The Relationship Between Dehydration and Parotid Salivary Gland Function in Young and Older Healthy Adults

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Background. Saliva is essential for the maintenance of oral health. The primary constituent of saliva is water and, traditionally, decreased body water homeostasis has been linked with salivary dysfunction. This is consistent with the greater prevalence of dehydration and salivary gland dysfunction among the elderly. However, this association between dehydration and salivary dysfunction has never been tested using objective criteria. The purpose of this study was to determine the effect of body dehydration upon parotid salivary flow rates in young and older healthy adults.

Methods. Twelve young (20-40 years) and 12 older (60-80 years) healthy subjects abstained from food and beverage intake for 24 h (dehydration) and then underwent intravenous rehydration to replace all lost weight. Unstimulated and stimulated parotid salivary flow rates, weight, hematocrit, hemoglobin, serum sodium, plasma protein, creatinine, and urine osmolality values were assessed at baseline, 24 h, and 1 h after the completion of rehydration.

Results. All subjects experienced a significant decrease in weight and increased levels of hematocrit, hemoglobin, plasma protein, and creatinine during dehydration with few age-related differences. Intravenous fluid replacement increased weight and decreased hematocrit, hemoglobin, plasma protein, and creatinine back to baseline values, demonstrating that subjects were metabolically rehydrated. Unstimulated (young and older, p < .0001) and stimulated (young, p < .05; older, p = .03) parotid flow rates decreased during the 24-h dehydration period, yet did not completely return (young and older unstimulated, p < .01; young and older stimulated, p > .05) to baseline values after rehydration.

Conclusions. These findings suggest that body dehydration is associated with decreased parotid salivary gland flow rates, and that these changes are generally age-independent in healthy adults. Furthermore, although subjects were metabolically rehydrated, unstimulated salivary flow rates remained significantly lower than baseline levels.

Saliva is essential for the maintenance of oral health (1). Saliva functions in lubrication, remineralization, buffering, and digestion, while it also has antiviral, antibacterial, and antifungal properties. Individuals who have a reduction in saliva output experience oral dysfunction, such as difficulties with speech, mastication, swallowing, changes in taste, and unpleasant breath (2). Deterioration of soft tissues resulting from salivary hypofunction may result in epithelial atrophy, fissuring, ulceration and soreness, mucositis, iatrogenic trauma, and alteration in oral microflora with increased secondary bacterial, fungal, or viral infections. Tooth structure deterioration may also occur as fractures, chipping, and dental caries. A quantitative decrease of saliva will reduce an individual’s ability to comfortably wear partial or complete dentures. Furthermore, salivary gland dysfunction has been linked to problems beyond the oral cavity, including esophageal dysfunction and aspiration pneumonia (3–6).

Traditionally, it was believed that salivary function decreased as a result of the aging process. It now appears that there is no significant decrease in major salivary gland function across the human life span in healthy individuals (7–13). Recent research has also attempted to explain the large prevalence of older patients with salivary gland dysfunction and complaints of a dry mouth (xerostomia) (14). Most likely, numerous medical conditions and their treatments (medications, head and neck radiation, chemotherapy) contribute significantly to salivary gland dysfunction in the elderly (2,15–18). Because older patients are becoming a greater proportion of the overall population, salivary gland dysfunction will become a more prevalent problem in the future.

Salivary gland dysfunction has also been attributed to dehydration in older adults. Dehydration and disorders of water balance occur more frequently among the elderly and have considerable morbidity and mortality (19–23). One study reported a mortality rate of 48% among elderly people with infections complicated by dehydration (24). In 1980, for all persons in the United States, 4.4 per 10,000 discharges from short-stay hospitals were for the primary diagnosis of dehydration (25). This rate increased to 13.1 per 10,000 discharges in 1991. With greater age, the rates increase dramatically. For example, in 1991, the rates per 10,000 discharges for persons aged 55–64 years, 65–74 years, and 75+ years were 12.1, 28.7, and 101.5, respectively. For persons aged 75+ years in 1991, only heart disease, injuries, cerebrovascular disease, malignant neoplasms, and pneumonia had greater rates of primary diagnosis at discharge compared to dehydration.

Despite the large prevalence of dehydration in the elderly, relatively little research has been conducted on the relationship between oral health and dehydration. Cannon
(26) made measurements on himself of the total flow of saliva before, during, and after simple dehydration through water deprivation, and he demonstrated a reduction in salivary flow during the periods of intense thirst. Winsor (27) reported that a hot bath causing excessive perspiration reduced parotid secretion rate by approximately 50% in 1 h in one person. Gregersen and Bullock (28) observed in two subjects that 24-h water deprivation reduced salivary flow by approximately 50%, and that after 48 h deprivation the flow was reduced from an initial 1.00 ml/min to 0.14 ml/min. Adolph (29) observed reduced salivary flow in four young men dehydrated under desert conditions. There are also several reports of complaints of dry mouth after exercise that may be due to dehydration as well as other oral and systemic phenomena. Ben-Aryeh et al. (30) reported elevated serum sodium, potassium, and lactate concentrations following submaximal and anaerobic exercise, with a concomitant decrease in unstimulated whole saliva.

There is evidence that increased hydration is associated with greater salivary output. Holmes (31) reported that salivary flow rates increased in 22 medical students following ingestion of 1,000 ml of water. Shannon and colleagues (32,33) demonstrated increased unstimulated parotid flow rates in 65 subjects following the forced ingestion of 1,000 ml or more of water, but no changes in stimulated parotid flow rates. Ingestion of less than 1,000 ml did not result in any change in either unstimulated or stimulated parotid flow rates.

These studies suggest that there may be a relationship between body hydration status and salivary gland function. However, most of these investigations did not control for several variables that are now known to influence salivary production. These include medications, systemic conditions, time of day and type of salivary collection, type of stimulation, proximity to meals, fluid intake, and smoking. Furthermore, many of these studies based their conclusions on small sample sizes. While it has been determined that unstimulated and stimulated major salivary gland flow rates are independent of age in healthy individuals (7–13), the relationship between age, fluid production, and altered hydration homeostasis has yet to be examined.

Therefore, the purpose of this study was to determine if dehydration would have a significant effect on parotid salivary gland flow rates in healthy young and older subjects. It was hypothesized that parotid salivary gland flow rates would decrease over a 24-h period in dehydrated individuals, and following a rehydration period they would increase and return to predhydration levels.

**Materials and Methods**

**Subject population.** — Healthy volunteer participants were recruited from The University of Michigan Geriatrics Center Research Participant/Human Subjects Core. Twelve males and females aged 20–40 years and 12 males and females aged 60–80 years were included in the study (Table 1). The consent and protocol were approved by the University of Michigan Institutional Review Board.

Inclusion criteria for subject participation were: (a) not taking any nonprescription or prescription medications within the previous 7 days with the exception of birth control medications and hormone replacement therapy; (b) not currently being treated for any systemic disease; (c) absence of salivary gland pathology/disease; (d) evidence of unstimulated parotid function; (e) no history of head and neck cancer treatment; and (f) completion of consent form.

**General procedure.** — Subjects were admitted as inpatients in The University of Michigan General Clinical Research Center. Subjects did not eat, drink, smoke, or perform any oral hygiene for at least 90 min prior to entry into the study. At 8:00 a.m. each subject received a complete physical exam by a physician or physician’s assistant to ensure that the participant had no clinical signs or symptoms of systemic disease or dehydration. Sitting and standing (1 min after standing) baseline blood pressures and pulses were measured with an automated Dinamap vital signs monitor (Critikon, Inc., Tampa, FL). Throughout the study period, if any standing systolic blood pressure decreased more than 20 mmHg or diastolic blood pressure decreased more than 10 mmHg compared to the sitting blood pressures, then dehydration would have been terminated and the subject hydrated. If any standing pulse rate increased more than 20 beats per minute compared to a sitting pulse rate, then dehydration would have been terminated and the subject rehydrated.

Following entrance into the study, each subject was asked to empty his/her bladder and was then weighed to determine the baseline weight. Baseline unstimulated and stimulated parotid salivas were collected (see below), a xerostomia questionnaire administered (see below), and a blood sample collected (see below). Participants refrained from drinking any beverages and eating any foods for a 24-h period, and also avoided any exercise or strenuous activity during the course of the study. All urine was collected for the 24-h dehydration period. Throughout the study, each participant was examined for any clinical signs or symptoms of dehydration. Sitting and standing blood pressure and pulse rates were measured at 12:00 p.m., 4:00 p.m., 8:00 p.m., and 8:00 a.m. the next morning. Compared to sitting blood pressures, no standing systolic blood pressures decreased more than 20 mmHg and no diastolic blood pressures decreased more than 10 mmHg. Furthermore, no standing pulse rates increased more than 20 beats per minute compared to sitting pulse rates. No subject experi-

### Table 1. Subject Population Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Young Males</th>
<th>Older Males</th>
<th>Young Females</th>
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</tr>
</thead>
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<td>Age (mean ± SD)</td>
<td>27.3 ± 2.6</td>
<td>70.8 ± 1.6</td>
<td>24.8 ± 1.5</td>
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<td>Age range (years)</td>
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<td>20–29</td>
<td>62–74</td>
<td>20–76</td>
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enced clinical signs or symptoms of dehydration, and therefore there was no need to terminate dehydration in any of the study subjects.

At 8:00 a.m. the following morning the subject was asked to empty his/her bladder and was then weighed on the same scale. Unstimulated and stimulated parotid salivas were collected, the xerostomia questionnaire was administered, sitting and standing blood pressure and pulse rates were documented, a blood sample was collected, and an intravenous (i.v.) infusion was started (see below). This collection period is referred to as "24 h" in this report. One hour after completion of the i.v. infusion period (approximately 1.5–2 h), the subject was asked to empty his/her bladder and was weighed. Unstimulated and stimulated parotid flow rates were collected, the xerostomia questionnaire was administered, sitting and standing blood pressure and pulse rates were documented, and a blood sample was collected. This collection period is referred to as "27 h" in this report. Following the completion of these tests, the subject was provided with food and beverages ad libitum.

Dehydration/rehydration techniques and intravenous blood collection. — Dehydration was achieved via fluid and food restriction for 24 h. Because changes in water content are most precisely measured by changes in body weight (34), the loss of body fluid (L) over the 24-h period of the study was determined by the change in body weight (kg). The amount of fluid (L) lost due to dehydration was replaced with an intravenous infusion of isotonic normal saline (rate = 1,000 ml/h) following the 24-h period of fluid and food restriction. IV isotonic normal saline infusions have been used in previous investigations without any complications (35) at rates in excess of 1,000 ml/h (36). Every 30 min during the hydration period, a nurse listened to each subject’s lungs for evidence of rales. If rales or any other adverse signs or symptoms of excessive hydration would have been present, the hydration would have been terminated immediately. This did not occur in any research subject.

An antecubital intravenous cannula was inserted after the subject was admitted into the study. A blood sample (approximately 10 ml) was taken following saliva collection at each of the three time periods (see General Procedures). All blood samples were analyzed at one time by The University of Michigan Hospital Clinical Laboratories. Changes in blood volume were estimated from measurements in hematocrit and hemoglobin (37). Hemoglobin values were measured spectrophotometrically, using a GenS Coulter Counter automated at an optical density of 526 nm (Coulter Co., Miami, FL). Hematocrit was calculated by the Coulter Counter from the mean corpuscular volume and red blood cell count and did not take into account trapped plasma, which was <1%. Levels of total proteins (38–42), sodium (35,38,42,43), creatinine (35,43), serum osmolality (39–42), and urinary osmolality (39–42) have been used in clinical studies as good estimates of osmoregulation. Serum determinations for sodium, total protein, and creatinine were performed by standard clinical laboratory techniques on an Ektachem 700XR chemistry analyzer (Johnson & Johnson Clinical Diagnostics, Rochester, NY) using Ektachem thin film slide reagents. Serum and urine osmolality were measured by a freezing point depression technique on an Advanced Micro-Osmometer 3MO (Advanced Instruments, Norwood, MA).

Salivary collection. — All parotid salivary samples were collected in an identical manner by two calibrated examiners, as described previously (8,9). Saliva flow is termed "unstimulated" when no exogenous or pharmacological stimulation is used, and is termed "stimulated" when secretion is increased by gustatory stimuli. Participants wearing removable dental prostheses (dentures) were asked to remove them for the duration of the study. Parotid saliva was collected by placing a modified Carlson-Crittenden cup (Stone Machine Co., Colton, CA) over the orifice of one parotid gland (Stenson’s duct). If no unstimulated parotid flow was noted after 5 min, collection was discontinued and unstimulated parotid flow rate was recorded as zero (44). Subjects with an unstimulated parotid flow rate of zero at baseline were disqualified from the study and dismissed. Parotid saliva was stimulated with 2% citric acid applied to the dorsal lateral surface of the tongue for 5 sec at 30-sec intervals (10,45). Following a 2-min equilibration period during which saliva was not collected, stimulated parotid saliva was collected for 2 min. All saliva samples were collected in preweighed plastic graduated conical tubes. Output of saliva was determined gravimetrically and reported as mL/min.

Saliva was collected from six healthy, unmedicated subjects in a separate investigation by two investigators who were calibrated for unstimulated and stimulated parotid salivary flow rates. Unstimulated and 2% citrate-stimulated parotid salivas were collected from six unmedicated and healthy subjects by both investigators. Inter-examiner correlation coefficients were .986 for unstimulated parotid and .965 for stimulated parotid flow rates.

Xerostomia questionnaire. — Participants were asked the following seven questions about oral dryness:

1. Are you thirsty? (No/Yes) (Thirst)
2. Are your lips dry? (No/Yes) (DryLip)
3. Does the amount of saliva in your mouth seem to be too little (Yes), too much (No), or you don’t notice it (No)? (Saliva)
4. Do you have difficulties swallowing? (No/Yes) (Swallow)
5. Do you have any difficulties speaking? (No/Yes) (Speak)
6. Does your mouth feel dry when eating a meal? (No/Yes) (DryEat)
7. Do you sip liquids to aid in swallowing dry foods? (No/Yes) (SipLiq)

The abbreviations are used in Table 5. Four of these questions (nos. 3, 4, 6, and 7) have been correlated with objective findings of salivary gland dysfunction (46). Three of them (nos. 1, 2, and 5) have been previously used (46,47) in investigations of dry mouth, and dryness of the lips successfully predicts salivary gland hypofunction (48).

Statistical analysis. — Data were entered into a computer using RSI software (BBN, Boston, MA) and Systat.
RESULTS

Weight loss. — Overall, body weight decreased significantly during the 24-h dehydration period (*p < .001; Table 2). Younger males experienced a greater weight loss (-2.68 kg) than older males (-2.10 kg; *p = .03) and younger females (-1.50 kg; *p = .0001). When weight loss was expressed as a percentage of baseline body weight, dehydration-related weight loss was greater in males (mean loss = -2.84%; *p < .001) than in females (mean loss = -2.31%; *p = .0001), but there were no significant Age by Gender interactions. Upon rehydration with fluids, the percentage weight gain was greater in males than females (*p = .04), yet similar in younger and older subjects (Table 2). Consequently, body weights in all subjects increased nearly to baseline weights; however, they still remained significantly (*p = .0001) lower than baseline weights.

Parotid salivary gland flow rates. — No differences were detected between male and female salivary gland flow rates; therefore, male and female data were combined. Unstimulated parotid salivary gland flow rates were statistically indistinguishable in younger and older subjects at all visits (Table 3). Unstimulated parotid salivary flow rates were approximately 90% lower than baseline after the 24-h dehydration period in both young and older subjects (*p < .001). Decreases in flow rates and in the percentage change from baseline values were similar in younger and older subjects (Figure 1). An increase in unstimulated flow occurred during and after rehydration and was similar in younger and older subjects (Figure 1). However, median unstimulated flow rates did not return to baseline values (*p < .001) and remained 97.3% lower than baseline values in younger subjects and 61.8% lower in older subjects.

Stimulated parotid flow rates also decreased due to dehydration (Figure 2). The percentage change from baseline was significant among older subjects (-27.9%; *p = .03) but was not statistically significant for younger subjects (-6.62%; *p > .05; Table 3). Following rehydration, stimulated flow rates remained stable and were similar in younger and older subjects (Figure 2). Median stimulated flow rates at the completion of the rehydration phase were indistinguishable from baseline values.

Blood values. — Overall, hematocrit levels increased significantly during the 24-h dehydration period (*p < .001; Table 2).

Table 2. Metabolic Values: Age Group Data

<table>
<thead>
<tr>
<th></th>
<th>Mean Baseline ± SEM</th>
<th>Mean 24 h ± SEM</th>
<th>Mean % Change, Baseline vs 24 h</th>
<th>Mean 27 h ± SEM</th>
<th>Mean % Change, 24 h vs 27 h</th>
<th>Mean % Change, Baseline vs 27 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hematocrit</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Young (%)</td>
<td>39.3 ± 1.21</td>
<td>42.2 ± 1.37</td>
<td>+7.40*</td>
<td>39.0 ± 1.32</td>
<td>-7.73''</td>
<td>-0.97</td>
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<tr>
<td>Old (%)</td>
<td>39.5 ± .74</td>
<td>41.9 ± .84</td>
<td>+6.08*</td>
<td>39.7 ± .78</td>
<td>-5.38''</td>
<td>+0.35</td>
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<td>Hemoglobin (g/dl)</td>
<td>13.6 ± .42</td>
<td>14.8 ± .48</td>
<td>+8.33*</td>
<td>13.7 ± .44</td>
<td>-7.51''</td>
<td>+0.13</td>
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<tr>
<td>Old (g/dl)</td>
<td>13.6 ± .22</td>
<td>14.5 ± .29</td>
<td>+6.43*</td>
<td>13.8 ± .26</td>
<td>-5.05''</td>
<td>+1.02</td>
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<tr>
<td>Weight</td>
<td>77.0 ± 5.07</td>
<td>74.9 ± 4.93</td>
<td>-2.71*</td>
<td>76.7 ± 5.03</td>
<td>+2.36'</td>
<td>-0.42'</td>
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<tr>
<td>Young (kg)</td>
<td>75.6 ± 2.26</td>
<td>73.7 ± 2.17</td>
<td>-2.44*</td>
<td>75.2 ± 2.25</td>
<td>+1.92'</td>
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<tr>
<td>Old (kg)</td>
<td></td>
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</table>

*Difference between baseline and 24 h, *p < .001.
†Difference between 24 h and 27 h, *p < .001.
‡Difference between young and old, *p < .05.
§Difference between baseline and 27 h, *p < .001.
Table 3. Parotid Salivary Flow Rates: Age Group Data

<table>
<thead>
<tr>
<th></th>
<th>Mean Baseline ± SEM</th>
<th>Median Baseline</th>
<th>Mean 24 h ± SEM</th>
<th>Median Change, Baseline vs 24 h</th>
<th>Mean 27 h ± SEM</th>
<th>Median Change, Baseline vs 27 h</th>
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<td></td>
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<tr>
<td>Young (mL/min)</td>
<td>0.069 ± 0.030</td>
<td>0.040</td>
<td>0.016 ± 0.006</td>
<td>0.007</td>
<td>-88.6*</td>
<td>0.011</td>
</tr>
<tr>
<td>Old (mL/min)</td>
<td>0.066 ± 0.011</td>
<td>0.064</td>
<td>0.016 ± 0.007</td>
<td>0.005</td>
<td>-90.2*</td>
<td>0.008</td>
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<tr>
<td>Stimulated saliva</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Young (mL/min)</td>
<td>0.249 ± 0.051</td>
<td>0.188</td>
<td>0.214 ± 0.051</td>
<td>0.151</td>
<td>-6.62</td>
<td>0.202</td>
</tr>
<tr>
<td>Old (mL/min)</td>
<td>0.287 ± 0.061</td>
<td>0.245</td>
<td>0.222 ± 0.069</td>
<td>0.122</td>
<td>-15.9</td>
<td>0.206</td>
</tr>
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</table>

*Difference between baseline and 24 h, p < .001.
\(\text{\textit{V}} = 9; 3\) subjects had 24-h values = 0.
\(\text{\textit{V}} = 10; 2\) subjects had 24-h values = 0.
**Difference between baseline and 24 h, p < .05.

Figure 1. Unstimulated parotid salivary flow rates over time in 12 young and 12 older healthy subjects. Twenty-four-hour dehydration was commenced at time 0 h, rehydration was initiated at 24 h, and rehydration was completed at 26 h.

Table 2), and increases were statistically similar in both gender and age groups. Upon rehydration with fluids, hematocrit values decreased to baseline values and were statistically indistinguishable from baseline values in both gender and age groups. Percentage decreases due to rehydration were greater in younger than older subjects (p = .03), particularly younger males (-7.70%) compared to older males (-3.62%; p = .02). However, there were no differences between males and females.

Changes in hemoglobin levels reflected the same patterns seen in hematocrit values (Table 2). In summary, hemoglobin levels increased (p < .001) during dehydration and returned to baseline values 1 h after the rehydration period. Rehydration-related percentage decreases were greater in younger compared to older subjects (p = .04), but no gender-related differences were found.

Overall, serum sodium levels did not change throughout dehydration. There were no gender-related differences, yet
younger and older subjects displayed significantly different patterns ($p = .01$; Table 4). Throughout the rehydration phase, serum sodium values increased to a level indistinguishable from baseline in younger subjects, while older subjects remained elevated ($+2.63\%$; $p = .004$).

Plasma protein levels increased throughout the 24-h dehydration period, and increases were greater in younger compared to older subjects ($p < .05$; Table 4), but were similar in males and females. During rehydration, plasma protein levels decreased significantly ($p = .005$) to baseline levels without any significant age or gender interactions. However, post-rehydration percentage of baseline values was significantly lower in older females ($-5.32\%$) compared to older males ($-0.16\%$; $p = .04$).

Creatinine levels significantly increased from baseline levels (Table 4). Percentage increases were greater in younger than older subjects ($p = .05$), but no gender differences were found. During rehydration, creatinine levels decreased, and percentage changes in younger subjects were greater than in older subjects ($p = .05$). One hour after rehydration, creatinine levels decreased to baseline levels and were indistinguishable among both gender and age groups.

During dehydration, serum osmolality values slightly increased in young subjects and decreased in older subjects, yet changes were not statistically significant. There was an Age by Gender interaction, with young males ($-1.26\%$) and young females ($+1.52\%$; $p = .0001$) experiencing different trends. Throughout the rehydration period, serum osmolality values slightly decreased to levels indistinguishable from baseline ($p > .05$). During rehydration, percentage changes increased in males ($+0.55\%$) but not in females ($-0.77\%$; $p = .04$) and were statistically similar 1 h after rehydration. No gender- or age-related differences were observed at the completion of rehydration.

**Urine osmolality.** — Urine osmolality levels increased as a result of the 24-h dehydration period, yet the increase was not significant (Table 4). Older males experienced a percentage of baseline decrease during dehydration ($-13.2\%$) that was significantly different from that observed in older females ($+37.9\%$; $p = .03$). The rehydration phase caused urine osmolality values to decrease to values that were statistically indistinguishable from baseline.

**Xerostomia questionnaire.** — No differences were detected between male and female responses; therefore, male and female data were combined. In six out of the seven questions, there were more complaints of a dry mouth after the dehydration period compared to baseline (Table 5). However, these increased complaints at 24 h were only significant compared to baseline for the thirst question (younger subjects, $p > .05$; older subjects, $p < .05$) and the dry lips question (younger subjects, $p < .025$; older

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Figure 2. Two percent citrate stimulated parotid salivary flow rates over time in 12 young and 12 older healthy subjects. Twenty-four-hour dehydration was commenced at time 0 h, rehydration was initiated at 24 h, and rehydration was completed at 26 h.
The results reveal that parotid salivary flow rates decreased after a 24-h period of food and fluid abstinence with a concomitant increase in complaints of xerostomia. Following rehydration during which weight, hemoglobin, hematocrit, plasma protein, and creatinine values returned to baseline levels, parotid flow rates did not return to baseline levels and complaints of xerostomia persisted. Overall, there were no age or gender differences in flow rates or responses to xerostomia.

Body weights decreased significantly during dehydration, reflecting fluid loss. Weights did not completely return to baseline levels, parotid flow rates did not return to baseline levels and complaints of xerostomia persisted. Overall, there were no age or gender differences in flow rates or responses to xerostomia.

**DISCUSSION**

**Correlation data.** — Correlations were performed to determine if there was a relationship between the level of hydration (assessed with seven metabolic parameters: hematocrit, hemoglobin, serum sodium, plasma protein, creatinine, serum osmolality, and urine osmolality) and salivary flow rates at baseline, 24 h, and 27 h. Overall, no statistically significant correlations were observed. Next, correlation tests were performed to determine if the change in salivary flow rate, due to dehydration and rehydration, was related to a similar change in hydration status. In general, very few significant trends were observed. Finally, analyses were conducted to determine if the percentage of baseline change in salivary flow rate was related to a percentage of baseline change in hydration status. Overall, no consistent trends were observed.

**Table 4. Metabolic Values: Age Group Data**

<table>
<thead>
<tr>
<th>Metabolic Parameter</th>
<th>Mean Baseline ± SEM</th>
<th>Mean 24 h ± SEM</th>
<th>Mean % Change, Baseline vs 24 h ± SEM</th>
<th>Mean 27 h ± SEM</th>
<th>Mean % Change, 24 vs 27 h ± SEM</th>
<th>Mean % Change, Baseline vs 27 h ± SEM</th>
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<tbody>
<tr>
<td>Serum sodium</td>
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<tr>
<td>Young (mEq/L)</td>
<td>138.8 ± .55</td>
<td>137.8 ± .76</td>
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<td>138.5 ± .66</td>
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<td>-0.17*</td>
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<tr>
<td>Old (mEq/L)</td>
<td>136.3 ± 1.35</td>
<td>137.5 ± 1.62</td>
<td>+9.4*</td>
<td>139.8 ± .82</td>
<td>+1.74*</td>
<td>+2.63*</td>
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<td>Plasma protein</td>
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<tr>
<td>Young (g/dL)</td>
<td>6.74 ± .14</td>
<td>7.28 ± .11</td>
<td>+8.98**</td>
<td>6.61 ± .11</td>
<td>-9.14*</td>
<td>-1.94*</td>
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<tr>
<td>Old (g/dL)</td>
<td>6.52 ± .07</td>
<td>6.72 ± .10</td>
<td>+3.21*</td>
<td>6.33 ± .08</td>
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<tr>
<td>Young (mg/dL)</td>
<td>0.89 ± .05</td>
<td>1.01 ± .06</td>
<td>+13.3**</td>
<td>0.91 ± .05</td>
<td>-9.45**</td>
<td>+2.21*</td>
</tr>
<tr>
<td>Old (mg/dL)</td>
<td>0.91 ± .038</td>
<td>0.91 ± .026</td>
<td>+1.37**</td>
<td>0.87 ± .036</td>
<td>-4.69*</td>
<td>-4.24*</td>
</tr>
<tr>
<td>Serum osmolality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young (mOsm/kg)</td>
<td>288.5 ± 1.43</td>
<td>288.8 ± 1.13</td>
<td>+13</td>
<td>288.5 ± 1.62</td>
<td>-10</td>
<td>+1.01</td>
</tr>
<tr>
<td>Old (mOsm/kg)</td>
<td>292.6 ± 1.50</td>
<td>291.2 ± 1.24</td>
<td>-47</td>
<td>290.8 ± 1.24</td>
<td>-11</td>
<td>-5.82</td>
</tr>
<tr>
<td>Urine osmolality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young (mOsm/kg)</td>
<td>785.8 ± 93.5</td>
<td>796.6 ± 49.8</td>
<td>+77.3</td>
<td>859.0 ± 61.6</td>
<td>-10.9</td>
<td>+53.1</td>
</tr>
<tr>
<td>Old (mOsm/kg)</td>
<td>752.8 ± 68.1</td>
<td>775.5 ± 42.3</td>
<td>+12.4</td>
<td>569.7 ± 57.4</td>
<td>-25.5*</td>
<td>-17.6</td>
</tr>
</tbody>
</table>

*Difference between young and old, p < .05.
*Difference between baseline and 24 h, p < .005.
*Difference between baseline and 24 h, p < .05.
*Difference between 24 h and 27 h, p < .05.

**Table 5. Percentage of Positive Responses to Xerostomia Questionnaire**

<table>
<thead>
<tr>
<th>Question</th>
<th>Baseline (%)</th>
<th>24 h (%)</th>
<th>27 h (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thirst</td>
<td></td>
<td>41.7%</td>
<td>75.0%</td>
</tr>
<tr>
<td>Young</td>
<td>0.0%</td>
<td>50.0%</td>
<td>33.3%</td>
</tr>
<tr>
<td>Old</td>
<td>16.7%</td>
<td>66.7%</td>
<td>58.3%</td>
</tr>
<tr>
<td>Dry Lip</td>
<td></td>
<td>33.3%</td>
<td>91.7%</td>
</tr>
<tr>
<td>Young</td>
<td>16.7%</td>
<td>25.0%</td>
<td>16.7%</td>
</tr>
<tr>
<td>Old</td>
<td>16.7%</td>
<td>8.3%</td>
<td>8.3%</td>
</tr>
<tr>
<td>Saliva</td>
<td></td>
<td>8.3%</td>
<td>8.3%</td>
</tr>
<tr>
<td>Young</td>
<td>0.0%</td>
<td>8.3%</td>
<td>8.3%</td>
</tr>
<tr>
<td>Old</td>
<td>0.0%</td>
<td>8.3%</td>
<td>8.3%</td>
</tr>
<tr>
<td>Swallow</td>
<td></td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Young</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Old</td>
<td>0.0%</td>
<td>8.3%</td>
<td>8.3%</td>
</tr>
<tr>
<td>Speak</td>
<td></td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Young</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Old</td>
<td>0.0%</td>
<td>8.3%</td>
<td>8.3%</td>
</tr>
<tr>
<td>Dry Eat</td>
<td></td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Young</td>
<td>0.0%</td>
<td>0.0%</td>
<td>8.3%</td>
</tr>
<tr>
<td>Old</td>
<td>0.0%</td>
<td>8.3%</td>
<td>8.3%</td>
</tr>
<tr>
<td>Sip Lq</td>
<td></td>
<td>16.7%</td>
<td>16.7%</td>
</tr>
<tr>
<td>Young</td>
<td>16.7%</td>
<td>25.0%</td>
<td>25.0%</td>
</tr>
<tr>
<td>Old</td>
<td>25.0%</td>
<td>25.0%</td>
<td>25.0%</td>
</tr>
</tbody>
</table>

*See Materials and Methods for actual questions.
*Difference between young and old, p < .05.
*Difference between baseline and 24 h, p < .05.
to baseline levels upon rehydration despite total fluid replacement; this was probably due to urination during rehydration. A greater weight loss in males compared to females was probably due to a greater ratio of total body water to body weight in males (49). However, dehydration-related weight losses were similar in younger and older subjects, consistent with previous reports (38).

Hematocrit and hemoglobin increases confirmed fluid loss and dehydration, and subsequent decreases to baseline levels indicated metabolic rehydration following the IV fluid intake. There was a larger rehydration-related decrease in hematocrit and hemoglobin levels in younger compared to older subjects due to greater total body water content in younger adults (50). Plasma protein and creatinine levels increased during dehydration, indicating a fluid deficit with loss of extracellular fluid and greater plasma concentration (42). Subsequent decreases to baseline levels mirrored metabolic rehydration. The changes in plasma protein due to dehydration and rehydration were greater in younger subjects, consistent with previous reports (40), suggesting that age-related alterations in peripheral circulation limit vasodilation (41).

Decreased age-related changes in creatinine may be due to reduced creatinine production with age (51). Urine osmolality changes also reflected dehydration and rehydration, and values were lower in older subjects, demonstrating an age-reduced urinary concentrating ability after water deprivation (52–55) and a decline in glomerular function with age (51). No significant changes were seen in serum sodium and osmolality, typical indicators of severe dehydration (56,57), which was not experienced in this study. Alternatively, mild dehydration is usually measured by altered body weight and altered hematocrit and hemoglobin levels, which were observed in this study.

The relationship between salivary output and hydration status is still unclear because overall there were no consistent correlations between salivary and metabolic parameters. The data from this study do suggest, however, that in healthy adults, gender and age are not major factors in the relationship between hydration and saliva output. Neurologic, endocrine, and other metabolic parameters control body hydration and salivary output; if a relationship does exist between these two factors, further studies will need to examine numerous parameters over a longer period of time.

Unstimulated parotid flow rates were significantly reduced after dehydration. This has been reported previously (26–29), yet to our knowledge this is the first investigation that has attempted to control for conditions (e.g., medications, medical problems, time of day, salivary collection method, type of stimulation) that are now known to influence salivary production. It was hypothesized that reduced body fluids would cause parotid hypofunction because the predominant fluid constituent of saliva is water, which enters saliva from plasma across acinar cells (58).

Stimulated parotid flow rates also decreased due to dehydration; however, these changes were considerably less than for unstimulated output. In order for water to move from plasma through acinar cells to form primary saliva, a trans-acinar cell salt gradient must be generated (58). Dehydration may cause the extracellular fluid to reflect an increased salt concentration. Accordingly, a greater salt concentration will have to be generated across the salivary acinar cell in order to drive fluid into the acinar lumen. This could account for the significant dehydration-induced decrease in unstimulated saliva. During stimulation, however, it is possible that cholinergic or muscarinic input from a gustatory (citric acid) stimulus could overcome the osmotic gradient and produce more saliva compared to the unstimulated state. For example, a recent report demonstrated that muscarinic stimulation of human acinar cells produces a transepithelial Cl⁻ secretion, driven by a Na⁺-K⁺-Cl⁻ co-transporter, which results in increased primary salivary fluid secretion into the acinar lumen (59).

An unexpected finding of the study was that unstimulated parotid flow rates did not return to pre-dehydration levels following metabolic rehydration. Perhaps the constant level of parasympathetic stimulation required for salivary production (60) is diminished during dehydration. Alternatively, while IV rehydration rapidly reversed the dehydration (measured by weight, hematocrit, and hemoglobin), the return to normal hydration homeostasis in the salivary acinar cell environment may be delayed beyond that measured in this investigation.

No significant differences in unstimulated or stimulated parotid flow rates were detected between younger and older subjects, consistent with other studies in healthy individuals (7–13). However, parotid glands undergo significant loss of acinar (fluid-producing) cells with aging (61). This discrepancy between histomorphometric and functional findings may be due to the presence of a secretory reserve (14,61). Wu et al. (62) postulated that this secretory reserve in older healthy adults may be sufficient to maintain salivary output while overcoming the loss of acinar cells. The current study found that the relationship between dehydration and salivary output was age-independent, which is consistent with the presence of a salivary secretory reserve.

Despite metabolic dehydration and reduced salivary output, responses to the subjective questionnaire indicated a significant increase in only two xerostomia complaints: dry lips and thirst. These results demonstrate that the complaint of a dry mouth may not be a good indicator of salivary hypofunction, consistent with previous reports (46). Interestingly, despite similar salivary changes in both age groups, younger subjects in the present study complained more often of thirst and dry lips than older subjects. Previous dehydration studies reported that older adults were less likely to complain of thirst and were subsequently less likely to replace lost fluids (38). There are probably multiple factors (e.g., baroreceptors, oral mucosal changes, major and minor salivary constituents, psychologic responses to physiological phenomena) that contribute to age-related differences in xerostomia and thirst complaints.

The results of this study have clinical ramifications. Unstimulated saliva plays a major role in the protection of the host (1), and dehydration caused a significant (90%) reduction in these secretions. This decrease occurred in the absence of systemic diseases and medications that are known to cause salivary dysfunction (17), and after only mild dehydration without overt signs of severe dehydration. Therefore, it is possible that adults (especially those with
medical conditions and taking drugs) who undergo an acute episode of dehydration or who are chronically dehydrated, may develop salivary gland dysfunction. Stimulated saliva is also essential for oral health because these fluids protect the host during mastication and deglutition (1). Stimulated flow rates were reduced 20% during dehydration, which could lead to chewing, swallowing, aspirational, and gastrointestinal problems. However, the effect of dehydration on stimulated flow rates was much less than on unstimulated flow rates. This finding suggests that increasing salivary output with gustatory, masticatory, or pharmacologic stimuli (17) could help overcome the influence of dehydration or other factors on salivary gland function.

Despite complete metabolic rehydration, salivary flow rates did not return to baseline levels. The potential clinical correlate of this finding is that while a systemic disorder may be corrected (e.g., dehydration), the oral sequelae of this disorder (e.g., salivary gland dysfunction) may manifest itself for a longer period of time.

Older adults in this study were less likely to complain of xerostomia; however, they experienced similar dehydration-related decrements in saliva output as younger subjects. In general, older individuals complain less frequently of pain and other symptoms compared to younger adults (63), which could increase the risk of developing stomatologic diseases. Therefore, older adults should be routinely queried and examined for salivary gland dysfunction. In conclusion, dehydration may predispose adults to salivary gland dysfunction. These results can assist health care practitioners identify and prevent oral-medical disorders among their patients.

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REFERENCES

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