Maximal Hyoid Excursion In Poststroke Patients

Authors
Youngsun Kim & **Gary H. McCullough**

Abstract
Reduced maximal hyoid excursion has been suspected as one of the primary physiologic causes of aspiration after a stroke. Vertical and anterior displacement of hyoid excursion is critical to epiglottic closure for airway protection and the opening of the upper esophageal sphincter (UES). Without these carefully timed and well- executed components, the bolus cannot pass safely through the pharynx. The purpose of this study was to evaluate vertical and anterior displacement of the hyoid bone during oropharyngeal swallowing in two groups of subjects: (1) 16 stroke patients who aspirate before or during the swallow (aspirators), and (2) 33 stroke patients who do not aspirate (nonaspirators). Means and standard deviations for anterior and vertical displacement were analyzed for 5- and 10-ml thin-liquid boluses using the ImageJ program (136 swallows). A two-way analysis of variance (ANOVA) was run with group and volume as independent variables. There was no significant difference between the two groups for vertical or anterior displacement. Maximal anterior displacement of the hyoid bone was slightly longer in nonaspirators than in aspirators. Aspiration before and during the swallow may be related more to the triggering of pharyngeal swallow than to the maximal extent of hyoid excursion.

Youngsun Kim & **Gary H. McCullough** (2010) "Maximal Hyoid Excursion In Poststroke Patients" *Dysphagia* 25:20–25 Version of Record Available At www.springer.com
[DOI 10.1007/s00455-009-9224-1]

Maximal Hyoid Excursion in Poststroke Patients

Aspiration has clearly been established as a precursor to negative health outcomes [1, 2]. In the past two decades, researchers have continued to refine diagnostic tools used to assess for aspiration and the underlying causal mechanisms of swallowing dysfunction. Videofluoroscopic evaluations of swallowing are necessarily brief and controlled (i.e., posture, method of intake, rate of intake), and such carefully controlled studies may be insufficient for ruling out aspiration in a more natural environment. It is, therefore, essential to collect information on specific physiologic indicators of swallowing that may lead to aspiration in order to determine the degree of risk associated with aspects of the swallow that may create more problems for patients at home or other situations outside the radiologic suite.

Vertical and anterior displacement of the hyoid bone during the pharyngeal swallow is often referred to collectively as "hyolaryngeal excursion." As the bolus passes into the pharynx, the tongue base, on which the hyoid bone rests, pulls the hyoid bone and larynx upward and forward. It contributes to protecting the airway through its impact on epiglottic tilt and seal, and to bolus passage into the esophagus via the cricopharyngeus muscle, which it pulls open during relaxation of the upper esophageal sphincter (UES) [3, 4].

Researchers have long suspected that reduced hyoid excursion is one of the primary causes of aspiration [5–7]. Perlman et al. [7] indicated that patients with reduced hyoid excursion showed 3.7 times greater risk of aspiration than those with adequate hyoid excursion. Perlman et al.

[8] reported that dysphagic patients with various etiologies had less displacement both anteriorly and vertically than normal subjects. No difference was observed between liquid and paste swallows.

The extent of hyoid excursion is believed to be influenced by the consistency and the volume of the bolus. However, Ishida et al. [9] reported that solid food demands more vertical than anterior displacement of the hyoid bone in normal individuals. Dodds et al. [10] and Cook et al. [11] similarly concluded that an increase in bolus volume demands an increase in maximal hyoid excursion. Bolus volumes may have different effects on vertical movement than anterior displacement, but few data exist to define such differences. Age also appears to have an effect. Kim and McCullough [12] reported that maximal anterior displacement of the hyoid bone decreases with increasing age, but maximal vertical displacement does not. Logemann [13, 14] reported that younger male subjects have more vertical movement of the hyoid than younger female subjects. However, older female subjects have more anterior hyoid movement to compensate for age-related swallowing changes.

While normative data have been collected for hyoid excursion in normal populations and results continue to be correlated and considered, no studies have compared hyoid movement in poststroke patients with and without aspiration. Our previous research [15] indicates that swallowing duration measures such as duration of stage transition (DST), a measure of the timeliness of hyoid excursion, can influence the occurrence of aspiration. The purpose of this study was to evaluate the extent of maximal vertical and anterior displacement of the hyoid bone during pharyngeal swallowing in poststroke patients to determine whether the extent of hyoid movement is as important as the timing for preventing aspiration. These data provide new insight into how hyoid excursion is reduced after a stroke, and when treatment or compensatory strategies should be initiated.

Methods

Subjects

Videofluoroscopic swallowing examinations (VFSEs) were recorded for 60 stroke patients (55 males, 5 females) at the VA Medical Center (Nashville, TN) and Vanderbilt University Medical Center for a prior investigation [16]. The mean age was 67.8 years and the mean number of days postonset was 5.98. Brain imaging revealed that 44 of the 60 patients suffered a single stroke and 16 suffered two or more strokes. Twenty-nine patients had suffered cortical stroke(s): 11 right hemisphere, 17 left, and 1 bilateral. Fourteen patients suffered subcortical stroke(s): nine right side, four left, and one bilateral. Six patients had a brainstem stroke(s): two right side, two left, and two bilateral. Three patients had cerebellar strokes, three had a mixed localization, and the lesion in three others could not be localized [16].

Twenty-two patients aspirated and 38 did not. For this investigation, 10 of the 22 patients with aspiration (aspirators) and 31 of the 38 patients without aspiration (nonaspirators) were selected for biomechanical measurement. Nineteen patients were excluded from this study due to poor visibility of the hyoid bone during the swallow. Detailed site of lesion, eating status, and other dysphagic signs are available in earlier publications [15, 16].

Videofluoroscopic Swallowing Examination (VFSE)

Videofluoroscopic swallowing examination (VFSE) data were collected on stroke patients [16] using the same research protocol for each patient. The fluoroscopic tube was focused in the lateral plane on the oral cavity (the lips anteriorly to the pharyngeal wall posteriorly) and the nasopharynx (superiorly) to just below the UES area (inferiorly). Each subject swallowed a wide array of boluses ranging from 5 ml to 3 oz. of thin liquid to solid consistency. For this investigation, however, data were analyzed for only two 5-ml boluses and two 10-ml boluses of thin liquid. The boluses were a mixture of water and barium sulfate powder (50/50 water and E-Z M barium sulfate powder for suspension). Each VFSE began with two swallows of 5 ml of thin liquid and two swallows of 10 ml of thin liquid. Each subject was instructed by the clinician to swallow after putting the liquid in his/her mouth by pill cup. The only variability occurred when “bailout criteria” were reached. The bailout criteria were used only if aspiration appeared to place the subject at risk and forced the use of compensatory strategies without completion of swallows in the standard position.

Procedures for Biomechanical Measurement

This study focused on two aspects of swallowing: (1) bolus flow, including laryngeal aspiration, and (2) vertical and anterior displacement of the hyoid bone. Of a total of 136 swallows analyzed from participants’ VFSEs, 19 swallows showed aspiration and 117 did not. Aspiration is defined as entry of the liquid below the true vocal folds. In addition, the investigator identified the timing of aspiration (e.g., before, during, after the swallow). Different mechanisms are likely responsible for aspiration depending on the timing of aspiration. Analyses of hyoid displacement were broken down into vertical and anterior displacement and were also analyzed for 5-ml and 10-ml thin–liquid boluses. Thin liquids were used because they are the primary material aspirated by individuals with dysphagia poststroke.

To analyze the sequence of maximal hyoid displacement, each VFSE S-VHS tape was digitized. Adobe Premier Pro 1.5, a video-editing program, was employed for digitization using a Sony DVMC-DA1 Media Converter. The digitization of VFSE tapes provided the investigator clear picture images and the investigator was able to manipulate these images for analysis. Then, for each swallow evaluated, two picture frames were generated: one showing the resting position of the hyoid, and the other showing the maximum displacement of the hyoid bone during the swallow.

Each picture frame was submitted to the ImageJ 1.32j program [17]. First, each subject's picture frame was rotated to be truly vertical, 90°. This simplified the anterior and vertical displacement of the hyoid and assured the calculation relative to the vertebral column. The angle of the line between the anterior–inferior corner of cervical vertebra 4 (C4) and the inferior–anterior corner of C2 was used to rotate the image to 90°. In addition, the distance between the anterior–inferior corner and the anterior–superior corner of C3 was used as the known length (15 m) to mark the points to actual size in millimeters. Fifteen millimeters is used because that was the average length of vertebra C3 found from skeletons at the Swallowing Physiology Laboratory at Northwestern University [18]. It was a relative measure, not an absolute measure. The following points were marked at each digitized picture frame: (1) a point on the anterior–inferior corner of C4, which serves as an anchor point, and (2-a) a point on the resting position of the hyoid bone, or (2-b) a point on the most superior–anterior position of hyoid bone, which represented maximum displacement (Fig. 1). The ImageJ program calculated the values of each point (x, y) for two frames: one resting frame and one maximum displacement frame. The following formulas were used to measure how far the hyoid bone moved vertically and anteriorly (B. Pauloski, personal communication, March 22, 2005):

anterior displacement: $(x2 - x1) — (C4x2 - C4x1)$

vertical displacement: $(y2 - y1) — (C4y2 - C4y1)$

where x1 and y1 are the starting (rest frame) coordinates of the structure of interest and x2 and y2 are the comparison image coordinates (e.g., maximum excursion coordinates). C4x1 and C4y1 are the coordinates of the anchor point in the rest frame, and C4x2 and C4y2 are the coordinates of the anchor point in the comparison frame.

Statistical Analysis

Statistical comparisons were made by two-way analysis of variance (ANOVA) with two groups and two bolus volumes as independent variables. The significance level was set at $P < 0.05$.

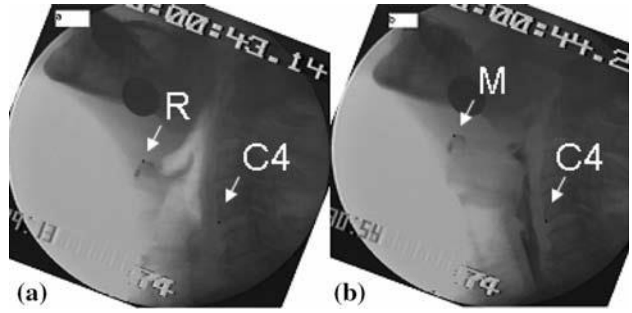

Fig. 1 a Rest frame of hyoid bone (R). b Maximum displacement frame of hyoid bone during swallowing (M), anchor point (C4)

Results

Reliability

For interjudge reliability, a second independent judge analyzed the designated randomly selected 90 swallows (66%). The measurements of the principal investigator and second judge were compared using a Pearson correlation coefficient. A significant correlation was observed ($r = 0.85$, $P < 0.01$). For intrajudge reliability, the principal investigator reanalyzed the same swallows a second time. Intrajudge reliability was also significant ($r = 0.90$, $P < 0.01$).

Maximum Vertical Displacement of the Hyoid Bone

Means and standard deviations for maximum vertical displacement of the hyoid bone of aspirators and nonaspirators are presented in Table 1 and Fig. 2. Maximum vertical displacement of the hyoid bone [$F(1,132) = 0.38$, $P = 0.54$] was not significantly different between aspirators and nonaspirators. Vertical displacement in nonaspirators averaged 1.49 cm for 5-ml boluses and 1.60 cm for 10-ml boluses. Vertical displacement for aspirators averaged 1.89 cm for 5-ml boluses and 1.39 cm for 10-ml boluses. There was no significant difference on bolus volumes and no group and volume interaction in maximum vertical displacement.

Table 1 Mean and standard deviation of maximal vertical displacement of the hyoid bone in poststroke patients for 5- and 10-ml thin-liquid boluses

Group	Volume (ml)	Mean distance (cm)	Standard deviation
Nonaspirators	5	1.49	0.78
	10	1.60	0.65
Aspirators	5	1.89	0.57
	10	1.39	0.44

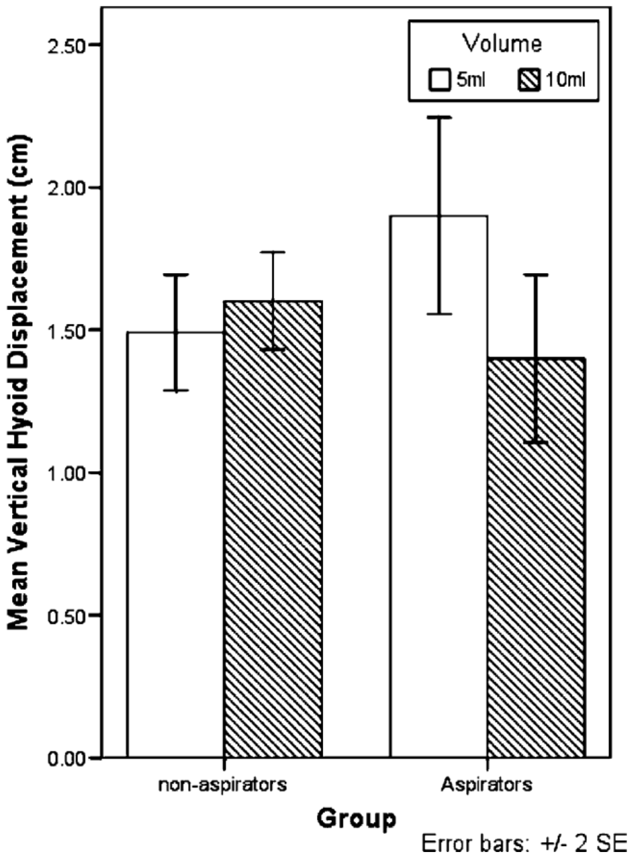

Fig. 2 Means (cm) and standard errors of the maximal vertical hyoid displacement of poststroke patients for 5- and 10-ml thin liquid boluses

Table 2 Mean and standard deviation of maximal anterior displacement of the hyoid bone in poststroke patients for 5- and 10-ml thin-liquid boluses

Group	Volume (ml)	Mean distance (cm)	Standard deviation
Nonaspirators	5	1.15	0.67
	10	1.07	0.64
Aspirators	5	1.07	0.54
	10	0.91	0.56

Maximum Anterior Displacement of the Hyoid Bone

Means and standard deviations of maximum anterior displacement of the hyoid bone of aspirators and nonaspirators are presented in Table 2 and Fig. 3. Maximum anterior displacement of the hyoid bone [$F(1,132) = 0.64$, $P = 0.43$] was not significantly different between aspirators and nonaspirators, although anterior displacement was slightly greater in nonaspirators. Anterior displacement for nonaspirators averaged 1.15 cm for 5-ml boluses and 1.7 cm for 10-ml boluses. Anterior displacement for aspirators averaged 1.07 cm for 5 ml boluses and 0.91 cm for 10 ml boluses. There was no group and volume interaction in maximum anterior displacement. In both groups, maximal vertical displacement was greater than maximal anterior displacement.

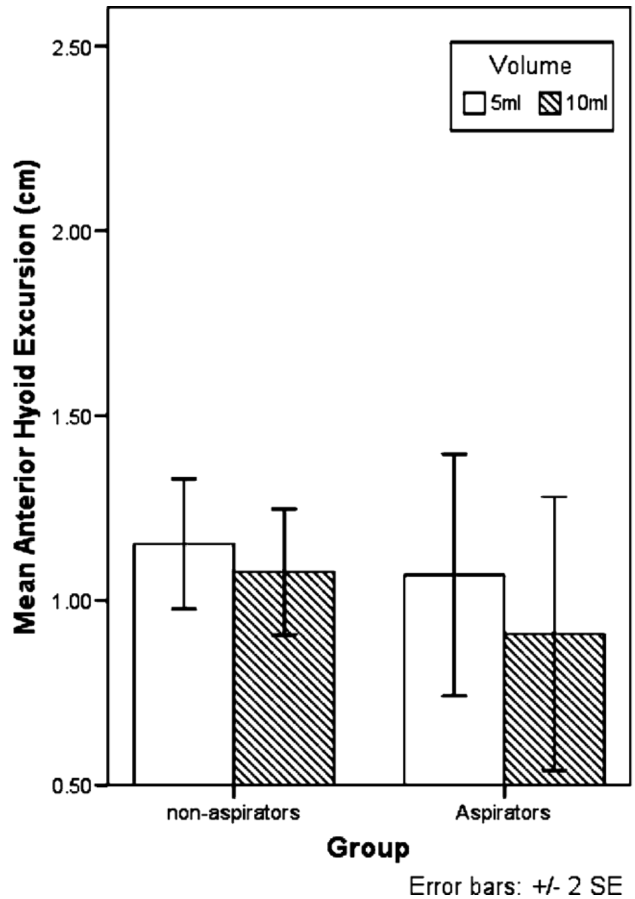

Fig. 3 Means (cm) and standard errors of the maximal anterior hyoid displacement of poststroke patients for 5- and 10-ml thin-liquid boluses

Discussion

Vertical and anterior displacement of the hyoid bone during pharyngeal swallow is considered to be very important for maintaining airway protection via epiglottic tilt and seal and for opening the upper esophageal sphincter (UES) via traction force to allow the bolus to be directed into the esophagus [3, 4]. Reduced hyoid movement has been reported to be a contributor to, or at least predictive of, aspiration [6, 7]. However, few data exist examining the importance of the vertical displacement of the hyoid compared with the anterior displacement. While results of our investigation indicate statistically insignificant differences in vertical and anterior displacement of the hyoid bone between aspirators and nonaspirators, they do provide some support for the importance of anterior displacement in protecting the airway during the swallow. Maximal anterior displacement was shorter in aspirators than in nonaspirators. While this result may not be statistically significant, it may very well be functionally significant. Maximal vertical displacement of the hyoid of aspirators versus nonaspirators showed mixed results and is more difficult to address meaningfully.

Perlman et al. [17] did report a significant correlation between reduced hyoid excursion and penetration/aspiration in their observations of 330 dysphagic patients with various neurogenic disorders. Sixty-two of their patients were observed to have reduced hyoid excursion. They surmised that reduced hyoid excursion was associated with epiglottic immobility and, therefore, subsequent penetration/aspiration. The authors did not report the timing of aspiration in their study (i.e., before, during, or after the swallow). The poststroke patients in our investigation showed aspiration before and during the swallow. Thus, a potentially causal difference is the reason for aspiration. Aspiration before and during the swallow, most typically with thin liquids which travel more quickly through the oropharynx, has been associated with the timing of hyoid excursion [15, 19], meaning the pharyngeal swallow response was delayed. It may very well be that the extent of maximal anterior or vertical displacement is more critical for completing the swallowing process (i.e., ridding traction forces for the opening the UES completely) and that aspiration of thicker consistencies and post-swallow aspiration may prove to have a stronger correlation. It is critical to present the timing of aspiration in current and future studies to determine the potential causes and correlates of aspiration.

To define the relationship between the timing of aspiration and the extent of hyoid excursion, it will be necessary to measure the hyoid excursion of poststroke patients who aspirate during and/or after the swallow as opposed to before the swallow. It would also be useful to measure the entire sequence of hyoid excursion rather than just maximal vertical and anterior displacement of the hyoid. A clinical database of these measurements could help train clinicians who could then apply these measurements to dysphagia diagnosis and treatment.

Future studies should also employ the most accurate biomechanical measurement methods available. The data from Perlman et al. [6] and other clinical investigations were collected through clinical observation because methods were not yet available for detailed measurements of hyoid excursion. Perlman et al. [8] indicated that the subjective measurement of hyoid excursion by VFSE was the least reliable predictor of aspiration. The development of a clinically accessible tool to measure the biomechanics of swallowing would be valuable. The tool should be easy to use and user-friendly to accommodate busy clinical schedules.

This study used only thin liquids which, as stated before, may produce different results and different reasons for aspiration to occur. It is possible that food or a thick liquid with high viscosity or a large bolus volume may require greater hyoid excursion [9–11]. Research suggests that solid food requires more vertical *and* anterior displacement of the hyoid bone and larger-volume boluses require a greater hyoid excursion [11]. Intraindividual and interswallow variability in maximal displacement of hyoid excursion was high for both aspirators and nonaspirators. It may be necessary to investigate biomechanics by analyzing each swallow independently, rather than averaging swallows by bolus volume as we did in this study. Finally, there were three times as many nonaspirators as aspirators in our study group. While such imbalances are typically well accounted for by using an ANOVA, the degree of subject imbalance could be a reason for lack of significance.

Conclusion

The limitations of this study were the small number of subjects enrolled and the use of VFSE data derived from a previous investigation. Future studies should focus on finding the biomechanically specific indicators of aspiration and should define and delineate movements of the hyoid in conjunction with epiglottic movement, UES opening, and the timing of aspiration. These measures should help with clinical decision-making in the diagnosis and treatment of dysphagia and may help identify and prevent aspiration for poststroke patients. Quantitative research with a large number of participants is critical to understanding the relationship between range of hyoid displacement and aspiration.

Acknowledgments This work has been made possible in part by a Scholarly Activity Award from the College of Health and Human Services, Ohio University.

References

1. Groher ME. The detection of aspiration and videofluoroscopy. Dysphagia. 1994;9:147–8. doi:10.1007/BF00341257.
2. Holas MA, DePippo KL, Reding MJ. Aspiration and relative risk of medical complications following stroke. Arch Neurol. 1994; 51(10):1051–3.
3. Cook IJ, Dodds WJ, Dantas RO, Kern MK, Massey BT, Shaker R, et al. Timing of videofluoroscopic, manometric events, and bolus transit timing during the oral and pharyngeal phases of swallowing. Dysphagia. 1989;4:8–15. doi:10.1007/BF02407397.
4. Jacob P, Kahrilas PJ, Logemann JA, Shah V, Ha T. Upper esophageal sphincter opening and modulation during swallowing. Gastroenterology. 1989;97(6):1469–78.

5. Kendall KA, Leonard RJ. Hyoid movement during swallowing in older patients with dysphagia. Arch Otolaryngol Head Neck Surg. 2001;127(10):1224–9.
6. Perlman AL, Grayhack JP, Booth BM. The relationship of vallecular residue to oral involvement, reduced hyoid elevation, and epiglottic function. J Speech Hear Res. 1992;35:734–41.
7. Perlman AL, Booth BM, Grayhack JP. Videofluoroscopic predictors of aspiration in patients with oropharyngeal dysphagia. Dysphagia. 1994;9(2):90–5. doi:10.1007/BF00714593.
8. Perlman AL, VanDaele DJ, Otterbacher MS. Quantitative assessment of hyoid bone displacement from video images during swallowing. J Speech Lang Hear Res. 1995;38(3):579–85.
9. Ishida R, Palmer JB, Hiiemae KM. Hyoid motion during swallowing: factors affecting forward and upward displacement. Dysphagia. 2002;17(4):262–72. 10.1007/s00455-002-0064-5.
10. Dodds WJ, Man KM, Cook IJ, Kahrilas PJ, Stewart ET, Kern MK. Influence of bolus volume on swallow-induced hyoid movement in normal subjects. AJR Am J Roentgenol. 1988; 150(6):1307–9.
11. Cook IJ, Dodds WJ, Dantas RO, Massey BT, Kern MK, Lang IM, et al. Opening mechanisms of the human upper esophageal sphincter. Am J Physiol. 1989;257(20):G748–59.
12. Kim Y, McCullough G. Maximum hyoid displacement in normal swallowing. Dysphagia. 2008;23:274–9. doi:10.1007/s00455-007-9135-y.
13. Logemann JA, Pauloski BR, Rademaker AW, Colangelo LA, Kahrilas PJ, Smith CH. Temporal and biomechanical characteristics of oropharyngeal swallow in younger and older men. J Speech Lang Hear Res. 2000;43(5):1264–74.
14. Logemann JA, Pauloski BR, Rademaker AW, Kahrilas PJ. Oropharyngeal swallow in younger and older women: videofluoroscopic analysis. J Speech Lang Hear Res. 2002;45(3):434–45. 10.1044/1092-4388(2002/034).
15. Kim Y, McCullough GH, Asp CW. Stage transition duration in patients post-stroke. Dysphagia. 2007;22:299–305. doi:10.1007/s00455-007-9085-4.
16. McCullough GH, Wertz RT, Rosenbek JC. Severity and specificity of clinical/bedside examination signs for detecting aspiration in adults subsequent to stroke. J Commun Disord. 2001;34:55–72. doi:10.1016/S0021-9924(00)00041-1.
17. Rasband W. Imag J 1.32j. National Institutes of Health. 2004. http://rsb.info.nih.gov/ij. Accessed 15 April 2005.
18. Pauloski BR, Logemann JA, Fox JC, Colangelo LA. Biomechanical analysis of the pharyngeal swallow in postsurgical patients with anterior tongue and floor of mouth resection and distal flap reconstruction. J Speech Lang Hear Res. 1995;38:110–23.
19. Robbins JA, Levine RL. Swallowing after unilateral stroke of the cerebral cortex: preliminary experience. Dysphagia. 1998;3:11–7. doi:10.1007/BF02406275.