A Randomized Control Trial Comparing the Yield of Bronchoalveolar Lavage Using Three Different Techniques in Patients Undergoing Flexible Bronchoscopy (BAL-3T)

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Background: Three techniques have been described for aspirating the bronchoalveolar lavage (BAL) fluid, namely the wall mount suction (WMS), manual suction (MS), and manual suction with tubing (MST). However, there is no direct comparison among the 3 methods.

Methods: We randomized patients undergoing flexible bronchoscopy and BAL in a 1:1:1 ratio to one of the 3 arms. The primary outcome was to compare the optimal yield, defined as at least 30% return of volume instilled and $<5\%$ bronchial cells. The key secondary outcomes were the percentage of volume and total amount (in millimeters) return of BAL, as well as complications (hypoxemia, airway bleeding, and others).

Results: We randomized 942 patients [MST (n = 314), MS (n = 314), WMS (n = 314)]. The mean age of the study population [58.7% (n = 553) males] was 46.9 years. The most common indication for BAL was suspected pulmonary infection. Right upper lobes and middle lobes were the commonest sampled lobes. The optimal yield was similar in all the groups [MST (35.6%) vs MS (42.2%) vs WMS (36.5%); $P = 0.27$]. A significantly higher proportion of patients had BALF return $>30\%$ ($P = 0.005$) in the WMS (54.2%) and MS (54%) than in the MST arm (42.9%). The absolute and the percentage volume of BALF was also higher in WMS and MS than in the MST arm. There was no difference in the complication rate or other secondary outcomes across the groups.

Conclusion: We found no difference in the optimal yield of BAL or complications using any one of the 3 methods for BAL fluid retrieval.

Key Words: bronchoalveolar lavage, wall mount suction, manual suction, manual with tube suction method, hypoxemia, TB

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Bronchoalveolar lavage (BAL) is the most frequently performed investigation during bronchoscopy. BAL has a high diagnostic value and is a crucial research tool for various lung diseases, including infections, malignancy, diffuse parenchymal lung diseases (DPLDs), and others.[1,2] The typical BAL fluid cellular components comprise alveolar macrophages 85%, lymphocytes 5% to 15%, neutrophils $\leq 3\%$, and eosinophils $<1\%$.[3,4] The presence of squamous epithelial cells indicates contamination by oropharyngeal secretions.[5] The optimal sample for BAL has been variably described, with some guidelines suggesting a 5% of the instilled volume as an optimal return, whereas others suggest $>30\%$ as optimal.[3–7]

The yield of BAL depends on several factors, including underlying disease, the amount of fluid instilled, dwell time, pressure of suction applied, segment or lobe aspirated, and others.[1,3,4,6] Another factor affecting the quality of BAL fluid is the technique used for aspiration. Three techniques have been described for aspirating the BAL fluid, namely wall mount suction (WMS), manual suction (MS), and manual suction with tubing (MST).[8–11] Wall suction is performed by applying negative pressure using continuous wall suction.[2,8] MS is performed by gently applying the negative pressure by pulling the plunger of a 50 mL syringe.[8,11] A modification to the manual technique is by using an extension rubber tubing (manual with tubing method) connected at the tip end of the syringe.[10] The tubing is then inserted into the bronchoscope's working channel, and the suction is applied by pulling the syringe's plunger.[10] Previous studies reported a higher BAL fluid return with the MST method than the WMS or the MS method of BAL retrieval.[10,11]

To our knowledge, a study has yet to compare the 3 methods of obtaining the BAL in the same cohort of patients. We report on the BAL-3T trial, a randomized trial that was designed to investigate whether the MST method has a better yield for BAL retrieval than the WMS or the

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MS methods in patients undergoing bronchoscopy for various respiratory diseases.

METHODS

We conducted an investigator-initiated, open-label, randomized controlled trial (clinicaltrials.gov:NCT05425875) between June 1, 2022 and June 30, 2023 in the interventional bronchoscopy suite of the Department of Pulmonary Medicine of our institute. No changes were made to the protocol after trial commencement.

Ethical Statement

We performed the study per the principles outlined in the Declaration of Helsinki involving human patients. The Institute Ethics Committee (INT/IEC/2021/SPL-1048) approved the study protocol. The first patient was enrolled on June 2, 2022, and the last was enrolled on May 15, 2023. The last patient was followed up on June 15, 2023. We obtained written informed consent from all study patients. We have reported the results following the "Consolidated Standards of Reporting Trials" statement.[12]

Study Population

We enrolled consecutive patients aged 18 years or older undergoing flexible bronchoscopy and BAL for various indications. We excluded patients with any of the following: (1) hemodynamic instability (systolic blood pressure <90 mm Hg), (2) baseline hypoxemia [peripheral blood oxygen saturation (SPO_2) $<92\%$ while breathing ambient air], (3) platelet count $<20{,}000$ cells/μL or uncorrected coagulopathy, (4) pregnancy, and (5) failure to provide informed consent.

Randomization

We randomized patients in a 1:1:1 ratio to one of the 3 arms. Group 1 included MST, group 2 included MS, and group 3 included WMS. Randomization was computer-generated block randomization (variable-sized blocks between 4 and 8), and the randomization sequence was concealed in an opaque envelope. The envelopes were opened by a bronchoscopy technician who was not involved in the data analysis. We used the Stats Direct software (StatsDirect Ltd Wirral) to generate the randomization sequence. There was no blinding.

Study Procedures

All the patients underwent chest computed tomography and other investigations performed routinely before the bronchoscopy procedure. Each patient was instructed to remain fasting for at least 6 hours. We sprayed ten puffs of 10% lignocaine solution (10 mg/puff) just before the procedure to anesthetize the oropharynx and posterior pharyngeal wall.[13] No sedation was used.

We performed bronchoscopy using the nasal or oral route, as described previously, with the patient lying comfortably in a supine position.[13,14] Bronchoscopy {Olympus BF 1T-150 [insertion tube outer diameter (OD: 6.0, working channel inner diameter, ID: 2.8)], Olympus BF 1T-180 (OD: 6.0, ID: 3.0), Olympus BF XT-160 (OD: 6.3, ID: 3.2)}, Olympus BF 1TH-190 (OD: 6.2, ID: 2.8) was performed mainly by fellows under the direct supervision of consultants. Four aliquots of 2 mL of 1% lignocaine were administered using the "spray-as-you-go" technique to anesthetize vocal cords, carina, and right and left main bronchi.[14]

Bronchoalveolar Lavage Procedure

The affected segment identified on the chest computed tomography was wedged using the bronchoscope to obtain the BAL procedure fluid (BALF) sample. We instilled 4 aliquots of 30 mL 0.9% saline using a 50 mL syringe (120 mL) in the wedged segment and used one of the 3 techniques for retrieval. Aspiration of the saline was done after the instillation of all 4 aliquots. We, in addition, used 30 mL aliquots if we failed to get a minimum sample volume

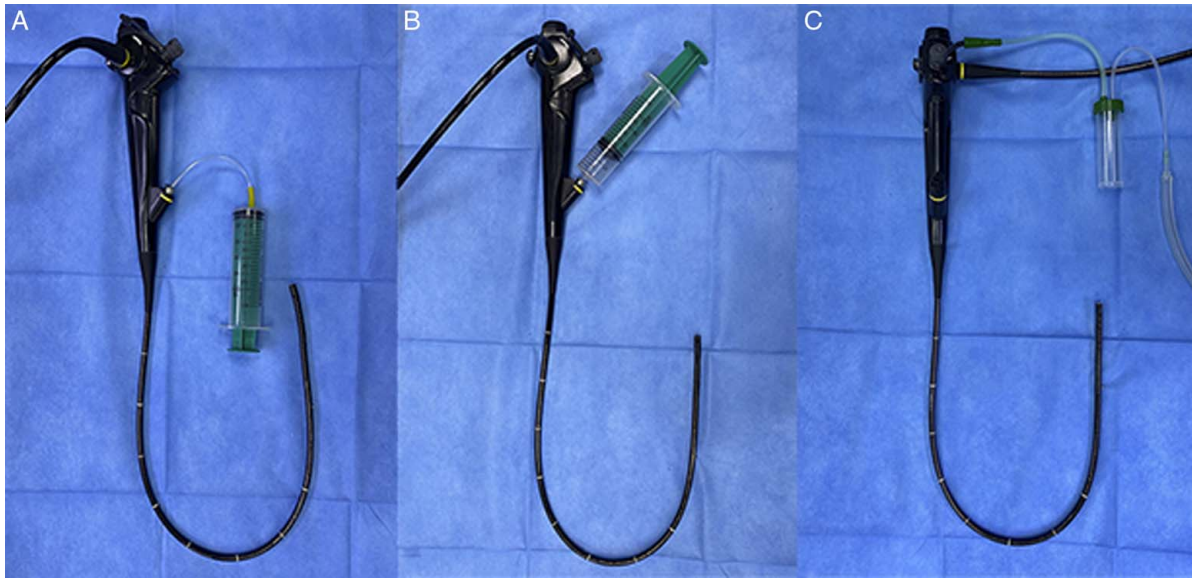

FIGURE 1. A, Manual suction with tubing method. The free end of the tubing is inserted into the bronchoscope's working channel. B, Manual method of BAL, where the free end of a 50 mL syringe is directly attached to the bronchoscope's working channel. C, Wall mount suction method of BAL retrieval. BAL indicates bronchoalveolar lavage.

(10 mL). We recorded the total volume instilled and the amount of fluid retrieved.

Group I (MST): we attached the rubber portion of the intravenous administration set (length: 15 cm) to a 50 mL syringe and inserted the tubing into the working channel (Fig. 1). We applied suction by pulling the syringe plunger.

Group II (MS): we used a 50 mL syringe to retrieve the fluid instilled. The syringe was attached directly to the working channel of the bronchoscope.

Group III (WMS): we used WMS at pressures ranging from 50 to 100 mm Hg.[5,6] One end of the trap was attached to the suction tube, and the other was connected to the suction valve on the bronchoscope. We applied continuous suction to aspirate the effluent. In case of airway collapse, we reduced the suction pressure or applied intermittent suction for sample retrieval.

If <10 mL fluid was obtained using the MS or MST method, we switched to the WMS method. We switched to the MS method when the WMS method retrieved <10 mL. We recorded the switch of methods as a failure, and the additional fluid retrieved after switching methods was not added to the final volume.

Monitoring of Patients

We monitored the SPO_2 (using a pulse oximeter), heart rate, blood pressure, and respiratory rate during and after the procedure. Supplemental oxygen was administered through the nasal prongs if SPO_2 was $<90\%$. We recorded the nadir SPO_2 and the number of desaturation events ($SPO_2 < 90\%$) during the procedure. All the study patients were monitored for at least 6 hours after the procedure. All the complications attributable to the BAL procedure were recorded. In addition, we contacted all the study patients telephonically after 48 hours of the procedure to record any delayed complications attributed to the BAL procedure.

Bronchoalveolar Lavage Fluid Sample Handling

The BAL sample was divided into 4 or 5 containers and sent for microbiological, cytologic, and other investigations to diagnose various diseases (Supplemental Table 1, Supplemental Digital Content 1, http://links.lww.com/LBR/A323 and Supplemental Table 2, Supplemental Digital Content 2, http://links.lww.com/LBR/A324), as appropriate.[5,7]

Definitions

- Adequate return: we considered a 30% return as the adequate return. For example, if 120 mL of fluid was instilled, we considered 36 mL as adequate.[5,6]
- Representative sample: we defined the BAL sample as representative if there were $<5\%$ bronchial cells.[6,7]
- Optimal yield (primary outcome): defined as a combination of adequate return and representative sample.
- Diagnostic yield: if a specific diagnosis was made by BAL fluid examination, the BAL was considered diagnostic (Supplemental Table 2, Supplemental Digital Content 2, http://links.lww.com/LBR/A324).[5,7] For example, if BALF analysis resulted in a diagnosis of pulmonary infection or malignancy, it was considered diagnostic.
- Final diagnosis: the final diagnosis was made during the follow-up (4 wk after the procedure). The patients were either followed in the chest clinic or were telephonically asked to share the treatment details.
- Study outcomes: The primary outcome was to compare the optimal yield (at least 30% return of volume and $<5\%$ bronchial cells). The secondary outcomes were: (1) the percentage (percentage of the instilled volume of saline for performing BAL that was retrieved) and the exact volume of BAL fluid retrieved, (2) the diagnostic yield of BAL, (3) the bronchoscopist ease of performance on a Visual Analog Scale (on a scale of 100 mm, 0 being not satisfied and 100 very satisfied), and (4) the proportion of patients experiencing complications in each arm. We recorded the following complications: (1) hypoxemia ($SPO_2 \leq 90\%$), (2) fever, (3) airway bleeding, (4) need for escalation of care (need for hospitalization, intensive care unit admission, or airway intubation), and (5) death.

Statistical Analyses

We used the statistical package SPSS (version 22.0, IBM Corp.) to perform the statistical analyses. Data are presented as mean (95% CI), median (interquartile range), or number (percentage). We used an intention-to-treat analysis to report the study's results. The difference between continuous and categorical variables was analyzed using analysis of variance and χ^2 test. A P value ≤ 0.05 was considered statistically significant.

Sample Size Calculation

No previous study has evaluated BAL for optimal yield ($>30\%$ return and $<5\%$ bronchial cells) and compared 3 techniques of BAL sampling. We assumed a 12% higher yield of MST compared with the other two groups. We calculated the sample size of 909 patients for the study to have a power of 85% with an alpha error of 0.025 (Bonferroni correction for multiple comparisons). We enrolled 942 patients to compensate for the follow-up loss.

RESULTS

We screened 1002 patients, of which 942 were randomized to undergo BAL with the MST (n = 314), the MS (n = 314), and the WMS (n = 314) method (Fig. 2). The baseline characteristics were similar in the 3 groups, except the frequency of smokers was significantly higher in the MS group (Table 1). The mean (95% CI) age of the study population was 46.8 (45.9-47.8) years, with 58.7% of the patients being men. The most common indication for performing BAL was suspected infections (65%), followed by DPLD (27.3%) and lung malignancy (4.5%). The mean (95% CI) baseline room air SPO_2 was 97.4 (97.2-97.8) % and was similar across the 3 groups. The most sampled lobes were the right upper and the middle, followed by the left upper lobe. There was no difference in the segments sampled across the 3 groups. The mean (95% CI) volume of normal saline instilled was 132.2 (130.6-133.8) mL, significantly higher in the WMS arm than in the other 2 groups.

Primary Outcome

Overall, 38.1% (359/942) BAL procedures had an optimal yield ($>30\%$ return and $<5\%$ bronchial cells). The optimal yield of BAL was similar across the 3 groups (MST vs MS vs WMS, 36% vs 41.7% vs 36.6%; $P = 0.269$; Table 2). However, the frequency of procedure with an adequate return ($>30\%$ of the volume instilled) was significantly higher in the WMS method [54.2% (169/312)] and the MS method [54% (169/313)] than the MST method [42.9% (136/317)]. The adequate return was similar in the WMS and MS methods. The BAL samples were representative ($<5\%$ bronchial cells) in 76.5% (721/942), and we

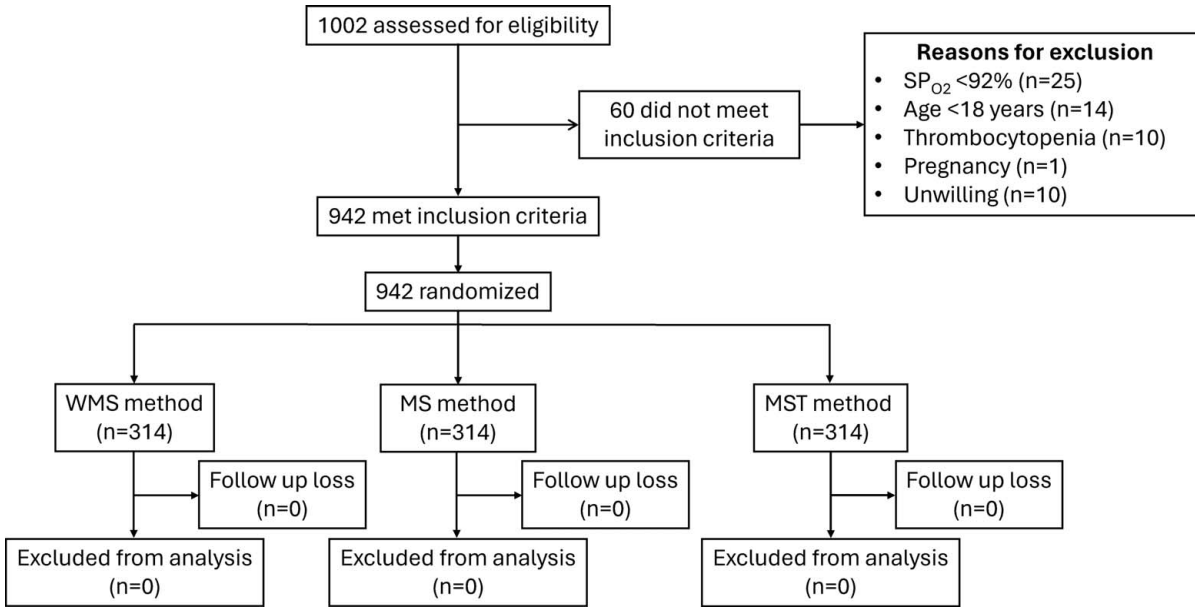

FIGURE 2. "Consolidated Standards of Reporting Trials" diagram depicting the flow of patients during the study. MS indicates manual suction; MST, Manual suction with tubing; SPO_2, oxygen saturation; WMS, wall mount suction

found no difference across the 3 groups. The optimal yield was significantly higher when BAL was performed from the right middle lobe or lingula than other lobes [136/307 (44.3%) vs 223/635 (35.1%), $P = 0.008$]. However, the optimal yield was similar across the 3 groups when BAL was performed from the right middle lobe or lingula (MST vs MS vs WMS, 47.1% vs 42.7% vs 43%; $P = 0.776$).

Secondary Outcomes

The percentages of BALF return and the exact volume (milliliter) were significantly higher with the WMS and MS methods than with the MST methods. A BAL was diagnostic in 525/914 (55.7%). Twenty-one procedures where a method switch was required were excluded from the analysis for diagnostic yield. However, we found no

TABLE 1. Baseline Characteristics and Procedural Details of Study Patients

Parameter	Total population (n = 942)	MST (n = 314)	MS (n = 314)	WMS (n = 314)	*P*
Age (y)	46.9 (45.9-47.8)	46.6 (44.9-48.3)	47.6 (45.9-49.3)	46.4 (44.6-48.1)	0.539
Sex (M), n (%)	553 (58.7)	172 (54.8)	201 (64)	180 (57.3)	0.052
Current or ever smokers, n (%)	199 (21.1)	55 (17.5)	81 (25.8)	63 (20.1)	0.034
Indications of BAL					0.376
Infections	636 (67.5)	205 (65.3)	220 (70.1)	211 (67.2)	—
DPLD	257 (27.3)	95 (30.3)	79 (25.2)	83 (26.4)	—
Malignancy	42 (4.5)	10 (3.2)	14 (4.5)	18 (5.7)	—
Miscellaneous*	7 (0.7)	4 (1.3)	1 (0.3)	2 (0.6)	—
Procedural details					
Baseline SPO_2	97.4 (97.2-97.8)	97.5 (97.2-97.8)	97.3 (97-97.5)	97.3 (97.1-97.5)	0.314
Sample site					
Right upper lobe	274 (29.1)	94 (29.9)	86 (27.4)	94 (29.9)	0.719
Right middle lobe	256 (27.2)	87 (27.7)	83 (26.4)	86 (27.4)	0.933
Right lower lobe	151 (16)	49 (15.6)	53 (16.9)	49 (15.6)	0.881
Left upper lobe	171 (18.2)	54 (17.2)	57 (18.2)	60 (19.1)	0.890
Lingula	52 (5.5)	18 (5.7)	20 (6.4)	14 (4.5)	0.566
Left lower lobe	109 (11.6)	36 (11.5)	38 (12.1)	35 (11.1)	0.930
Volume instilled (mL)	132.2 (130.6-133.8)	129.8 (128.8-134.9)†	131.9 (128.8-134.9)	134.9 (132.1-137.7)†	0.042
No. of saline aliquots‡	4 (4-4)	4 (4-4) †§	4 (4-4)‖	4 (4-5)	0.001
Additional saline aliquots ‡	0	0 †§	0‖	0 (0-1)	0.001

All the values are represented as mean (95% CI) or numbers (percentage) unless otherwise stated.
*Includes diffuse alveolar hemorrhage, vasculitis, and lipoid pneumonia.
†Significantly different between the wall mount suction method and the manual suction with tube method.
‡Median (interquartile range).
§No difference between the manual suction method and the manual suction with tube method.
‖Significantly different between the wall mount suction method and the manual suction method.
DPLD indicates diffuse parenchymal lung disease, MS, manual suction; MST, manual suction with tubing; SPO_2, oxygen saturation; WMS, wall mount suction.

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TABLE 2. Study Outcomes

	Total (n = 942)	MST (n = 314)	MS (n = 314)	WMS (n = 314)	*P*
Primary outcome					
Optimal yield	359 (38.1)	113 (36)	131 (41.7)	115 (36.6)	0.269
Adequate return (>30% return)	474 (50.3)	134 (42.7)*†	170 (54.1)‡	170 (54.1)‡	0.004
Representative sample (<5% bronchial cells)	721 (76.5)	248 (79)	245 (78)	228 (72.6)	0.127
Secondary outcomes					
Percentage BALF return	30.3 (29.5-31.1)	27.8 (29.5-31.1)*†	31.3 (29.9-32.7)‡	31.7 (30.5-32.9)‡	<0.001
Exact volume of return, mL	39.6 (38.5-40.6)	35.8 (33.8-37.8)*†	40.8 (38.9-42.7)‡	42 (40.3-43.7)‡	<0.001
Diagnostic yield, (%)	506 (56)¶	171/288 (59.4)	153/303 (50.5)	182/313 (58.1)	0.060
VAS for bronchoscopist ease of performance (mm)#	76 (48-88)	72 (34.8-87)*†	78 (57.8-89)‡	77 (56-88)	0.001
Switch of procedure, n (%)	38 (4)	26 (8.3)	11 (3.5)	1 (0.3)	<0.001
Duration of procedure (mim)#	7 (6-9)	7 (6-9)	7 (6-9)	7 (6-9.25)	0.354
Complications					
During procedure					
Nadir SPO_2	88.3 (87.9-88.7)	88.7 (87.9-89.4)	88.5 (87.8-89.2)	87.7 (86.9-88.5)	0.124
Hypoxemia (SPO_2 ≤90%), n (%)	545 (57.9)	169 (53.8)	180 (57.3)	196 (62.4)	0.090
No. desaturation events#	1 (0-1)	1 (0-1)*	1 (0-1)§‖	1 (0-2)	0.017
Minor-moderate bleeding	42 (4.5)	15 (4.8)	8 (2.5)	19 (6.1)	0.099
Massive airway bleeding	2 (0.2)	2 (0.6)	0	0	0.135
Postprocedure					
Nadir SPO_2	94.1 (93.8-94.4)	93.9 (93.4-94.5)	94.3 (93.8-94.8)	94.1 (93.6-94.6)	0.626
Hypoxemia (SPO_2 ≤90%)	141 (15)	51 (16.2)	48 (15.3)	42 (13.4)	0.591
Wheezing, n (%)	35 (3.7)	14 (4.5)	12 (3.8)	9 (2.9)	0.569
Postprocedure fever	124 (13.2)	40 (12.7)	41 (13.1)	43 (13.7)	0.937
Postprocedure chest pain	32 (3.4)	7 (2.2)	12 (3.8)	13 (4.1)	0.367
Hemoptysis	7 (0.7)	3 (0.9)	0	4 (1.3)	0.154
Need for hospitalization	3 (0.3)	1 (0.3)	1 (0.3)	1 (0.3)	1.000
Intubation	2 (0.2)	0	1 (0.3)	1 (0.3)	0.606
Death	4 (0.4)	1 (0.3)	1 (0.3)	2 (0.6)	0.531

All the values are represented as mean (95% CI) or numbers (percentage) unless otherwise stated.
*Significantly different ($P < 0.001$) between WMS and MST.
†Significantly different ($P < 0.001$) between MS and MST.
‡Not different between WMS and MS.
§Significantly different between WMS and MS.
‖Not different between MS and MST.
¶Twenty-one cases were excluded from this analysis due to a switch of technique.
#Median (interquartile range).
BALF indicates bronchoalveolar lavage fluid; MS, manual suction; MST, manual suction with tubing; SPO_2, oxygen saturation; VAS, Visual Analog Scale; WMS, wall mount suction.

difference ($P = 0.060$) in the diagnostic yield of BAL between the groups (Table 2). The operators found the MST method least satisfactory.

Transient hypoxemia was the most common complication attributed to the BAL procedure. No procedure was aborted due to hypoxemia. The mean nadir SPO_2 was similar across the 3 arms. However, desaturation events were higher in the WMS method than in the MS or MST method (Table 2). The proportion of patients experiencing hypoxemia during the procedure was similar between groups (Table 2). There was no difference in airway bleeding across the 3 arms.

Postprocedure transient hypoxemia was the commonest complication, followed by fever. The 3 study groups did not differ in the nadir SPO_2 during recovery. Other complications like postprocedure fever, hemoptysis, chest pain, and escalation of care (hospitalization or airway intubation) were also similar in the 3 groups. Three patients required hospitalization due to respiratory failure (2 required invasive mechanical ventilation). All 3 patients were discharged after recovery. There were 4 deaths (all patients were already hospitalized due to some illness before the BAL procedure). Deaths were attributed to the underlying diseases. One patient had aplastic anemia (died of bacterial sepsis and acute respiratory failure), one was a post-renal transplant recipient (died of severe respiratory failure), one patient died of disseminated tuberculosis with stage IV lung cancer, and one patient died of invasive mucormycosis.

DISCUSSION

We found a similar optimal yield of BAL with different methods of lavage fluid retrieval. However, the frequency of procedures with >30% retrieval of the volume instilled (adequate return) was significantly higher with the WMS and the MS method than with the MST method. The volume and the percentage BALF return were also lowest with the MST method.

We found no difference in the optimal yield (>30% return and <5% bronchial cells) of BAL using any method. Our results are different from those of previous studies that compare different BAL techniques (Table 3). All previous studies have compared two methods, WMS versus MS or MS versus MST (Table 3).[4,8–11] Two previous studies found the MS superior to the WMS method for BAL fluid retrieval (volume and percentage) but found no difference in the diagnostic yield.[11,15] A study involving 73 children found

TABLE 3. Studies Describing Different Techniques for Obtaining BAL

Author	Study design	Study population	WCD (mm)	Volume instilled	Dwell time	Control arm	Comparator arm	Primary outcome	Results	Complications
Herath et al, 2021[8]	RCT	73 children (age:1 mo-18 y)	1.2	2 aliquots of 1 mL/kg; third aliquot used if aspirate < 5 mL (mean volume: 22.7 mL)	Immediate	WMS (n = 37; pressure: 100-150 mm Hg)	MS (n = 36)	% BAL retrieval (mean ± SD)	WMS: 43.6 ± 8.4 vs MS: 37.8 ± 8.5 (P = 0.004)	Not reported clearly
Seijo et al, 2016[11]	RCT	220 adults (mean age 61 y)	2	150 mL (3 aliquots of 50 mL)	Aspiration performed after each aliquot	WMS (n = 105; pressure up to 50 mm Hg)	MST (n = 115) but tubing not inserted in working channel	BAL volume return (mean ± SD)	WMS: 55 ± 22 mL vs MST: 67 ± 20 mL (P < 0.001) > 30% return (WMS: 59% vs MST: 81%). Diagnostic yield: 22% (n = 48)	Not reported clearly
Radhakrishna et al, 2015[9]	Observational	66 adults (age: 18-89 y)	NR	100 mL (4 aliquots of 25 mL), maximum 5 aliquots	Not recorded. Aspiration performed after each aliquot in MS group	WMS (n = 33; pressure 60-100 mm Hg)	MS (n = 33)	% volume return (mean ± SD)	WMS: 40 ± 3 vs MS: 42 ± 3 (P = 0.63)	—
Rosas-Salazar et al, 2014[15]	Retrospective	539 children (118 patients were matched after propensity scoring)	1.2-2	1-3 aliquots of 1 mL/kg	Immediately after each aliquot	WMS (n = 392)	MS (n = 147)	% volume return (mean ± SD)	WMS: 49.1 ± 16.4 vs MS: 56.3 ± 13.7 (P < 0.001); > 40% return [WMS: 74.6% (88/118) vs 90.7% (107/118)]	—
Rosell et al, 2006[10]	RCT Multicenter	295 adults	—	150 mL	—	MST (n = 140)	MS (n = 155)	% volume recovered (mean ± SD)	MST: 64.8 ± 24.4 vs MS: 52.8 ± 27.8 (P = 0.005); % volume (MST: 43.2% vs MS: 35.2%).	Overall complications (MS vs MST) (8.3% vs 1.4%; P = 0.002)
Current study	RCT	942 adults	2.8-3.2	120 mL	Aspiration done after instillation of all aliquots	WMS (n = 314)	MS (n = 314) and MST (n = 314)	Optimal yield (> 30% return and < 5% bronchial epithelial cells)	WMS vs MS vs MST: 36.6% vs 41.7% vs 36%	More desaturation events in WMS than others. No difference in other complications

BAL indicates bronchoalveolar lavage; MS, manual suction; MST, manual suction with tubing; NR, not reported; RCT, randomized control trial; WCD, working channel diameter; WMS, wall mount suction.

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the WMS method better than the MS method in BAL retrieval, but the proportion of representative samples (5% to 10% bronchial cells) was similar.[8] A multicenter randomized control trial that compared the MS with the MST method found the latter yielding a higher percentage of BAL fluid return and better diagnostic yield than the MS,[10] unlike the current study. Most previous studies have used either the absolute volume of fluid retrieved or the percentage of the instilled volume of saline retrieved during BAL as the study outcome. None of the previous studies evaluated the quality of BAL fluid return as a primary objective. We considered BAL optimal if there was $>30\%$ volume retrieval and $<5\%$ bronchial epithelial cells. A BAL fluid with $>5\%$ epithelial cells represents the proximal airway sampling and is not representative of alveolar sampling.[3,4,6] The exact volume or percentage of BALF return in the current study is comparable to previous studies (Table 3).

Most previous studies carried out immediate withdrawal of each aliquot of saline, unlike our study, where we withdrew saline after instilling the entire 120 mL. Immediate withdrawal of the instilled saline could compromise the BAL quality. Previous studies have shown that the initial aspirate represents the airways, not the alveolar sample.[16–19] Sampling from proximal airways could impact the diagnostic yield, especially in DPLD. The overall diagnostic yield in the current study was 56%, whereas Seijo et al[11] reported a diagnostic yield of 22%. The higher yield in our study is likely due to a higher proportion of patients with suspected or diagnoses of an infection. The diagnostic yield in the present study was similar in all groups, like in a previous study.[9] The BAL fluid return was significantly lower with the MST method than the other 2 methods, possibly due to the insertion of tubing into the bronchoscope's working channel, which reduces the effective diameter.

What are the clinical implications of the current study? Three standard methods of BAL fluid recovery are MS, manual suction with tube extension, and mechanical suction using a negative pressure of 50 to 100 mm Hg. A tube extension between the syringe and the bronchoscope's working channel could reduce the transmitted negative pressure to the bronchi, changing the fluid dynamics by transforming a turbulent flow to a laminar flow.[10] The MS by handheld syringe provides feedback to the operator regarding the negative pressure applied. The operator can manipulate the negative suction applied by changing the speed of the plunger.[11] WMS can cause abrupt changes in the applied negative pressure that could cause airway trauma and collapse. However, adjustment of the applied pressure could prevent airway collapse. We found 3 different techniques of BAL retrieval similar for obtaining an optimal volume and quality of BAL fluid. Although the 3 methods were similar, the operators found the MST least satisfactory. With the WMS method, we had to instill a larger volume of saline as we could not always control the suction pressure to avoid airway collapse. The MS method was technically easy, as the same syringe could be used to instill and aspirate the BAL sample. It was also easier to control the negative suction applied with the syringe. However, we did not record the number of times such variations in the applied suction pressure were employed across 3 arms. The results of our study suggest that the operator could choose any method with which he or she is comfortable. We did not use sedation to perform BAL, which could have impacted the study's results. Finally, we also did not record patient-centered outcomes. Future studies should also compare patient-centered outcomes using different BAL methods.

Our study has a few limitations. The wall suction pressure was not uniform for all BAL procedures, as we needed to adjust the pressures to prevent airway collapse. The study was not blinded due to the nature of the procedures. We could not achieve the assumed 12% difference in optimal yield between procedures. Thus, our study could be underpowered to detect smaller differences in the yield. Different operators with variable skill sets performed the bronchoscopic procedures. A large sample and comparison of 3 BAL techniques are the study's main strengths.

CONCLUSIONS

We found a similar yield of BAL using WMS, MS, or MST methods of BAL fluid retrieval.

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