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Comparison of Two Aspiration Techniques of Bronchoalveolar Lavage in Children

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Summary

Background—Although bronchoalveolar lavage (BAL) via flexible bronchoscopy is an essential diagnostic tool, its technique is not standardized in children. Our objective was to compare two different aspiration techniques of BAL in children (continuous wall suction vs. handheld syringe suction) in regards to the percentage of fluid recovered and the odds of performing a technically-acceptable procedure (i.e., >40% of volume return).

Methods—We conducted a review of all pediatric flexible bronchoscopies with BAL conducted at our institution over a two-year period. To minimize the differences between groups at baseline and reduce the possibility of bias, we used one-to-one propensity score (PS) caliper matching with no replacement for statistical analyses.

Results—We identified 539 procedures that met pre-specified criteria. There were considerable covariate imbalances between procedures in the handheld syringe group (n=147) and those in the continuous wall group (n=392); however, these imbalances were substantially reduced after the PS matching. In the matched sample (n=236), children in the handheld syringe group had ~7% higher volume return (95%CI=3.4–11.0, $P<0.001$) from BAL and three-fold higher odds (95%CI=1.5–8.6, $P=0.002$) of performing a technically-acceptable procedure.

Conclusions—Our results suggest that handheld syringe suction offers a higher percentage of volume return from BAL and increases the odds of performing a technically-acceptable procedure in children when compared to continuous wall suction.

Keywords

Bronchoalveolar lavage; bronchoscopy; children; propensity score

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Introduction

Respiratory illnesses are a leading cause of morbidity and mortality in children worldwide.¹ An early and accurate diagnosis is fundamental to direct therapy and to reduce the burden associated with these diseases. Bronchoalveolar lavage (BAL) via flexible bronchoscopy is a valuable diagnostic and research tool in children with respiratory illnesses of different etiologies (such as immunologic, inflammatory, and infectious processes).^{2–5} In this procedure, a flexible bronchoscope is advanced into a segmental or subsegmental bronchus until the lumen is occluded. Non-bacteriostatic normal saline solution is subsequently instilled through the working channel of the flexible bronchoscope and suctioned into a sterile trap. The fluid recovered is then sent for cytological and microbiological studies. The minimal volume of fluid needed for these studies can vary according to an institution's laboratory requirements and/or the number or type of tests requested (which depends on the particular clinical scenario).⁶ The value of this procedure is thus directly linked to the volume of fluid recovered and, as a result, a common practice among providers is to recover as much fluid as possible. In addition, a BAL can be considered technically unacceptable if 40% of the volume instilled is recovered,^{7,8} as an inadequate return may represent a more proximal (non-alveolar) sample, decrease its diagnostic yield, and/or compromise the validity of results.^{6,9–11}

Despite the fact that it is one of the most common invasive procedures performed by pediatric pulmonologists worldwide,^{12,13} the BAL technique is not standardized in children. An essential aspect that varies among practitioners is the suction method used, which could potentially affect the volume of fluid recovered.^{7,14} The two suction methods most commonly employed are continuous wall suction and handheld syringe suction. In continuous wall suction, a mechanical source of negative pressure is used to recover the fluid instilled. In handheld syringe suction, the fluid is retrieved using gentle manual aspiration. The only available guideline for BAL in children supports the use of either technique,⁸ although literature comparing these two methods is limited.

We hypothesized that the type of suction would affect the volume return from BAL in children. To test this hypothesis, we conducted a retrospective review of all flexible bronchoscopies with BAL performed at our institution between January 2011 and December 2012.

Material and Methods

Study Setting and Data Sources

Children's Hospital of Pittsburgh of UPMC is a tertiary-care pediatric hospital located in southwestern Pennsylvania, United States. At this institution, BALs via flexible bronchoscopy are performed by a physician member of the Division of Pediatric Pulmonology (either an attending or a fellow in-training) and assisted by a respiratory therapist. Procedures are done under sedation or anesthesia in an endoscopy suite, an operating room, or one of the intensive care units (pediatric intensive care unit [ICU], neonatal ICU, or cardiac ICU). Post-procedure notes are entered into the electronic medical record by the physician doing the bronchoscopy using the Olympus EndoWorks suite

version 7.3 (Olympus America Inc., Center Valley, PA) and within one hour after completing the procedure. A separate electronic database containing information about all flexible bronchoscopies is maintained at the hospital's pulmonary function laboratory for logistical reasons. Information in this electronic database is entered on the same day of the procedures by the assisting respiratory therapists.

The size of the flexible bronchoscope, the type of airway used (e.g., laryngeal mask airway, endotracheal tube, or tracheostomy), and the anatomical site of the BAL varies according to the procedure's indication and/or the patient's clinical status. No specific protocol exists for conducting BALs at our center. In general, one to three aliquots of 1 ml/kg of non-bacteriostatic normal saline (up to a maximum of 50 ml per aliquot) at room temperature are instilled through the working channel of the bronchoscope. Fluid is recovered immediately after each aliquot is instilled (i.e., no dwell time) using either continuous wall suction or handheld syringe suction, according to the physician's preference. For continuous wall suction, a constant negative pressure is set at the beginning of the procedure and no further adjustments are made. For handheld syringe suction, the same syringe used to instill the normal saline (typically a 20 ml, 30 ml, or 60 ml syringe) is utilized to aspirate the BAL fluid (i.e., no adapters are used); the operator then adjusts the suction based on the degree of airway collapse (as reflected in a monitor). Samples are then pooled and sent to the hospital's laboratory for cytological and microbiological analyses.

Data Collection

We reviewed the two electronic databases described above to gather information on all flexible bronchoscopies with BAL conducted at our institution between January 2011 and December 2012. We collected information on patient's demographics, personnel performing the procedure, indication for and location of the procedure, and technical aspects of the flexible bronchoscopy and BAL. We excluded from analyses procedures in patients ≥ 21 years of age and those without information on the type of suction, the total volume instilled for the BAL, or the total volume recovered from the BAL. For patients who underwent more than one BAL during the study period, we only included the earliest procedure in analyses in order to maintain independence among observations. This study was approved by the Institutional Review Board of the University of Pittsburgh (Pittsburgh, PA).

Statistical Analyses

Our independent variable was the type of suction used for the BAL (continuous wall vs. handheld syringe). Our dependent variable was the percentage of volume recovered from the BAL (calculated as $\text{total volume recovered} \times 100 / \text{total volume instilled}$), which was treated as continuous variable and as a binary variable ($\leq 40\%$ vs. $>40\%$ based on previous published guidelines^{7,8} [see above]).

Due to the non-random assignment of patients to one of the two suction techniques, we opted to conduct a propensity score (PS) analysis to minimize the differences between groups at baseline and reduce the possibility of bias.¹⁵ To this end, we first estimated the PS using the following covariates: patient's age and gender, physician's level of training (fellow vs. attending as marker of experience), anatomical site of the BAL (right middle lobe vs.

other), flexible bronchoscope's suction channel size (1.2 vs. 2.0 mm), indication for the procedure (cystic fibrosis vs. other), type of airway used (laryngeal mask airway vs. other), location of the procedure in the hospital (any ICU vs. other), and total volume instilled for the BAL (ml). We then randomly sorted the dataset and matched procedures in the handheld syringe group with those in the continuous wall group on the basis of the logit of their PS and within a pre-specified caliper distance, using a one-to-one matching algorithm with no replacement.^{15,16} The caliper distance selected was 0.2 of the pooled standard deviation of the logit of the propensity score, as this has been shown to eliminate most of the bias due to the measured confounders.¹⁶ Next, we assessed whether the matching had been adequately conducted by visually comparing descriptive statistics between groups before and after matching and by calculating standardized differences.¹⁷ In line with current recommendations, covariate balance was considered satisfactory if the absolute standardized differences of all baseline variables between groups in the matched sample did not exceed 10%.^{16,17} Last, we assessed the association between the type of suction and the outcomes of interest in the matched sample using statistical techniques that took into account the paired nature of the sample (i.e., paired t-tests and McNemar's tests).¹⁸

To confirm the results of the PS analysis, we built multivariable linear and logistic regression models using a stepwise approach in the whole sample. Covariates (described earlier) were subjected to a backward elimination procedure and remained in the final models if they were statistically significantly associated with the outcome of interest at $P < 0.05$ or if they changed the parameter estimate (β) by 10%. All analyses were performed using Stata version 12.1 (StataCorp, College Station, TX).

Results

A total of 647 BALs via flexible bronchoscopy were performed at our institution during the study period. After excluding those performed in adults ($n=5$), those without information on the type of suction or percentage of volume recovered from BAL ($n=10$), and those conducted as follow-up procedures ($n=93$), 539 (~83%) of the 647 observations remained for analyses.

The baseline characteristics of the procedures included in analyses prior to the PS matching are summarized in Table 1 - *Before PS analysis*. Continuous wall suction was the technique most commonly used among providers at our institution (~73% of all BALs). Compared to procedures that used continuous wall suction, those using handheld syringe suction were more likely to be done in females, to be performed in a non-ICU setting, to be conducted through a laryngeal mask airway, to be in a site different than the right middle lobe, and to have a higher total volume instilled for the BAL.

Through the PS analysis, 118(~80%) of the 147 BALs in the handheld syringe suction group were paired to a similar number of procedures in the continuous wall suction group. There were no longer substantial differences in the baseline characteristics between the two groups after the PS matching, with absolute standardized differences not exceeding 10% for any variable (Table 1 - *After PS analysis*).

In the matched sample, handheld syringe suction was statistically significantly associated with ~7% higher volume return from BAL and with three-fold higher odds of performing a technically-acceptable procedure (i.e., >40% of volume return from BAL) when compared to continuous wall suction (Table 2).

We found similar results to those of the PS analysis by using multivariable linear and logistic regression in the whole sample. In models adjusting for the patient's age and gender, the physician's level of training, the anatomical site of the BAL, and whether the procedure was done in an ICU; handheld syringe suction continued to be statistically significantly associated with a higher percentage of volume return from BAL ($\beta=7.0$, 95%CI =4.0–9.9, $P<0.001$ [Figure 1]) and with higher odds of performing a technically-acceptable procedure (Table 3).

Because of high collinearity between the type of airway used and whether the procedure was done in an ICU ($P<0.001$), we did not include these two covariates the same regression models. Replacing one with the other produced negligible changes in our results (E-table 1 and E-table 2 in the Supplemental Material).

Discussion

In our study, we found that handheld syringe suction offers a higher percentage of volume return from BAL and increases the odds of performing a technically-acceptable procedure in children when compared to continuous wall suction. In spite of these advantages, more than two-thirds of the procedures in our center were performed using the latter technique. This is consistent with literature that has shown that continuous wall suction is the technique most commonly used among adult providers.¹⁹

To our knowledge, this is the first study comparing handheld syringe suction and continuous wall suction in children or adults. In a multicenter randomized trial comparing two different techniques of handheld syringe suction in 295 adult participants, attaching a tube extension between the syringe and the working channel of the bronchoscope allowed for ~8% higher fluid return when compared to recovery without the extension.¹⁴ This increased percentage of volume return was also associated with 17.4% higher number of final diagnoses. In both groups, patients in whom a final diagnosis was achieved had a greater amount of recovered fluid. A similar difference in the percentage of fluid recovered from BAL between these two techniques was found in a study of 20 healthy adult rhesus macaques.²⁰ Although differential cell counts and cell viability were not different between groups in this study, attaching a tube extension led to a higher concentration of cells recovered. In another study of 12 healthy middle-aged dogs, manual aspiration using a syringe attached to polyethylene tubing wedged in a bronchus led to decreased BAL fluid retrieval, reduced quantity of foam (a marker of the presence of surfactant), and lower neutrophil count when compared to automatic suction.²¹ However, this study was limited by use of unadjusted analysis, the small sample size, and the utilization of a tube to occlude the bronchus for the BAL (instead of wedging the actual bronchoscope). Taken together, these three studies suggest that the suction technique may have an indirect impact on diagnostic yield of BAL.

Since its first description in 1974,²² BAL has emerged as an important clinical and research tool in patients of all ages.^{8,23–25} As many other authors and international societies have noted, standardization of this procedure is crucial to achieve the full potential of BAL in both the clinical and research settings.^{23–26} To date, efforts to achieve standardization of the BAL technique have been attempted primarily through the way of professional consensus,^{8,27} as only a few hypothesis-driven studies to optimize the BAL technique have been completed. Whereas some standardization of the procedure has been achieved in adults,^{6,28} it is largely lacking in children.²⁹ Our findings reflect the need to conduct further studies to compare the different techniques of BAL in children with the goal of improving the efficacy of this procedure in this population.

We can only speculate on the mechanisms through which handheld syringe suction leads to a better volume return, since the relation between suction and fluid dynamics during BAL is complex.^{23,30} The negative pressure applied during BAL should be sufficient to retrieve fluid while not collapsing the airway, as this will reduce the volume return, cause trauma to the bronchial wall, produce contamination of the fluid with blood, and possibly increase the frequency of complications.^{4,9,25} Handheld syringe suction offers easier manipulation of this negative pressure,⁷ which may result in less airway collapse during the BAL. Handheld syringe suction may also influence fluid dynamics by partially converting turbulent flow into laminar flow.²⁰ It is important to note that modifications to the continuous wall suction technique (such as progressive adjustment of the negative pressure based on the volume recovered) have also been described and may be associated to a return similar to that of handheld syringe suction.³¹ Nonetheless, handheld syringe suction is likely to be more widely-available, less labor-intensive, and less costly.⁷

Our study has considerable strengths, such as the large number of procedures reviewed and analytical approaches controlling for potential confounders of the relation between type of suction and volume return. We also acknowledge several limitations to our findings. First, our study had a retrospective design. As such, it relies on the accuracy of the electronic databases used and the recall of the healthcare personnel entering the data, which may lead to misclassification. Second, selection bias is possible in any observational study. However, selection bias is an unlikely explanation to our findings as the imbalances between groups were minimized through the PS analysis. Third, there could be residual confounding by variables that were measured (e.g., indication for the BAL, size of bronchoscope, or level of experience of the physician performing it) or unmeasured (e.g., use of positive-pressure ventilation during the BAL, amount of negative pressure applied for suction, dwell time to aspirate fluid, length of suctioning, or other operator-dependent factors) in our study. For instance, we examined balance between groups after the PS analysis mainly in terms of standardized differences, but this does not ensure that bias from measured variables is fully eliminated.¹⁷ Furthermore, unmeasured or unobservable factors could still have influenced the choice of suction method and, consequently, led to biased results. Fourth, we lacked data on other relevant markers of the procedure's diagnostic yield. However, as mentioned earlier, similar increments in the percentage of BAL return have been associated to clinically-relevant outcomes in other studies.^{14,20} In addition, larger BAL samples could potentially provide investigators with more cells for culture and analyses and, thus, be important to advance high-quality pediatric pulmonary research.²⁰ Finally, our results may

not be generalizable to children in other populations due to the nature of the patients seen at our institution. However, our findings merit replication as consistent results can lead to the standardization of BAL technique in children.

In summary, our results suggest that handheld syringe suction is strongly associated with a higher percentage of volume return from BAL and higher odds of performing a technically-acceptable procedure in children when compared to continuous wall suction. Prospective studies, including randomized trials, are needed to compare the different BAL techniques in children with the goal of standardizing this procedure, enhancing its diagnostic accuracy and, ultimately, improving patient care.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Abbreviations

BAL	Bronchoalveolar lavage
ICU	Intensive care unit
PS	Propensity score

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Figure 1.

Box plots of percentage of volume return from BAL according to type of suction in the whole sample (n=539). Percentage of volume return from BAL shown as predicted values from a linear regression model adjusting for patient's age and gender, ICU setting, anatomical site of BAL, and level of training of the physician performing the procedure. BAL = Bronchoalveolar lavage, ICU = Intensive care unit.

Table 1

Baseline characteristics of pediatric flexible bronchoscopies with BAL according to type of suction before and after PS analysis^{a,b}

Covariate	Before PS analysis			After PS analysis		
	Handheld syringe suction (n=147)	Continuous wall suction (n=392)	Standardized difference ^c	Handheld syringe suction (n=118)	Continuous wall suction (n=118)	Standardized difference ^c
Patient's age (years)	5.8(4.9)	5.6(5.4)	-0.2%	5.3(5.0)	5.2(5.0)	0.6%
Female gender	76(51.7%)	151(38.5%)	-25.5%	56(47.5%)	54(45.8%)	-3.4%
Procedure performed in an ICU	7(4.9%)	52(13.5%)	-33.9%	6(5.1%)	3(2.5%)	8.9%
Procedure performed by a fellow	85(59.0%)	221(57.3%)	-5.1%	67(56.8%)	69(58.5%)	-3.4%
Patient with CF	8(5.4%)	17(4.3%)	2.1%	4(3.4%)	6(5.1%)	-7.9%
Flexible bronchoscope with a 2.0 mm suction channel	37(25.3%)	74(18.9%)	10.3%	23(19.5%)	22(18.6%)	2.1%
Flexible bronchoscopy through an LMA	125(86.2%)	280(76.5%)	23.2%	99(83.9%)	103(87.3%)	-8.9%
BAL in the RML	100(69.0%)	324(84.4%)	-34.7%	89(75.4%)	85(72.0%)	8.0%
Total volume instilled for BAL (mL)	46.3(22.5)	34.6(20.7)	50.9%	41.6(19.9)	42.4(26.7)	-3.6%

^aData are presented as the mean (standard deviation) for continuous variables and number (%) for binary variables.

^bPercentages were calculated for procedures with complete data.

^cAbsolute standardized differences >10% are considered unsatisfactory.

BAL = Bronchoalveolar lavage, CF = Cystic fibrosis, ICU = Intensive care unit, LMA = Laryngeal mask airway, PS = Propensity score, RML = Right middle lobe.

Table 2

Outcomes of pediatric flexible bronchoscopies with BAL according to type of suction before and after PS analysis^{a,b}

Outcome	Before PS analysis			After PS analysis		
	Handheld syringe suction (n=147)	Continuous wall suction (n=392)	Difference in means (95%CI), P value ^c	Handheld syringe suction (n=118)	Continuous wall suction (n=118)	Difference in means (95%CI), P value ^d
Total volume recovered from BAL (mL)	25.4(13.3)	16.6(10.8)	8.8(6.6–11.0), <0.001	22.8(11.1)	20.1(13.9)	2.7(–0.02–5.3), 0.05
Percentage of volume recovered from BAL	56.0(14.5)	49.2(15.1)	6.8(4.0–9.7), <0.001	56.3(13.7)	49.1(16.4)	7.2(3.4–11.0), <0.001
Outcome	Handheld syringe suction (n=147)	Continuous wall suction (n=392)	Odds ratio (95%CI), P value ^c	Handheld syringe suction (n=137)	Continuous wall suction (n=137)	Odds ratio (95%CI), P value ^d
>40% of volume return from BAL	130(88.4%)	302(77.0%)	2.3(1.3–4.2), 0.003	107(90.7%)	88(74.6%)	3.4(1.5–8.6), 0.002

^aData are presented as the mean (standard deviation) for continuous variables and number (%) for binary variables.

^bPercentages were calculated for procedures with complete data.

^cCalculated using two-sample t-tests and Fischer's exact tests, as appropriate.

^dCalculated using paired t-tests and McNemar's tests, as appropriate.

BAL = Bronchoalveolar lavage, PS = Propensity score.

Table 3

Multivariable regression analysis of type of suction and more than 40% of volume return from BAL in the whole sample (n=539)^a

Covariate	>40% of volume return from BAL
<u>Unadjusted</u>	
Handheld syringe suction	2.3(1.3–4.0), 0.004
<u>Adjusted^b</u>	
Handheld syringe suction	2.6(1.4–4.7), 0.003
Procedure performed in an ICU	0.6(0.3–1.1), 0.08
BAL in right middle lobe	2.4(1.4–4.1), 0.001

^aData presented as odds ratio (95%CI), *P* value.

^bMultivariable model adjusted for patient's age and gender, level of training of the physician performing the procedure, and covariates listed in the first column.

BAL = Bronchoalveolar lavage, ICU = Intensive care unit.