0.410	100
Extracellular water/total body water	0.135	0.395	100
Muscle Assessment			
Skeletal muscle mass (kg)	0.054	0.239	100
Skeletal muscle index (kg/m²)	0.103	0.339	100
Fat free mass (kg)	0.141	0.405	100
Soft lean mass (kg)	0.128	0.383	100
Fat assessment			
Fat mass (kg)	0.110	0.352	100
Body fat percentage (%)	0.255	0.585	100
Visceral fat area (cm²)	0.042	0.209	100
Other parameters			
Whole-body phase angle (°)	0.085	0.305	100
Body cell mass (kg)	0.061	0.255	100
Bone mineral content (kg)	0.209	0.514	100

1 = Reference; 2 = ABW; 3= DIBW

TBW:



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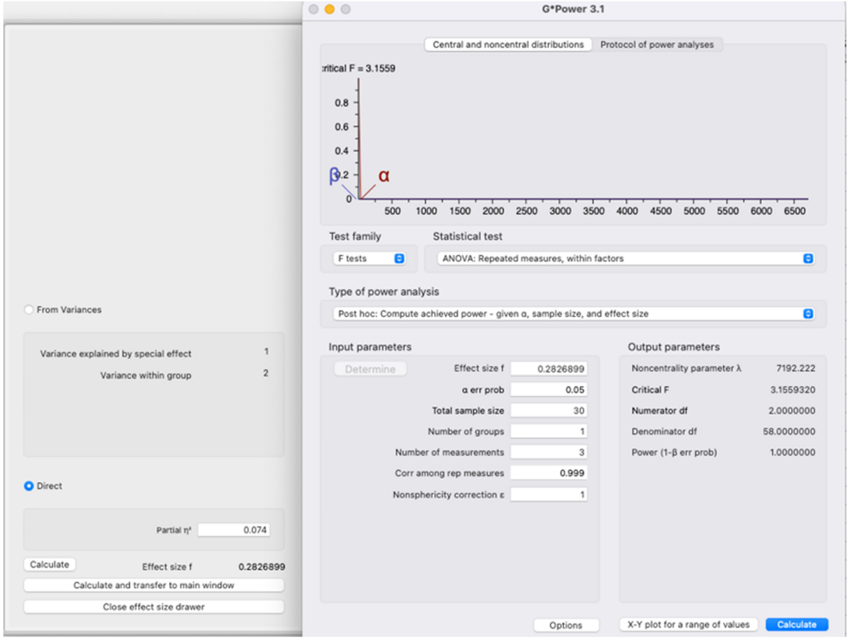
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Protocol of power analyses
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Test family
F tests
Statistical test
ANOVA: Repeated measures, within factors
Type of power analysis
Post hoc: Compute achieved power – given α, sample size, and effect size
Input parameters
Effect size f 0.2826899
α err prob 0.05
Total sample size 30
Number of groups 1
Number of measurements 3
Corr among rep measures 0.999
Nonsphericity correction ε 1
Output parameters
Noncentrality parameter λ 7192.222
Critical F 3.1559320
Numerator df 2.0000000
Denominator df 58.0000000
Power (1-β err prob) 1.0000000
From Variances
Variance explained by special effect 1
Variance within group 2
Direct
Partial η² 0.074
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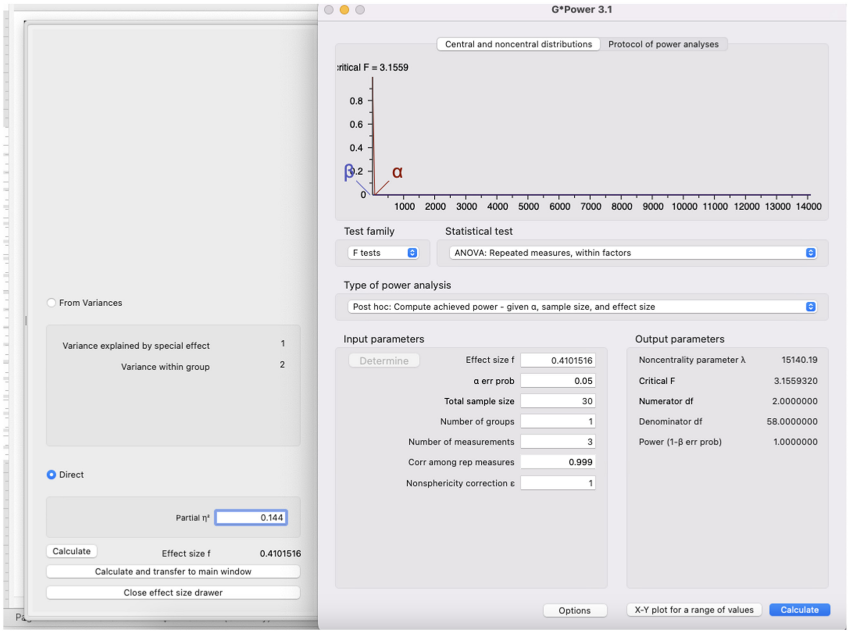
Effect size f 0.2826899
Calculate and transfer to main window
Close effect size drawer
Options
X-Y plot for a range of values
Calculate

ECW: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Central and noncentral distributions
Protocol of power analyses
critical F = 3.1559
Test family
F tests
Statistical test
ANOVA: Repeated measures, within factors
Type of power analysis
Post hoc: Compute achieved power – given α, sample size, and effect size
Input parameters
Effect size f 0.4101516
α err prob 0.05
Total sample size 30
Number of groups 1
Number of measurements 3
Corr among rep measures 0.999
Nonsphericity correction ε 1
Output parameters
Noncentrality parameter λ 15140.19
Critical F 3.1559320
Numerator df 2.0000000
Denominator df 58.0000000
Power (1-β err prob) 1.0000000
From Variances
Variance explained by special effect 1
Variance within group 2
Direct
Partial η² 0.144
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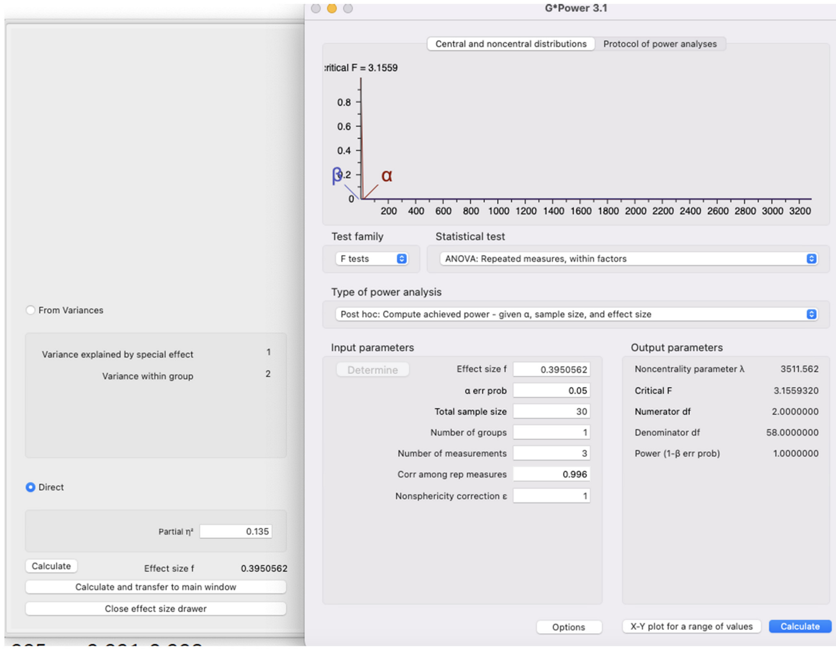
Effect size f 0.4101516
Calculate and transfer to main window
Close effect size drawer
Options
X-Y plot for a range of values
Calculate

ECW Ratio



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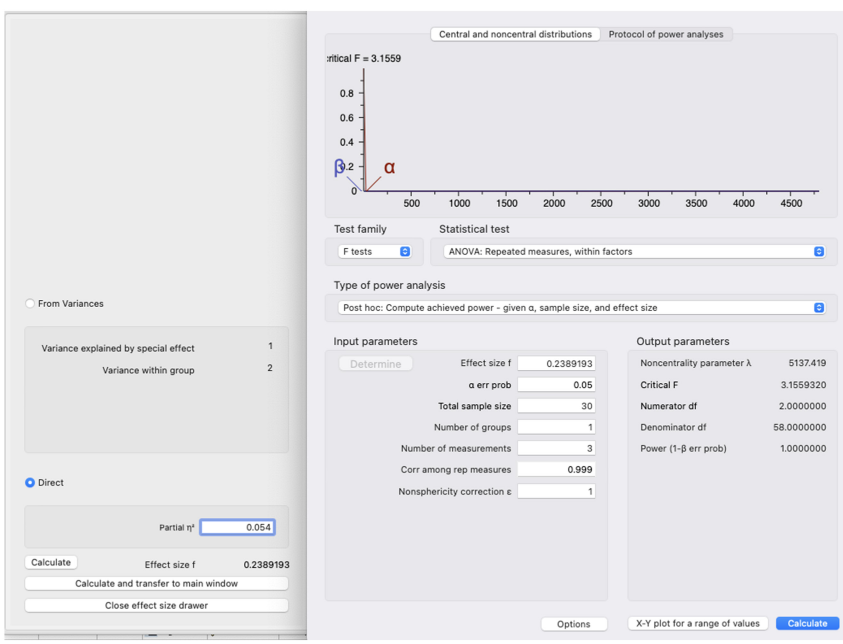

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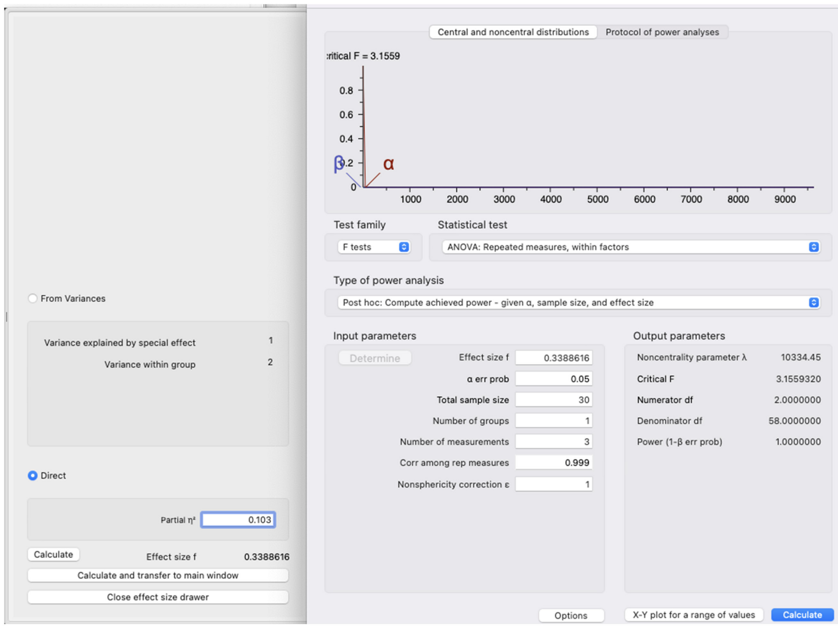
Central and noncentral distributions
Protocol of power analyses
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0.6
0.4
β
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α
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1000
2000
3000
4000
5000
6000
7000
8000
9000
Test family
F tests
Statistical test
ANOVA: Repeated measures, within factors
Type of power analysis
Post hoc: Compute achieved power - given α, sample size, and effect size
Input parameters
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α err prob 0.05
Total sample size 30
Number of groups 1
Number of measurements 3
Corr among rep measures 0.999
Nonsphericity correction ε 1
Output parameters
Noncentrality parameter λ 10334.45
Critical F 3.1559320
Numerator df 2.0000000
Denominator df 58.0000000
Power (1-β err prob) 1.0000000
From Variances
Variance explained by special effect 1
Variance within group 2
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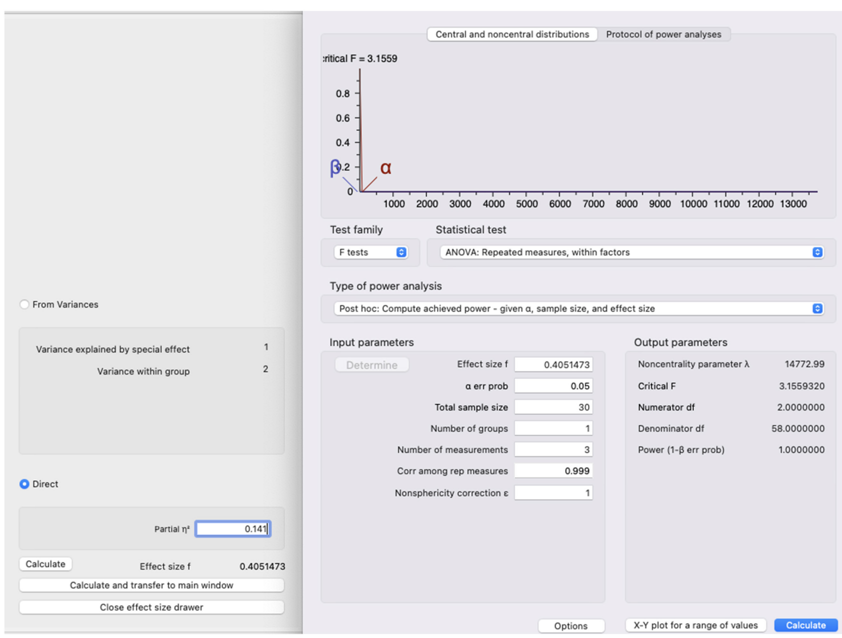
Effect size f 0.3388616
Calculate and transfer to main window
Close effect size drawer
Options
X-Y plot for a range of values
Calculate

FMM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Protocol of power analyses
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0.4
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α
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3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
Test family
F tests
Statistical test
ANOVA: Repeated measures, within factors
Type of power analysis
Post hoc: Compute achieved power - given α, sample size, and effect size
Input parameters
Determine
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α err prob 0.05
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Number of measurements 3
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Nonsphericity correction ε 1
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Noncentrality parameter λ 14772.99
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Denominator df 58.0000000
Power (1-β err prob) 1.0000000
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Variance explained by special effect 1
Variance within group 2
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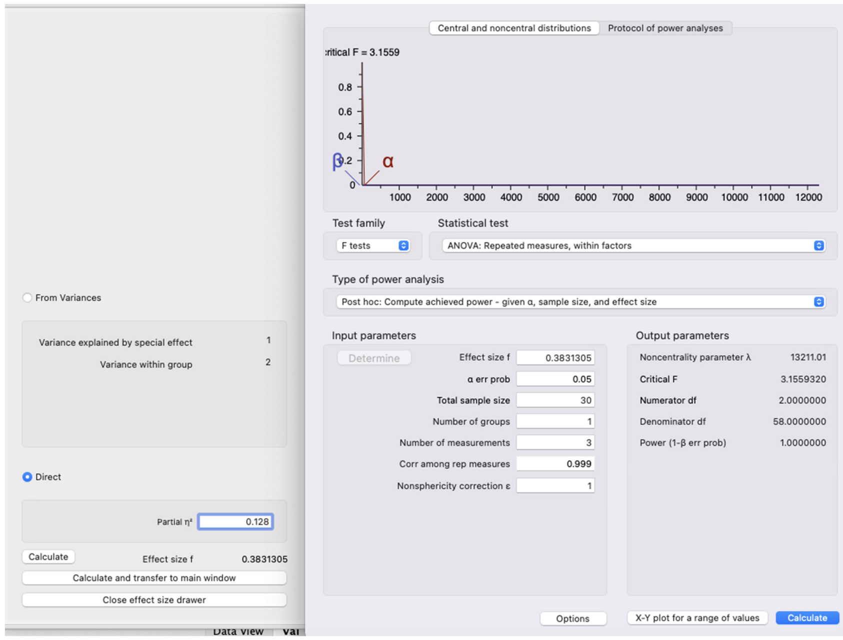
Effect size f 0.4051473
Calculate and transfer to main window
Close effect size drawer
Options
X-Y plot for a range of values
Calculate

SLM:


Central and noncentral distributions
Protocol of power analyses
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0.6
0.4
β
0.2
α
0
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Test family
Statistical test
F tests
ANOVA: Repeated measures, within factors
Type of power analysis
Post hoc: Compute achieved power - given α, sample size, and effect size
Input parameters
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α err prob 0.05
Total sample size 30
Number of groups 1
Number of measurements 3
Corr among rep measures 0.999
Nonsphericity correction ε 1
Output parameters
Noncentrality parameter λ 13211.01
Critical F 3.1559320
Numerator df 2.0000000
Denominator df 58.0000000
Power (1-β err prob) 1.0000000
Options
X-Y plot for a range of values
Calculate
From Variances
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Variance within group 2
Direct
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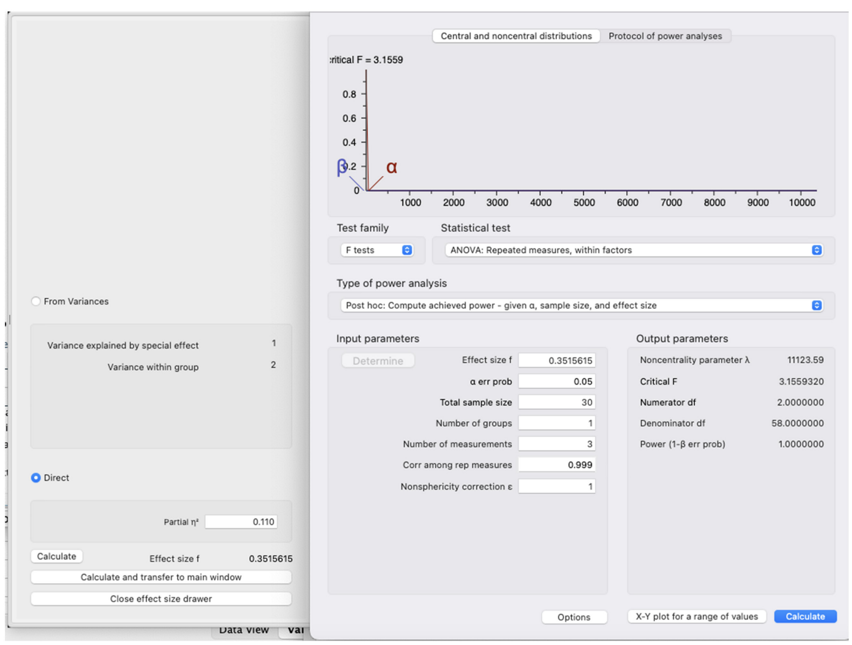
Calculate and transfer to main window
Close effect size drawer
Data view

FM


Central and noncentral distributions
Protocol of power analyses
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0.6
0.4
β
0.2
α
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Test family
Statistical test
F tests
ANOVA: Repeated measures, within factors
Type of power analysis
Post hoc: Compute achieved power - given α, sample size, and effect size
Input parameters
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Effect size f 0.3515615
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Total sample size 30
Number of groups 1
Number of measurements 3
Corr among rep measures 0.999
Nonsphericity correction ε 1
Output parameters
Noncentrality parameter λ 11123.59
Critical F 3.1559320
Numerator df 2.0000000
Denominator df 58.0000000
Power (1-β err prob) 1.0000000
Options
X-Y plot for a range of values
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From Variances
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Variance within group 2
Direct
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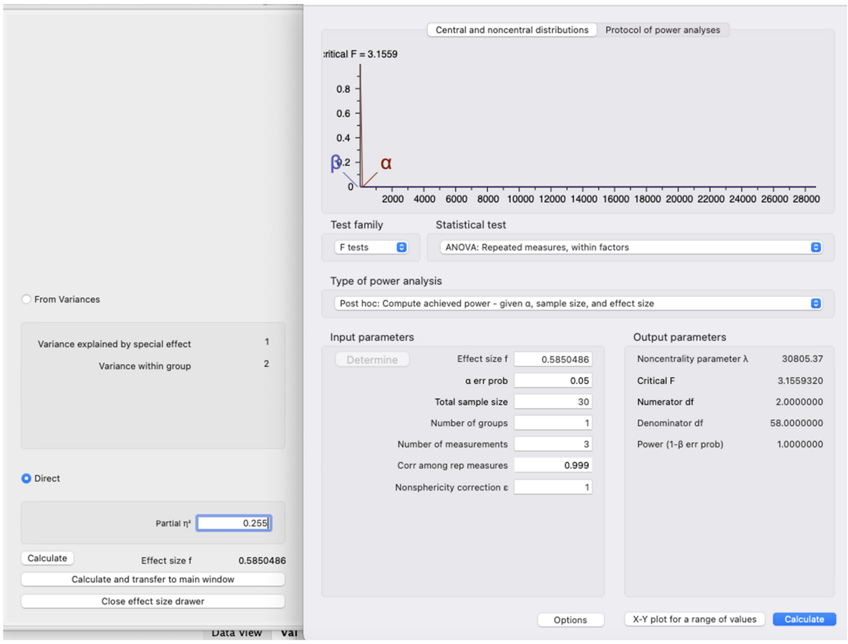
Calculate and transfer to main window
Close effect size drawer
Data view

BF%



Central and noncentral distributions
Protocol of power analyses
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Test family
F tests
Statistical test
ANOVA: Repeated measures, within factors
Type of power analysis
Post hoc: Compute achieved power - given α, sample size, and effect size
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Number of measurements 3
Corr among rep measures 0.999
Nonsphericity correction ε 1
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Noncentrality parameter λ 30805.37
Critical F 3.1559320
Numerator df 2.0000000
Denominator df 58.0000000
Power (1-β err prob) 1.0000000
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Variance within group 2
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Options
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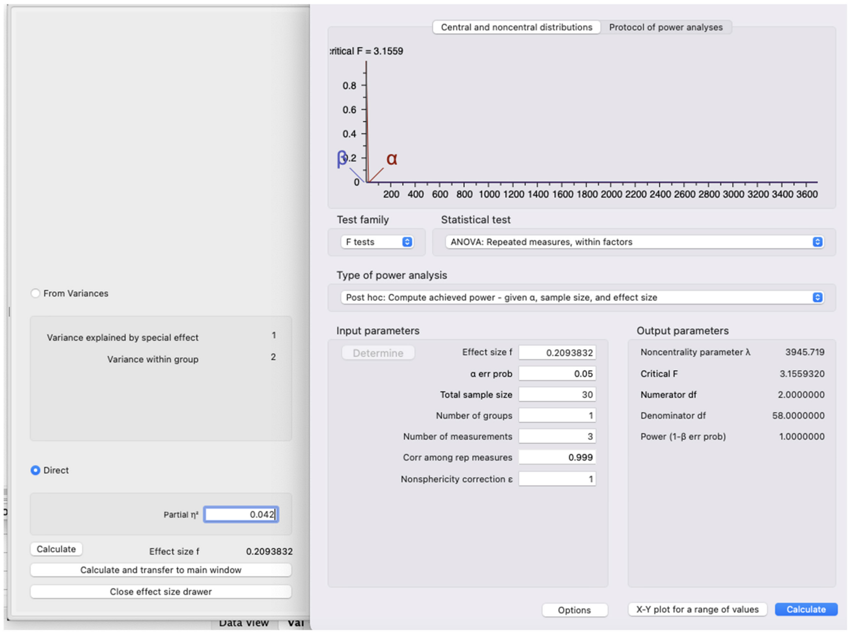

Central and noncentral distributions
Protocol of power analyses
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Test family
F tests
Statistical test
ANOVA: Repeated measures, within factors
Type of power analysis
Post hoc: Compute achieved power - given α, sample size, and effect size
Input parameters
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Nonsphericity correction ε 1
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Variance within group 2
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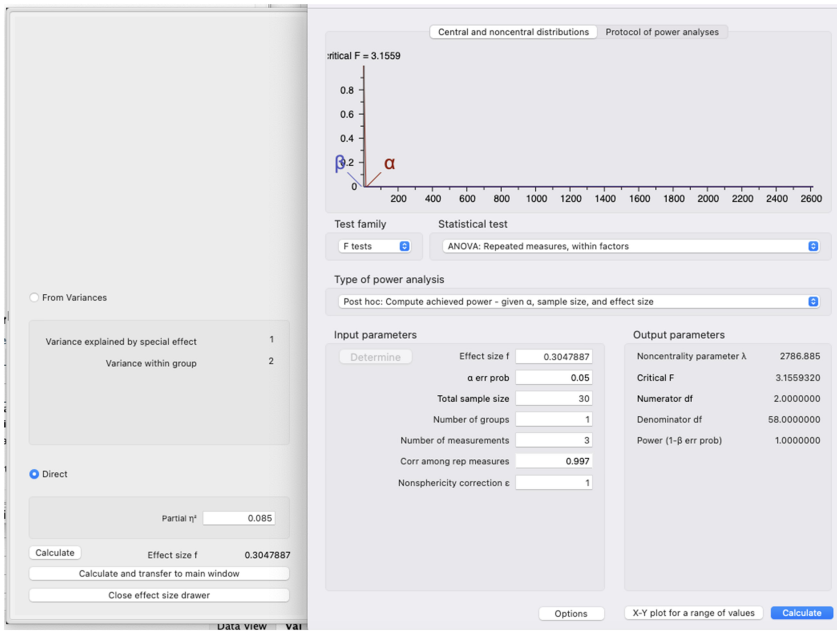
Central and noncentral distributions
Protocol of power analyses
critical F = 3.1559
Test family
F tests
Statistical test
ANOVA: Repeated measures, within factors
Type of power analysis
Post hoc: Compute achieved power - given α, sample size, and effect size
Input parameters
Determine
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Number of groups 1
Number of measurements 3
Corr among rep measures 0.997
Nonsphericity correction ε 1
Output parameters
Noncentrality parameter λ 2786.885
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Denominator df 58.0000000
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Options
X-Y plot for a range of values
Calculate
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Close effect size drawer

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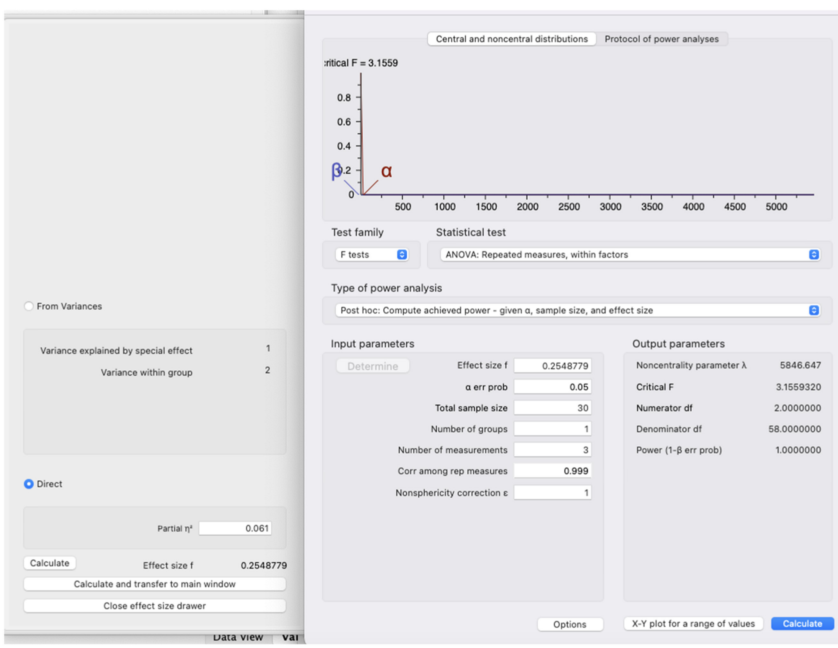
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Protocol of power analyses
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Test family
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Statistical test
ANOVA: Repeated measures, within factors
Type of power analysis
Post hoc: Compute achieved power - given α, sample size, and effect size
Input parameters
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Number of measurements 3
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Nonsphericity correction ε 1
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X-Y plot for a range of values
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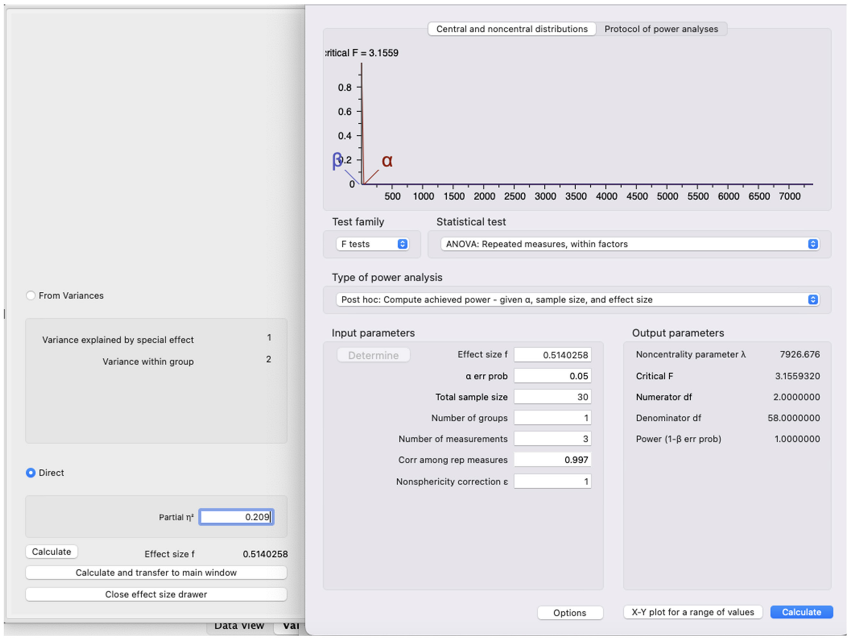
Close effect size drawer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Protocol of power analyses
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F tests
Statistical test
ANOVA: Repeated measures, within factors
Type of power analysis
Post hoc: Compute achieved power - given α, sample size, and effect size
Input parameters
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Number of measurements 3
Corr among rep measures 0.997
Nonsphericity correction ε 1
Output parameters
Noncentrality parameter λ 7926.676
Critical F 3.1559320
Numerator df 2.0000000
Denominator df 58.0000000
Power (1-β err prob) 1.0000000
Options
X-Y plot for a range of values
Calculate