The Effects of Lingual Exercise on Swallowing in Older Adults

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OBJECTIVES: To determine the effects of an 8-week progressive lingual resistance exercise program on swallowing in older individuals, the most "at risk" group for dysphagia.

DESIGN: Prospective cohort intervention study.

SETTING: Subjects were recruited from the community at large.

PARTICIPANTS: Ten healthy men and women aged 70 to 89.

INTERVENTION: Each subject performed an 8-week lingual resistance exercise program consisting of compressing an air-filled bulb between the tongue and hard palate.

MEASUREMENTS: At baseline and Week 8, each subject completed a videofluoroscopic swallowing evaluation for kinematic and bolus flow assessment of swallowing. Swallowing pressures and isometric pressures were collected at baseline and Weeks 2, 4, and 6. Four of the subjects also underwent oral magnetic resonance imaging (MRI) to measure lingual volume.

RESULTS: All subjects significantly increased their isometric and swallowing pressures. All subjects who had the MRI demonstrated increased lingual volume of an average of 5.1%.

CONCLUSION: The findings indicate that lingual resistance exercise is promising not only for preventing dysphagia due to sarcopenia, but also as a treatment strategy for patients with lingual weakness and swallowing disability due to frailty or other age-related conditions. The potential effect of lingual exercise on reducing dysphagia-related comorbidities (pneumonia, malnutrition, and dehydration) and healthcare costs while improving quality of life is encouraging. **J Am Geriatr Soc 53:1483–1489, 2005.**

Key words: deglutition; tongue; exercise; therapeutics; prevention

Among the most serious and common conditions suffered by elderly individuals are swallowing problems and associated life-threatening sequelae: pneumonia, malnutrition, and dehydration. Estimates of as many as 40% of adults aged 60 and older currently suffer from dysphagia, with an exponential increase in the total dysphagic population likely as the geriatric population grows. [1–3]

Of the deleterious dysphagia-related health outcomes, pneumonia may be the most devastating—the fifth leading cause of death in those aged 65 and older and the third leading cause of death in those aged 85 and older.[4] Over the past decade, the number of hospitalized elderly Medicare beneficiaries admitted to the hospital with a diagnosis of aspiration pneumonia increased 93.8%.[5]

Dysphagia is commonly associated with age-related diseases such as stroke. Patients who have suffered a cerebrovascular accident with dysphagia and aspirate are significantly more at risk of suffering from pneumonia than those who do not [6–12] and have greater mortality. Other age-related diseases such as Parkinson's disease also are associated with greater mortality, attributed, in part, to bronchopneumonia.[13–16]

Perhaps of even greater importance to national health, because our aging population is increasing exponentially,[17] is the emerging evidence that more-generalized and chronic age-related conditions such as congestive heart failure, diabetes mellitus, and frailty are associated with dysphagia and its devastating consequences. Awareness of these circumstances is occurring simultaneously with a growing focus in geriatric medicine on sarcopenia, the pervasive loss of muscle mass in normal aging that is associated with reduced muscle strength.[18] Functional decline is a known result of sarcopenia in the striated musculature of the extremities,[19,20] with implications for smaller striated muscle groups such as those involved in swallowing.

In support of the notion that sarcopenia may affect the head and neck muscles and may be a contributing risk factor for the prevalence of age-related dysphagia, previous work[21] focused on the tongue. The tongue has an entirely

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muscular composition and plays a critical role as the major propulsive force in moving food, liquid, secretions, and medications through the oropharynx and into the esophagus during swallowing. The results of that work demonstrated that normal, healthy older adults swallow more slowly and generate lower maximum lingual isometric pressures than their younger counterparts, indicating diminished reserve in older adults that is likely related to sarcopenia of the head and neck musculature.[21] These physiological changes that affect function define the term "presbyphagia," that is, aspects of swallowing that change with age, specifically healthy aging. Most importantly, it follows that older adults lack the necessary temporal and pressure reserve to use for increased swallowing demands (e.g., during physiologically stressful situations such as chronic disease states, perturbations such as nasogastric tube placement,[22] or secondary to acute changes such as stroke), thus increasing their risk for developing dysphagia.[23]

Treatment for dysphagia often involves the prescription of compensatory strategies with the intention of minimizing required effort so that energy is preserved, allowing older people to perform activities of daily living, including eating. Compensatory strategies, in the form of dietary modification, such as the thickening of liquids, or behavioral modification, such as reducing bolus size or moistening dry food to facilitate flow, indirectly manipulate bolus flow. Such techniques, when employed effectively, may prevent aspiration of food/liquid, but they offer nothing to influence or improve the underlying pathophysiology of the swallow directly or the future risk of dysphagia and may negatively affect quality of life.

Alternatively, the benefits of rehabilitative exercises for reversing age-related muscle changes and improving related functional outcomes, such as gait speed and endurance, are prevalent in studies of limb musculature.[19,20,24–26] Beneficial adaptations to exercise once thought to be restricted to genetically endowed individuals now are being demonstrated in frail older people with chronic disease, opening the door to vastly improved physical function and associated health benefits,[27] yet little attention has been paid to the effects of active exercises for head and neck musculature on swallowing and related outcomes. The current study examined the hypothesis that older adults who perform an 8-week progressive lingual resistance exercise program would increase lingual isometric strength. A second hypothesis was that increased lingual isometric strength would carry over into swallowing function, as indicated by increased lingual strength/pressures generated during swallowing. Finally, additional hypotheses that lingual muscle volume would increase and functional swallowing outcomes could be improved in older adults who perform an 8-week progressive lingual resistance exercise program designed to increase tongue strength were examined.

METHODS

Participants

This research was conducted with the approval of the institutional review board of the University of Wisconsin Health Sciences Center and the Research and Development Committee of the William S. Middleton Memorial Veterans Hospital. Ten healthy older adults (4 men and 6 women) aged 70 to 89 participated in the study. Each completed an extensive health history questionnaire before enrollment. None of the subjects had a history of swallowing problems or medical conditions that would affect oral motor performance, such as a history of acute or degenerative neurological condition or head/neck cancer. Common conditions for this age group, including controlled hypertension and diabetes mellitus, were acceptable. Participants were recruited from the Department of Veterans Affairs hospital volunteer office, from a pool of previous research participants, and from the community at large.

Exercise Regimen

All subjects performed an 8-week lingual exercise program consisting of compressing an air-filled bulb between the tongue and hard palate using the Iowa Oral Performance Instrument (IOPI) (Figure 1). The IOPI measures tongue pressure using a nickel-sized air-filled plastic bulb connected through plastic tubing to a hand-held instrument. As subjects apply pressure with their tongue to the IOPI bulb positioned in their mouth, the instrument measures the pressure change in the plastic tubing. Biofeedback is relayed to the user through a numerical display (in kPa) and through a series of lights changing from red to green to indicate successful achievement of the target pressure. Subjects exercised the tongue blade 30 times, three times a day, on 3 days of the weeks as recommended for strength training by the American College of Sports Medicine.[28] Before beginning the exercise program, a baseline 1-repetition maximum pressure was identified. A 1-repetition maximum is defined as the highest amount that can be generated one time.[29] Each subject's maximum pressure was identified as the highest value from two sets of three trials, with the averages of the sets differing by 5% or less to account for variability. Subjects exercised with a goal of 60% of the baseline maximum pressure for the first week of the program and 80% of the maximum pressure for the remaining

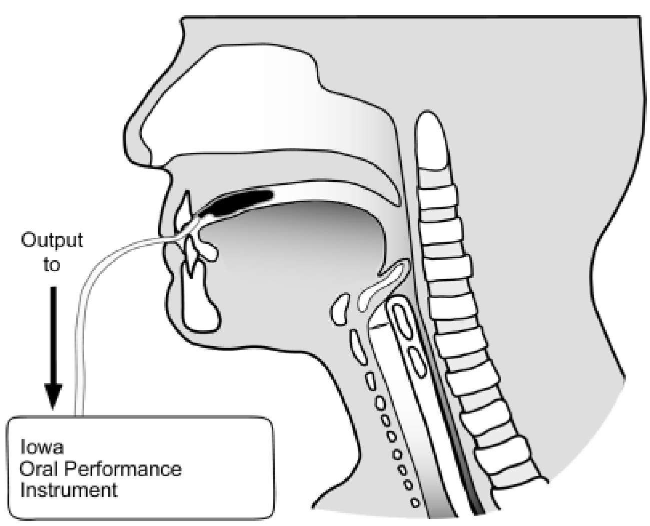

Figure 1. Positioning of air-filled lingual pressure sensor between tongue blade and hard palate attached to the Iowa Oral Performance Instrument.

7 weeks. Baseline was remeasured at the end of Weeks 2, 4, and 6, and the 80% target was recalculated. A speech-language pathologist team member (ST, JH) recalculated the maximum pressure and reset the colored light visual feedback of the target value to assure accuracy. In addition, each participant maintained a daily log documenting exercise activity.

Data Collection

Oral Pressure Sensor Instrumentation and Placement

Pressures were obtained during two conditions: isometric exercise and swallowing.

Isometric Exercise. Oral pressures generated during isometric tasks were collected using the IOPI. Subjects were seated upright and asked to "press your tongue against the roof of your mouth as hard as possible." Two sets of three trials of maximum performance were collected once a subject was trained sufficiently. Peak isometric pressures were measured at baseline and Weeks 2, 4, and 6.

Swallowing. Oral pressures generated during swallowing were gathered simultaneously during a videofluoroscopic study described in the next section. Swallowing pressures were measured using three air-filled bulbs (13-mm diameter, 8-mm spacing) mounted on a silica strip. The strip was secured longitudinally to the hard palate at midline using Stomahesive (ConvaTec, Princeton, NJ), with the anterior bulb positioned at the alveolar ridge and the posterior bulb at the approximate junction of the hard and soft palates (Figure 2). The bulbs were connected to a transducer (Kay Elemetrics, Lincoln Park, NJ) suspended from the neck by a strap. Pressure data was sampled at a temporal resolution of 0.004 seconds and time-linked to videofluoroscopic swallowing images using the Kay Swallowing Workstation, model 7100 (Kay Elemetrics). Swallowing pressures were measured at baseline and Week 8.

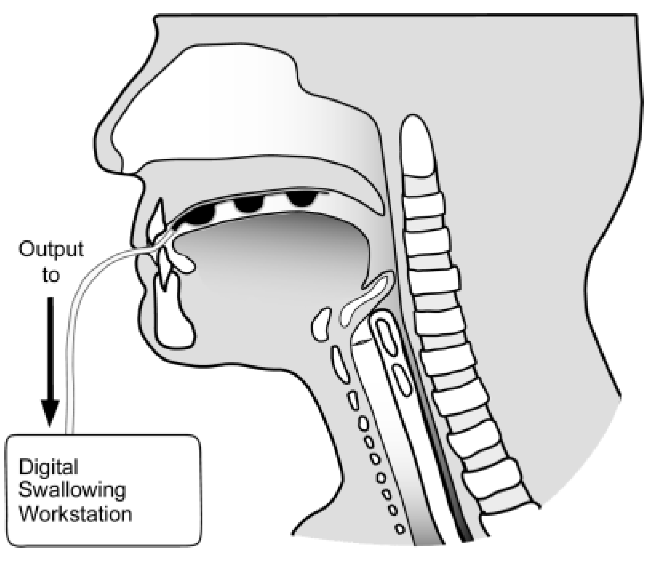

Figure 2. Positioning of the three-bulb array (which is attached to the Kay Swallowing Workstation (Kay Elemetrics)) along the midline of the hard palate to measure lingual pressures during swallowing.

Videofluoroscopic Swallow Studies

Fluoroscopy was performed in the lateral view with the camera focused on the lips anteriorly, the pharyngeal wall posteriorly, the hard palate superiorly, and just below the upper esophageal sphincter inferiorly. Each subject performed a total of 11 swallows under four randomized conditions: three swallows each of 3-mL thin liquid, 10-mL thin liquid, and 3-mL semisolid, and two effortful swallows of 3-mL thin liquid. All 3-mL boluses were presented to participants via a spoon, and 10-mL boluses were administered via a catheter-tip syringe. For effortful swallow trials, subjects were instructed to "swallow as hard as you can." Effortful swallowing was included in this study because it is a common treatment technique and has been shown to increase lingual pressures with associated changes in oropharyngeal biomechanics that enhance swallowing.[30] Thin liquid boluses were a 3:1 mixture of water:Liquid Polibar Plus (EZ-EM Inc., Westbury, NY) with a viscosity of 15 centipoise. Semisolid boluses were Varibar Pudding (EZ-EM Inc.) with a viscosity of 6,000 centipoise. A videofluoroscopic swallow study was completed at baseline and Week 8.

Magnetic Resonance Imaging

High-resolution anatomical images progressing from the anterior incisors to the posterior epiglottis were obtained using a 1.5 Tesla scanner (Signa LX, GE Medical Systems, Milwaukee, WI) and anterior neck surface coil. Coronal T1-weighted fast spin-echo pulse sequence images were acquired with the following scan parameters: repetition time/echo time between pulses, 600/23 msec; field of view, 20 cm; 26 coronal slice locations with 3-mm thickness/0-mm skip; 512-by-256 matrix (yielding a spatial resolution of 0.39 mm × 0.78 mm). All subjects were instructed to touch their tongue tip to the edge of their lower front teeth and attempt to maintain that position during all of the scans. The duration of the scans was approximately 3 minutes 36 seconds. Magnetic resonance imaging (MRI) scans were obtained on only four of the participants because of artifact created by movement or the presence of dental crowns or other dental work, which distorted the clarity of the scans and interfered with data measurement.

Data Reduction

Oral Pressures

Maximum peak pressures were recorded for isometric and swallowing pressures. In addition, pressure rise rate was calculated for the swallowing pressures from waveforms recorded at each bulb during the swallowing study and time-linked to the video images on the Kay Swallowing Workstation. To ensure that the pressures measured corresponded to lingual activity related to bolus transport, pressure data analysis extended from the first posterior bolus motion that transported the bolus functionally into the pharynx until the point when the bolus tail passed into the upper esophageal sphincter and the oropharyngeal swallow was completed. Peak pressures falling before the initiation of posterior bolus movement were judged to correspond to bolus manipulation or a bolus "holding" pattern (i.e., holding the bolus between the tongue and hard palate to prevent premature flow) when viewed repeatedly with the

Table 1. Durational Measures of Oropharyngeal Swallowing Used to Measure the Timing of Bolus Flow and Hyoid Movement

Duration	Definition
Oral transit duration	Time from beginning of posterior bolus movement until arrival of bolus head at ramus of mandible
Stage transition duration	Time from arrival of bolus head at ramus of mandible until beginning of hyoid excursion
Pharyngeal transit duration	Time from arrival of bolus head at ramus of mandible until bolus head entering UES
Pharyngeal response duration	Time from beginning of hyoid excursion until hyoid return to rest
Duration of hyoid maximum elevation	Time from first maximum hyoid elevation until last maximum hyoid elevation
Duration of hyoid maximum anterior excursion	Time from first maximum hyoid anterior excursion until the last maximum hyoid anterior excursion
Duration to UES opening	Time from beginning of posterior bolus movement in oral cavity until UES opening
Duration of UES opening	Time from UES opening until UES closed
Total swallowing duration	Time from beginning of posterior bolus movement in oral cavity until hyoid returns to rest

UES = upper esophageal sphincter.

simultaneously collected fluoroscopic images. Therefore, only pressure peaks occurring at or after the initiation of posterior bolus flow was visualized were included in data analysis.[31]

Videofluoroscopic Swallow Studies

Residue Measures. Postswallow residue was measured from the videofluoroscopic image when the hyoid bone returned to rest. Measurements were taken in the oral cavity, vallecula, posterior pharyngeal wall, pyriform sinus, and upper esophageal sphincter. Ratings were scaled on a 3-point system, with 0 corresponding to no residue, 1 to a coating of residue, and 2 to pooling of residue. Inter- and intrajudge reliability have been established as acceptable by these researchers using similar data sets.[30]

Penetration and Aspiration Scale. The 8-point Penetration and Aspiration Scale[32,33] was used to quantify any penetration and aspiration events observed during the videofluoroscopic swallowing evaluation. Scores on this scale reflect the occurrence, anatomic depth, subject response to, and clearance of material invading the laryngeal vestibule or trachea.[32,33]

Durational Measures. To examine the effects of rehabilitative intervention on the duration of upper aerodigestive tract kinematics (hyolaryngeal excursion and upper esophageal sphincter opening) and bolus flow, measures were obtained using standard criteria and definitions[22,30,34] (Table 1 for definitions).

Magnetic Resonance Imaging

Images were electronically transmitted to a dedicated laboratory computer and measured using SIP-II, a computer-assisted image analysis program developed at the UW/VA Swallowing Clinical Research Program[35] that allows a user to identify and manually outline a region of interest within a single MRI slice. Outlined regions included the longitudinal, vertical, transverse, genioglossus, hyoglossus, and styloglossus lingual muscles but carefully excluded the geniohyoid, anterior belly of the digastric, and submandibular gland. SIP-II automatically calculated the area of each tongue region outline and multiplied it by the slice thickness, yielding a measure of total tongue volume when the individual slices were summated. The validity of deriving tongue volume and tissue composition measurements from MRI scans using the SIP-II program was assessed in primate model studies and resulted in less than 0.1% error. Reliability was assessed by repeating the outlines and volume measurements on six subjects. Measurement error ranged from 0.4% to 7.0%, with a mean error of 3.3%. These positive results match others in which high correlations between MRI volumes and those achieved via alternative methods are reported.[36-39]

Statistical Analysis

Repeated measures analysis of variance models were used to assess the effect of the 8-week lingual resistance exercise

Table 2. Effect of Lingual Resistance Exercise Regimen on Peak Isometric Pressures (kPa) as Measured Using the Iowa Oral Performance Instrument (IOPI)

	Peak Isometric Pressure (IOPI)		
Time	Current Mean (Range), kPa	Change from Baseline Mean, kPa	*P*-value
Baseline	41 (36–46)		
Week 2	44 (39–49)	3	.14
Week 4	47 (43–51)	6	.002*
Week 6	49 (45–53)	7	.001*

* Statistically significant.

program on the following sets of parameters: isometric pressures measured using the IOPI, swallowing pressures measured using a three-bulb array, and bolus flow measures (residue, penetration/aspiration, and durations). All models included age (continuous) and sex as covariates. Isometric pressures were measured using the IOPI at Weeks 2, 4, and 6. Models for swallowing pressures included visit, bulb type, and bolus type, along with all possible interactions between the three factors. Models for bolus flow measures included visit, bolus type, and visit-by–bolus type interaction. Separate models were fit for each follow-up visit. Analyses were conducted using Proc Mixed in SAS (SAS Institute, Inc., Cary, NC). A nominal *P*-value of .05 was regarded as being statistically significant.

RESULTS

Oral Pressures

Isometric Pressures

There was a significant increase in peak isometric pressure as measured using the IOPI at Week 4 ($P = .002$) and Week 6 ($P = .001$). See Table 2.

Swallowing Pressures

The 8-week lingual resistance exercise regimen significantly affected peak swallowing pressure measured using the three-bulb array. This effect varied based on bolus type ($P = .047$). The increase in peak swallowing pressures was observed for all swallowing conditions with the exception of the 3 mL of thin liquid. The effortful swallow changed most significantly ($P = .001$). Peak swallowing pressures also increased significantly for the 10 mL of thin liquid ($P = .04$) and the semisolid ($P = .01$) (Figure 3). There were no significant changes in pressure rise rate overall ($P = .48$) or by bolus type ($P = .42$, .28, .94, and .73, respectively).

Videofluoroscopic Swallowing Data

There were no significant changes in the penetration/aspiration scale, duration of upper aerodigestive tract kinematics, bolus flow duration, or residue at any location associated with the 8-week lingual resistance exercise program by these normal healthy subjects.

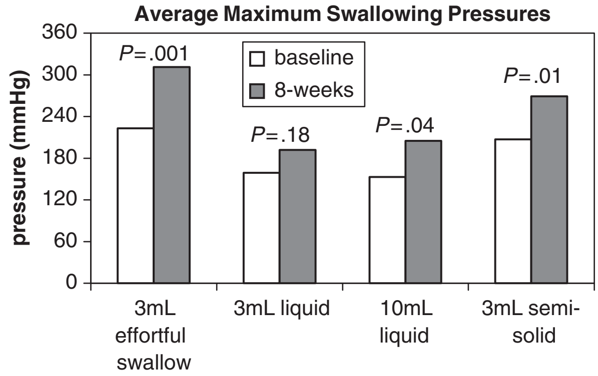

Figure 3. Average maximum swallowing pressures baseline versus post 8-week lingual exercise intervention.

Table 3. Lingual Volume (cm^3) at Baseline and After 8-Week Lingual Exercise Regimen

Subject	Baseline	8 week	Change
	cm^3		%
74-year-old man	78.7	87.1	↑ 10.68
84-year-old woman	58.5	60.2	↑ 2.91
71-year-old woman	71.4	72.9	↑ 2.16
75-year-old woman	89.1	93.3	↑ 4.67

Magnetic Resonance Imaging

All four of the subjects who completed the 8-week lingual exercise regimen and the MRI protocol demonstrated increased lingual volume, with an average of 5.1% (Table 3).

DISCUSSION

The major finding of this study was that healthy older individuals successfully and significantly increased their lingual maximal isometric pressure over an 8-week period of exercise following a traditional sports medicine protocol. Although demonstrating the potential for strength building in striated musculature in older people has been done, albeit in the extremities, this is a report of the first demonstration specific to the bulbar-innervated tongue musculature as it relates to swallowing function. Pressures increased steadily from Week 1 to Week 6, indicating that no less than 6 weeks of exercise at the weekly rate prescribed in this protocol and performed by these normal older individuals would have produced the extent of pressure gain achieved by this group.

A second major, and perhaps most impressive finding, was that the healthy subjects, none of whom had difficulty swallowing, demonstrated higher swallowing pressures after 8 weeks of isometric lingual exercise. This is of interest in light of the fact that the 8-week practice did not include swallowing as a task. Nonetheless, after 8 weeks of isometric lingual exercise, significantly higher swallowing pressures were observed under three of the four swallowing conditions. That is, during swallowing of 10-mL liquid boluses and 3-mL semisolid boluses and performing the 3-mL "hard swallow" task, subjects spontaneously generated higher pressures after the 8 weeks of exercise. Thus, carryover of the increased isometric strength to swallowing function occurred spontaneously.

The third major finding of this investigation was that the subset of four subjects who were able to undergo successfully the MRI protocol all showed anatomical changes in the same positive direction; that is, all of them demonstrated increased lingual volume. Although the specific tissue composition of the increased tongue volume was not discernible with the methods employed in this study, it is reasonable to assume that the volume increase may have been due to muscle mass increase during the 8-week intervention rather than fatty or connective tissue, indicating a reversal of sarcopenia through exercise. These findings will motivate new measures that will facilitate differentiation of tissue type in future work.

The absence of significant change in airway penetration or residue after the swallow is not surprising, given that this was a sample of healthy, normal swallowers. As expected, these individuals propelled the bolus safely and effectively before participating in the exercise protocol because none of them had any symptoms or complaints of dysphagia upon entry into the study.

The finding of increased lingual pressures in this group of elderly adults after isometric exercise and its direct carryover into pressures during swallowing in the absence of such practice is promising. Lingual weakness is a major contributor to dysphagia, secondary to numerous neuromuscular conditions and generalized weakness and frailty. The current findings indicate that the pervasive weakness that accompanies sarcopenia in limb musculature is mirrored in the head and neck muscles[21,31] and, most importantly, may be reversed with exercise. This work fosters a foundation for speculation that elderly patients with age-related disease in addition to sarcopenia may make even greater gains than demonstrated in the healthy subjects in this sample. Although coordination, endurance, and other parameters contribute to optimal motor function, increased muscle strength may directly enhance progress toward normalizing neurological underpinnings essential for diminishing disability. Future work will clarify the promise of potential gains that dysphagic older people may achieve.

This group of older people not only was able to complete an 8-week exercise protocol, but many of them also expressed delight in doing so. The work indicates that older adults can perform a structured, gradually progressive program independently. Moreover, these 10 participants appeared to enjoy the process and expressed a sense of empowerment through this self-help model of health care. It will be critical to determine in future efforts whether older people with dysphagia are able to perform the 8-week protocol as willingly and as successfully as this healthy older group of participants or if modifications to the protocol will be necessary.

Finally, the promise of prevention or delay of presbyphagia and dysphagia is implicit in these findings. The effect of lingual exercise on reducing healthcare costs that arise from the treatment of dysphagia-related pneumonia, malnutrition, and dehydration while improving quality of life for older individuals and their loved ones is encouraging and warrants pursuit.

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