Published in final edited form as:
Curr Opin Otolaryngol Head Neck Surg. 2010 June ; 18(3): 171–175. doi:10.1097/MOO.0b013e3283393784.

The role of hydration in vocal fold physiology

Mahalakshmi Sivasankar, Ph.D., CCC-SLP[1] and **Ciara Leydon, Ph.D., CCC-SLP**[2]

[1]Department of Speech, Language, and Hearing Sciences Purdue University West Lafayette, IN

[2]Department of Speech Communication Arts and Sciences Brooklyn College of The City University of New York New York, NY

Abstract

Purpose of review—Increased vocal fold hydration is a popular target in the prevention and management of voice disorders. Current intervention strategies focus on enhancing both systemic (internal) and superficial (surface) hydration. This paper will review relevant bench and human subject research on the role of hydration in vocal fold physiology.

Recent findings—Bench and human subject studies provide converging evidence that systemic and superficial dehydration are detrimental to vocal fold physiology. Dehydration challenges increase the viscous properties of excised vocal fold tissue. Systemic, superficial, and combined drying challenges increase aerodynamic and acoustic measures of voice production in speakers. Emerging theoretical and clinical evidence suggest that increasing both systemic and superficial hydration levels may benefit voice production, however, robust evidence for positive outcomes of hydration treatments is lacking.

Summary—Increased systemic and superficial vocal fold hydration as a component of vocal hygiene may improve overall health and efficiency of the vocal apparatus. However, continued exploration of biological mechanisms regulating vocal fold hydration is needed to optimize clinical hydration interventions. Specifically, the development of hydration treatments that maximize positive phonatory outcomes will necessitate understanding of the signaling pathways linking systemic and superficial hydration.

Keywords

vocal folds; hydration; voice production; laryngeal physiology

Introduction

Vocal fold hydration is maintained by fluid in several water compartments. Systemic hydration refers to fluid within body and vocal fold tissue. Superficial hydration is the fluid lining the vocal fold surface and laryngeal lumen. Clinical interventions aim to increase both systemic and/or superficial hydration to facilitate optimal voice production. Traditionally, patients are counseled to drink at least 64 fl. oz. of water each day and to limit intake of caffeinated and alcoholic beverages to maintain adequate systemic hydration [1]. To increase superficial hydration, speakers are advised to humidify inhaled air with nebulizers,

Address for Correspondence: Mahalakshmi Sivasankar Department of Speech, Language, and Hearing Sciences Purdue University West Lafayette, IN 47907 msivasankar@purdue.edu Phone: (765) 496 6628 Fax: (765) 494 0771.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

humidifiers, and steam inhalation [1,2]. However, these clinical recommendations are based largely on anecdotal reports of the beneficial effects of hydration on voice function. Bench and clinical studies have been conducted to quantify the effects of hydration on vocal fold physiology and to confirm these anecdotal reports. This paper will review literature on the importance of hydration in vocal fold physiology, with special emphasis on how hydration challenges affect vocal fold biomechanical properties and vocal function. Additionally, we will explore the purported role of hydration treatments in the prevention and management of voice problems.

Hydration effects on vocal fold biomechanics and vocal function

The biomechanical properties of vocal fold tissue govern the dynamics of vocal fold vibration. Titze (1988) proposed that the energy required to drive small-amplitude oscillation of the vocal folds depends on tissue biomechanical properties [3]. This driving energy referred to as phonation threshold pressure (PTP) is a measure of ease of phonation [4–6] and an indicator of vocal fold health. The theoretical expression proposed by Titze [3] relates PTP to vocal fold biomechanical properties including tissue thickness, elasticity, and viscosity. Viscosity is an important biomechanical property when considering vocal fold hydration and viscosity has a linear relationship with PTP. Hence, hydration treatments that theoretically lower vocal fold viscous properties should reduce PTP, while dehydration challenges should increase PTP. In this section, we review data demonstrating that hydration status influences vocal fold biomechanics and physiology in bench models, and that hydration status affects vocal function, including PTP, in bench and human subject research.

Bench research on hydration, vocal fold biomechanics, and physiology

The relationship between hydration levels and vocal fold viscosity was examined using rheologic measurements in excised, canine vocal folds [7]. Vocal folds were dehydrated by withdrawing water from the tissue. Dehydration increased vocal fold viscous properties. Conversely, rehydrating the tissue by incubation in sterile water reduced vocal fold viscous properties, supporting the hypothesis that systemic hydration positively regulates vocal fold biomechanical properties. The role of superficial dehydration in altering vocal fold biomechanics and physiology has also been explored. Hemler *et al.* [8] characterized the viscous properties of excised ovine vocal fold tissue after surface drying challenge. Superficial dehydration induced by brief exposure to desiccated air (0% humidity) increased tissue viscosity while exposure to saturated air (100% humidity) did not, supporting the hypothesis that superficial hydration impacts vocal fold biomechanical properties. The negative consequences of dehydrating events on vocal fold physiology have also been investigated. Sivasankar *et al.* [9*] demonstrated that the application of concentrated salt solution to the vocal fold surface, disrupts epithelial barrier function. A compromised epithelial barrier could make vocal fold tissue more susceptible to damage during vocal fold oscillation.

Bench research on hydration and vocal function

The relationship between hydration and vocal function has been assessed in bench models. Vocal function has been measured in excised animal larynges by quantifying changes in vocal fold vibration patterns via electroglottography and laryngeal imaging, and by analyzing the driving force for vocal fold vibration. Nakagawa *et al.* [10] demonstrated a reduction in amplitude of vocal fold motion after superficial dehydration simulated by applying viscous solutions to the surface of excised larynges. Ayache *et al.* [11] documented a transient increase in vocal fold contact time after surface exposure to synthetic fluids of high viscosity. Both these studies provide support for the adverse effects of superficial dehydration on vocal fold vibration.

The effects of hydration treatments and dehydration challenges on threshold airflow and pressure values have also been assessed. Finkelhor *et al.* [12] demonstrated that superficial dehydration increased PTP in excised canine larynges. Conversely, rehydrating the tissue reduced PTP. In excised canine larynges, Jiang *et al.* [13] showed that exposure to dry air (20% to 30% humidity) for approximately 5 minutes increased PTP and lowered vocal efficiency. In a separate experiment, larynges were first dehydrated with the passage of dry air and then rehydrated in an isotonic saline bath for 30 minutes [14]. Rehydration restored PTP and glottal efficiency to pre-drying values, confirming the hypothesis that drying challenges have detrimental effects on vocal function which can be reversed with rehydration. Further evidence for the negative effects of dehydration on vocal function result from research demonstrating that exposure to dry air (25% ± 3% humidity) for approximately 5 minutes increased the minimum airflow required for oscillation (phonation threshold flow) in excised canine larynges [15**].

Human subject research

The impact of hydration challenges on vocal function has also been examined in human subjects using aerodynamic, acoustic, and laryngeal imaging techniques [2,6,16–21]. An early study by Verdolini *et al.* sought to compare the effects of hydration treatment and dehydration challenges on PTP in healthy adults [6]. The hydration treatment consisted of increased ambient humidity, water intake, and mucolytic ingestion. Vocal fold dehydration was induced by lowering ambient humidity, decongestant use, and decreasing water intake. Hydration treatments reduced PTP and the reduction in PTP was most evident around the extreme limit of the vocal range (80^{th} percent pitch). These results were later confirmed by the researchers using a double-blinded, placebo controlled research design [22]. Twelve subjects participated in placebo (no-treatment), dehydration, and hydration conditions in counterbalanced order. Dehydration increased PTP while the placebo and hydrations conditions did not, demonstrating that drying challenges have detrimental effects on vocal function. To further quantify the effects of hydration state on voice, researchers have induced dehydration via diuretics, anti-histamines, and hemodialysis. In healthy adults with no prior voice problems, PTP increased after systemic dehydration induced by a diuretic [23]. In patients undergoing hemodialysis, PTP increased at the 30^{th} percent pitch of the vocal range after a 3% reduction in systemic fluid volume [24]. Acute xerostomia induced artificially by an intramuscular injection of glycopyrrolate increased PTP in healthy subjects [25].

The studies reviewed above primarily used systemic means to induce dehydration. However, reducing surface fluid alone may also have adverse effects on vocal function. Inhaling poorly-humidified air for 15 minutes through the mouth increased PTP in healthy subjects [18,26] and individuals reporting symptoms of vocal fatigue and throat dryness [2,19]. Dehydration challenge induced by rapid, deep breathing also demonstrated a tendency to increase PTP [27], suggesting that the laryngeal mechanism may be sensitive to both the rate and extent of surface dehydration.

PTP is the most-widely used tool to assess the impact of hydration challenges on vocal function. However, other voice measures including acoustic analysis, laryngeal imaging, and vocal effort ratings have also been utilized to quantify the importance of hydration in vocal physiology. In healthy individuals with no previous history of voice problems, superficial dehydration induced by brief exposure to desiccated air increased jitter and shimmer. Conversely, inhaling saturated air at 100% humidity for the same duration did not adversely affect acoustic measures [17]. Likewise, dehydration secondary to glycopyrrolate-induced acute xerostomia resulted in reduced vocal range profile, while saline control treatment did not [25]. Visualization with laryngeal imaging has also revealed minor effects of hydration status on vocal fold configuration. Reduced thickness (defined as the width/length ratio of each vocal fold), accompanying a reduction in total body water as a consequence of hemodialysis, was observed in patients with end-stage renal disease [28]. A trend for incomplete glottal closure and the presence of a posterior glottal gap was also observed following administration of a pharmacological agent to induce xerostomia [25].

Dehydration challenges may also increase vocal effort. A tendency for a transient increase in patient perceived vocal effort was observed in association with combined systemic and superficial dehydration [22] and hemodialysis [24]. Oral breathing was associated with a trend for increase in vocal effort compared to baseline ratings in healthy patients [18,19]. Similarly, administration of glycopyrrolate to reduce salivary secretions resulted in increased vocal effort as rated using a visual analogue scale [25]. Subjective reports of fatigue and `neck, shoulder, and back' discomfort were reported to increase after prolonged voice use under conditions of low humidity as compared to high ambient humidity [29].

Importance of hydration in prevention and treatment of voice problems

Data on the adverse vocal effects of dehydration has spurred research on the potential role of hydration in the prevention and treatment of voice problems [2,20,21,30–33,34*]. Recent computational modeling research suggests that fluid pressure buildup at the mid-membranous regions of the vocal folds during vibration may cause considerable tissue damage [35*]. Reducing the driving force for vibration (lowering PTP, by increasing the availability of hydration), may potentially lower fluid pressure build-up and the extent of damage. This is consistent with findings that maintaining good hydration status as part of a vocal hygiene regime may help sustain voice production [20,21,36].

Yiu and Chan [36] demonstrated that untrained singers who received both systemic hydration and vocal rest during karaoke performance were able to sing for longer durations than untrained singers in a control group who were not provided hydration and vocal rest. Additionally, singers who received a combination of systemic hydration and vocal rest demonstrated lower jitter values as compared to the control group. Increased systemic hydration was also observed to mitigate some of the adverse phonatory effects of vocally-fatiguing tasks. Untrained speakers completed a two-hour loud reading task under high systemic hydration and low systemic hydration conditions. PTP increased in the majority of subjects after loud reading in the low systemic hydration condition [20,21]. The beneficial effects of increasing superficial hydration on vocal function have also been investigated. Increasing environmental humidity countered some of the adverse drying effects of mouth breathing on voice production in female speakers [2]. Enhancing surface hydration by nebulizing fluid to the vocal fold surface was also effective at lowering PTP temporarily. Roy *et al.* [37] compared the vocal effects of three solutions of varying chemical concentration that were nebulized into the airway. Only one nebulized solution (mannitol) reduced PTP while the other solutions did not show any significant effect on vocal function. The beneficial effects of mannitol likely resulted from increased water secretion to the vocal fold surface (increased superficial hydration) [37,38]. Tanner *et al.* [26] examined the beneficial effects of nebulized solutions on reversing the detrimental effects of superficial dehydration on PTP. The dehydrating challenge increased PTP, however, the nebulized treatments did not reverse the effects of dehydration on PTP. Lastly, the effects of combined systemic and superficial hydration treatments on vocal function have also been studied. Verdolini *et al.* [39] conducted a study where speakers with vocal nodules or polyps received either hydration or placebo treatment for 5 days each, in counterbalanced order. The hydration treatment (increased water intake, inhaling humidified air, and ingesting a mucolytic) reduced PTP, vocal effort, and jitter while the placebo treatment did not. However, these beneficial vocal outcomes were of small magnitude.

Summary and Future Research

In summary, bench and human subject studies have provided converging evidence that dehydration adversely affects vocal fold physiology and voice production. In bench models, hydration treatments may optimize vocal fold biomechanical properties. In human subjects, investigations on the beneficial phonatory outcomes of current hydration treatments (e.g. increasing water intake, humidifying ambient air, nebulizing solutions into the airway) have revealed positive trends [40]. However, the improvements in vocal function with these systemic and/or superficial hydration treatments have typically been highly variable, of small magnitude, and transient duration [40]. It remains unclear whether increased hydration is both a prophylactic or therapeutic target. The development of effective clinical hydration intervention awaits continued, rigorous exploration of the sensitivity of the laryngeal mechanism to changes in the hydration status. Simultaneously, the development of optimal hydration treatments must be based on sound knowledge of the mechanisms that regulate vocal fold hydration. Superficial hydration is provided by glands lining the airway [41] and by ion movement across the vocal fold epithelium [38,42,43,44*]. Within the vocal folds, proteins, electrolytes, and extracellular matrix macromolecules such as hyaluronan regulate internal hydration. The interconnectedness of fluid compartments within the vocal folds and the presence of vectorial water fluxes [38,42], suggest a signaling pathway linking superficial and systemic hydration. The elucidation of this pathway would aid in developing hydration treatments that can selectively exploit mechanisms intrinsic to the vocal folds, to maximize positive outcomes on phonation. Additionally, the role of hormones, nutrients, and the nervous system in mediating superficial and systemic vocal fold hydration are yet to be described. Altered hydration state affects cell volume, ionic composition, protein synthesis, inflammatory gene expression, signaling pathways, and tissue mechanical and material properties in other systems. The identification of effective hydration treatments will mandate an understanding of the complex interactions between hydration levels, phonation, vocal fold biological activity, and vocal fold material properties.

Conclusions

Data from animal and human subject studies have revealed that systemic and superficial dehydration are detrimental to vocal fold physiology. The negative effects of dehydration on voice support a clinical focus on hydration intervention. While there is some evidence for increased systemic and superficial hydration in promoting laryngeal health, further research is needed to validate current clinical recommendations. Continued study of the biological mechanisms mediating vocal fold hydration will be necessary to design optimal treatments that have sustained, beneficial effects on voice.

Acknowledgments

Grant DC 008690 from the National Institutes of Health (NIH).

References

1. Sataloff, RT. Professional voice: The science and art of clinical. 2 ed.. Singular Publishing Group, Inc.; San Diego: 1997.

2. Sivasankar M, Erickson E, Schneider S, et al. Phonatory effects of airway dehydration: Preliminary evidence for impaired compensation to oral breathing in individuals with vocal fatigue. J Speech Lang Hear Res 2008;51:1494–506. [PubMed: 18664688]

3. Titze IR. The physics of small-amplitude oscillation of the vocal folds. JAcoust Soc Am 1988;83:1536–52. [PubMed: 3372869]

4. Titze IR. Phonation threshold pressure: A missing link in glottal aerodynamics. J Acoust Soc Am 1992;91:2926–35. [PubMed: 1629485]
5. Titze, IR. Principles of voice production. Prentice-Hall; Englewood Cliffs, NJ: 1994.
6. Verdolini K, Titze I, Druker D. Changes in phonation threshold pressure with induced conditions of hydration. J Voice 1990;4:142–51.
7. Chan RW, Tayama N. Biomechanical effects of hydration in vocal fold tissues. Otolaryngol Head Neck Surg 2002;126:528–37. [PubMed: 12075228]
8. Hemler RJ, Wieneke GH, Lebacq J, et al. Laryngeal mucosa elasticity and viscosity in high and low relative air humidity. Eur Arch Otol Rhinol Laryngol 2001;258:125–9.
9. Sivasankar M, Erickson E, Rosenblat M, et al. Hypertonic challenge to the vocal folds: Effects on barrier function. Otolaryngol Head Neck Surg 2010;142:79–84. [PubMed: 20096227] *This study utilized electrophysiology and electron microscopy to demonstrate that the surface application of concentrated salt but not sham solution increases the leakiness of vocal fold epithelia.
10. Nakagawa H, Fukuda H, Kawaida M, et al. Lubrication mechanism of the larynx during phonation: An experiment in excised canine larynges. Folia Phoniatr Logo 1998;50:183–94.
11. Ayache S, Ouaknine M, Dejonckere P, et al. Experimental study of the effects of surface mucus viscosity on the glottic cycle. J Voice 2004;18:107–15. [PubMed: 15070230]
12. Finkelhor BK, Titze IR, Durham PL. The effects of viscosity changes in the vocal folds on the range of oscillation. J Voice 1988;1:320–35.
13. Jiang J, Verdolini K, Aquino B, et al. Effects of dehydration on phonation in excised canine larynges. Ann Otol Rhinol Laryngol 2000;109:568–75. [PubMed: 10855568]
14. Jiang J, Ng J, Hanson D. The effects of rehydration on phonation in excised canine larynges. J Voice 1999;13:51–9. [PubMed: 10223675]
15. Witt R, Regner M, Tao C, et al. Effect of dehydration on phonation threshold flow in excised canine larynges. Ann Otol Rhinol Laryngol 2009;118:154–9. [PubMed: 19326767] ** This article presents bench data on the effects of dehydration on an aerodynamic measure that can be incorporated into the clinic setting. Phonation threshold flow increased after short exposure to surface dehydration at seasonally-relevant humidity levels (22–28% humidity).
16. Fujita R, Ferreira A, Sarkovas C. Videokymography assessment of vocal fold vibration before and after hydration. Rev Bras Otorrinol 2004;70:742–6.
17. Hemler RJ, Wieneke GH, Dejonckere PH. The effect of relative humidity of inhaled air on acoustic parameters of voice in normal subjects. J Voice 1997;11:295–300. 295–300. [PubMed: 9297673]
18. Sivasankar M, Fisher K. Oral breathing increases Pth and vocal effort by superficial drying of the vocal fold mucosa. J Voice 2002;16:172–81. [PubMed: 12150370]
19. Sivasankar M, Fisher K. Oral breathing challenge in participants with vocal attrition. J Speech Lang Hear Res 2003;46:1416–27. [PubMed: 14700365]
20. Solomon N, DiMattia M. Effects of a vocally fatiguing task and systemic hydration on phonation threshold pressure. J Voice 2000;14:341–62. [PubMed: 11021502]
21. Solomon N, Glaze L, Arnold R, et al. Effects of a vocally fatiguing task and systemic hydration on men's voices. J Voice 2003;17:31–46. [PubMed: 12705817]
22. Verdolini K, Titze IR, Fennell A. Dependence of phonatory effort on hydration level. J Speech Lang Hear Res 1994;37:1001–7.
23. Verdolini K, Min Y, Titze IR, Lemke J, Brown K, van Mersbergen M, Jiang J, Fisher K. Biological mechanisms underlying voice changes due to dehydration. J Speech Lang Hear Res 2002;45:268–81. [PubMed: 12003510]
24. Fisher KV, Ligon J, Sobecks JL, Roxe DM. Phonatory effects of body fluid removal. J Speech Lang Hear Res 2001;44:354–67. [PubMed: 11324657]
25. Roh J, Kim H, Kim A. The effect of acute xerostomia on vocal function. Ann Otol Rhinol Laryngol 2006;132:542–6.
26. Tanner K, Roy N, Merrill R, et al. The effects of three nebulized osmotic agents in the dry larynx. J Speech Lang Hear Res 2007;50:635–46. [PubMed: 17538106]
27. Sivasankar M, Erickson E. Short-duration accelerated breathing challenges affect phonation. Laryngoscope 2009;119:1658–63. [PubMed: 19522007]

28. Ori Y, Sabo R, Binder Y, et al. Effect of hemodialysis on the thickness of vocal folds: A possible explanation for postdialysis hoarseness. Nephron Clin Prac 2006;103:c144–c8.
29. Vintturi J, Alku P, Sala E, et al. Loading-related subjective symptoms during a vocal loading test with special reference to gender and some ergonomic factors. Folia Phoniatr Logo 2003;55:55–69.
30. Zhang Y, Czerwonka L, Tao C, et al. A biphasic theory for the viscoelastic behaviors of vocal fold lamina propria in stress relaxation. J Acoust Soc Am 2008;123:1627–36. [PubMed: 18345850]
31. Yiu EM, Chan RM. Effect of hydration and vocal rest on the vocal fatigue in amateur karaoke singers. J Voice 2003;17:216–27. [PubMed: 12825654]
32. Richter B, Lohle E, Knapp B, et al. Harmful substances on the opera stage: Possible negative effects on singers' respiratory tracts. J Voice 2002;16:72–80. [PubMed: 12002889]
33. Jones K, Sigmon J, Hock L, et al. Prevalence and risk factors for voice problems among telemarketeers. Arch Otolaryngol Head Neck Surg 2002;128:571–7. [PubMed: 12003590]
34. Behlau M, Oliveira G. Vocal hygiene for the voice professional. Curr Opin Otolaryngol Head Neck Surg 2009;17:149–54. [PubMed: 19342952] * This review article provides a comprehensive overview of hydration therapy as a component of vocal hygiene and offers suggestions for further research on vocal fold hydration.
35. Tao C, Jiang J, Zhang Y. A fluid-saturated poroelastic model of the vocal folds with hydrated tissue. J Biomech 2009;42:774–80. [PubMed: 19268294] * These authors used finite element modeling to characterize the build-up of stress in vocal folds during oscillation, laying the groundwork to understand tissue property changes underlying clinical voice disorders.
36. Yiu E, Chan R. Effects of hydration and vocal rest on vocal fatigue in amateur singers. J Voice 2003;17:216–27. [PubMed: 12825654]
37. Roy N, Tanner K, Gray S, et al. An evaluation of the effects of three laryngeal lubricants on phonation threshold pressure. J Voice 2003;17:331–42. [PubMed: 14513956]
38. Sivasankar M, Fisher K. Vocal fold epithelial response to luminal osmotic perturbation. J Speech Lang Hear Res 2007;50:886–98. [PubMed: 17675594]
39. Verdolini-Marston K, Sandage M, Titze IR. Effect of hydration treatments on laryngeal nodules and polyps and related voice measures. J Voice 1994;8:30–47. [PubMed: 8167785]
40. Leydon C, Wroblewski M, Eichorn N, et al. A meta-analysis of outcomes of hydration intervention on phonation threshold pressure. J Voice. in press.
41. Fukuda, H.; Kawaida, M.; Tatchara, T., et al. A new concept of lubricating mechanisms of the larynx. Fujimura, O., editor. Raven Press Ltd.; New York: 1988.
42. Fisher K, Telser A, Phillips J, et al. Regulation of vocal fold transepithelial water fluxes. J Appl Physiol 2001;91:1401–11. [PubMed: 11509542]
43. Sivasankar M, Nofziger C, Blazer-Yost B. Camp regulation of ion transport in porcine vocal fold mucosa. Laryngoscope 2008;118:1511–7. [PubMed: 18596479]
44. Leydon C, Sivasankar M, Lodewyck D, et al. Vocal fold surface hydration: A review. J Voice 2009;23:658–65. [PubMed: 19111440] * This paper reviews the biological mechanisms that regulate superficial hydration in vocal fold tissue and provides a framework for understanding why certain types of hydration treatments may be beneficial to voice production.