Qualification of a Swab-Sampling Procedure for Cleaning Validation

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This article presents a simple way to qualify a swab-sampling procedure for its ability to recover residues of a small-molecule API from cleaned equipment surfaces. Spiking studies were specifically designed to assess the impact of sampling parameter variability on swab recoveries. The qualification characteristics included accuracy, precision, linearity, and robustness. An eight-run Plackett-Burman design was used to assess the procedure's robustness. Recovery factors for correcting analytical results, taking into account recovery variability, were estimated from the data. The average and individual recoveries for each spiked level were greater than 70%, and the percentage relative standard deviations for overall precision at each spiked level were <20%. The method was found to be robust because none of the factors examined had a statistically significant effect on swab recovery. Results demonstrated that the swab-sampling procedure is suitable for use in cleaning validation.

Residues of APIs, excipients, and cleaning agents that remain on product contact surfaces after cleaning can affect patient safety and product quality. Current good manufacturing practice (CGMP) regulations require that pharmaceutical and biological manufacturers demonstrate that their equipment cleaning processes remove contaminants from product contact surfaces or reduce them to acceptable levels (1, 2).

To assess the levels of contaminant that are likely to remain on equipment surfaces after cleaning, samples must be collected and tested. Swabbing and rinsing are typically used for sampling, while recovery or spiking studies (3) are used to demonstrate that sampling methods are effective. In recovery studies, known amounts of test substances are spiked onto representative surface(s), which are dried, sampled, and analyzed using validated procedures. Levels found in samples are then compared to spiked levels to estimate recoveries, and a correction factor for analytical result is calculated. This factor compensates for the variability of analyte recovery incurred due to sampling and/or analytical errors (4, 5).

Regulatory guidance documents currently focus on sampling method effectiveness and demonstrating recovery (3–6). They do not provide specific recommendations on how recovery studies should be designed. A number of different approaches are currently used (7), but methods can be inconsistent, potentially resulting in poorly designed recovery studies, biased results, and misleading recovery factors.

Swab method variability

For swab sampling, variable recovery results could be due to variability in the following:

- Technique or procedures (e.g., number of swabs used and number or direction of swabbing strokes)
- Materials (e.g., characteristics of swabs and solvent)
- Surface (e.g., material of construction and surface finish of the equipment or swab area)
- Residue chemistry and concentration
- Staff readiness, training, experience, and cognitive state.

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This article focuses on improving the understanding and assessment of potential sources of variability, presenting a real-world study of sampling methods. The objectives of this study were to:

- Examine the effect of the potential sources of variation on swab recovery of a small molecule (molecular weight: approximately 300 g/mol) API from cleaned equipment surfaces
- Identify variables that influence sampling recoveries and determine which variables should be controlled for consistent recoveries.

The study's experiments were designed to assess the accuracy, precision, linearity, and robustness of the procedure. Because swab sampling methods, like manual cleaning, are very technique-dependent, this study also examined the effect that samplers (i.e., the technicians performing the sampling) had on results.

Design-of-experiment (DoE) techniques (specifically, a Plackett-Burman design) were used to assess the robustness of the sampling procedure. The study was performed alongside the validation of analytical method used for testing swab samples. The resulting data were statistically evaluated to assess qualification parameters. Recovery factors for correcting analytical results were also estimated.

Materials and methods

Chemicals and materials. High-performance liquid chromatography (HPLC)-grade methanol (Merck, Germany) was used in the study; all other chemicals were of analytical-reagent grade. Flathead knit polyester swabs with polypropylene handles (SP-3) were used (Contec Inc., USA), and the sterile cotton swabs used for surface sampling were obtained from Premier Diagnostics Sdn. Bhd., Malaysia.

Teepol cleaning agent was purchased from Fisher Scientific, Malaysia. Two 316-L stainless steel plates, 61cm x 30cm, were cut out from the same sheet and used as representative surfaces for the study. Whatman UNIFLO 25/0.45 RC syringe filters were used for filtering sample solutions.

Study design. To assess the recovery effectiveness of the swab-sampling procedure, 18 determinations (i.e., three levels of spiking repeated three times by two different sampling technicians) were made at spike levels that covered 50% to 200% of the expected cleaning analytical limit (i.e., 10 µg/mL). Spiked levels were set at 50, 100, and 200 µg/25cm². Each spiked level was swabbed three times by two trained sampling technicians. This study was performed in parallel with the validation of analytical procedure for cleaning validation. Hence, for comparison purposes, samples prepared in triplicate by spiking known amounts directly onto the swab tips for testing the accuracy of analytical procedure were included as controls in this study.

The representative surface and swabs were also seeded with the spiking solvent alone (i.e., without the test substance) to provide blanks. This allowed researchers to check cross-contamination and interference from items that were used during the study (e.g., labware, plate surface, solvents, and solutions).

Design of experiments. An eight-run Plackett-Burman design was used to assess the procedure's robustness. Plackett-Burman designs allow researchers to identify, economically, the most important factors out of many potential ones. These designs are useful for investigating main effects, because they assume that interaction effects are negligible (8). Using these designs only, N runs can be used to explore N-1 factors. Due to the method's efficiency, these designs are preferred for robustness/ruggedness studies.

In the study, seven factors, both quantitative and qualitative, were selected and considered: surface finish, swab area, type of swabs used, swabbing direction, sampling personnel, spiked amount, and percent of methanol solution used for swabbing. **Table I** summarizes the factors and their levels. **Table II** presents the DoE scheme and the results obtained from each DoE run. The percent recovered from the surface was used as the response variable. The experiments were performed at random and the amounts recovered were obtained for statistical evaluation. For each of the eight treatment combinations, two replicates were taken.

Recovery study procedures

Preparation of spiking solution. The spiking solution was prepared by dissolving about 0.05g of the test substance in 100 mL of methanol so that the concentration was 0.5mg/mL.

Preparation of stainless steel plates. The plates were cleaned thoroughly with Teepol detergent solution and potable water, then final rinsed with Milli-Q water and allowed to dry. Prior to spiking, the plates were further cleaned with methanol and dried.

Table I. Robustness factors and their levels.

Factor	Unit	Low value (-1)	Nominal value (0)	High value (+1)	Variation (%)
A. Surface finish	-	Milled	-	Finished	-
B. Spiked area	cm²	20.25	25	30.25	-
C. Swabbing method	Method	B	A	C	-
D. Methanol percent	%	95	99.8	99.8	~5
E. Swab type	-	Cotton	-	SP-3	-
F. Sampling personnel	-	Sampler 1	-	Sampler 2	-
G. Amount spiked	µg	90	100	110	10

Table II. Design of experiments for assessing the robustness of the sampling procedure.

Exp. no.	Plate surface finish	Spiked surface area	Swabbing method	Methanol %	Swab type	Sampling personnel	Amount spiked	Average recovery [a]
1	Finished	30.25	C	95	SP-3	Sampler 1	90	1.043
2	Milled	30.25	C	99.8	Cotton	Sampler 2	90	1.018
3	Milled	20.25	C	99.8	SP-3	Sampler1	110	0.865
4	Finished	20.25	B	99.8	SP-3	Sampler 2	90	1.127
5	Milled	30.25	B	95	SP-3	Sampler 2	110	0.900
6	Finished	20.25	C	95	Cotton	Sampler 2	110	1.354
7	Finished	30.25	B	99.8	Cotton	Sampler 1	110	1.022
8	Milled	20.25	B	95	Cotton	Sampler 1	90	1.002

[a]Average recovery from two replicates

Spiking onto stainless steel plate. Using a micropipette, six replicates, each of 100-, 200-, and 400-µl aliquots of the spiking solution, were spiked separately (and equidistant from one another) onto the finished surfaces of the plates. Using the pipette tip, aliquots were spread over a 5 x 5 cm area. Similarly, control samples were prepared by spiking each aliquot directly onto the tips of two swabs. Amounts spiked per 25 cm^2 area or two swabs were 50, 100, and 200 µg, respectively.

To test for robustness, a micropipette was used to spike eight replicates (four each on the finished and milled surfaces). Each 180-µl and 220-µl aliquot of the spiking solution was spiked separately (and placed so that the aliquots were equidistant from one another) onto the plate and spread over 4.5 x 4.5 cm and 5.5 x 5.5 cm areas, respectively, with the pipette tip. Amounts spiked over 4.5 x 4.5 cm and 5.5 x 5.5 cm areas were – 90, and 110µg, respectively.

Swabbing procedures. Standard procedures for obtaining swab samples (Method A) were used to obtain swab samples. This involves moistening swabs with solvent and swabbing the area to be sampled in an overlapping zigzag pattern—first horizontally, and then vertically. Two swabs were used for each sample, and methanol was used as the swabbing solvent.

Two variations of this method (Method B and Method C) were also used to determine robustness. In Method B, the spiked area was first swabbed horizontally and then, after rotating/flipping the swab, again horizontally. In Method C, the spiked area was swabbed first diagonally upwards and then, after rotating/flipping the swab, diagonally downwards. These methods are illustrated in **Table III**.

Sample preparation. The collected swab samples were extracted with 10.0 mL of methanol by sonicating for 15 minutes. After sonicating, the tubes were shaken, and excess solvent was removed from the swabs by lightly pressing their tips against the test tube wall. The swabs were then discarded, and the solution was analyzed using a validated HPLC method. The expected concentrations for the three spike levels were 5-, 10-, and 20-µg/mL, respectively.

Statistics. R software, version 3.2.3 (R Foundation for Statistical Computing, Vienna) was used for statistical and graphical analysis, along with Minitab Version 16.2.3 (Minitab, Inc.) and Microsoft Excel 2007. The level of significance for all analysis was set at α=0.05. Prior to data analysis, the recovery and bias were calculated for each swab sample using equations 1 and 2.

$$\text{Recovery (R)} = \text{Concentration Found} / \text{Expected Concentration} \quad \textbf{[Eq. 1]}$$

$$\text{Bias} = \text{Concentration Found} - \text{Expected Concentration} \quad \textbf{[Eq. 2]}$$

Results

Data generated from the recovery study are shown in **Figure 1.** These data were used to analyze the sampling qualification characteristics of accuracy (recovery), precision, and linearity. Analysis of blanks did not suggest cross contamination, as expected.

Exploratory data analysis. Plots used for exploratory analysis are provided in **Figure 2.** Box plots for the recovery data are shown in **Figures 2a and 2b** and summarize visually the distribution of recoveries by spiked level and Series, respectively. As seen from the box plots (**Figure 2a**), Sampler 1 showed lower recoveries than the Control or Sampler 2 at each

Figure 1. Interval plot of accuracy data (with lower one-sided 95% confidence interval for the mean shown as dashed line). "Pooled" and the vertical long dash dot line in the plot represent pooled recoveries of both the samplers and the reference line for 70% recovery, respectively. The red (◊) symbol in the plot denotes mean of recoveries.

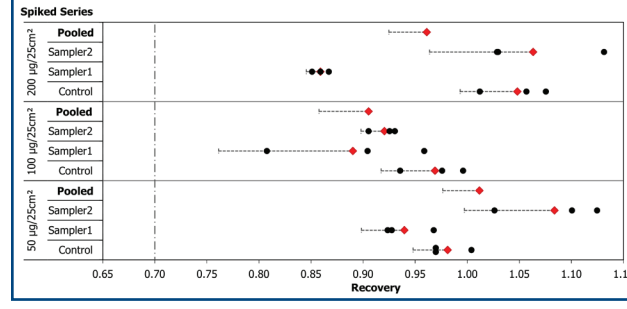

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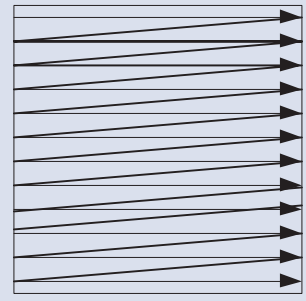
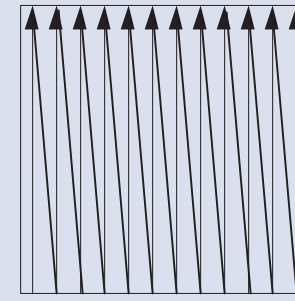
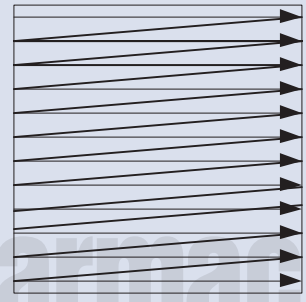
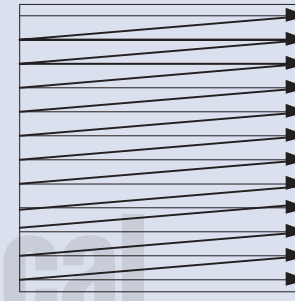
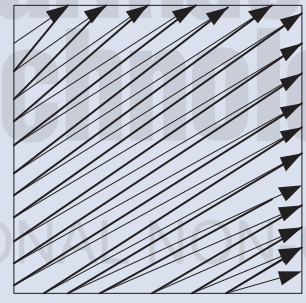
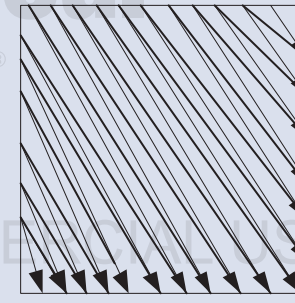
Table III. Variants of swabbing directions.

Sampling method	With the first side of the swab	After rotating/flipping the swab
Method A (usual procedure)		
Method B		
Method C		

spiked level. For Sampler 1, the average recoveries could also be seen decreasing with increasing spiked amounts. In addition, the box plots (**Figure 2b**) indicated that the overall recovery and variation in recoveries for Sampler 2 were greater than that for Sampler 1 or Control. Examination of the scatter plots (**Figure 2c**) for Control and Sampler 1 indicated linear relationships between concentrations found and expected concentrations. The scatterplot for Sampler 2 showed a possible slight curvature. The plot of bias values against the spiked levels is shown in **Figure 2d**. For Control and Sampler 2, the average bias values at spiked level of 100µg/25cm^2 were lower than those observed at other levels. The plot of bias values for Sampler 1 showed increasing negative bias with increasing spiked amounts.

Linearity. Simple regression analysis was used to evaluate the relationship between expected and found concentrations. The summary statistics, including the regression coefficients (slope and y-intercept) with 95% confidence intervals, correlation coefficient (r), coefficient of determination (r^2), and residual sum of squares, for the series-specific regressions are provided in **Table IV**.

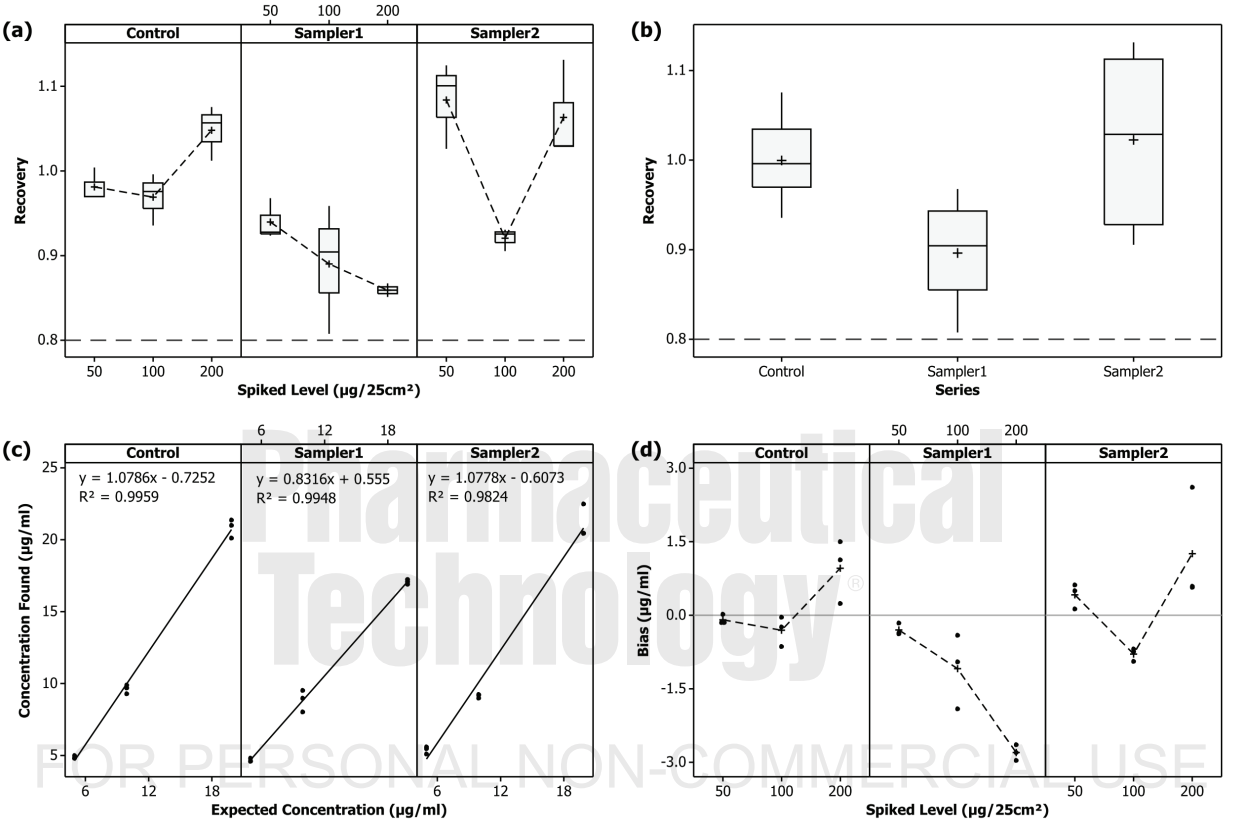
Linearity of the recovery curves was assessed from the

Table IV. Linearity summary statistics for the recovery data.

Series	r	r^2	Intercept[a]	Slope[a]	RSS	Sy/x	PLoF
Control	0.998	0.996	-0.726 (-1.545, 0.093)	1.079 (1.016, 1.141)	1.680	0.490	0.110
Sampler 1	0.997	0.995	0.557 (-0.150, 1.265)	0.832 (0.778, 0.885)	1.253	0.423	0.901
Sampler 2	0.991	0.982	-0.607 (-2.300, 1.086)	1.078 (0.949, 1.207)	7.178	1.013	0.025

[a] 95% Confidence intervals are provided in the parenthesis; r: Correlation coefficient; r^2: Coefficient of determination; Sy/x: Residual standard deviation; RSS: Residual sum of squares; PLoF: P-value for the lack of fit test

Figure 2. Exploratory data analysis of recovery study data: (a) Multi-panel box plots (paneled by Series) of the recoveries by spiked level; (b) box plots of the recoveries by Series; (c) Multi-panel scatter plot (paneled by Series) of concentration found versus expected concentration, overlaid with the linear regression lines; (d) Multi-panel scatter plot (paneled by Series) of bias versus spiked level with mean connecting lines. The (+) symbols in box plots and bias scatter plot denote average of recoveries and bias, respectively. The horizontal dashed line in (a) and (b) denotes the reference line for 80% recovery.



correlation coefficients and lack of fit tests. The correlations coefficients indicated that the concentrations found were strongly correlated (r>0.99) to the expected concentrations. Except for the Sampler 2 data, the lack of fits was not significant (p > 0.05). A p-value <0.05 for lack of fit suggested that the linear model did not fit the data well, and a higher order (e.g., quadratic) model would be required. Nevertheless, for the purpose of estimating recovery factor, a linear model was assumed.

The 95% confidence intervals for the slope and intercept were used to identify proportional and constant bias, respectively. For Control and Sampler 1, the confidence intervals for slopes did not include one, indicating the presence of proportional bias.

Comparison using analysis of covariance (ANCOVA) showed no significant difference in the slopes (p = 0.99) and intercepts (p=0.88) of Control and Sampler 2 regression lines. However, the regression line of Sampler 1 was significantly different from that of Control and Sampler 1. The plot of the series data with the fitted regression line is shown in **Figure 2c.**

Precision. The precision of the swabbing procedure was evaluated by considering repeatability and overall precision (i.e., repeatability + sampler-to-sampler variability) at the three spike levels. For each spiked level, using one-way analysis of variance (ANOVA), a method of moments estimation, average concentration found and recovery between and within sampler variance components were estimated. The measures of precision—repeatability and overall precision, respectively, were estimated from within sampler and total (between + within) variance by dividing the square root of these quantities by the average and multiplying by 100. The variance components and precision estimates are summarized in **Table V**. The repeatability precision ranged from 4.01 to 6.10%, and the overall precision ranged from 6.10 to 15.43%.

Accuracy

Recovery effectiveness. The recovery effectiveness of the swab sampling procedure was evaluated by spiking stainless steel plate with known amounts of the API. The spiked samples were collected, analyzed, and the results expressed as re-

Table V. Linearity accuracy and precision results for the qualification of the swab-sampling procedure.

Expected concentration (µg/mL)	Level of recovery		Variance components		Precision RSD (%)	
	Concentration found (µg/mL) [$\bar{X}$; LCLA]	% Recovery [$\bar{X}$; LCLA]	Between	Within	Repeatability	Intermediate
5.00	5.03; 4.85	101.24; 97.65	0.24	0.04	4.01	10.54
10.00	8.99; 8.52	90.53; 85.77	0.00	0.30	6.10	6.10
20.00	19.10; 18.37	96.14; 92.47	7.99	0.70	4.37	15.43

Xbar: Average; LCLA: Lower one-sided 95% confidence limit of average; RSD: Relative standard deviation

coveries (i.e., ratio of concentration found to expected concentration). The individual recoveries, as shown in **Figure 1**, ranged from 0.81–0.97 for Sampler 1, 0.91–1.13 for Sampler 2 and 0.94–1.08 for Control. The average recoveries at different spiked levels ranged from 0.86–0.94 for Sampler 1, 0.92–1.08 for Sampler 2, and 0.97–1.05 for Control. The overall minimum and average recovery values for combined sampler data were 0.81 and 0.96, respectively.

For each level spiked onto the stainless steel plate, the average recoveries and their lower one-sided 95% confidence limits were computed and are shown in **Table V**. Lower one-sided limits for recoveries were used because expectations were only set for recoveries on the lower side (i.e., the objective was to verify if the observed recoveries were higher than 70%). The average recoveries at spiked levels of 50, 100, and 200 µg/25cm² were 1.01, 0.91, and 0.96, respectively. The lower one-sided 95% confidence limits of mean were above 70% recovery in all the cases.

The interval plot of recovery data is shown in **Figure 1.** The figure shows series-specific individual and average (and their lower one-sided 95% confidence intervals) recoveries for each spiked level.

Estimation of recovery factor. Because the recovery results for Sampler 1 showed significant proportional bias, a recovery factor needs to be applied for correcting future results. In cases where concentration found is linearly related to expected concentration, slope of the recovery curve can be used as an estimate of the overall recovery (9). However, because this overall recovery does not reflect the variability observed in the recovery data, it cannot be used as the correction factor. Hence, to account for statistical uncertainty and provide confidence in corrected results, lower one-sided 95% confidence limit of the slope was set as the recovery factor.

The lower one-sided 95% confidence limits of the slope for Sampler 1 and Sampler 2 regression lines were computed to be 0.79 and 0.97, respectively. These values were then used to correct results obtained from swab samples of the respective sampler. The corrected results were obtained by dividing the measured result by the estimated recovery factors.

Robustness. To assess the robustness of the swab sampling procedure, the factors that could potentially influence the effectiveness of the procedure were evaluated using an eight run Plackett-Burman design. Both quantitative and qualitative factors were examined in the test. The results obtained from the test (**Table II**) were statistically (using ANOVA) and graphically analyzed to identify significant effects. Based on ANOVA results (not shown here), the p-value for each effect was greater than 0.1. A p-value of less than 0.05 indicates a statistically significant difference from zero at the 95% confidence level.

The Pareto chart, normal probability plot, and half normal plot of the standardized effects (i.e., the estimated effects divided by their corresponding standard errors) are shown in **Figure 3**. The Pareto chart (**Figure 3a)** shows the absolute standardized effects sorted by magnitude in descending order. From the chart, it is seen that none of the bars crosses the vertical line at 2.306 indicating that none of the factors showed an effect that was statistically significant at the 95% confidence level. The magnitude of the standardized effects ranged from 0.09 to 1.43. In addition, both the Pareto chart and half normal plot (**Figure 3c**) shows that the effects for Surface Finish (Factor A) and Amount Spiked (Factor G) were the largest and smallest, respectively. On the other hand, the normal probability plot (**Figure 3b)** shows the direction of the effects. The plot reveals that of the seven factors examined, Spiked Area (B), Methanol Percent (D), Swab Type (E), and Amount spiked (G) have negative standardized effects implying that the swab recovery decreases with increase in levels of these factors. Whereas Surface Finish (A), Swabbing Method (C), and Sampling Personnel (F) have positive standardized effects indicating that the swab recovery increases when the low levels of these factors are changed to high levels.

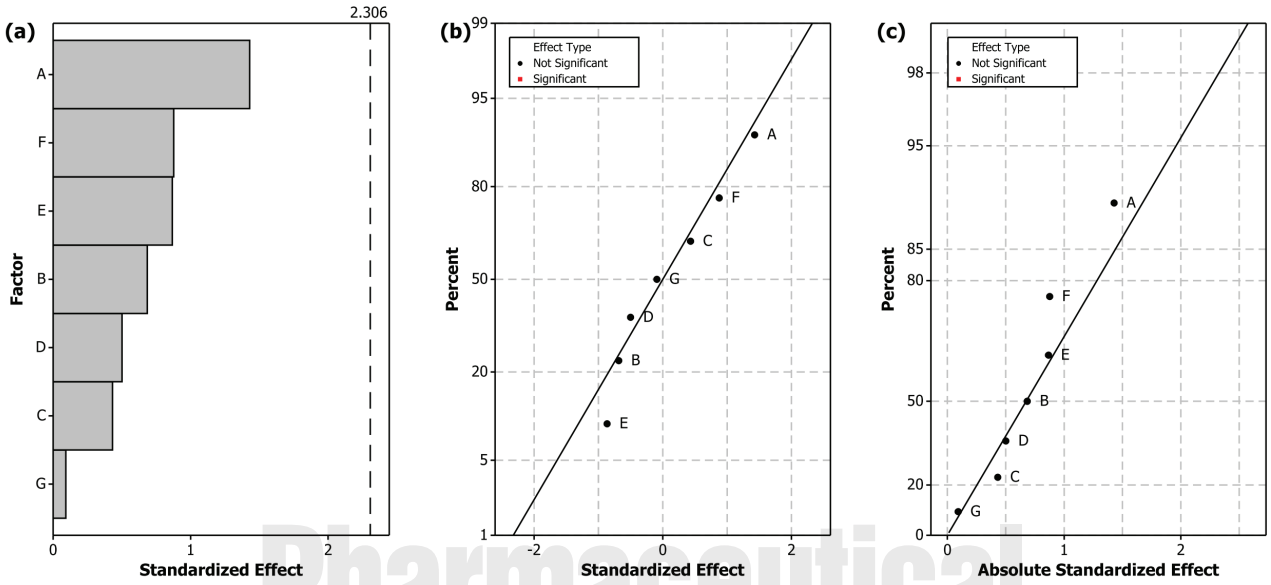
Furthermore, all the recoveries obtained in the robustness test were greater than 80%. Based on the evaluation of robustness results, the swab sampling procedure can be considered robust.

Discussion

Key findings. The objective of this study was to qualify a swab-sampling procedure to recover residues of an API from cleaned equipment surfaces. Data from a swab-sampling recovery study were statistically evaluated and assessed for accuracy, precision, and linearity. This evaluation determined the following:

- Average and individual recoveries for each spiked level were greater than 70%.
- % relative standard deviations (RSDs) for overall precision at each spiked level were <20%.
- The highest variability (overall %RSD > 15%) in recovery was observed at the highest spiked level (i.e., 200 µg/25cm²).

Figure 3. Graphical analysis of effects: (a) Pareto chart of the standardized effects; (b) Normal probability plot of the standardized effects; (c) Half normal plot of the standardized effects. The vertical dashed line in the Pareto chart indicates the smallest magnitude for an effect to be statistically significant. Level of significance = 0.05.



- For Sampler 1 and Control, the concentrations found were linearly related to the expected concentrations. A potential curvature was observed in the data for Sampler 2.
- The effect from different samplers was significant. The recovery data for Sampler 1, for example, exhibited significant proportional bias (i.e., recovery was statistically different from one).
- Based on the recovery results, taking into account the uncertainty in recovery results, recovery factors for Sampler 1 and Sampler 2 were found to be 0.79 and 0.97, respectively.
- From the robustness test, it was found that none of the factors that were examined had a statistically significant effect on swab recovery (at a 95% confidence level) and all the recoveries were above 80%.

Sources of variability

The following potential sources of variation were found:

Sampling personnel. As seen earlier, the sampler-to-sampler variation was significant with Sampler 1, showing lower recoveries at each spike level. Although both the samplers received the same level of training, Sampler 2 showed similar performance in other recovery studies. This may be because of the individual's sampling technique (i.e., pressure applied in sampling, over-wetting of swabs, and inconsistency in number of swabbing strokes).

These experiments also highlight the importance of including data from staffers who actually perform the sampling in recovery studies (rather than results from laboratory staff performing the research) to obtain a true picture of performance and variability. Because only two samplers are typically included in these studies, one cannot make inferences about the variability that would be associated with the whole population of samplers.

Surface finish. In the robustness experiment, the effect due to equipment surface finish (i.e., Factor A) was found to be statistically insignificant. However, as seen from **Figure 3a**, the effect due to this factor is the largest, which suggests that surface finish or imperfections (e.g., scratches or pits) could influence the recovery of process residues.

Apart from these results, it was also observed that over-wetting of swabs (in sampling solution) prior to sampling can also contribute to variable recoveries. When swabs are over-wetted, when technicians swab along the edges of the template, the extra solution would seep under the template, likely taking some dissolved residue along with it.

Swabbing is a widely used sampling method. However, results depend heavily on the swabber's technique. A number of variable factors may influence its ability to recover process residues accurately and consistently.

Considering these potential sources of variability, recovery studies should be designed to assess their impact on swab recoveries. Properly designed experiments could help achieve this objective in an efficient and cost-effective manner. When designing such experiments, the factors and their levels can be determined, either based on prior knowledge or by using risk-assessment methodologies (e.g., failure mode and effects analysis). Identified factors should be the ones that are expected to vary during actual sampling and that are likely to influence residue recovery.

Setting of recovery factors

Understanding variability and uncertainty in recovery results is vital to setting reliable recovery factors. Poorly designed studies and improper evaluation of recovery results may lead to misleading recovery factors. In order to be used in correcting

Table VI. Comparison of recovery factors.

Approach	Recovery factor	Analytical result (µg/mL)	Corrected result (µg/mL)
Recoveries above 70% (5)	1.00	10.00	10.00
Overall minimum recovery	0.81	10.00	12.35
Lowest average recovery	0.86	10.00	11.63
Average of all the recoveries	0.96	10.00	10.42
Recovery at the cleaning acceptance level (100 µg/cm2)	0.91[a]	10.00	10.99
Lower one-sided 95% confidence limit of the slope	Sampler 1 = 0.79 Sampler 2 = 0.97	10.00	Sampler 1 = 12.66 Sampler 2 = 10.31

[a] Average of all the recoveries at this spike level.

analytical results, estimated recovery factors should be data-derived and reflect the variability observed in recovery data (7).

Table VI provides a simple comparison of recovery factors and corrected results estimated using conventional approaches versus the approach used in this study. An analytical result of 10µg/mL is used as an example to calculate the corrected result. The corrected results were obtained by dividing the analytical result by the estimated recovery factor.

As shown in the table, conventional approaches pool all the recovery values regardless of differences between recovery results from the two samplers. From a practical standpoint, where the recovery data for samplers differ significantly, correcting for recovery using conventional approaches can give misleading results. This study shows that use of conventional approaches will result in either overestimation or underestimation of the amounts recovered.

Swab sampling procedures and training

Swab sampling is the preferred method for sampling equipment surfaces. However, it is highly variable, and its effectiveness depends on a number of factors. In order to harmonize this cleaning validation process variable across the industry, efforts should be taken to include detailed and specific instructions on how swab sampling should be performed. Details on potential sources of variation and failure modes, and critical parameters identified during qualification studies should be provided in written procedures.

This should help cleaning validation scientists minimize uncertainty and maximize consistency in sampling results. In addition, technicians and operators who perform the sampling should be qualified in the procedures. Samplers responsible for collecting swab samples should be trained to ensure that they are well-versed in swabbing procedures.

Conclusion

This article presents a systemic approach of qualifying swab sampling procedures. These simple experiments can help identify variables that affect sampling recoveries, so that cleaning validation professionals can decide which factors need to be controlled or optimized for best results, or whether additional studies are needed to better understand sources of potential variation.

The proposed approach was applied to qualification of a swab-sampling procedure. Results have demonstrated that the procedure is effective, precise, and robust, and hence qualified for its intended applicability, and that recovery data can be used to estimate recovery factors. In addition, it should be noted that these experiments can be easily completed in a day or two, performed alongside analytical method validation studies, and harmonized across the industry.

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