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Anatomic landmarks facilitate predictable partial lower limb loading during aquatic weight bearing

Ami R. Stuart, Ph.D., Justin Doble, B.S., Angela P. Presson, Ph.D, and Erik N. Kubiak, M.D.
University of Utah, Salt Lake City

INTRODUCTION

Periarticular fractures of the lower extremity and pelvis are common and can lead to temporary or permanent disability.¹ A long-term complication of these injuries is post-traumatic arthritis that can lead to arthrodesis or arthroplasty. Protecting these articular fractures from excessive loading during the postoperative recovery period is thought to play an important role in prevention of posttraumatic arthritis potentiated by premature implant failure, limb malalignment and fracture nonunion.^{2,3} Despite these concerns, some degree of weight bearing is necessary to activate osteoblasts and other cells responsible for bone healing.⁴ Further complicating matters, prolonged immobilization of a postsurgical joint can lead to fibrosis and scarring that can cause significant functional loss.^{5–9}

In an attempt to produce an optimal mechanical environment at various stages of fracture healing, clinicians routinely prescribe partial weight bearing for lower extremity fracture after a period of nonweight bearing.⁴ Partial weight bearing prescription includes progressively increasing limb loading over time, which varies between patients based on the extent of the injury and the discretion of the clinician.

Alternatively, aquatic therapy is inexpensive, convenient in most US cities and towns, uncomplicated, has high compliance, and is easy to monitor.^{7,10,11,12} Patients also return to work 30–60% earlier using aquatic therapy,^{13,14} and generally tend to favor this option.^{8,15}

Aquatic therapy has several characteristics that make it ideal for early mobilization. Buoyancy in water serves as a protective medium and allows for less strenuous exercise compared with “dry land” techniques.^{6,7} Buoyancy decreases effective body weight and reduces load on joints^{6–8,11,12,16} and increases active range of motion of the joint to facilitate movements that would otherwise be too difficult postoperatively.^{10,11,12,15,16}

Patients have reported increased exercise security with aquatic therapy because there is no risk of falling or refracture while immersed in the pool.^{10,15} Furthermore, the reduction in stiffness, swelling and pain associated with aquatic therapy promotes an earlier return to everyday activities and work, which is desirable.^{10,11} Additional characteristics that make

Correspondence to: Erik Kubiak, M.D., 590 Wakara Way, Salt Lake City, Utah 84108, Tel. (801) 587-5400, Fax. (801) 587-7117, erik.kubiak@hsc.utah.edu.

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aquatic therapy ideal for early mobilization include the allowance of graduated increases of lower extremity loading due to the decrease in displacement with depth of immersion. Since the water provides the partial weight-bearing environment, upper extremity muscle mass is not required to protect the lower extremity. In elderly patients and those who have decreased upper extremity muscle mass resulting in a diminished ability to effectively protect the lower extremity this is especially important.^{10,17–21}

Research on static weight while submerged in water has been conducted with healthy adults. A study performed in 1987 found that with immersion to the C-7 (neck) level weight bearing was reduced to 5.9–10% of actual body weight; with immersion to the xiphosternum (nipple), a 25–37% reduction was noted, and with immersion to the anterior superior iliac spine (navel) 40–56%.²² A follow-up study in 1992 examined aquatic weight bearing while standing and slow and fast walking in nine subjects and found that weight was reduced to 25–50% of dry land weight with water at trunk level and 50–75% at clavicle level.²³ These studies suggest aquatic weight bearing to be a safe means of reducing limb loading while allowing patients to partially weight bear but are limited in applicability to orthopaedic fracture patients as the participants in these studies were healthy volunteers.

We have employed aquatic therapy as a means by which to facilitate progressive weight bearing in a controlled fashion. Decreasing the depth of immersion based on anatomic landmarks allows for a graduated increase in lower extremity loading. As the body is immersed in water, joints are naturally unloaded, and the effective weight of the body is reduced. This facilitates a greater range of motion and allows for exercises that would otherwise be too difficult under normal weight conditions.^{10,12,15,16} Since the water provides the partial weight-bearing environment, there is no significant demand on the patient's upper extremities to protect the lower extremity.

We sought to determine if anatomic landmarks (neck, nipple, and navel) can be used to facilitate, in a controlled fashion, a graduated progression in lower-limb loading during rehabilitation for a periarticular fracture. We hypothesized that (1) immersion to the level of the three anatomic landmarks will correlate with the degree of loading as a percentage of dry weight, (2) loading to each anatomic landmark will be reliable, and (3) using the anatomic landmarks in aquatic therapy will ensure the patient does not overload the lower extremity during partial weight bearing.

MATERIALS AND METHODS

The aim of this study was to determine if the anatomic landmarks of neck, nipple, and navel could be used to facilitate a controlled, graduated progression in lower limb loading for rehabilitation from a periarticular fracture. Along these lines, we studied whether limb load reduction was maintained in both male and female patients regardless of their percent body fat and dry weight. Furthermore, we investigated the difference in weight bearing at the extremes of the breath cycle (full exhalation and full inhalation) to ensure consistency under normal conditions.

After Institutional Review Board approval, all patients referred to aquatic therapy at the University Orthopaedic Center were considered for participation. Prior to enrollment, all patients completed informed consent. Data were collected prospectively at our orthopaedic center pool by a licensed physical therapist and our research staff. These prospectively obtained data were used to characterize weight bearing.

Sixty-one consecutive patients with periarticular fractures who were referred by their surgeon to and attended pool therapy between November 2008 and January 2009 and were willing to submit to body fat percentage measurements were included in the study. No enrolled patients dropped out of the study, but data were lost in nine patients because of irreparable failure of the submersible force plate used to measure weight during immersion.

Before measuring submersion weights, the subjects underwent land-based weight measurements on a calibrated force plate. Additionally, they were subjected to three caliper measurements of soft-tissue by a single licensed physical therapist trained in measuring body fat. Males were measured at the thigh, suprailiac, and chest regions, and females were measured at the thigh, suprailiac, and tricep regions.²¹ For each patient the measures were summed and converted to body fat percentage using the Drunin and Womersley empiric formula.²¹

To gather weight in water data, patients either lowered themselves or were lowered using a mechanical lift into the therapy pool. The patients were then asked to stand on a S-type hermetically sealed submersible load cell (Load Cell Central, Milan, PA, USA) affixed to a flat plate platform that was zeroed for each patient and submerged into the pool. Force measurements were recorded at the level of the navel (approximately 10 cm superior to the anterior superior iliac spine) and averaged. Next, patients were immersed to the level of the nipple (midsternum) and the above process was repeated. Finally, the process was repeated with immersion to the level of the neck (C7) with full lung inhalation and full exhalation to verify consistency in weight reduction at the extremes of a breath cycle. Three measurements were taken at each level for test-retest reliability.

Submerged body weights were standardized to percent dry weight for analysis by dividing each patient's submerged weight by his or her dry weight. Age, sex, dry weight, body fat percentage, and percent dry weights across submersion levels were summarized by the mean, standard deviation and range. Percentage dry weight was compared between men and women using Welch two-sample t-tests. Percentage dry weight was compared with percent body fat and dry weight using Pearson correlation stratified by submersion level and sex. Percentage dry weight at the neck while inhaling was compared with weight at the neck while exhaling across the combined samples using a paired t-test. Nonparametric tests were considered if distributions did not achieve approximate normality. Significance was assessed at the 0.05 level, and all tests were two-tailed. Statistical analyses were conducted in R (version 2.15.2, <http://www.R-project.org>).

RESULTS

Sixty-one patients attended pool therapy and were willing to submit to weight and body fat percentage measurements. There were 44 women and 17 men, with a mean age of 55.4 years (SD = 15.9, range: 21.0–84.0). The mean dry weight of women was 76.9 kg (SD = 19.5) while men were measured at 87.1 kg (SD = 13.3)(Table 1). Mean body fat for women was 40.3% (SD = 8.7%) and 29.3% (SD = 7.2%) for men.

Percentage dry body weights were similar across men and women for most immersion levels, with a mean of 7.9% (SD = 3.3%) at the neck while exhaling and 6.0% (SD = 2.7%) at the neck while inhaling, 23.9% (SD = 5.9%) at the nipple, and 51.4% (SD = 5.6%) at the navel (Figure 1; Table 1). While men had a tendency to experience slightly less load bearing than women (by about 1–5%) only the navel-level difference was statistically significant ($P = 0.012$).

Across all samples, the mean percent dry weight at the neck level while inhaling was 6.0% (SD = 2.7%), which was significantly different from the mean while exhaling 7.9% (SD = 3.3%, $P < 0.001$)(Table 1). These differences were maintained when men and women were analyzed separately ($P < 0.001$).

To check for consistency between percent dry weight and percent body fat, we plotted these values and calculated correlations at each submersion level within men and women (Figure 2). As expected, most correlations were not significant, ranging from -0.34 to 0.28 . The exception was among women at the neck level while exhaling, where increasing percent body fat was correlated with a decrease in percent dry body weight ($r = -0.64$, 95% CI: -0.78 to -0.42 ; $P < 0.001$). Similarly, percent dry body weight was consistent across dry weight values, where most correlations were not significant, ranging from -0.43 to 0.12 . The exceptions were again among women at the neck level, where both inhale ($r = -0.36$, 95% CI: -0.60 to -0.07 ; $p = 0.016$) and exhale status ($r = -0.61$, 95% CI: -0.77 to -0.38 ; $P < 0.001$) achieved statistical significance.

DISCUSSION

Available data suggests patient compliance with physician restrictions on weight bearing is poor. Partial weight bearing is routinely prescribed for lower extremity fracture and involves a gradual increase in the amount of weight that is placed on the affected limb.^{4,10,24,25} The ability of patients to comply with their partial weight bearing prescription presents a great barrier. Patients given touch down partial weight bearing instructions show a large variation in the amount of partial weight bearing experienced.¹³

In this study, we sought to determine if anatomic landmarks (neck, nipple, and navel) can be used to facilitate, in a controlled fashion, a graduated progression in lower limb loading during rehabilitation for a periarticular fracture. Similar to previous studies we found that immersion to the level of the three anatomic landmarks correlates with the degree of loading as a percentage of dry weight, loading to each anatomic landmark is reliable, and using the anatomic landmarks in aquatic therapy ensures that the patient does not overload the lower extremity during partial weight bearing.

Using a Salter spring balance, Harrison and Bulstrode²² found immersion to the C-7 (neck) level reduced weight bearing to 5.9–10% of actual body weight, to xiphisternum (nipple) level reduced to 25–37%, and to anterior superior iliac spine (navel) 40–56%.²² In 1992 the same authors compared aquatic weight bearing while standing, slow and fast walking in nine subjects and found that weight was reduced to 0–25% of dry land weight at C7 (neck), 25–50% at the xiphisternum (nipple), and 50–75% at the anterior superior iliac spine (navel) level.²³ The ranges found in that study are large and unspecific and of little use in partial weight bearing prescription. This data supports our findings but is limited in its applicability to patients with orthopaedic fracture because of the participant characteristics, small sample sizes (18 in the 1987 study and nine in the 1992 study) and no reported sample size determination. Participants in both studies weighed less than 91 kg. The mean weight for women in our study was 76.9 kg (SD = 19.5); men were measured at 87.1 kg (SD = 13.3). Participants in the 1992 were “fit and had no gait abnormalities;”²³ participant characteristics in the 1987 study were not described.

More recent research on loading forces in shallow water running,²⁶ biomechanical characteristics while walking on land and in water,^{27, 28} and joint forces and torques when walking in shallow water³⁸ found similar percentages of body weight at the same immersion levels reported in this paper, but all studies included participants free from musculoskeletal, neurological, cardiac, or pulmonary diagnoses and reportedly “healthy.”

While Harrison et al.’s 1987 and 1992^{22,23} work reported similar findings, our study employed vastly improved technology for weighing participants while immersed. In Harrison and Bulstrode’s study (1987)²² the authors used a Salter spring balance scale that read from 0–90 kg. It can be argued that spring scales can stretch with repeated use and are currently used when the accuracy of other scales can be sacrificed for simplicity or expense. The authors do not report in the earlier paper the accuracy of the scale, nor do they offer data on multiple measurements. They report only that their procedure was repeated multiple times. In Harrison et al.’s 1992 paper²³ the authors employed a device based on paired electronic bathroom scales with only the strain-gauge measuring beams retained in the shells of the scales. Outputs from the strain-gauges were amplified and recorded. The research team developed this device; nowhere in their manuscript do they discuss the validity or reliability of the measurement system. We employed a force plate similar to that used in shallow water walking and running studies previously mentioned^{26–29} built specifically for underwater weight determination.

Our findings show that percentage dry body weights were similar for men and women for most immersion levels, with a mean of 7.9% (SD = 3.3) at the neck while exhaling and 6.0% (SD = 2.7) at the neck while inhaling, 23.9% (SD = 5.9) at the nipple, and 51.4% (SD = 5.6) at the navel. Physiotherapists can use the anatomic landmarks in aquatic therapy to ensure patients with periarticular fracture do not overload the lower extremity during partial weight bearing. This has been shown to be a safe and effective practice in aquatic weight bearing controlled trials in patients rehabilitating after rotator cuff repair, total knee replacement, total hip replacement, and anterior cruciate ligament reconstruction.³⁰ It is known that aquatic therapy has several characteristics that make it ideal for early mobilization including reducing load on joints;^{6–8,11,12,16} increasing the active range of motion of the joint to

facilitate movements that would otherwise be too difficult postoperatively;^{10–12,15,16} increased exercise security because there is no risk of falling or refracture while immersed in the pool;^{10,15} reduction in stiffness, swelling and pain; earlier return to everyday activities and work; and a decrease in loss of work^{10–12,15,16} Our study showed the percentage of weight bearing experienced by patients after periarticular fracture during aquatic weight bearing at three easily recognizable anatomic landmarks. This information will allow physiotherapists to facilitate, in a controlled fashion, a graduated progression in lower limb loading during rehabilitation for a periarticular fracture.

This study, like most aquatic research, is limited by participant population skewed in favor of elderly female patients. Our male subject cohort was smaller than the female cohort. Epidemiology indicates that lower extremity injuries are more common in the elderly, and specifically, elderly obese women. This bias was expected in our data as we included all patients referred to the orthopaedic center. As our male enrollment was not large, we were arguably underpowered to evaluate the relationships between load bearing and anatomic landmarks in this group of subjects. However, there were very similar results in men and women, and the efficacy of load reduction did not depend on percent body fat or dry weight in most patients. Thus, it seems reasonable to assume that both men and women, regardless of type, will benefit from aquatic therapy. Obese elderly female patients may benefit the most because they are the least able to protect the lower extremity.

In summary, anatomic landmarks can facilitate a graduated progression in lower limb loading during periarticular lower extremity fracture rehabilitation. We found that the experienced load increased from 5.7–9.2% of dry weight at the neck, to 23.3–25.5% at the nipple, and finally to 50.0–55.1% at the navel immersion level. Load reduction was not heavily influenced by percent body fat or dry weight, and thus our study recommends aquatic therapy for both sexes with a range of body types. Clinicians and physiotherapists can use these anatomic landmarks in aquatic therapy to ensure that patients recovering from periarticular fracture do not overload the lower extremity during partial weight bearing therapy.

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Figure 1.
Percentage of body weight experienced by the lower extremity when submerged to the corresponding body level (neck (C7), nipple, and navel).

Figure 2.

Percentage dry weight versus percent body fat at three immersion levels in (A) females and (B) males. The C7 (neck) level was analyzed at the extremes of the breath cycle (exhale and inhale). The navel immersion level delivered the highest load at 51% of dry weight, followed by the nipple (24%), C7-exhale (8%) and C7-inhale (6%). The percent dry weight at each immersion level was fairly consistent across percent body fat values, with most correlations ranging from -0.37 to 0.27 ($P > 0.05$), with the exception of C7-exhale in females which had an $r = -0.64$ ($P < 0.001$).

Table 1

Participant demographics and weight measurements at three different immersion levels

Variable	All (n=61)	Women (n=44)	Men (n=17)	P-value*
Age				
Mean $\pm$ Std. Dev.	55.4 $\pm$ 15.9	55.0 $\pm$ 16.2	56.3 $\pm$ 15.7	----
Minimum-Maximum	21.0 – 84.0	21.0 – 84.0	22.0 – 77.0	
95% CI	(51.4,59.4)	(50.3,59.8)	(48.8,63.8)	
Dry weight (kgs)				
Mean $\pm$ Std. Dev.	79.7 $\pm$ 18.5	76.8 $\pm$ 19.5	87.0 $\pm$ 13.3	----
Min – Max	43.5 – 127.1	43.5 – 127.1	72.1 – 117.1	
95% CI	(75.0,84.3)	(71.1,82.6)	(80.7,93.3)	
Percent Dry Weight at Navel				
Mean $\pm$ Std. Dev.	51.4% $\pm$ 5.6%	50.0% $\pm$ 4.0%	55.1% $\pm$ 7.2%	0.012
Minimum-Maximum	33.9% – 69.4%	33.9% – 59.6%	47.9% – 69.4%	
95% CI	(50.0%,52.8%)	(48.8%,51.2%)	(51.7%,58.6%)	
Percent Dry Weight at Nipple				
Mean $\pm$ Std. Dev.	23.9% $\pm$ 5.9%	23.3% $\pm$ 5.4%	25.5% $\pm$ 7.1%	0.261
Minimum-Maximum	12.8% – 38.6%	14.0% – 35.6%	12.8% – 38.6%	
95% CI	(22.4%,25.4%)	(21.7%,24.9%)	(22.1%,28.9%)	
Percent Dry Weight at C7 (Neck) - Exhale				
Mean $\pm$ Std. Dev.	7.9% $\pm$ 3.3%	7.4% $\pm$ 3.2%	9.2% $\pm$ 3.3%	0.069
Minimum-Maximum	2.5% – 18.1%	2.5% – 16.7%	3.9% – 18.1%	
95% CI	(7.1%,8.7%)	(6.5%,8.4%)	(7.6%,10.8%)	
Percent Dry Weight at C7 (Neck) - Inhale				
Mean $\pm$ Std. Dev.	6.0% $\pm$ 2.7%	5.7% $\pm$ 2.6%	6.6% $\pm$ 3.1%	0.0302
Minimum-Maximum	0.6% – 14.4%	0.6% – 12.7%	2.3% – 14.4%	
95% CI	(5.3%,6.7%)	(5.0%,6.5%)	(5.2%,8.1%)	
Sum of Caliper measurements (mm)				
Mean $\pm$ Std. Dev.	110.9 $\pm$ 36.5	118.0 $\pm$ 37.4	92.8 $\pm$ 27.1	----
Minimum-Maximum	44.4 – 179.7	49.7 – 179.7	44.4 – 137.7	
95% CI	(101.8,120.1)	(106.9,129.0)	(79.9,105.7)	
Percent Body Fat Percentage				
Mean $\pm$ Std. Dev.	37.2% $\pm$ 9.7%	40.3% $\pm$ 8.7%	29.3% $\pm$ 7.2%	----
Minimum-Maximum	12.6% – 50.1%	21.8% – 50.1%	12.6% – 39.3%	
95% CI	(34.8%,39.7%)	(37.7%,42.9%)	(25.8%,32.7%)	

* For two-sample t-tests comparing men versus women. CI, confidence interval; Std Dev, standard deviation