ORIGINAL ARTICLE

External Control of Exhalation for Cough Assistance: A Method for Patients With Glottis Dysfunction and/or Tracheostomy

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ABSTRACT. Lee SC, Park JH, Kang S-W, Kim DH, Song SH. External control of exhalation for cough assistance: a method for patients with glottis dysfunction and/or tracheostomy. Arch Phys Med Rehabil 2009;90:1402-7.

Objective: To investigate the effectiveness of our method of assisting a cough by mimicking the functions of the glottis in patients with bulbar muscle weakness or paralysis and/or those who had a tracheostomy tube.

Design: Before-after trial.

Setting: University rehabilitation hospital.

Participants: Patients (N=35) with bulbar muscle weakness or paralysis and/or those who had a tracheostomy tube.

Interventions: Not applicable.

Main Outcome Measures: The unassisted peak cough flow (PCF), the assisted PCF, and the assisted PCF with the external control method mimicking glottis function by an end-inspiratory external closure of the airways.

Results: Of the 35 patients, 13 were tracheostomized cervical cord injury patients, 11 were neuromuscular disease (NMD) patients with glottis dysfunction only, and 11 were NMD patients with a tracheostomy and glottis dysfunction. Assisted PCF with the external control method were higher than unassisted PCF and/or assisted PCF in all patients. Assisted PCF with the external control methods were measured in all of the patients even when the unassisted PCFs and/or assisted PCFs could not be measured. For patients with measurable assisted PCFs, the assisted PCF with the external control methods were significantly higher than the assisted PCFs.

Conclusions: We showed the effectiveness of our method of assisting a cough by external control of the glottis in patients with bulbar muscle weakness or paralysis and/or those who had a tracheostomy tube who cannot effectively cough with the help of existing cough assistance methods.

Key Words: Cough; Glottis; Rehabilitation; Tracheostomy.

THE ABILITY TO COUGH is indispensable for clearing airway mucus. Pneumonia or atelectasis may develop in those who have difficulty expectorating intratracheal mucus products by coughing, and the development of these illnesses is one of the main causes of death in patients with NMDs or a high cervical SCI.[1,2] This negatively impacts their quality of life and increases the economic cost of treating these patients.

Cough effectiveness correlates with PCF.[3] PCF depends on lung/chest wall recoil, which can be increased by packing the lungs with consecutively delivered air volumes to the maximum that can be held with a closed glottis for patients with diminished vital capacity. The maximum volume that can be held in this manner is defined as the MIC.[4,5] Manual thrust can increase PCF for patients with weak expiratory muscles by thoracoabdominal pressure.[6]

For some patients with NMDs, such as ALS, bulbar-innervated muscles are extremely impaired[7] and may prevent effective coughing. Patients with impaired glottis function cannot obtain sufficient intrathoracic pressure to produce enough cough flow when in the expulsion phase because of an inability to hold precough volume. In this case, holding precough volume can be provided only by bypassing the glottic function, which can be performed by using a cough machine (mechanical insufflation-exsufflation) at delivered volumes.[8]

Patients with high cervical SCI who have a tracheostomy tube also cannot obtain enough cough flow. These patients have intact bulbar-innervated musculature and no glottic dysfunction. However, when measuring PCF or expectorating intratracheal secretion through a tracheostomy tube, not only can these patients not hold precough volume by using the glottis, but they also have expiratory and inspiratory muscle paralysis. If there is a way to create artificial glottic closure in patients with glottis dysfunction and/or tracheostomy who cannot complete the compression phase of coughing, these patients may be able to perform an effective cough.

In this study, we investigated the effectiveness of our method in increasing airflow to support the compression phase of coughing in different patient populations. The purpose of this work was to determine whether this method could be used to assist a cough by mimicking the functions of the glottis in patients with bulbar muscle weakness or paralysis and/or those who had a tracheostomy tube.

List of Abbreviations

ALS	amyotrophic lateral sclerosis
FSHD	facioscapulohumeral muscular dystrophy
MIC	maximum insufflation capacity
NMD	neuromuscular disease
PCF	peak cough flow
SCI	spinal cord injury

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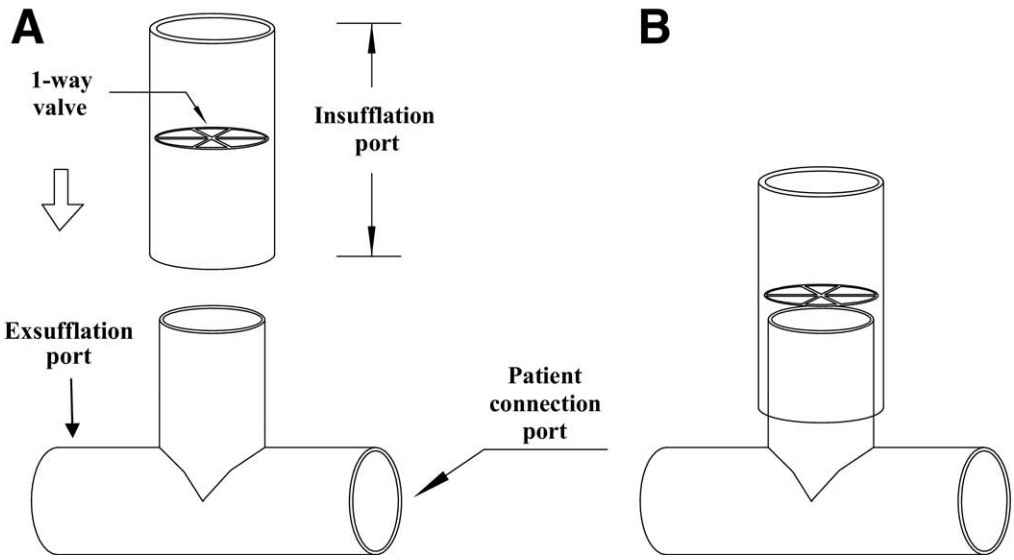

Fig 1. Detailed diagram of the connection part: when measuring assisted PCF with the external control method, previous inhaled air does not leak because of the 1-way valve. (A) Disassembled view and (B) assembled view showing the inner parts. When the pushing bar is released and the patient coughs, the assisted PCF with the external control method can be measured as the air passes though the measuring part.

METHODS

Patients

The study subjects were patients diagnosed with NMDs or SCI. This study included 35 patients with bulbar muscle weakness and/or a tracheostomy tube as well as inspiratory and expiratory muscle weakness. Bulbar muscle weakness was defined as clinically apparent dysarthria and/or dysphagia and problems with holding inhaled air when measuring assisted PCF with MIC in the preliminary study. We excluded patients that had intrinsic lung diseases or who were uncooperative because of mental or physical problems. The institutional review board approved our study, and informed consent was obtained from all of the study subjects.

Design for External Control of Exhalation

The artificial control method was designed to assist glottis function externally and to measure the PCFs. The method is composed of 2 parts: the connection part and the control part (figs 1–3).

The connection part. As shown in figure 1, the connection part is a T-shaped plastic pipe with 3 main pathways: the patient connection port, the insufflation port, and the exsufflation port. The patient connection port is the pathway that connects directly with the patient's airway through a tracheostomy tube or an oronasal mask (see fig 3B). The insufflation port is located in the middle of the cylindrical structure at a right angle, and it serves as a pathway of air-volume support with the manual insufflating bag for cough induction. To supply air-volume effectively, the previous inhaled air should not leak through to the prior air pathway. Therefore, a 1-way valve is installed in the insufflation port (see fig 1A). The exsufflation port is an air pathway that is connected to the control part.

The control part. As shown in figure 2, the control part, which takes charge of the core function in this design, artificially modulates the function of glottic opening and closing. We modified the commercially available peak flow meter[a] for our study design. This modified peak flow meter was attached to the control part and was used to evaluate the PCFs during the tests (see fig 3).

Functions that substitute for glottic opening and closing are regulated by a bar that can be released. When the pushing bar is pressed, the springs that are attached to the inner wall of the control part are stretched, and the head of the pushing bar is then pressed against the membranous 1-way valve (see fig 2B). The airflow from the connecting tube is then completely interrupted by the head of the pushing bar. We instilled additional air by using a manual insufflating bag after the patient's voluntary maximal inhalation when the pushing bar was pressed. This insufflated air does not leak and generates enough intrathoracic pressure for a cough-like exhalation. The control part acts exactly like the glottis when the pushing bar is pressed. When the pushing bar is released, the springs shrink and the head of the pushing bar moves away from the 1-way valve so that the exhaled air is passed freely from the connection part to the measuring part through the 1-way valve (see fig 2A). In this way, we were able to let the patients exhale with fast airflow, which is similar to the normal cough mechanism with unimpaired glottis function. The cough flow could be measured with the measuring part when the patient exhaled with fast airflow.

Clinical Evaluation

We evaluated the subjects to confirm the effects of the external control method as follows. First, the unassisted PCF was measured by having the subject cough as forcefully as possible through a commercial peak flow meter.[a] Second, the assisted PCF with the peak flow meter was evaluated. To assist with the inspiratory phase of the cough, the subjects were insufflated to their MIC.[5] To assist with the expulsive phase of the maximal voluntary cough, the subject was asked to cough as forcefully as possible with the help of a manual abdominal thrust. Third, the assisted PCF with the external control method that assists the glottic function was measured by using the same method as the assisted PCF, whereas the abdominal thrust was timed so that it corresponded with the release of the pushing bar. For tracheostomized patients, the PCFs under different conditions were measured through a tube with the cuff inflated. The largest value of 5 or more attempts was recorded for the unassisted PCF, assisted PCF, and assisted PCF with the external control method. We compared the PCFs under different conditions. When the PCFs were measured as the value less than 80L/min, these values were uncheckable.

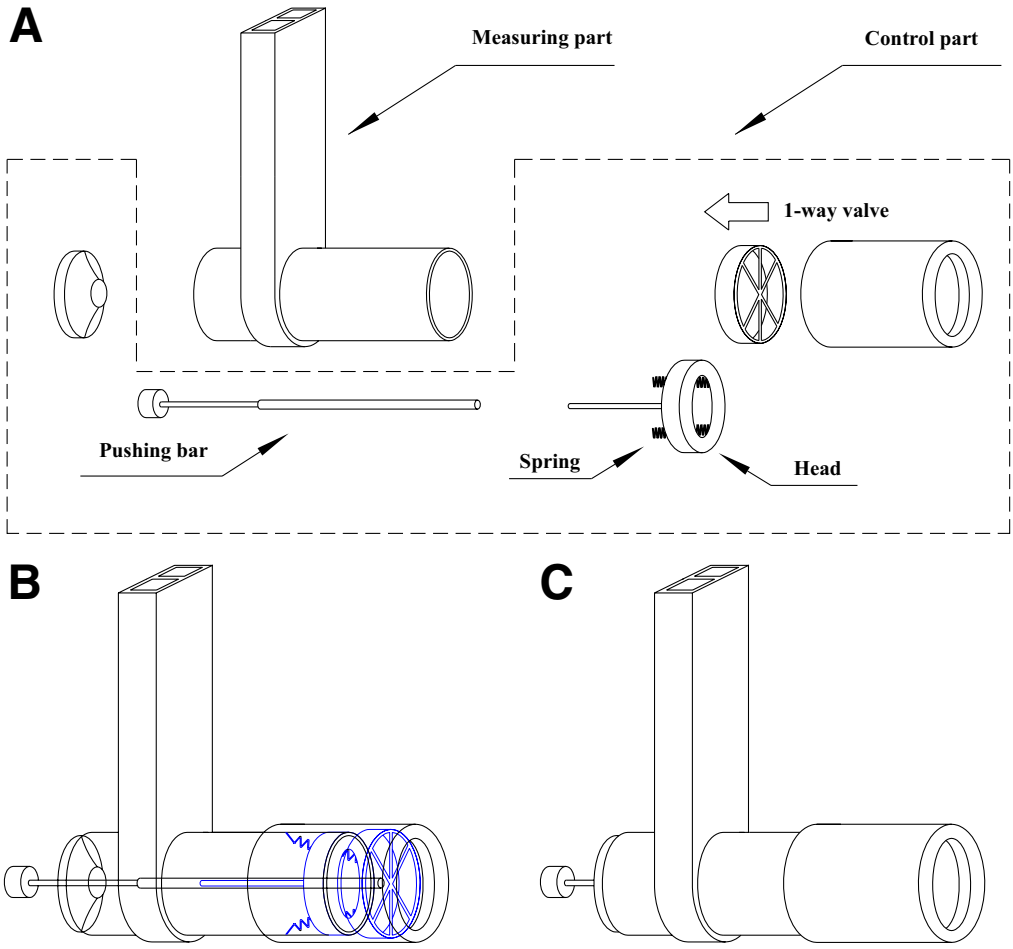

Fig 2. Detailed diagram of the control part. (A) Disassembled view, (B) assembled view showing the inner parts, and (C) external view.

Data Analysis

A Wilcoxon signed-rank test was used to determine the significance in the difference between the unassisted PCF, assisted PCF, and assisted PCF with the external control method. Data were analyzed by using SPSS 12.0.[b] A *P* value less than .05 was considered statistically significant.

RESULTS

A total of 35 subjects who met the criteria were evaluated to assess the clinical usefulness of the new method described in this study (table 1). Twenty-two of the study subjects were men and 13 were women. The mean age was 44.2±13.3 years old. Fourteen of these study subjects were ALS patients with bulbar muscle weakness. Five of the ALS patients had a tracheostomy tube. Of the remaining 21 patients, 13 were cervical SCI patients with indwelling tracheostomy tubes. The remaining 8 patients suffered from spinal muscular atrophy, Kennedy syndrome, FSHD, limb-girdle muscular dystrophy, congenital myopathy, cerebral palsy (athetoid type), mitochondrial myopathy, and Duchenne muscular dystrophy, respectively. All patients, except those with FSHD and Kennedy syndrome, had a tracheostomy tube.

To analyze the differences among the unassisted PCF, assisted PCF, and assisted PCF with the external control method, the patients were divided into 3 subgroups. Group 1 included patients in whom only the unassisted PCFs were uncheckable, but the assisted PCFs were measurable. Group 2 included patients for whom the unassisted PCFs and the assisted PCF were uncheckable. Group 3 included patients whose unassisted PCFs and assisted PCFs were measurable (table 2). In group 1, the mean assisted PCF and the mean assisted PCF with the external control method were 120.9±45.8 and 311.4±151.4L/min, respectively. The assisted PCF with the external control method was significantly higher than the assisted PCF (P=.003). In group 2, the mean assisted PCF with the external control method was 174.3±49.2L/min. For group 3, the mean PCFs under the various conditions tested were unassisted PCF, 149.4±69.5L/min; assisted PCF, 215.0±92.5L/min; and assisted PCF with the external control method, 330.0±123.4L/min. The assisted PCF was significantly higher than the unassisted PCF (P=.021), and the assisted PCF with the external control method was significantly higher than the assisted PCF (P=.008).

DISCUSSION

Coughing is a protective function of the body that expels airway secretions to prevent pulmonary complications when the airway is filled with mucus because of a chest cold.[9] To cough effectively, a normal cough requires 3 phases of operation: the inspiration, compression, and expulsion phases.[10] During the inspiration phase, healthy subjects have precough volumes that are about 85% to 90% of their inspiratory capacity and have a total cough volume of 2.3±0.5L to obtain optimal PCFs.[9] After enough air volume is inhaled, the glottis,

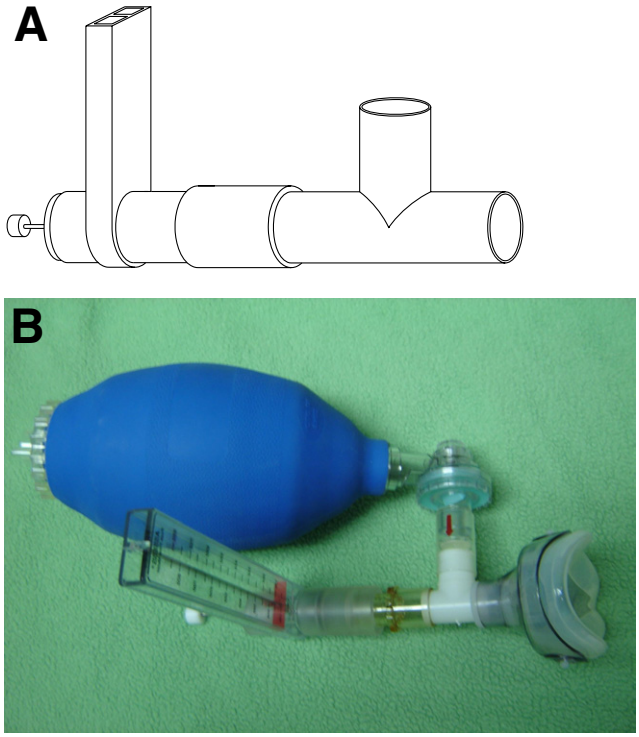

Fig 3. A fully assembled device for measuring assisted PCF with the external control method. (A) Assembled external view. (B) A resuscitation bag is connected to the connecting part of the device.

which automatically closes in intervals of 0.2 seconds, prevents any outflow of inhaled air.[11,12] The contraction of the expiratory muscles while the glottis is open initiates the expulsion phase during which air from the lungs is forcibly expelled.[10,13] Coughing becomes ineffective when any one of these phases do not work properly. When the expiratory muscles contract against a closed glottis, the intrathoracic pressure increases to a level as high as 300cmH_2O.[14] The pressure developed when the glottis is closed approximately 50% to 100% greater than that obtained during other forced expiratory maneuvers in which the glottis is opened.[14] This augmentation of the pleural pressure during a cough, as compared with other expiratory maneuvers, may be related to the neuroreflexes that are elicited by the closure of the glottis.[15,16] In addition, glottis closure allows peak pleural pressures to be reached at higher lung volumes when the force-length relationships of the expiratory muscles are more advantageous.[14]

For NMD patients, such as those with ALS accompanied by weakness of the respiratory muscles, it is impossible to obtain sufficient precough volume because of inspiratory muscle weakness and chest wall contracture,[7] and it is difficult for them to expel the air with sufficient force because of the weakness of their expiratory muscles. Moreover, if there are additional problems such as bulbar muscle weakness, then the cough flow decreases even more because glottis closure does not occur properly.[17] This is also true for high cervical SCI patients with respiratory muscle paralysis who experience problems during the cough compression phase because of the existence of a tracheostomy tube. With our methods, when respiratory secretions are expelled by coughing through a tracheostomy tube, the glottis is bypassed and the compression phase of the cough is not complete. A patient can try to cough through the mouth instead of through a tube after tube occlusion with a cap. However, when using a dual-cannula tracheostomy tube, the inner diameter of the tube can affect the airflow resistance, and the outer diameter of the tube can affect airflow when the cuff is deflated because of the space between the tracheal wall and the tube when the cuff is down. Therefore, the PCF measurements of SCI patients with a tracheostomy tube may not reflect their actual cough capacity. We believe that if our device helps patients during the compression phase, it may not only accurately measure the cough capacity of tracheostomized SCI patients but also help expel the respiratory secretions.

The existing assistance methods for coughing are unable to produce an effective cough in patients with respiratory muscle weakness or paralysis combined with bulbar muscle weakness and/or a tracheostomy. In the case of glottic dysfunction, an effective cough flow cannot be established, even though the air has been supplemented, because the inhaled air leaks out from the lungs. Tracheostomized patients also cannot produce a normal cough mechanism. These patients have difficulty initiating the compressive phase among the 3 phases of coughing, and, because of this problem, cough flow cannot be increased sufficiently by using the existing cough-assisted methods.[18,19] When coughing is difficult because of weakness or paralysis of the respiratory muscles, the expiratory muscle can be assisted by an abdominal thrust.[20] When the volume of the precough is decreased, an additional volume of air may be supplied through a manual insufflating bag.[5] The combination of both MIC and thrust is much more effective than either alone.[6] However, when the cause of an inefficient cough is a problem at the compressive phase, very few methods can help. In these cases, a cough machine (mechanical insufflation-exsufflation) is very helpful,[7] but, because of its high cost, not all patients can afford one. Our device is advantageous for patients with glottic dysfunction because it is a cheap and simple method for assisting the compression phase of cough. Furthermore, it can be used in combination with abdominal thrust and MIC. Therefore, this study aimed to design a method that would allow external control of exhalation in patients with glottis dysfunction to assist them with coughing and to evaluate how this method influences PCF in these patients.

The method described in this study is designed to provide external control of the air pathway in patients by using a pushing bar, which operates like an artificial external glottis, in the control part of the device. Our method produced sufficiently high intrathoracic pressure for an effective cough even in patients who had problems with their glottis function that caused difficulties in measuring their PCFs. The control part can be opened simultaneously with the expulsion, and measurement of the PCF is possible without air leakage.

Study Limitations

The limitations of the study include the heterogenicity of the patients. To address this topic, it might be helpful to separate patients into 3 groups: (1) glottis dysfunction, (2) tracheostomy without glottis dysfunction, and (3) tracheostomy and glottis dysfunction. A further analysis of the effects of our device on a larger group of patients is warranted. In addition, although attempts were made to standardize abdominal thrust by conducting the test with the same examiner, the added air volume and the force of the thrust may have affected the PCF. It will be helpful to measure the amount of added volume by using our device quantitatively. Currently, we are conducting a study on this matter.

Table 1: Subject Characteristics and Pulmonary Evaluation Results

Case	Sex	Age	Tracheostomy	Diagnosis	UPCF (L/min)	APCF (L/min)	APCFE (L/min)
1	M	44	Yes	SCI (4A)	U	80	195
2	F	48	Yes	SCI (2A)	U	80	290
3	M	42	Yes	SCI (3A)	U	85	130
4	M	59	Yes	SCI (4A)	U	100	320
5	M	37	Yes	SCI (3B)	U	110	210
6	M	40	Yes	SCI (7B)	U	210	520
7	M	25	Yes	SCI (3A)	U	U	120
8	M	21	Yes	SCI (2A)	U	U	150
9	M	39	Yes	SCI (2C)	U	U	160
10	M	20	Yes	SCI (7A)	U	U	200
11	F	25	Yes	SCI (2C)	U	U	225
12	M	63	Yes	SCI (3A)	U	U	230
13	F	41	Yes	SCI (5A)	U	U	280
14	F	34	Yes	MM	120	140	270
15	M	55	Yes	ALS	U	80	170
16	M	39	Yes	ALS	U	115	330
17	M	50	Yes	SMA3	U	130	220
18	F	29	Yes	LGMD	U	U	120
19	F	50	Yes	ALS	U	U	130
20	M	18	Yes	DMD	U	U	130
21	F	38	Yes	CM	U	U	160
22	M	33	Yes	ALS	U	U	190
23	M	38	Yes	CP	U	U	230
24	M	55	Yes	ALS	70	115	160
25	F	56	No	FSHD	U	145	600
26	M	56	No	ALS	U	195	440
27	M	57	No	ALS	U	U	160
28	F	70	No	ALS	U	U	130
29	F	55	No	ALS	80	235	275
30	F	54	No	ALS	120	135	280
31	M	65	No	KS	125	225	355
32	F	54	No	ALS	150	155	445
33	F	45	No	ALS	170	270	340
34	M	43	No	ALS	220	250	260
35	M	49	No	ALS	290	410	585

Abbreviations: APCF, assisted peak cough flow; APCFE, assisted peak cough flow with the external control method; CM, congenital myopathy; CP, cerebral palsy; DMD, Duchenne muscular dystrophy; LGMD, limb-girdle muscular dystrophy; KS, Kennedy syndrome; MM, mitochondrial myopathy; SMA3, spinal muscular atrophy type 3; SCI (4A), spinal cord injury (neurologic level of injury, American Spinal Injury Association Impairment Scale); U, uncheckable; UPCF, unassisted peak cough flow.

CONCLUSIONS

Our method is effective for increasing airflow to facilitate the coughing mechanism in different patient populations. This method assists coughing by mimicking the functions of the glottis and can be used in NMD patients with bulbar muscle weakness or SCI patients with a tracheostomy who cannot effectively cough with the help of existing cough-assistance methods.

Table 2: Comparisons of Peak Cough Flow Under Different Conditions

Groups	UPCF	APCF	APCFE
Group 1 (n=11)	X	120.9±45.8	311.4±151.4*
Group 2 (n=15)	X	X	174.3±49.2
Group 3 (n=9)	149.4±69.5	215.0±92.5†	330.0±123.4*

NOTE. Mean values ± SD (L/min).
Abbreviations: UPCF, unassisted peak cough flow; X, uncheckable; APCF, assisted peak cough flow; APCFE, assisted peak cough flow with the external control method.
*$P<.05$, comparison between APCF and APCFE; †$P<.05$, comparison between UPCF and APCF.

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