AQUATIC THERAPY IS USED IN PHYSICAL REHABILITATION OF HUMANS.1 Water is used because of buoyancy, drag, inertia, turbulence, hydrostatic pressure, and thermal effects.2 Aquatic therapy allows humans to perform exercises similar to those performed without immersion but at a lower heart rate or lower speed.3,4 It improves functional fitness and well-being.5 Aquatic exercise decreases pain and joint stiffness and increases physical function, quality of life, and muscle strength in humans with osteoarthritis of the hip and knee joints,6 and it has similar benefits for osteopenic patients.7 Aquatic therapy has been used during the rehabilitation and conditioning of companion animals.8–10,a

EFFECTS OF PARTIAL IMMERSION IN WATER ON VERTICAL GROUND REACTION FORCES AND WEIGHT DISTRIBUTION IN DOGS

David Levine, PhD; Denis J. Marcellin-Little, DEDV; Darryl L. Millis, DVM, MS; Verena Tragauer, Mag Med Vet; Jason A. Osborne, PhD

**Objective**—To assess the impact of partial immersion in water on vertical ground reaction force (vGRF) and vGRF distribution in dogs.

**Animals**—10 healthy adult dogs.

**Procedures**—Weight placed on each limb of each dog was measured 3 times (1 scale/limb). Dogs were then immersed in water to the level of the tarsal, stifle, and hip joints, and vGRFs were measured. Coefficients of variation for triplicate measurements were calculated. Mixed-effects ANOVAs were used to compare the vGRF for thoracic versus pelvic limbs and the vGRF at various immersion levels as well as the vGRF distributions among limbs at various immersion levels.

**Results**—Mean ± SD vGRF before immersion was 249 ± 34 N. It was significantly decreased by 9% after immersion to the tarsal joints (227 ± 32 N), by 15% after immersion to the stifle joints (212 ± 21 N), and by 62% after immersion to the hip joints (96 ± 20 N). The vGRFs were significantly higher for the thoracic limbs than for the pelvic limbs before immersion and at all immersion levels. Dogs placed 64% of their weight on the thoracic limbs before immersion. That ratio did not differ significantly after immersion to the tarsus (64%) or stifle (63%) joints, but was significantly larger after immersion to the hip joints (71%).

**Conclusions and Clinical Relevance**—vGRF decreased as the depth of immersion increased. The thoracic limb-to-pelvic limb vGRF ratio was unchanged in dogs after immersion to the tarsal or stifle joints, but it increased after immersion to the hip joints. (Am J Vet Res 2010;71:1413–1416)

**Abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>UWMT</td>
<td>Underwater treadmill</td>
</tr>
<tr>
<td>vGRF</td>
<td>Vertical ground reaction force</td>
</tr>
</tbody>
</table>

Little is known about the buoyancy and weight distribution between the thoracic and pelvic limbs for dogs at various levels of immersion. Therefore, the purpose of the study reported here was to assess changes in vGRF and vGRF distribution in dogs standing on the ground without immersion and standing in water on a UWMT with immersion to the level of the tarsal, stifle, and hip joints. We hypothesized that increasing the depth of immersion would result in a decrease in vGRF for all limbs and that there would be a proportionally higher vGRF for the thoracic limbs as compared with that for the pelvic limbs.

**Materials and Methods**

**Dogs**—Ten mixed-breed dogs that each weighed > 20 kg were randomly selected from a group of university-owned dogs used for teaching purposes. Body condition score was 5 (scale of 1 to 9).11 Orthopedic and neurologic examinations were performed, and dogs were excluded from the study when orthopedic or...
Data collection—Four scales were calibrated for use without immersion and after immersion under water. All measurements were made in triplicate. Each limb of each dog was placed on a separate scale, and the vGRF was recorded simultaneously. The dogs were then placed on a UWTM. Similar measurements were made in triplicate with the dogs immersed in water to the level of the lateral malleolus, lateral femoral epicondyle, and greater trochanter. These anatomic landmarks corresponded to the tarsal, stifle, and hip joints, respectively. All dogs stood squarely and symmetrically on the scales, with each foot placed in the middle of the weighing platform. In addition, the head of each dog was maintained in a neutral position without turning to either side.

Statistical analysis—The sums of vGRF measurements from both thoracic limbs and both pelvic limbs were used for analysis. Coefficients of variation for all triplicate measurements and for thoracic and pelvic limbs at various immersion levels were calculated. A mixed-effects ANOVA with limbs and immersion levels as fixed effects and dogs as random effects was used to compare the vGRF of thoracic and pelvic limbs and the vGRF at various immersion levels. A mixed-effects ANOVA with dogs and the dog X immersion interaction as random effects was used to compare the vGRF distribution between the thoracic and pelvic limbs at various immersion levels. Significance was set at values of .05.

Results

Five sexually intact male and 5 sexually intact female dogs were used in the study. Dogs ranged from 2 to 7 years of age (mean, 5.7 years). The coefficient of variation for measurements made in triplicate ranged from 0% to 24.1% (mean, 4.0%). Mean ± SD body weight of the dogs was 25.4 ± 3.5 kg, which corresponded to a mean vGRF of 249 ± 34 N before immersion. Mean vGRF decreased significantly (P < 0.001) by 9% (227 ± 32 N) after immersion to the level of the tarsal joints, by 15% (212 ± 21 N) after immersion to the level of the stifle joints, and by 62% (96 ± 20 N) after immersion to the level of the hip joints. Mean vGRFs were significantly (P < 0.001) higher for the thoracic limbs than for the pelvic limbs before immersion and at all immersion levels. The dogs placed 64% of their body weight on the thoracic limbs before immersion (Figure 1). The thoracic limb-to-pelvic limb vGRF ratio did not differ significantly after immersion to the level of the tarsal (64%) or stifle (63%) joints, but was significantly (P < 0.001) larger after immersion to the level of the hip joints (71%). Coefficients of variation among dogs for the thoracic and pelvic limbs before immersion were 14% and 13%, respectively. These coefficients of variation were 14% and 17%, respectively, after immersion to the level of the tarsal joints; 14% and 13%, respectively, after immersion to the level of the stifle joints; and 18% and 14%, respectively, after immersion to the level of the hip joints.

Discussion

Walking on a UWTM has been used in companion animal rehabilitation, but little is known about the impact exercise on a UWTM has on decreases in joint loads and vGRF distribution as well as the relative benefits of exercise performed on a UWTM, compared with benefits of exercise performed without immersion. The benefits of walking with partial immersion are clearly established in humans. Aquatic exercises appear equally beneficial to exercise performed without immersion with regard to increasing strength and improving cardiovascular fitness. Exercising in water allows people to exercise at a lower heart rate and at lower walking or jogging speeds while maintaining an energy expenditure identical to that of exercise without immersion. A similar cardiovascular response has been suggested for dogs exercising on a UWTM. In humans with osteoarthritis, exercising in water appears to be associated with less pain and fewer adverse events than does exercising without immersion. Aquatic therapy alone appeared to be beneficial in short-term trials. However, the long-term functional benefits of aquatic therapy were inferior to the long-term benefits of exercise performed without immersion in a prospective controlled trial.

In the study reported here, we determined the changes in vGRF and vGRF distribution in dogs standing on a UWTM. The impact of immersion in water on joint loads and vGRF distribution while walking or trotting on a UWTM is not known in dogs and cannot be determined from this study. However, because joint loads are proportional to the vGRF, it is logical to assume that the vGRF decreases for dogs immersed in water while on the UWTM would lead to proportional decreases in joint loads during walking and trotting. Similar decreases in joint loads when exercising with partial immersion have been confirmed in humans. A 3- to 5-fold decrease in vertical forces was detected...
in humans walking under several conditions while immersed in 1.3 m of water, compared with results for locomotion while not immersed in water." The vGRF for thoracic and pelvic limbs decreased only slightly after immersion up to the tarsal and stifle joints. This slight decrease could have positive clinical effects in patients with osteoarthritis. Also, walking or trotting in shallow water appears to lead to a gait with a larger active range of motion; thus, flexion of the hip, stifle, and tarsal joints is increased maximally with immersion to the level of the stifle joints, compared with flexion without immersion or with flexion during immersion to the level of the tarsal joint or greater trochanter. This may be attributable to the fact that dogs immersed to the level of the pelvis increased their range of motion in the hip, stifle, and tarsal joints to allow walking or trotting in water rather than through air. Because of the decrease in active range of motion may be desirable during rehabilitation. The vGRF for thoracic and pelvic limbs decreased by more than half after immersion up to the hip joints. As a consequence, the loads placed on injured or healing tissues would be substantially lower for dogs exercising with a high water level on a UWTM, compared with loads for dogs exercising at similar speeds without immersion. However, it is possible that muscle forces placed on limbs and joints during the swing phase of the gait may be greater as a result of the drag and turbulence present when moving the limbs through water rather than through air. Because of the quadruped stance in dogs, the decreases in vGRF that resulted from increased depth of immersion of dogs are less than those in humans, whereby the vGRF decreased after women and men were immersed to the level of the anterior superior iliac spine (49% to 60% and 44% to 50%, respectively), xiphoid process of the sternum (69% to 73% and 63% to 70%, respectively), and seventh cervical vertebra (91% to 94% and 90% to 93%, respectively).21

Exercising dogs on a UWTM that is sloped upward could potentially lead to a further decrease in weight bearing in partially immersed dogs. This would allow the entire body of a dog to be immersed (except for the neck and head), similar to the situation in immersed humans. However, this would most likely affect the thoracic limb-to-pelvic limb weight distribution. In addition, walking in deeper water leads to a gait with a decreased range of motion in the hip, stifle, and tarsal joints of dogs, compared with the gait when walking on land. This may also be of benefit when conducting therapeutic exercises that cause joint pain or when joints have suboptimal stability. In humans, the range of motion of the stifle joint is decreased when walking immersed in water up to the axilla, compared with that when walking without immersion.22

The thoracic limb-to-pelvic limb vGRF ratio was not affected when dogs were immersed in water up to the tarsal or stifle joints, but a shift toward the thoracic limbs was evident when dogs were immersed up to the hip joints. Although the proportion of vGRF for the thoracic limbs was greatest with immersion up to the hip joints, the actual vGRF for the thoracic limbs was decreased, compared with values for immersion up to the tarsal or stifle joints. The lack of a significant increase in the coefficient of variation among dogs after immersion up to the hip joints, compared with that for dogs before immersion or after immersion up to the tarsal or stifle joints, indicated that the forward shift of the vGRF was uniform among dogs. A larger thoracic limb-to-pelvic limb vGRF ratio may be desirable when exercising dogs on a UWTM, such as when attempting to minimize the loads placed on the pelvic limbs. The level of water at which the vGRF increase was initiated could not be determined in this study because an increase in the thoracic limb-to-pelvic limb vGRF ratio was not detected with immersion to the stifle joints. The effect of body conformation and the amount of adipose tissue would potentially impact the reduction and distribution in vGRF for dogs walking after partial immersion. The amount and distribution of adipose tissue influences buoyancy in humans.23

We concluded from the study reported here that the vGRF for all limbs decreased proportionally with increasing depth of immersion in water. The thoracic limb-to-pelvic limb vGRF ratio was not affected by immersion in water to the level of the tarsal or stifle joints, but that ratio increased after immersion in water to the level of the hip joints.

References