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How Do Novice Runners With Different Body Mass Indexes Begin a Self-chosen Running Regime?

One of the major barriers to persistent running is running-related injury, which can lead to long periods of absence from this physical activity and may even force an individual to quit running permanently.¹⁶ Novice runners have been found to be particularly vulnerable to injury; their injury incidence reaches 17.8 per 1000 hours of running, compared with 7.7 injuries per 1000 hours among recreational runners.¹⁹ Still, considerable differences in anthropometric and demographic characteristics exist among individuals who take up running,

and these differences also may influence injury risk.¹

Among novice runners, overweight and obese runners appear to be particularly susceptible to injury.^{5,7,11,13} As an example, 25% of novice runners with

a body mass index (BMI) above 25 kg/m² sustained an injury in preparing for a 4-mile (6.7-km) race, compared with 15% of normal-weight novice runners, who had a BMI below 25 kg/m².⁴

Training load appears to play a fundamental explanatory role in the etiology of running-related injury.^{1,6} Overweight and obese runners are subjected to a greater load per stride because of their increased body weight, which implies that fewer stride repetitions are needed to archive a cumulative load equal to that of a normal-weight runner.¹ Therefore, overweight and obese runners may be at greater injury risk earlier in running than normal-weight runners. Further, overweight and obese runners probably have a reduced load capacity when they begin running, because of the well-documented association between a high BMI and a sedentary lifestyle.⁹ A sedentary lifestyle is associated with lower bone mineral density and reduced skeletal muscle power and strength,³ which may negatively affect the runner's capacity for load.¹ Fortunately, both of these mechanisms may be minimized by reducing the number of strides/distance accordingly, and thereby adjusting the cumulative load to a level that is less likely to cause injury. Positive adaptations may be made to enhance the structure-specific load capacity for novice

• **BACKGROUND:** Overweight and obese novice runners are subjected to a higher load per stride than their normal-weight peers. Do they reduce their running dose accordingly when beginning a self-chosen running regime?

• **OBJECTIVES:** To describe and compare the preferred running dose in normal-weight, overweight, and obese novice runners when they commence a self-chosen running regime.

• **METHODS:** In this exploratory, 7-day prospective cohort study, 914 novice runners were categorized into 1 of 3 exposure groups, based on their body mass index (BMI): (1) normal weight (BMI less than 25 kg/m², n = 405; reference group), (2) overweight (BMI of 25 to less than 30 kg/m², n = 341), and (3) obese (BMI of 30 kg/m² or greater, n = 168). All runners were equipped with a global-positioning-system running watch, which provided information about distance, duration, speed, and date of each running session during the first week of a self-chosen running regime.

• **RESULTS:** During the first session, overweight runners (difference, -0.5 km/h; 95% confidence interval [CI]: -0.8, -0.2 km/h; *P* < .05) and obese runners (-1.7 km/h; 95% CI: -2.0, -1.4 km/h; *P* < .05) ran slower than normal-weight runners. Obese runners also ran a shorter distance compared to normal-weight runners (-0.4 km; 95% CI: -0.7, -0.2 km; *P* < .05). During the first week, overweight runners (-0.5 km/h; 95% CI: -0.7, -0.2 km/h; *P* < .05) and obese runners (-1.7 km/h; 95% CI: -2.0, -1.4 km/h; *P* < .05) ran slower than normal-weight runners, while running distance and duration were similar.

• **CONCLUSION:** Overweight and obese runners selected a similar training dose to that of normal-weight runners when starting a self-chosen running regime. This may partly explain the higher running-injury risk among overweight and obese runners compared with normal-weight runners observed by other studies. *J Orthop Sports Phys Ther* 2018;48(11):873-877. Epub 22 Jun 2018. doi:10.2519/jospt.2018.8169

• **KEY WORDS:** BMI, running injury, training load

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runners before the distance they run is increased.¹

Given this background, it is appropriate to ask how novice runners of different sizes take up running, a question that remains unexplored in the scientific literature. The aim of the present study was to describe and compare the running distance, duration, frequency, and speed for normal-weight, overweight, and obese runners during the initial week that these runners start a self-chosen running program. The authors hypothesized that normal-weight, overweight, and obese runners would expose themselves to a similar dose of running when they begin a self-chosen running regime.

METHODS

THE DATA FOR THIS PAPER ORIGINATE from the Danish Novice Running (DANO-RUN) study, which was an epidemiological observational cohort study with a 1-year follow-up.¹⁵ Participants were recruited from June 2011 to August 2011. The study was conducted in Denmark and required no ethics committee approval (request M-20110114, Ethics Committee of Central Denmark Region). The Danish Data Protection Agency approved the study, and all participants provided written informed consent prior to the baseline investigation.

The cohort included novice runners (those who ran less than 10 km in total over the previous 12 months) with no injury to the lower extremity for at least 3 months prior to their inclusion in the study. All participants received a global-positioning-system (GPS) watch (Forerunner 110 M; Garmin Ltd, Schaffhausen, Switzerland) and a neutral running shoe (Supernova Glide 3; adidas Group, Herzogenaurach, Germany). The GPS running watch provided information about session-specific distance, duration, and speed and recorded the date of the session.

Participants were instructed to upload the GPS data to a personal web-based training diary. No prescriptions or guidelines regarding the training were

given, except for the expectation that a minimum of 52 training sessions would be performed during the 1-year follow-up. The recruitment and enrollment procedure and data-collection process have been reported in detail elsewhere.¹⁵

The outcomes of interest were the first-session and first-week running distance (kilometers), duration (minutes), and average speed (kilometers per hour) during the initial session of running and the initial week. Additionally, the number of first-week sessions (count) and the time between first and second sessions (number of calendar days with no running between the sessions) were determined. The measurement error of commercial GPS running watches (6.2% or less) is acceptable in detecting relevant differences in running distances in scientific studies on running-related injuries.¹⁴ The first week was defined as 7 consecutive calendar days from, and including, the first running session.

The exposure of interest was BMI, categorized according to the cutoffs used by the World Health Organization into (1) normal BMI (less than 25 kg/m²; reference), (2) overweight BMI (25 kg/m² to less than 30 kg/m²), and (3) obese BMI (30 kg/m² or greater).²⁰ The BMI was calculated based on the baseline measurements of weight and height. Furthermore, age, dichotomized according to the masters runner definition cutoff (younger/older than 40 years of age),¹⁰ and sex (male/female) were included as effect-measure modifiers.

Statistical Analysis

Differences between BMI groups were analyzed for significant differences using unpaired *t* tests (parametric data) or a Mann-Whitney *U* test (nonparametric data). The proportion of participants engaging in 1 to greater than 6 training sessions during the first week was reported for each BMI group separately. The difference in the distribution between the groups was tested using the chi-square statistic; a first-session distance between less than 1 to greater than 6 km (category

interval, 1 km) and a first-week distance between less than 3 to greater than 18 km (category interval, 3 km) were reported and tested in the same manner. Differences were considered statistically significant at *P* < .05. All analyses were performed using Stata/IC Version 15.0 (StataCorp LLC, College Station, TX).

RESULTS

A TOTAL OF 914 PERSONS (459 MALE, 455 female) were included in the analyses, after excluding 17 persons because they never started running and 2 persons because they were injured prior to baseline. A detailed flow chart of the DANO-RUN cohort study has been published elsewhere.¹² Of the 914 participants, 405 (44.3%) had a BMI of less than 25 kg/m² (57% female; mean ± SD age, 35.7 ± 10.5 years), 341 (37.3%) had a BMI of 25 to less than 30 kg/m² (34% female; mean ± SD age, 38.2 ± 10.1 years), and 168 (18.4%) had a BMI of 30 kg/m² or greater (34% female; mean ± SD age, 39.1 ± 9.2 years).

The first-session and first-week running distance, duration, and average speed for the 3 BMI groups are presented in **TABLE 1**. The median number of first-week running sessions was 2 for all 3 groups. The median time between the first and second sessions was 2 days for the overweight runners and the obese runners, and 3 days for the normal-weight runners (*P* > .05). The proportions of participants engaged in 1 to greater than 6 training sessions during the first week are reported for each BMI group in **TABLE 2**. Similarly, the BMI group-specific proportions with first-session distance between less than 1 to greater than 6 km are shown in **TABLE 3**, and the proportions with a first-week distance between less than 3 to greater than 18 km in **TABLE 4**. No difference in the association between BMI and training dose was found in strata of runners according to sex (male or female) and age (younger than 40 years or 40 years or older) (**APPENDIX**, available at www.jospt.org).

DISCUSSION

THIS IS THE FIRST PROSPECTIVE cohort study to describe and compare the training approaches of normal-weight, overweight, and obese novice runners when they begin a self-structured running program. Our results reveal only minor differences in training approaches across BMI groups. Nevertheless, the first-session and first-week average speed of the overweight and obese runners was 0.5 and 1.7 km/h slower than the average speed of the normal-weight runners. Also, the obese runners had a 400-m shorter first-session distance compared with the normal-weight runners. However, the total first-week distance, first-session and total first-week duration, the number of first-week training sessions, and the time between first and second sessions were not different in the overweight and obese runners compared with the normal-weight runners. These observations may constitute an important explanation for the higher risk of running-related injuries in overweight and obese runners compared to normal-weight runners.^{5,7,11,13}

Health Gain

Health improvement has been reported as the dominant motivator for novice runners when commencing a running regime.¹⁷ However, persistent running over time, rather than the running dose, appears to be the most important factor in mortality reduction.⁸ The appropriate dose of running must be evaluated based on the risk of sustaining a running-related injury when beginning a running program. If more runners sustain a running-related injury and become inactive following a high running dose, then they do not benefit from the health gains associated with an active lifestyle. Consequently, a low running dose may be recommended.

However, advising all overweight and obese runners to adopt a low running dose may be inappropriate, as characteristics other than BMI will also influence

injury risk.¹ As a theoretical example that warrants formal investigation, a younger obese runner with experience in other sports may tolerate more running without elevated injury risk compared to an older, sedentary obese runner. Ironically, from a public health perspective, general, simplified, and overly restrictive advice on training dose could disrupt the adherence to running to a greater extent than running-related injuries.

The Dose of Running, BMI, and Injury

The minimal difference in training dose between BMI groups raises the question, “Do novice runners actually consider their BMI in relation to the risk of running-related injuries when they structure their running regime?” Seem-

ingly not, as the first-session mean ± SD distance of the obese runners (2.7 ± 1.3 km) was almost equivalent to the 3-km maximum total first-week running dose recommended for novice runners with a BMI of 30 kg/m² or greater.¹¹ In addition, 31.5% of the obese runners commenced their running regime with a first-session distance of greater than 3 km. In fact, only 19.1% of the obese runners completed less than 3 km total during the first week. Currently, no evidence-based recommendations exist regarding an appropriate first-week running dose for overweight runners. However, it would be reasonable to assume that the appropriate dose would be lower than that for normal-weight runners but higher than that for obese runners. Nevertheless, the

TABLE 1		THE FIRST-SESSION AND FIRST-WEEK DOSE OF RUNNING BY BMI GROUP		
	Normal Weight (<25 kg/m ²)	Overweight (25 – 30 kg/m ²)	Obese (≥ 30 kg/m ²)	
First session*				
Distance, km				
Mean $\pm$ SD	3.1 $\pm$ 1.5	3.1 $\pm$ 1.4	2.7 $\pm$ 1.3	
Difference [†]	Reference	0.0 (–0.2, 0.2)	–0.4 (–0.7, –0.2) [‡]	
Duration, min				
Median (interquartile range)	19 (12)	20 (12)	20 (10.5)	
Difference	Reference	1	1	
Average speed, km/h				
Mean $\pm$ SD	9.3 $\pm$ 1.9	8.7 $\pm$ 1.9	7.6 $\pm$ 1.6	
Difference [†]	Reference	–0.5 (–0.8, –0.2) [‡]	–1.7 (–2.0, –1.4) [‡]	
First week [§]				
Distance, km				
Median (interquartile range)	6.0 (6.0)	6.5 (5.6)	5.9 (4.9)	
Difference	Reference	0.5	–0.1	
Duration, min				
Median (interquartile range)	42 (39)	45 (38)	47 (39)	
Difference	Reference	3	5	
Average speed, km/h				
Mean $\pm$ SD	9.3 $\pm$ 1.7	8.8 $\pm$ 1.9	7.6 $\pm$ 1.5	
Difference [†]	Reference	–0.5 (–0.7, –0.2) [‡]	–1.7 (–2.0, –1.4) [‡]	
Abbreviation: BMI, body mass index.				
*The first session was the first running session completed after the baseline assessment.				
[†] Values in parentheses are 95% confidence interval. Differences between BMI groups were analyzed for statistically significant differences using unpaired <i>t</i> tests (parametric data) or a Mann-Whitney <i>U</i> test (nonparametric data).				
[‡] <i>P</i> < .05.				
[§] The first week was defined as 7 consecutive calendar days, starting from the first session and including the first session.				

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overweight runners also appeared to have a similar training pattern to that of the normal-weight runners.

The main difference between the BMI groups was observed in their mean average speed. The overweight runners were 0.5 km/h slower, and the obese runners 1.7 km/h slower, than the normal-weight runners. However, the influence of speed on injury development is unclear. Even though the load per stride is lower when the speed is slower,¹⁸ the cumulative load of the running session can increase with a slower speed. This is due to the fact that bodily structures are subjected to more

load applications, as the stride length is shorter when the speed is slower and more strides are needed to cover a similar distance.¹⁸

Furthermore, the distribution of load is influenced by running speed, and the risk of injury may increase in some structures when the speed is slower, because more load is distributed to those specific structures (eg, more load to the knee at slower speeds).^{1,18} Hence, the influence of running speed on injury development in normal-weight, overweight, and obese novice runners would be an interesting topic for future studies.

Limitations

THE MAIN LIMITATION OF THIS study concerns the distances reported, as they may include walking. Still, the mean average speed of the obese runners was 7.6 km/h. This indicates that a large proportion of the training consisted of running, as a normal walking speed is suggested to be approximately 5 km/h.² The 0.5-km/h difference between the overweight runners and normal-weight runners points to a more or less similar training regime with an equal amount of walking and running.

TABLE 2

NUMBER OF SESSIONS DURING THE FIRST WEEK

BMI, kg/m ²	1	2	3	4	5	6	7	Total
<25	104 (25.7)	157 (38.8)	101 (24.9)	32 (7.9)	9 (2.2)	1 (0.2)	1 (0.2)	405 (100)
25-<30	84 (24.6)	137 (40.2)	82 (24.0)	30 (8.8)	7 (2.1)	1 (0.3)	0 (0)	341 (100)
≥30	38 (22.6)	70 (41.7)	43 (25.6)	10 (5.9)	5 (3.0)	2 (1.2)	0 (0)	168 (100)
Total	226 (24.8)	364 (39.8)	226 (24.8)	72 (7.8)	21 (2.3)	4 (0.4)	1 (0.1)	914 (100)

Abbreviation: BMI, body mass index.

*Values are n (percent). The first week was defined as 7 consecutive calendar days from, and including, the first running session completed after the baseline assessment. The chi-square test revealed a P value of .90.

TABLE 3

FIRST-SESSION DISTANCE*

BMI, kg/m ²	0-1 km	>1-2 km	>2-3 km	>3-4 km	>4-5 km	>5-6 km	>6 km	Total
<25	13 (3.2)	84 (20.7)	112 (27.7)	93 (23.0)	51 (12.6)	34 (8.4)	18 (4.4)	405 (100)
25-<30	8 (2.3)	61 (17.9)	108 (31.7)	86 (25.2)	47 (13.8)	21 (6.2)	10 (2.9)	341 (100)
≥30	7 (4.2)	44 (26.2)	64 (38.1)	31 (18.4)	8 (4.8)	12 (7.1)	2 (1.2)	168 (100)
Total	28 (3.1)	189 (20.7)	284 (31.0)	210 (23.0)	106 (11.6)	67 (7.3)	30 (3.3)	914 (100)

Abbreviation: BMI, body mass index.

*Values are n (percent). The first session was the first running session completed after the baseline assessment. The chi-square test revealed a P value of .01.

TABLE 4

FIRST-WEEK DISTANCE*

BMI, kg/m ²	0-3 km	>3-6 km	>6-9 km	>9-12 km	>12-15 km	>15-18 km	>18 km	Total
<25	62 (15.3)	137 (33.8)	81 (20.0)	58 (14.3)	34 (8.4)	21 (5.2)	12 (3.0)	405 (100)
25-<30	64 (18.8)	89 (26.1)	94 (27.5)	48 (14.1)	19 (5.6)	14 (4.1)	13 (3.8)	341 (100)
≥30	32 (19.1)	55 (32.7)	51 (30.3)	17 (10.1)	5 (3.0)	3 (1.8)	5 (3.0)	168 (100)
Total	158 (17.3)	281 (30.7)	226 (24.7)	123 (13.5)	58 (6.4)	38 (4.1)	30 (3.3)	914 (100)

Abbreviation: BMI, body mass index.

*Values are n (percent). The first week was defined as 7 consecutive calendar days from, and including, the first running session completed after the baseline assessment. The chi-square test revealed a P value of .02.

Generalizability

The present study included novice runners with the following criteria: no lower extremity injuries in the past 3 months, less than 4 hours of other sports activity per week, and willingness to complete 52 running sessions within a year. This group might have a more restrictive approach to running than a population of novice runners who are more physically active in general. Conversely, receiving the GPS watch and new running shoes and being “observed” might have motivated some participants to run more than novice runners not included in the study. In addition, the study can only be generalized to the first week of training, but there may be important differences in the training patterns of different BMI groups beyond 1 week that alter the risk for injury. These possible differences are worth investigating in future studies.

CONCLUSION

OVERWEIGHT AND OBESE NOVICE RUNNERS complete a similar amount of running as normal-weight novice runners in the first week of their running careers. The similar running dose may partly explain the higher risk of running-related injuries among overweight and obese runners compared with normal-weight runners observed by other studies. Hence, future research needs to clarify the need for developing BMI-tailored injury preventive training guidance for subgroups of novice runners and evaluating the effects of implementation of such guidance. ●

KEY POINTS

FINDINGS: Overweight and obese novice runners chose a similar dose of running to that of normal-weight novice runners when commencing a self-chosen running regime.

IMPLICATIONS: A similar running dose across body mass index (BMI) groups may be inappropriate in relation to the risk of running-related injury. Therefore, future research needs to elucidate the need for developing BMI-tailored

injury preventive training guidance for subgroups of novice runners.

CAUTION: A plethora of other factors besides BMI may influence the dose of running that novice runners are able to tolerate without sustaining an injury. Therefore, studies are needed to identify subgroups of overweight and obese novice runners who possibly can tolerate more running without an elevated injury risk. General, simplified, and overrestrictive advice on training dose could disrupt the adherence to running to a greater extent than running-related injuries.

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APPENDIX

THE ASSOCIATION BETWEEN BMI AND FIRST-SESSION DISTANCE IN SUBGROUPS OF SEX AND AGE*

BMI, kg/m ²	Female	Male	Difference	Aged <40 y	Aged ≥40 y	Difference
<25	Reference [†]	Reference [‡]	...	Reference [§]	Reference	...
25-<30	-0.05 (-0.3, 0.2)	-0.18 (-0.5, 0.1)	-0.12 (-0.5, 0.3)	0.08 (-0.2, 0.3)	-0.15 (-0.5, 2)	-0.23 (-0.7, 0.2)
≥30	-0.37 (-0.7, 0.0)	-0.61 (-1.0, -0.2)	-0.24 (-0.8, 0.3)	-0.37 (-0.7, 0.0)	-0.43 (-0.9, -0.1)	-0.06 (-0.6, 0.5)

Abbreviation: BMI, body mass index.

*Values are mean difference (95% confidence interval) kilometers. A linear regression model was applied to test for statistically significant differences across strata.

[†]Reference: 2.84 km (95% confidence interval: 2.7, 3.0 km).

[‡]Reference: 3.52 km (95% confidence interval: 3.3, 3.8 km).

[§]Reference: 3.16 km (95% confidence interval: 3.0, 3.3 km).

^{||}Reference: 3.10 km (95% confidence interval: 2.8, 3.3 km).

THE ASSOCIATION BETWEEN BMI AND FIRST-SESSION DURATION IN SUBGROUPS OF SEX AND AGE*

BMI, kg/m ²	Female	Male	Difference	Aged <40 y	Aged ≥40 y	Difference
<25	Reference [†]	Reference [‡]	...	Reference [§]	Reference	...
25-<30	11 (0, 24)	2 (-8, 14)	-9 (-21, 6)	12 (3, 22)	0 (-13, 14)	-12 (-24, 4)
≥30	11 (-4, 26)	4 (-9, 18)	-7 (-22, 3)	13 (1, 26)	1 (-14, 19)	-12 (-26, 8)

Abbreviation: BMI, body mass index.

*Values are mean difference (95% confidence interval) percent change in geometric mean. A linear regression model was applied to test for statistically significant differences across strata. First-session duration was log transformed to make the data approximately normally distributed. The percent change in geometric mean was reported because $\exp[\ln(\text{mean}^1)] - [\ln(\text{mean}^0)] = \text{geometric mean}^1 / \text{geometric mean}^0$.

[†]Reference: 18 minutes (95% confidence interval: 17, 19 minutes).

[‡]Reference: 19 minutes (95% confidence interval: 18, 21 minutes).

[§]Reference: 18 minutes (95% confidence interval: 17, 19 minutes).

^{||}Reference: 19 minutes (95% confidence interval: 17, 21 minutes).

THE ASSOCIATION BETWEEN BMI AND FIRST-SESSION AVERAGE SPEED IN SUBGROUPS OF SEX AND AGE*

BMI, kg/m ²	Female	Male	Difference	Aged <40 y	Aged ≥40 y	Difference
<25	Reference [†]	Reference [‡]	...	Reference [§]	Reference	...
25-<30	-0.74 (-1.0, -0.4)	-0.71 (-1.1, -0.3)	0.03 (-0.5, 0.5)	-0.49 (-0.8, -0.2)	-0.39 (-0.8, 0.0)	0.1 (-0.5, 0.6)
≥30	-1.80 (-2.2, -1.4)	-1.95 (-2.4, -1.5)	-0.15 (-0.8, 0.5)	-1.82 (-2.2, -1.4)	-1.33 (-1.9, -0.8)	0.5 (-0.2, 1.2)

Abbreviation: BMI, body mass index.

*Values are mean difference (95% confidence interval) kilometers per hour. A linear regression model was applied to test for statistically significant differences across strata.

[†]Reference: 8.6 km/h (95% confidence interval: 8.4, 8.8 km/h).

[‡]Reference: 10.1 km/h (95% confidence interval: 9.6, 10.4 km/h).

[§]Reference: 9.5 km/h (95% confidence interval: 9.2, 9.7 km/h).

^{||}Reference: 8.8 km/h (95% confidence interval: 8.5, 9.1 km/h).

APPENDIX

THE ASSOCIATION BETWEEN BMI AND FIRST-WEEK DISTANCE
IN SUBGROUPS OF SEX AND AGE*

BMI, kg/m ²	Female	Male	Difference	Aged <40 y	Aged ≥40 y	Difference
<25	Reference [†]	Reference [‡]	...	Reference [§]	Reference	...
25–<30	–3 (–16, 12)	0 (–13, 15)	3 (–16, 26)	8 (–4, 22)	–10 (–25, 7)	–18 (–33, 1)
≥30	–16 (–30, 1)	–7 (–22, 10)	9 (–14, 42)	–6 (–21, 9)	–13 (–30, 7)	–7 (–28, 19)

Abbreviation: BMI, body mass index.

*Values are mean difference (95% confidence interval) percent change in geometric mean. A linear regression model was applied to test for statistically significant differences across strata. Weekly distance was log transformed to make the data approximately normally distributed. The change in geometric mean was reported because $\exp[\ln(\text{mean}^{\dagger})] - [\ln(\text{mean}^{\circ})] = \text{geometric mean}^{\dagger}/\text{geometric mean}^{\circ}$.

[†]Reference: 5.60 km (95% confidence interval: 5.1, 6.1 km).

[‡]Reference: 6.39 km (95% confidence interval: 5.8, 7.1 km).

[§]Reference: 5.88 km (95% confidence interval: 5.4, 6.3 km).

^{||}Reference: 6.02 km (95% confidence interval: 5.3, 6.8 km).

THE ASSOCIATION BETWEEN BMI AND FIRST-WEEK DURATION
IN SUBGROUPS OF SEX AND AGE*

BMI, kg/m ²	Female	Male	Difference	Aged <40 y	Aged ≥40 y	Difference
<25	Reference [†]	Reference [‡]	...	Reference [§]	Reference	...
25–<30	7 (–8, 24)	7 (–7, 24)	0 (–18, 23)	15 (1, 30)	6 (–21, 12)	–9 (–34, 1)
≥30	5 (–13, 27)	16 (–3, 38)	10 (–15, 42)	16 (–2, 36)	2 (–18, 26)	–14 (–32, 14)

Abbreviation: BMI, body mass index.

*Values are mean difference (95% confidence interval) percent change in geometric mean. A linear regression model was applied to test for statistically significant differences across strata. First-week duration was log transformed to make the data approximately normally distributed. The change in geometric mean was reported because $\exp[\ln(\text{mean}^{\dagger})] - [\ln(\text{mean}^{\circ})] = \text{geometric mean}^{\dagger}/\text{geometric mean}^{\circ}$.

[†]Reference: 40 minutes (95% confidence interval: 36, 44 minutes).

[‡]Reference: 38 minutes (95% confidence interval: 34, 42 minutes).

[§]Reference: 38 minutes (95% confidence interval: 35, 41 minutes).

^{||}Reference: 41 minutes (95% confidence interval: 37, 47 minutes).

THE ASSOCIATION BETWEEN BMI AND FIRST-WEEK AVERAGE SPEED
IN SUBGROUPS OF SEX AND AGE*

BMI, kg/m ²	Female	Male	Difference	Aged <40 y	Aged ≥40 y	Difference
<25	Reference [†]	Reference [‡]	...	Reference [§]	Reference	...
25–<30	–0.75 (–1.0, –0.5)	–0.66 (–1.0, –0.3)	0.09 (–0.4, 0.5)	–0.47 (–0.8, –0.2)	–0.36 (–0.8, 0.1)	0.11 (–0.4, 0.6)
≥30	–1.75 (–2.1, –1.4)	–1.97 (–2.4, –1.5)	–0.22 (–0.8, 0.3)	–1.80 (–2.2, –1.4)	–1.34 (–1.8, –0.8)	0.46 (–0.2, 1.1)

Abbreviation: BMI, body mass index.

*Values are mean difference (95% confidence interval) kilometers per hour. A linear regression model was applied to test for statistically significant differences across strata.

[†]Reference: 8.6 km/h (95% confidence interval: 8.4, 8.7 km/h).

[‡]Reference: 10.2 km/h (95% confidence interval: 9.9, 10.4 km/h).

[§]Reference: 9.4 km/h (95% confidence interval: 9.2, 9.6 km/h).

^{||}Reference: 8.9 km/h (95% confidence interval: 8.6, 9.2 km/h).



FIGURE 1. Ultrasound image (linear transducer in long axis) showing disruption of cortical bone of the fifth metatarsal.

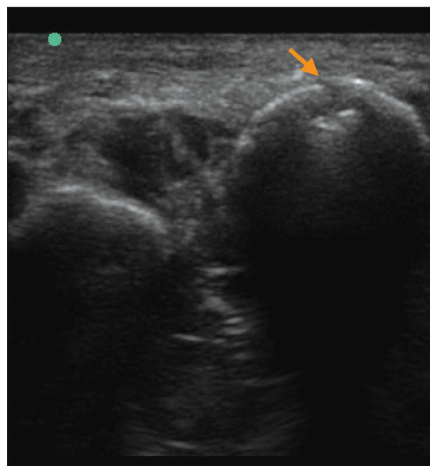


FIGURE 2. Ultrasound image (linear transducer in short axis) demonstrating disruption of cortical bone of the fifth metatarsal.



FIGURE 3. Oblique foot radiograph showing a displaced spiral fracture of the distal aspect of the fifth metatarsal.

Musculoskeletal Ultrasonography to Detect a Displaced Fracture of the Fifth Metatarsal

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A 27-YEAR-OLD MAN PRESENTED TO an outpatient physical therapy clinic with left lateral foot pain after playing lacrosse 1 day prior. The patient experienced the pain after landing on his left lateral foot but could ambulate without support immediately after the injury and resumed playing. Although the screening for fracture using the Ottawa ankle rules² did not support referral for radiographs, concordant pain was reproduced with palpation over the head and distal shaft of the fifth metatarsal. Inspection of the foot revealed moderate swelling and ecchymosis on the lateral and dorsal surfaces. Provocative testing, including the use of a tuning fork and pulsed ultrasound, which have

poor sensitivity, did not increase symptoms.¹ Fracture could not be excluded due to bony tenderness, swelling, and ecchymosis.

Ultrasound imaging was performed immediately by the physical therapist, focusing on the fifth metatarsal distal shaft. Images obtained with a 13- to 6-MHz linear transducer demonstrated cortical bone disruption (**FIGURES 1 and 2**). The high accuracy of ultrasound imaging for this condition has been previously reported.³ The patient's primary care physician subsequently ordered radiographs, which demonstrated an obliquely oriented fracture through the shaft of the fifth metatarsal (**FIGURE 3**). The patient was referred to an orthopaedist and placed in

a walking boot for 6 weeks. The patient could ambulate and stand for prolonged periods without pain at 9 weeks and returned to pain-free treadmill running at 15 weeks.

This case highlights the practical application of diagnostic ultrasound in an outpatient clinic to rule in a fracture when clinical testing fails to provide a definitive diagnosis. While the Ottawa ankle rules² may be an accurate tool for excluding fractures of the ankle and midfoot, suspicion should remain high if the mechanism, history, and physical exam suggest a possible fracture of the forefoot. ● *J Orthop Sports Phys Ther* 2018;48(11):903. doi:10.2519/jospt.2018.7884

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Does Health Care Utilization Before Hip Arthroscopy Predict Health Care Utilization After Surgery in the US Military Health System? An Investigation Into Health-Seeking Behavior

• **BACKGROUND:** The influence of prior patterns of health care utilization on future health care utilization has had minimal investigation in populations with musculoskeletal disorders.

• **OBJECTIVES:** The purpose of this study was to explore the relationship between presurgical health care utilization and postsurgical health care utilization in a population of patients undergoing hip surgery in the US Military Health System.

• **METHODS:** In this observational cohort study, person-level data were collected for patients undergoing hip arthroscopy in the Military Health System from 2003 to 2015, capturing all encounters 12 months before and 24 months after surgery for every individual. Cluster analysis was used to categorize individuals with high and low health care utilization, based on preoperative health care visits. Unadjusted and adjusted Poisson and generalized linear models were generated. Health care utilization outcomes were targeted, including costs, visits, and medication use.

• **RESULTS:** There were 1850 individuals in the final cohort (mean age, 32.18 years; 55.4% male). The high health care utilization group averaged

5769 ± 25.87 visits, compared to 20.43 ± 8.36 visits in the low utilization group. There were significant differences between groups for total health care visits (58.17; 95% confidence interval [CI]: 57.39, 58.58), total health care costs (\$11539.71; 95% CI: \$10557.26, \$12595.04), hip-related visits (12.77; 95% CI: 12.59, 12.96), hip-related costs (\$3325.07; 95% CI: \$2886.43, \$3804.51), days' supply of pain medications (752.67; 95% CI: 751.24, 754.11), opioid prescriptions (48.83; 95% CI: 48.47, 49.21), and cost of pain medications (\$1074.80; 95% CI: \$1011.91, \$1137.68).

• **CONCLUSION:** Presurgical patterns of health care utilization were associated with postsurgical patterns of health care utilization, indicating that those patients who used more care before surgery also used more care after surgery. Clinicians should consider prior patterns of health care utilization, including utilization unrelated to the index condition, when determining care plans and prognosis. *J Orthop Sports Phys Ther* 2018;48(11):878-886. Epub 22 Jul 2018. doi:10.2519/jospt.2018.8259

• **KEY WORDS:** health care-seeking behavior, health care utilization, hip, orthopaedic surgery

The study of health care-seeking behavior strives to explain the behavioral features associated with health care utilization.⁵ Where access to care is relatively unrestricted, aggressive health care seeking may lead to the overutilization of health services.^{4,21} In certain health systems, like the US Military Health System (MHS), financial incentives for the providers are lacking, and it may be more likely that patient, rather than system, factors are related to seeking care. A number of reasons driving people to seek health care services have been suggested. These include external factors, such as access to care, along with internal factors, such as the diagnosis or presence of comorbidities coupled with the perceived severity and irritability of the symptoms associated with the condition.¹

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Health care-seeking behavior has been minimally investigated, especially for musculoskeletal disorders.^{3,10,11,14} One possible explanation for a lack of literature on health care-seeking behavior is that the construct has not been well described, including a consensus on how it should be measured.²¹ By nature, health care-seeking behavior is a complex construct, and to improve our understanding, individual components of the construct should be examined further. One component of health care-seeking behavior is health care utilization.¹ The amount and type of health care an individual seeks may be an important component of health care-seeking behavior. There are a number of approaches that can be used to measure health care utilization, including the use of medical records and retrospective surveys. Survey methods rely on patient recall, and therefore are prone to bias.^{8,25,43} Alternatively, health care utilization can be more accurately assessed through the use of databases that track medical encounters, especially if the indexed event is well defined and measurable (ie, surgery or trauma).¹⁶

Globally, musculoskeletal disorders are the second most common cause of disability, and a source of significant economic burden.⁵³ A common musculoskeletal condition seen by health care providers is hip pain.^{18,40} While there are several conditions that can cause hip pain, one of the most prevalent hip conditions in younger adults is femoroacetabular impingement (FAI) syndrome.^{12,36} There has been an 18-fold rise in surgical procedures for FAI syndrome over the last decade in the United States alone,¹³ making it an important target for the study of health care utilization.

Therefore, the purpose of this study was to use a sophisticated single-payer health system claims database to explore 24-month health care utilization after hip surgery, based on health care utilization before surgery. Predictive models should be used to evaluate this noncausal relationship, and after

a stronger consensus for health care-seeking behavior and contributing factors are agreed on, further explanatory modeling may be helpful.^{20,50} The authors hypothesized that high health care utilization after surgery would be predicted by high health care utilization in the year leading up to surgery, even after adjusting for demographic factors and comorbidities.

METHODS

Study Design

THIS WAS AN OBSERVATIONAL COHORT of consecutive patients undergoing hip arthroscopy in the MHS, with data collected from July 1, 2003 through June 30, 2015. Data for each unique subject were abstracted for a period that represented 12 months before and 24 months after surgery.

Reporting Guidelines

The researchers used the reporting standards recommended in the REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) extension of the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) statement.^{7,29} Ethics approval was obtained through Institutional Review Boards at Brooke Army Medical Center and Duke University.

Data Sourcing

Data were pulled from the MHS data repository (MDR), which serves as the centralized data repository for all Defense Health Agency corporate health care data. Data within the MDR are collected from a worldwide network of more than 260 Department of Defense health care facilities and non-Department of Defense entities. Data include every person-level interaction for health care, both inpatient and outpatient. All MDR data are carefully processed by the Defense Health Agency, updated monthly, and are available to a select group of researchers for specific purposes only.

Selection of Variables

Sample The researchers targeted all patients who had undergone arthroscopic hip surgery, identified by Current Procedural Terminology codes 29914, 29915, 29916, and 29860. The authors excluded any patient who was not an eligible beneficiary for the entire 12 months before and 24 months after the surgery date. They then excluded persons with a diagnosis code for osteoarthritis, avascular necrosis, osteomyelitis, or fracture of the hip, as well as malignant neoplasms of the pelvis, hip, or lower extremity or other arthritic hip condition present any time in the 12 months before the surgery. The authors did this to improve homogeneity of the sample, as these conditions could indicate a reason other than FAI syndrome for this surgical procedure. The researchers chose to use surgery for FAI syndrome as the index event because it is a condition that has been associated with a high volume of diagnostic and treatment health care utilization.^{17,35} By selecting a population that ultimately received surgery, the authors were better able to capture a well-defined period of health care-seeking patterns. This also allowed them to examine a cohort of patients with a relatively similar baseline, rather than conditions that begin by way of insidious onset or are limited by patient recall.

Presurgical Health Care Utilization In an attempt to capture a behavioral component of health care utilization, the researchers selected total health care visits before surgery, which is more likely to represent persistent behavior.^{21,24} To better categorize high and low health care utilization, the authors ran a 2-step cluster analysis to create distinct groups with more homogeneous clinical profiles. They assessed differences in health care utilization, including medical visits, costs, and medication use, and demographic factors between the 2 groups of health care seekers. The 2-step cluster identifies relatively homogeneous subgroups while maximizing the variability between the final, defined clusters.²² Two-step clustering is

particularly useful when analyzing differences in subgroups within a large data set.

Descriptive Variables The researchers were interested in a well-defined description of the sample, which included age, sex, military service branch, active status, rank category (socioeconomic status), whether the surgical procedure occurred in a network or military hospital, and the presence of comorbidities. The authors also reported prescription opioid use (yes or no) and total medical visits and costs, all occurring before surgery.

Outcome Variables The authors targeted a series of systems outcomes that reflected utilization (costs and visits) and behaviors (medication use). Further, costs and visits were defined as total sums of all health care for any reason, and then specifically for hip-related care as well (procedures, imaging, primary and specialty care, etc). Total postoperative days' supply of pain medication was used to reflect the dosage for pain management, total number of opioid prescriptions was used to identify initial or recurrent management with opioids, and total medication costs were used to reflect economic impact.

Comorbidities The researchers preidentified a list of medical comorbidities within the MDR present before surgery that were found to have a significant association with orthopaedic injury and surgical outcomes. To qualify, these variables had to be coded during a visit that occurred in the preoperative period. These included systemic arthropathy, cardiovascular disorders, chronic pain, metabolic disorders, substance abuse, sleep disorders, mental health problems, and posttraumatic stress disorder. A specific list and rationale for each of these comorbidity variables has been previously defined.⁴⁴

Confounding Variables Potential confounders were identified as variables found to be significantly different between the 2 health care utilization groups. These variables were also selected based on their potential to explain differences in health care utilization, such as comorbidities, demographic factors, military beneficiary category, a proxy measure of

socioeconomic status (officer or enlisted), and, as costs change over time, the year that surgery was performed.

Missing Values

The MDR is a comprehensive database that uses multiple checkpoints to improve the quality of the data that arrive from multiple sources; consequently, it has minimal missing values. Data feeds into the MDR are initially given a "raw" designation as they go through a 90-day validation process, where missing values are imputed by cross-referencing across multiple other databases, continuously feeding into the MDR. After this validation process, data are transformed from "raw" to final and are then sourced for analyses such as the one in this paper. Missing data are minimal.

Data Analysis

The authors reported descriptive statistics for the groups based on level of health care utilization before surgery, and compared each group using SPSS Version 23.0 (IBM Corporation, Armonk, NY). Nominal variables were compared using chi-square analyses. Continuous variables were evaluated using *t* tests. After clustering the presurgical health care utilization variables using only preoperative health care visits (total for any reason and for a specifically hip-related reason), the authors used Poisson log-linear analysis for all outcomes involving count data (number of visits and days' supply of medication) and a generalized linear model with gamma distribution for all cost outcomes. Both models account for values that are greater than zero. For skewed data, common with health care services, Poisson analysis and a generalized linear model with gamma distribution are appropriate for count and cost data, respectively.^{32,60} The researchers ran 2 sets of analyses, unadjusted and adjusted, in which they controlled for confounding variables that included comorbid conditions and demographic characteristics. For all analyses, a *P* value of less than .05 was used to determine statistical significance.

RESULTS

THERE WERE 1870 INDIVIDUALS UNDERGOING arthroscopic hip surgery who met the initial criteria (TABLE 1). Twenty individuals were removed from the analysis because they did not receive any preoperative health care, resulting in a final sample size of 1850. There were no missing values for any of the outcomes measures used in the study, thus no imputation was needed. By comparison, the average $\pm$ SD number of medical visits before surgery in the high utilization group was 57.69 ± 25.87 , versus 20.43 ± 8.36 visits for the low utilization group. Those in the high utilization group ($n = 650$) were proportionally more likely to be female and in an enlisted rank. Significant differences were also found between military services. The mean difference in medical costs before surgery between high and low utilization groups was \$6818.

TABLE 2 demonstrates significant differences in the number of presurgery comorbidities between both groups, with the high utilization group having significantly higher proportions of systemic arthropathy, posttraumatic stress disorder, chronic pain, cardiovascular disorder, metabolic disorder, substance abuse, mental health disorder, and insomnia compared to the low utilization group.

There were statistically significant differences for all 7 outcomes measures. Total health care visits, total health care costs, hip-related health care visits, hip-related health care costs, total days' supply of pain medications, total opioid prescriptions, and costs of pain medications after surgery were all predicted by high health care utilization before surgery (TABLE 3). Even after adjusting for all covariates, the results were unchanged (TABLE 4).

DISCUSSION

THE AUTHORS ATTEMPTED TO EXPLORE a relationship between patterns of health care utilization

before and after hip surgery. The results of this study support the hypothesis that higher presurgical health care utilization was associated with higher health care utilization rates after surgery. While no clinical outcomes were assessed in this study, these findings suggest that individuals may seek care, to some extent, based on a predisposition to utilize health services. The researchers believe that these results are important and warrant further discussion.

Patterns of Health Care Utilization Before Surgery

One unique aspect of the present study was the method used to measure presurgical patterns of health care utilization. The authors identified 2 very distinct

clusters of health care users based on primary care physician utilization before surgery (high and low). As a construct, health care utilization predicted by prior patterns of health care utilization has been minimally investigated, and as such there are no standardized approaches to measurement. In the few studies that have attempted to investigate this construct, low-threshold categorical approaches are often used,⁵ meaning that if a patient saw a provider, regardless of number of visits, then he or she was classified as a health care user. With this approach, the number of different types of health care providers determines whether someone is a low or high health care user. This method of measuring preindex health care utilization is more often used

in studies that have a shorter preindex surveillance period, or that investigate access to specific care-related issues.²¹ Another approach to measuring health care utilization is to calculate the total health care consumption (ie, cumulative visits or costs).^{21,31} This study accounted for health care utilization for a period of 1 year prior to hip surgery. Because of the longer period, the authors were able to assess total utilization (ie, health care visits) in order to identify a more robust distinction between high and low presurgical health care utilization.

The authors recognize that total health care visits are also related to other factors, including demographics, comorbidities, and condition severity.^{56,58} In the present study, baseline demographic

TABLE 1

DESCRIPTIVE STATISTICS ANALYZING HIGH PRESURGICAL HCU VERSUS LOW PRESURGICAL HCU GROUPS*

Variable	Total Sample (n = 1850)	High HCU (n = 650)	Low HCU (n = 1200)	P Value
Age, y	32.18 ± 8.10	31.95 ± 8.34	32.31 ± 7.93	.34
Sex (female), %	44.6	57.4	37.7	<.01
Active duty (yes), %	67.7	69.4	66.8	.25
Service, %				
Army	44.7	47.4	43.3	
Coast Guard	1.6	1.7	1.6	<.01
Air Force	24.6	28.5	22.6	
Marines	12.2	10.3	13.2	
Navy	16.3	11.5	18.9	
Other	0.4	0.5	0.4	
Rank (enlisted), %	77.6	82.3	75.1	<.01
Location of surgery (military hospital), %	52.1	44.3	56.3	<.01
HCU 1 y prior to FAI surgery				
Hip-related medical costs	\$2433.72 ± \$1944.08	\$3271.05 ± \$2484.95	\$2020.72 ± \$1378.19	<.01
Hip-related medical visits, n	12.19 ± 9.55	18.04 ± 12.35	9.22 ± 5.46	<.01
Total medical costs	\$6696.53 ± \$7024.87	\$11191.44 ± \$9344.21	\$4373.39 ± \$3544.08	<.01
Total medical visits, n	33.52 ± 24.43	57.69 ± 25.87	20.43 ± 8.36	<.01
Conditions occurring in the 2 y after surgery, %				
Hip osteoarthritis	21.7	22.9	21.1	.36
Heterotopic ossification	0.5	0.2	0.8	.09
Avascular necrosis	0.4	0.3	0.5	.57
Hip replacement	1.6	1.1	1.8	.21
Hip infection	0.3	0.3	0.3	.82
Hip stress fracture	0.2	0.0	0.3	.20
Hip fracture	1.7	1.4	1.8	.47

Abbreviations: FAI, femoroacetabular impingement; HCU, health care utilization.

*Values are mean ± SD unless otherwise indicated.

RESEARCH REPORT

TABLE 2

COMORBIDITY MEASURES AMONG HIGH AND LOW HCU GROUPS*

Variable	Total Sample (n = 1850)	High HCU (n = 650)	Low HCU (n = 1200)	P Value
Preoperative systemic arthropathy	1.8	3.1	1.2	<.01
Preoperative PTSD	3.6	8.5	1.0	<.01
Preoperative chronic pain	9.4	20.6	5.2	<.01
Preoperative cardiovascular condition	10.7	15.2	8.2	<.01
Preoperative metabolic disorder	15.8	21.1	13.0	<.01
Preoperative substance abuse history	15.5	18.0	11.3	<.01
Preoperative mental health disorder	19.9	36	12.3	.03
Preoperative insomnia diagnosis	8.9	15.4	5.3	<.01

Abbreviations: HCU, health care utilization; PTSD, posttraumatic stress disorder.

*Values are percent unless otherwise indicated.

characteristics between the 2 groups were not significantly different, except for a few notable exceptions. Those in the high health care utilization group were more likely to be female, to have undergone their surgical procedure in a civilian hospital, and to be in an enlisted- versus officer-rank family.

Military rank can serve as a proxy measure of socioeconomic status and education, as the pay is higher for officers, who all have college degrees. Higher levels of socioeconomic status and education are typically associated with greater health care utilization.³⁴ In the MHS, access to care is less of a barrier than in other health systems, especially if care is accessed in military hospitals, and this may explain why this study's findings are in conflict with the literature.

Also, there were significant differences noted in comorbidities between the 2 groups of health care users, and these can be significant drivers of additional health care utilization.⁴⁵ However, while these differences in comorbidities and demographic factors are important to note, after adjusting for them, presurgical health care utilization predicted post-surgical utilization. This finding suggests that health care utilization is influenced by more than demographic and disease severity factors and may have a behavioral influence.^{1,2,5}

TABLE 3

UNADJUSTED PRESURGICAL HCU ASSOCIATION WITH VISITS AND COSTS AFTER SURGERY*

Postoperative Variable	High HCU (n = 650)	Low HCU (n = 1200)
Total health care visits, n	124.85 (124.01, 125.72)	66.68 (66.62, 67.14)
Total health care costs	\$35930.44 (\$33952.38, \$38023.74)	\$24390.73 (\$23395.12, \$25428.70)
Total hip-related visits, n	36.46 (36.00, 36.93)	23.69 (23.41, 23.97)
Total hip-related costs	\$17720.49 (\$16616.38, \$18897.95)	\$14395.42 (\$13729.95, \$15093.44)
Total days' supply of pain-related medications, n	1581.42 (1578.31, 1584.54)	828.75 (827.07, 830.43)
Total opioids, n	90.58 (89.85, 91.32)	41.75 (41.38, 42.11)
Cost of pain medications	\$1460.17 (\$1212.95, \$1707.39)	\$385.37 (\$201.04, \$569.71)

Abbreviation: HCU, health care utilization.

*Values are mean (95% confidence interval) per person. All analyses involve Poisson modeling for count data and a general linear model with gamma distribution for cost data.

TABLE 4

ADJUSTED PRESURGICAL HCU ASSOCIATION WITH VISITS AND COSTS AFTER SURGERY*

Postoperative Variable	High HCU (n = 650)	Low HCU (n = 1200)
Total health care visits, n	109.66 (102.24, 117.61)	70.71 (67.25, 74.35)
Total health care costs	\$34248.54 (\$31464.32, \$37032.75)	\$25674.77 (\$23681.61, \$27667.94)
Total hip-related visits, n	38.03 (34.48, 41.95)	24.61 (22.95, 26.40)
Total hip-related costs	\$19040.36 (\$17136.24, \$20944.47)	\$15186.64 (\$13823.52, \$16549.76)
Total days' supply of pain-related medications, n	1269.43 (1146.43, 1405.62)	814.31 (756.48, 876.59)
Total opioids, n	102.05 (87.84, 118.57)	60.42 (53.99, 67.62)
Cost of pain medications	\$1496.86 (\$1083.50, \$1910.23)	\$455.79 (\$158.17, \$753.42)

Abbreviation: HCU, health care utilization.

*Values are mean (95% confidence interval) per person. All analyses involve Poisson modeling for count data and a general linear model with gamma distribution for cost data, with controls for sex, service, officer status, network/military hospital, active-duty status, calendar year in which the surgery took place, preoperative opioid use, and preoperative comorbidities of arthropathy, chronic pain, posttraumatic stress disorder, cardiac condition, metabolic condition, substance abuse, mental health, and insomnia.

Health Care Utilization After Surgery

Significant disparity between the high and low health care utilization groups was observed in the total and hip-related health care visits after surgery. Actual visits are more influenced by patient factors than health care costs, supported by Andersen's behavioral model of health care utilization.^{1,5} One of the key features of the behavioral model is access to care, which is less of a problem in the MHS compared to other third-party-payer health systems in the United States. The MHS is a closed, single-payer health system, with no copay needed at any facility (military or civilian) while on active military duty. Others who are not on active duty but still

in this system (spouses, some retired military, etc) may have copays if seeking care in the network. Less than 3% of this cohort had any additional health insurance, making it more likely that the researchers captured all care that actually occurred.

Given that there were no differences between active-duty status in users with low versus high health care utilization, the authors do not believe that this was a significant confounder. While it is necessary to note that these findings may not be applicable to other health systems, the underlying concepts may still be relevant and should be explored in other settings, especially in areas where health care services are readily available to the public.

Medication use is also important to consider as part of assessing health care utilization, including total days' supply and unique prescription counts for pain medications.⁴⁹ Those considered to be high health care users in this study were also the highest users of pain medication. High users had roughly twice the amount of total days' supply of pain-related medications and unique opioid prescriptions when compared to the low health care users. The costs of pain medications were nearly 4 times greater in the high health care users than in the low health care users.

These findings suggest that patterns of health care utilization should be considered as a factor related to persistent opioid use after surgery for FAI syndrome, as well as other musculoskeletal conditions, but require further investigation. Surgery is an event in which patients are commonly exposed to opioids for the management of perioperative pain.¹⁹ In fact, 87% of the patients in this study received an opioid prescription after discharge, which was consistent with other literature that identified similar results.³⁹

Further, the potential for opioid misuse is higher in postoperative than in nonoperative populations,⁶ and has been associated with higher rates of health care utilization after elective orthopaedic surgery.³³ In addition, the use of opioids in the management of chronic pain, in-

cluding hip pain, has not been shown to be effective at reducing long-term pain, improving function, or improving quality of life,²⁷ and it is possible that behavioral components are partially driving long-term use of opioids.

A Behavioral Explanation of Health Care Seeking

The decision to seek health care services can be thought of as a process in which individuals move through stages: health behavior, illness behavior, sick-role behavior.⁴⁸ In this approach, health behavior describes the person who seeks health care services on the basis of prevention.²⁴ As a part of maintaining soldier readiness, the MHS has a commitment to provide preventive health services, with the goal of decreasing downstream health-related events.^{38,39} Other health systems promote preventive care seeking, such as annual physician wellness checks, preventive dental work, annual eye exams, and age-dependent tests for early detection of certain diseases.⁵⁵

It is after the onset of symptoms (or signs) that an individual may demonstrate illness behavior attributes.⁴⁸ Health care seeking at this stage includes behavior that an individual demonstrates after the onset of symptoms in order to define (ie, diagnose) the state of health and determine a remedy.^{51,52} However, the onset of symptoms alone is not completely predictive of care seeking. Only those who perceive the condition to be serious enough to cross a health care-seeking threshold are thought to engage in the health care system.⁴⁸

Presumably, all of the patients in the present study perceived hip-related symptoms to be serious enough to initiate medical care, leading all the way through surgical repair. This coincides with evidence suggesting that technological advancements in diagnostic procedures may generate greater consumer demand for care, which the authors also accounted for in the adjusted model by including the year surgery was performed.⁵⁴ The health care seeking that occurs during

illness behavior should not be underestimated, for it has been demonstrated that the average cost per person associated with diagnosing FAI syndrome is nearly \$2500 and requires an average of 3.4 diagnostic visits.²⁶

On the other hand, sick-role behavior has been described as health care seeking for the purpose of getting well and is typically the steps taken after a diagnosis has been made that is acceptable to the patient.⁴⁸ At some point, all of the patients in the present study demonstrated sick-role behavior attributes based on the utilization of treatment, with everyone ultimately undergoing hip arthroscopy. Sickness behavior can be influenced by beliefs and expectations about the benefit of the treatment strategy.²³

Undoubtedly, some of this increase in health care utilization specific to FAI syndrome is related to the advancement of surgical techniques,^{9,30} as the rates of surgery rose year after year in this cohort, from 51 surgeries in 2005 to 358 in 2012. Utilization rates can also be influenced by the perceived severity of the condition, but perhaps to a lesser extent than beliefs and expectations.^{41,42} The most efficient progression from the sick-role behavior stage to a health behavior stage is when a singular treatment approach leads to an acceptable reduction of symptoms, or a state in which the patient is content with his or her current health status.

However, if a patient is not content with his or her current status after undergoing a given treatment, then he or she will likely opt for another approach, and will continue to do so until satisfied with his or her health status.⁴⁸ This hypervigilance in the sick-role stage has been linked to excessive care seeking.⁴⁷ The persistence of a sick-role behavior after arthroscopic hip surgery helps to explain why some patients in this study had higher health care utilization rates after surgery. Persistence of symptoms after hip arthroscopy for FAI syndrome is common, and acceptable symptom resolution only occurs in about 60% of cases who have been treated with surgery.^{15,46}

Clinical Implications

The findings from this study suggest that downstream utilization of health care services may be predicted by prior patterns of health care utilization. Health care providers should consider health care utilization, especially when making diagnostic, treatment, and prognostic decisions. Furthermore, because health care utilization prior to surgery predicted chronic opioid use after surgery, anyone involved in the management of postoperative pain should be aware of patterns of health care utilization and be attentive to what role they might play in potential opioid misuse.

Health care providers can also influence appropriate health care utilization by providing proper education and helping set acceptable expectations about the course of diseases, the prognosis, and the anticipated effects of given interventions. The framework by which patients evaluate their state of health can be heavily influenced by the interactions with health care providers. This includes resisting the financial incentives in a fee-for-service model, and providing only necessary care.

Study Limitations

Our study has several limitations. Particularly, the data in this study were observational, and causal inferences cannot be made. Generalizability of these findings is another potential limitation. The Andersen behavioral model of health care utilization describes access to care as an enabling factor.^{1,2,5} In health systems where access to care is unlike that of the MHS, health care utilization may be different. The MHS consists primarily of military service members; however, there are also many civilian beneficiaries (spouses, children, retired military and their families, etc), representing about one third of our sample. Considering that there were no significant differences between high and low health care utilization groups based on military status, these findings may be applicable to civilian settings. To that end, the authors acknowledge that there are inherent differences

at the systems level between the military and other health systems that limit the generalizability of these findings.

Fee-for-service reimbursement models have been associated with higher health care utilization, but without improvement in outcomes.³⁷ While high-volume utilization may not necessarily correlate well with value,^{28,57} it is unknown whether high health care utilization is associated with patient-centric, self-reported outcomes (better or worse) of pain, function, and disability. Therefore, future research is needed to investigate the relationship between health care utilization and patient-reported outcomes.

Finally, the authors acknowledge that the constructs of health care utilization, especially the behavioral influences, are more complex than consumption of health care resources alone. Multifaceted models have been proposed that better account for these behavioral complexities.²¹ Implementation of these complex models to produce quantifiable health care-seeking measures may become possible as electronic medical records and databases become more sophisticated in tracking patterns of health care utilization. In those cases, health care-seeking behavior may become a more meaningful component of a multivariate approach to better understanding and managing health care utilization.

CONCLUSION

FINDINGS FROM THIS STUDY SUGGEST that a number of postoperative health care utilization measures are predicted by presurgical health care utilization. Health care providers should be aware of patterns of health care utilization when making decisions about treatment and prognosis. ●

KEY POINTS

FINDINGS: The results of this study demonstrated that patterns of health care utilization prior to orthopaedic surgery predicted health care utilization after

surgery, including costs, visits, and medication use. Even after adjusting for comorbidities and other demographic factors, patterns of health care utilization prior to surgery still predict downstream utilization of health care services.

IMPLICATIONS: Clinicians should consider patterns of health care utilization when making clinical decisions about treatment and prognosis. Future studies should investigate the behavioral features that may influence health care utilization.

CAUTION: This retrospective cohort was from the US Military Health System, in which access to health care is different from that of other health systems, and therefore results may not be applicable to other populations.

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Manual Therapy Cures Death: I Think I Read That Somewhere

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We have all been in situations where we could recall information but failed to remember the origin of that information. This phenomenon is known as *source amnesia*, and it is a problem that can markedly bias our understanding of the context of the information acquired and how we interpret and scrutinize that information. By definition, source amnesia is the inability to recall where, when, or how one has learned knowledge that has been acquired and retained.¹⁰ Source amnesia is a problem in the political landscape, can influence business marketing practices, and is often the reason for incorrect recollections and confabulation/distortion of memory.⁶ The problem increases exponentially when potentially flawed information is openly available to the public.

In this editorial, we describe the ease with which bogus information can be published in predatory journals, and outline 3 risks to credible science associated with published information and downstream referencing, which may occur through source amnesia bias.

The Scourge of Predatory Journals

Every day, we open our inbox to find 10 to 20 e-mails that open with, “Greetings for the day!” encouraging us to submit our “scientific excellences” to their “esteemed” journal. These predatory journals are a fraud, and their existence threatens to infect the scientific literature with false or low-quality research.⁵ Within the world of scientific publishing, predatory journals fit the genre of supermarket tabloids. We define a predatory journal as an open-access publisher that actively solicits and publishes articles for a fee, with little or no real peer review. To date, there are almost 9000 predatory journals.¹³

Predatory journals are compromising the scientific credibility of “published”

research.³ These journals reportedly often forgo peer and editorial review and potentially pollute the scientific landscape. Past concerns with predatory journals have included the lack of a peer-review process, lack of an editorial board, and little to no description of the publication’s ethical standards.¹

Frequently, manuscript publication is solicited by predatory journals via e-mail—preying on young or inexperienced researchers who are under pressure to “publish or perish” in order to be promoted. The lure of getting something published quickly is attractive in high-pressure academic settings, and having papers accepted quickly and easily can give a false sense of success. Publication-ready proofs are often quickly returned to the author without peer review, and the journal demands an article processing charge.

Often, predatory journal webpages are poorly designed, contain 10 times more spelling errors than legitimate peer-

Dr Cook received honoraria from book sales (Pearson) and educational videos (MedBridge Education and Agence EBP). He also is a paid research consultant for the Hawkins Foundation of the Carolinas, and receives an editor stipend from the *Journal of Orthopaedic & Sports Physical Therapy*. Dr Cleland receives honoraria from book sales (Elsevier), and receives an editor stipend from the *Journal of Orthopaedic & Sports Physical Therapy*. Dr Mintken receives honoraria from book sales (Evidence In Motion) and is affiliate faculty at Evidence In Motion.

reviewed journal websites, display unauthorized images, and advertise bogus impact metrics.¹¹ In addition to duping inexperienced researchers, these journals also contribute to the dissemination of “fake science” by failing to provide rigorous peer review and quality control. This may allow fake science, rejected by reputable peer-reviewed journals, to find the light of day and enter the body of published literature.

Although predatory journals indicate that they perform rigorous peer review, our and others’ experiences suggest otherwise. Many times, these journals will publish any article, as long as the author pays. One author had a paper accepted that only contained one sentence (“Get me off your fucking mailing list”) repeated throughout the paper, and included 2 figures with the same words.⁸ Clearly, such an article is not a meaningful contribution to science—a well-functioning peer-review process would have identified this and rejected the manuscript.

The Sting

Most predatory journals claim to offer robust peer review.⁷ Based on our experience, we highly doubt that peer review occurs. In September 2018, we decided to test our hypothesis by writing a fabricated manuscript involving a fictitious patient. We accepted the first solicitation we received after writing our paper. In our fabricated manuscript, the patient was (1) deceased for 5 years; (2) unproductive at work; (3) not benefiting from prior care (because he was dead); (4) treated with repeated spinal manipulations (250 thrusts to the low back); (5) revived with the treatment; (6) treated by his family with this same procedure for an additional 3 months (home exercise program); and (7) given a questionable outcome because, despite being revived, he had a global rating of change score that was not clinically meaningful.

As if these rather obvious features weren’t enough, we laced the manuscript with ridiculous findings, including the key word *gouda*, a baseline quality-of-

life score of “0,” a timed up-and-go test of “infinite,” and a posttreatment hand-grip score of 14 kilotons. We included complicated figures involving seed germination over time and an unrelated Piet Mondrian painting, despite no relevance to the case. We did our best to “flag” the manuscript as a hoax, so that if any breathing human read it, one could tell it was a fake. These obvious fabricated findings notwithstanding, we soon received a publication-ready PDF of the article (we refused to sign the publishing agreement), which was slated for publication within 2 weeks of the original submission (upon payment of an article processing charge). To our astonishment, the publication-ready PDF included no changes to our original submission, and the article was primed for online publication/posting from the only journal we submitted it to.

Why Should You Care?

Publishing in a well-respected, reputable, medical or rehabilitation journal is an honor and contributes to the distribution of scientific knowledge, which can potentially influence the care provided to patients. Sadly, fake information has influenced legitimate research dissemination in at least 3 ways: (1) a wide range of scientific results are false and well-cited studies are infrequently replicated,⁴ (2) results are notably influenced by the research funder and by one’s sponsorship or vested interests,^{2,9} and (3) retractions of scientific papers have increased markedly over the last several years.¹²

Predatory journals compromise the traditional scholarly publishing process and have the potential to propagate “fake science.” We argue that the ease in publishing false information and its potential interaction with source amnesia could lead to a wealth of cited papers with garbage results. We shudder to think of the ramifications of our hoax article being published, and envision charlatans proclaiming that manual therapy can bring back the dead. Even bogus information can infiltrate clinical practice, either through clinician- or patient-driven mechanisms.

Three Key Risks to Credible Science From Predatory Publishers

1. In the world of predatory publishing, blatantly false information can be published for a fee.
2. Despite their statements, predatory journals frequently lack any form of peer-review system. This is important, because low-quality or fabricated research may compete with legitimate research that has been carefully vetted in a peer-review process.
3. Source amnesia risks elevating fake research to credible status once the information is published. With over 2 million yearly scholarly publications, remembering the source of information we gather is challenging enough. ●

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Does a Diagnostic Classification Algorithm Help to Predict the Course of Low Back Pain? A Study of Danish Chiropractic Patients With 1-Year Follow-up

In Denmark, low back pain (LBP) is the most common reason for consulting a primary care clinician, the most costly expense in primary care, and the most common cause of sick leave.⁸ Up to 85% of patients with LBP have nonspecific LBP, with no known underlying pathoanatomic cause of the pain, a condition in which there are only modest effects from the best available treatments.⁴

Low back pain is a symptom influenced by many factors, and people with LBP constitute a heterogeneous group with different sources of pain, different treatment responses, and different prognoses.^{30,38} Much effort has been put into identifying homogeneous subgroups of patients with nonspecific LBP, and, in recent years, these efforts have focused on psychological and social factors, some of which have shown promise.^{14,15,29} Nonetheless, primary care clinicians largely rely on structural/biomechanical models, based on the notion that the structural/biomechanical source of the pain must be identified to choose the right treatment.¹⁹

In 2003, Petersen et al³¹ presented a diagnostic classification system based on elements that were typical in the examination of a patient with LBP, and elements that had some empirical support. The “Petersen classification” has subsequently been implemented in 3 of 5 regions in Denmark as an evidence-based examination protocol for patients with nonspecific LBP³⁴⁻³⁶ who are at high risk of developing chronicity according to the STarT Back Tool (SBT),¹⁴ at risk of sick

● **BACKGROUND:** A diagnostic classification algorithm, “the Petersen classification,” consisting of 12 categories based on a standardized examination protocol, was developed for the primary purpose of identifying clinically homogeneous subgroups of individuals with low back pain (LBP).

● **OBJECTIVES:** To investigate whether a diagnostic classification algorithm is associated with activity limitation and LBP intensity at follow-up assessments of 2 weeks, 3 months, and 1 year, and whether the algorithm improves outcome prediction when added to a set of known predictors.

● **METHODS:** This was a prospective observational study of 934 consecutive adult patients with new episodes of LBP who were visiting chiropractic practices in primary care and categorized according to the Petersen classification. Outcomes were disability and pain intensity measured with questionnaires at 2 weeks and 3 months, and 1-year trajectories of LBP based on weekly responses to text messages. Associations were analyzed with linear and logistic regression models. In a sub-

group of patients, the numbers of visits to primary and secondary care were described.

● **RESULTS:** The Petersen classification was statistically significantly associated with all outcomes ($P < .001$) but explained very little of the variance ($R^2 = 0.00-0.05$). Patients in the nerve root involvement category had the most pain and activity limitation and the most visits to primary and secondary care. Patients in the myofascial pain category were the least affected.

● **CONCLUSION:** The Petersen classification was not helpful in determining individual prognosis in patients with LBP receiving usual care in chiropractic practice. However, patients should be examined for potential nerve root involvement to improve prediction of likely outcomes.

● **LEVEL OF EVIDENCE:** Prognosis, level 1b. *J Orthop Sports Phys Ther* 2018;48(11):837-846. Epub 8 May 2018. doi:10.2519/jospt.2018.8083

● **KEY WORDS:** back pain, classification, Petersen, primary care, prognosis

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leave or continued sick leave, or have experienced inadequate or no improvement 2 weeks after the initial consultation. The intention is to contribute to diagnostic clarification and stratification of patients for intervention to prevent long-lasting pain and chronicity,³⁴⁻³⁶ although the usefulness of the classification system to guide treatment remains unclear.

The classification consists of 12 categories based on the most likely source of pain and 1 category based on abnormal illness behavior³¹ (APPENDIX A, available at www.jospt.org). The specific criteria for each diagnostic category are met by items assessing patient history and a comprehensive clinical examination protocol that incorporates neurological signs, symptom responses to end-range testing, tests for sacroiliac joint and facet joint pain, adverse neural tension tests, and nonorganic signs. The order of the clinical tests in the examination procedure follows a specific algorithm, generated for several reasons. Clinical tests are likely to stress several lumbar structures simultaneously, thereby generating false-positive responses.^{5,25} Considering the category expected to have the highest prevalence first¹⁰ was expected to diminish the likelihood of false-positive tests in the remaining categories. Furthermore, the more specific pathoanatomical pain sources (eg, disc, sacroiliac joint, facet joint) are considered in the algorithm before those based on pain originating from connective tissue of the low back and nonspecific structures (eg, dysfunction syndrome and postural syndrome). Interexaminer reliability was found to be acceptable for the largest categories in 2 small cohorts (74%-100%), while reliability for the smaller categories is unknown.^{23,32}

In a primary care cohort of 110 patients,²³ the classification categories were shown to be associated with both pain-course patterns and the total duration (days) of LBP. Furthermore, some of the individual categories have been shown to be valid as prognostic factors of poor outcome (abnormal pain syndrome^{6,13} and

nonmechanical disc syndrome¹²), whereas several studies have found centralization of the patient's most distal pain toward the low back on end-range testing to be associated with good outcome.^{1,37,40,41}

Because there are no universally accepted gold standards for the diagnostic categories of this classification, we do not know whether the diagnoses proposed by the classification categories are associated with anatomical structure or "pathobiomechanics." Therefore, the classification categories are to be regarded as labels, not specific diagnoses. However, because the primary concern is patient outcomes³ and our present ability to accurately predict individual prognosis is limited, it would be helpful for patients and clinicians if the categories of the classification were shown to be associated with outcomes. Therefore, we investigated the association of these categories with prognosis.

The primary objective of this paper was to investigate whether the Petersen classification was associated with activity limitation and LBP intensity at 2 weeks and 3 months, and with 1-year trajectories of LBP intensity. The secondary objective was to investigate whether the Petersen classification improved the prediction of LBP intensity, activity limitation, and LBP trajectories when added to a set of known clinical predictors (SBT, age, sex, duration of pain, LBP in the last year, and patient recovery expectations). Last, we described the treatment chosen and treatment intensity in each diagnostic category.

METHODS

Study Design

CHIROPRACTORS (N = 36) FROM 17 chiropractic clinics in a Danish clinical research network invited consecutive patients with LBP, independent of previous LBP history, from September 2010 to January 2012 to participate in a prospective observational study. Patient recruitment and the cohort characteristics have been described previously.^{6,13}

Participating chiropractors attended a 1-day seminar covering the study procedures, as well as the theory and practice of the examination protocol. Following the seminar and prior to the start of the study, a research assistant with extensive clinical experience and a diploma in Mechanical Diagnosis and Therapy²⁷ visited all clinics to ensure that clinical examination procedures were standardized.

Participation in the study did not influence treatment, and therefore the local ethics committee declared that the study did not need ethics approval according to Danish law (DNcoBR, 2011). The project was approved by the Danish Data Protection Agency (J-number 2012-41-0762).

Patients were included if they had LBP of any duration (with or without leg pain), were 18 to 65 years of age, could read and understand Danish, had access to a mobile phone, and were able to use text messaging (SMS). Exclusion criteria were pain-related pathology or inflammatory pain, need for acute referral for surgery, pregnancy, or having received treatment for LBP within the previous 3 months. All questionnaires were sent directly to the research department, and answers were anonymized.

Data Collection

Patients completed questionnaires in the reception area prior to the first consultation. Those patients who were included were given a 2-week follow-up questionnaire and a prepaid envelope at the end of the initial consultation. Additionally, follow-up questionnaires were mailed after 3 and 12 months. Nonresponders were contacted by telephone to make sure they had received the questionnaire. Patients received an SMS question each Sunday for 52 weeks asking about their typical LBP intensity during the preceding week. The SMS message responses went directly into a data file, accessible only to the researchers.

The initial examination by the chiropractor followed the standardized examination protocol for the Petersen classification,³¹ as described (APPENDIX A).

Measurements

Patient-Reported Baseline Information

The following data were collected: age, sex, physical workload (mainly sitting, sitting and walking, light physical work, or hard physical work), sick leave taken (days off work due to LBP within the previous month), educational level (no qualification, vocational training, higher education of less than 3 years, higher education of 3 to 4 years, or higher education of more than 4 years), activity limitation (on the Danish version of the Roland-Morris Disability Questionnaire [RMDQ] converted to a proportional score, with 0% as no disability and 100% as maximum disability²⁰), LBP characteristics (pain duration of less than 2 weeks, 2 to 4 weeks, 1 to 3 months, or greater than 3 months), number of previous LBP episodes (0, 1 to 3, or more than 3), days with LBP during the previous year (up to 30 days or greater than 30 days), LBP intensity (typical intensity of back pain during the previous week, measured on a numeric rating scale [NRS], ranging from 0 to 10, where 0 is no pain and 10 is the worst imaginable pain¹⁶), leg pain intensity (typical intensity of leg pain during the previous week, measured on the NRS), psychological factors (recovery expectations ["How likely do you think it is that you will be fully recovered in 3 months?"], measured on an NRS, ranging from 0 to 10, where 0 is no chance and 10 is high chance²⁴), depressive symptoms (Major Depression Inventory, 0 to 50, sum score²), Fear-Avoidance Beliefs Questionnaire physical activity subscale (0 to 24, sum score), Fear-Avoidance Beliefs Questionnaire work subscale (0 to 42, sum score³⁹), general health (self-perceived general health using the Euro-Qol-5 Dimensions 0-to-100 visual analog scale, where 0 is the worst imaginable health state and 100 is the best imaginable health state³³), and the SBT (3 prognostic profiles: low-, medium-, and high-risk groups for persistent LBP disability¹⁴).

The Petersen Classification

Based on the results of the examination, chiropractors categorized patients ac-

cording to the Petersen classification.³¹ If the patient fulfilled the criteria for more than 1 category, then the chiropractor could give a secondary diagnosis. In our study, we added a category named "partly reducible disc" to the first part of the examination algorithm. This category included patients whose pain centralized on end-range testing, but not sufficiently to meet the criteria for a reducible disc (APPENDIX A). When choosing the primary diagnosis, chiropractors had to adhere to the hierarchy of the classification algorithm: nerve root involvement (NRI) greater than discogenic pain (reducible, partly reducible, nonreducible, nonmechanical) greater than adherent nerve root, stenosis greater than sacroiliac joint pain, facet joint pain greater than dysfunction, and postural syndrome greater than myofascial pain, abnormal nerve tension, and abnormal pain syndrome (APPENDIX A).

Outcome Measures

Low back pain intensity was measured on an NRS at 2-week and 3-month follow-ups.¹⁶ Activity limitation was measured using the RMDQ at 2-week and 3-month follow-ups.²⁰

Low back pain intensity trajectories were based on a weekly SMS asking, "Over the last week, how intense was your LBP typically on a scale from 0 to 10?" (0, no pain; 10, severe pain) for 1 year. Based on the SMS answers, 5 distinct LBP trajectories (recovery, recovery with mild relapses, slow improvement, moderate ongoing or relapsing, and severe ongoing) (APPENDIX B, available at www.jospt.org) were identified by latent class analysis in a previous study based on the same cohort.²¹ Not all patients in the cohort could be assigned in an unequivocal manner to a trajectory. This is reflected by posterior probabilities assigned by the latent class analysis to each patient and each trajectory. We included only patients with a 95% certainty for 1 trajectory. To facilitate the interpretation of the results, we merged the 5 LBP trajectories into 3 trajectory groups of

good outcome ("recovery" trajectory), intermediate outcome ("recovery with mild relapses" and "slow improvement" trajectories), and poor outcome ("moderate ongoing or relapsing" and "severe ongoing" trajectories).

The intended treatment was registered by the chiropractor at the first consultation. The number of visits to primary and secondary care was obtained from regional and national registries for a subgroup of 444 patients from the Region of Southern Denmark.

Data Analysis

Cases in which the secondary diagnosis, according to the hierarchy of the classification algorithm, should have been the primary diagnosis were recoded before further analysis. Categories with fewer than 10 patients were excluded from further analyses, as the limited sample size could have only provided very imprecise estimates of the average prognoses.

The statistical analysis was performed in 5 steps:

1. Baseline characteristics and continuous variables were summarized using the median and 10th and 90th percentiles. For categorical variables, proportions were reported.
2. Dropout analyses were performed to compare patients who responded to activity limitation and LBP intensity at 3 months with patients who did not, and patients who could be allocated to an LBP trajectory were compared with those who could not. A Wilcoxon rank-sum test was used for continuous variables and a Pearson chi-square test for categorical variables.
3. Primary objective: distributions of the RMDQ scores in the diagnostic categories were illustrated in box plots, and distributions of LBP intensity scores and LBP trajectories were illustrated in stacked bar charts. To assess prognostic capacity, a model (A) that included only the Petersen classification as an independent categorical covariate was evaluated using linear regression analyses, taking potential

clustering within clinics into account. The predictive capacity of the Petersen classification was assessed by the amount of explained variation in the outcomes and reported as adjusted R^2 . The statistical significance of the association between the Petersen classification and each outcome at each time point was reported as a P value. In this analysis, the 3 trajectory groups were handled as a continuous outcome and coded as 1, 2, and 3. To facilitate the clinical interpretation, we further dichotomized activity limitation (RMDQ proportional score of 8/100 or less and greater than 8/100), as a score of 2/24 or less on the RMDQ (0-24 scale) has been shown to most accurately identify patients who consider themselves completely recovered.¹⁷ The proportions of patients with an activity limitation proportional score of 8/100 or less at 2-week and 3-month follow-ups were reported, and logistic regression analysis was used to assess the statistical significance of the associations.

4. Secondary objective: a predictive model (B) that included a set of known prognostic variables as covariates and a model (C) that included all prognostic variables (the Petersen classification and the set of known prognostic variables) were evaluated using linear regression analysis, and presented as adjusted R^2 values. Comparison of the prognostic capacity (adjusted R^2) of models B and C was performed, and reported as P values to show whether adding the Petersen classification substantially increased the prognostic capacity compared to known prognostic factors alone. For all analyses, only patients with complete information on both classification and outcomes were included. No imputations were performed.
5. The choice of treatment was summarized using proportions with 95% confidence intervals (CIs), and the number of chiropractic and general practitioner visits over 1 year in each category was

summarized using median, and 10th and 90th percentiles. The proportion of patients with back-related visits in secondary care during the year after inclusion was reported for each category. Because these proportions were only used descriptively, a test of statistical significance was not performed.

For all analyses, the significance level was $P < .05$. Analyses were performed using Stata Version 14 (StataCorp LLC, College Station, TX).

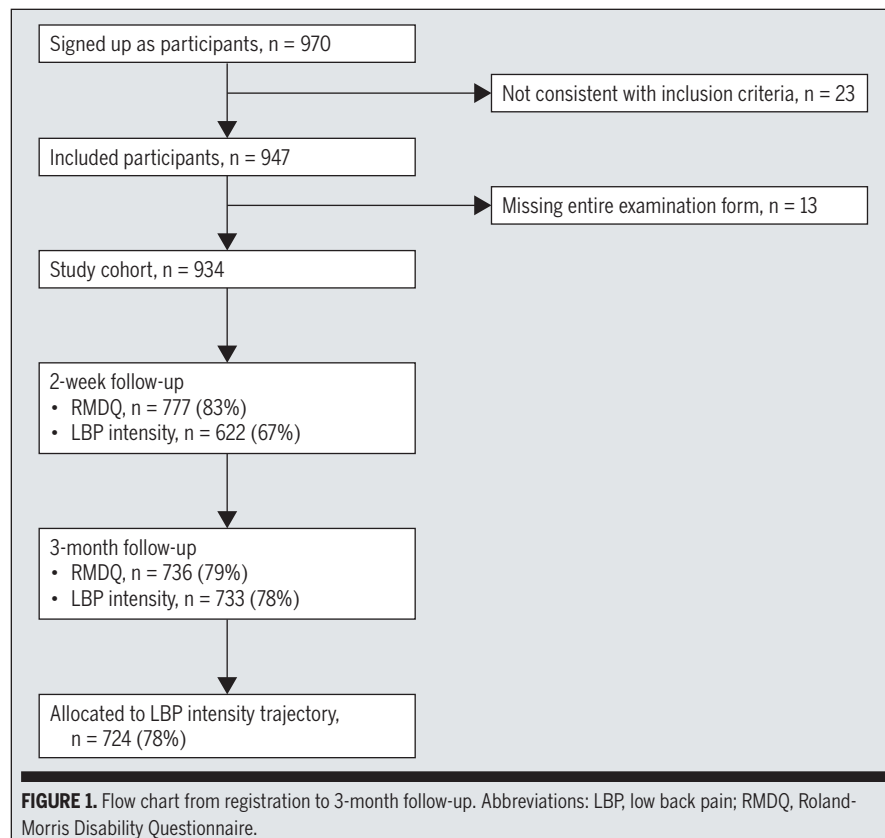
RESULTS

THE COHORT CONSISTED OF 934 patients with an average $\pm$ SD age of 43 ± 12 years and 45% of whom were female. About 3 out of 4 had LBP of less than 1 month in duration (TABLE 1). Loss to follow-up was 17% to 33% in relation to LBP intensity and activity limitation across all time points. Twenty-two percent could not be allocated to an LBP trajectory (FIGURE 1). In relation to LBP intensity

and activity limitation, the nonresponders tended to be younger (mean age, 39 versus 44 years), more often male (60% versus 54%), to have LBP of longer duration (20% versus 12% with pain of greater than 3 months in duration), more depressive symptoms (median, 8 versus 6), lower educational level (44% versus 34% with no qualification or vocational training), heavier physical work (30% versus 19% with heavy physical work), and more fear-avoidance beliefs in relation to work (median, 15 versus 11) (APPENDIX C, available at www.jospt.org).

The numbers of patients in the non-mechanical disc ($n = 3$), postural syndrome ($n = 7$), adherent nerve root ($n = 2$), stenosis ($n = 3$), adverse neural tension ($n = 0$), and abnormal pain syndrome ($n = 0$) categories were too low to describe sufficiently.

The primary diagnosis of the classification was recoded for 86 participants for whom the chiropractor had not adhered to the hierarchy of the classifica-



tion algorithm. About one third of these were primary diagnoses of dysfunction, with a secondary diagnosis of facet pain being converted to a primary diagnosis of facet pain.

The Petersen classification was associated with both activity limitation and LBP intensity at 2 weeks and 3 months (FIGURES 2 and 3, TABLE 2), as well as with 1-year trajectories of LBP (FIGURE 4, TABLE 2), but to a low degree (R^2 always equal to or less than 0.05). The most extreme categories were NRI and myofascial pain, with patients in the NRI category having the most and patients in the myofascial pain category having the least pain and activity limitation. Based on the dichotomized disability score, 7% (95% CI: 1%, 44%) of patients in the NRI category and 70% (95% CI: 47%, 86%) of patients in the myofascial pain category considered themselves to be completely recovered at 3-month follow-up (TABLE 3). In the rest of the categories, between 42% and 57% considered themselves to be completely recovered at 3-month follow-up.

To examine whether significant differences were due to the NRI category having very distinct outcomes, we did a post hoc analysis without the NRI category. The Petersen classification was still associated with activity limitation at 2 weeks ($P < .01$, adjusted $R^2 = 0.017$) and 3 months ($P = .02$, adjusted $R^2 = 0.008$), LBP intensity at 2 weeks ($P < .001$, adjusted $R^2 = 0.006$) but not 3 months ($P = .32$, adjusted $R^2 = 0.002$), and not associated with 1-year trajectories of LBP intensity ($P = .08$, adjusted $R^2 = 0.000$).

Regarding the choice of treatment in dependence on the classification (APPENDIX D, available at www.jospt.org), we observed that NRI patients as well as patients classified as nonconclusive differ in several aspects from the other patients. Moreover, centralizing exercises were a popular choice in the case of disc involvement, but not otherwise, and stretching exercises and soft tissue treatment were more popular in patients with myofascial pain. Otherwise, planned treatment for patients in the 9 categories was quite similar.

In 444 patients with data on health care utilization, the number of visits to primary care was similar across all categories, with the exception of the NRI category. While patients in the NRI cate-

gory had a median of 13 visits (10th-90th percentiles, 5-17) at 3-month follow-up, the rest of the categories had a median of 5.5 to 7.0 visits (10th-90th percentiles, 1.2-16.1). The same pattern was present

TABLE 1

DESCRIPTIVE BASELINE FACTORS*

All Patients (n = 934)	
Mean $\pm$ SD age, y	43 $\pm$ 12
Sex (female)	45
Physical workload	
Sitting	24
Sitting/walking	34
Light physical work	21
Heavy physical work	21
Sick leave	
Any days off work within previous month	22
Educational level	
No qualification	9
Vocational training	26
Higher education for <3 y	16
Higher education for 3-4 y	34
Higher education for >4 y	15
Duration of pain	
0-2 wk	63
2-4 wk	14
1-3 mo	10
>3 mo	13
Previous LBP episodes	
0 episodes	16
1-3 episodes	35
>3 episodes	49
LBP in the last year	
$\leq$ 30 d	74
>30 d	26
LBP intensity (0-10) [†]	7 (3-9)
Leg pain intensity (0-10) [†]	2 (0-7)
Recovery expectations [†]	9 (4-10)
Depressive symptoms [†]	6 (1-18)
Fear-avoidance beliefs-physical activity [†]	13 (6-20)
Fear-avoidance beliefs-work [†]	11 (3-26)
STarT Back Tool	
Low risk	54
Medium risk	38
High risk	8
Activity limitation (0-100) [†]	52 (17-83)
General health (0-100) [†]	70 (35-90)

Abbreviation: LBP, low back pain.

*Values are percent unless otherwise indicated.

[†]Values are median (10th-90th percentile).

RESEARCH REPORT

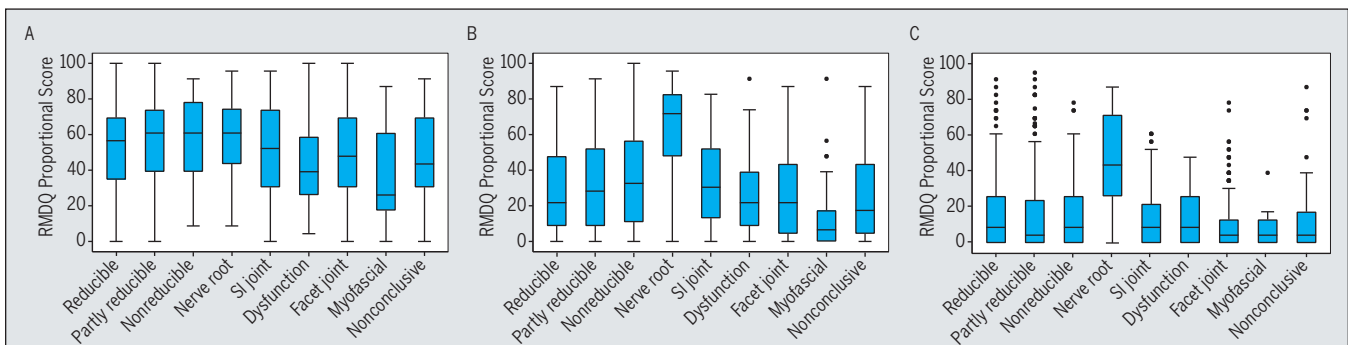
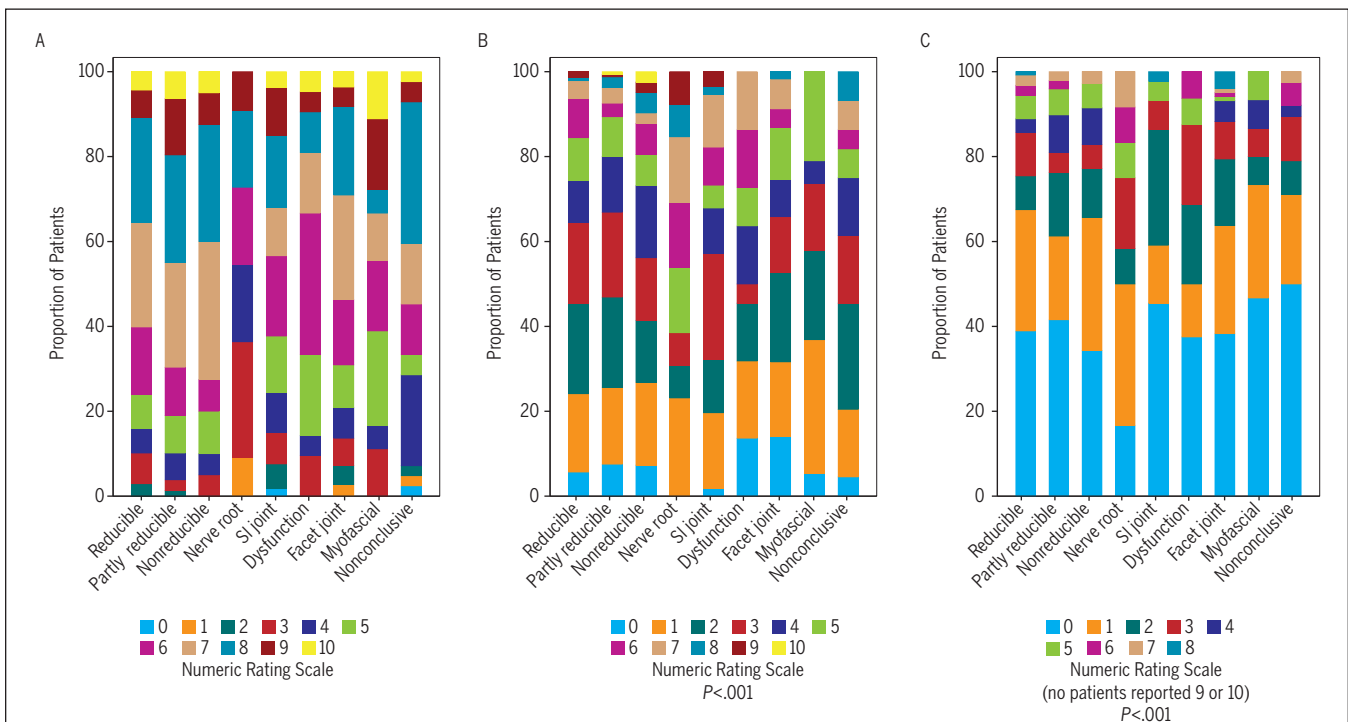


FIGURE 2. Distribution of the RMDQ scores in the 9 diagnostic categories in 934 chiropractic patients at (A) baseline, (B) 2-week follow-up, and (C) 3-month follow-up. Abbreviations: RMDQ, Roland-Morris Disability Questionnaire; SI, sacroiliac. Dots are outliers representing 1.5 times the interquartile range.



Low Back Pain Intensity (0-10)*

	Baseline	2 wk	3 mo
Reducible disc	7 (7, 7)	3 (2, 3)	1 (1, 1)
Partly reducible disc	7 (7, 8)	3 (2, 3)	1 (1, 1)
Nonreducible disc	7 (7, 8)	3 (2, 4)	1 (0, 1)
Nerve root involvement	5 (3, 8)	5 (1, 7)	2 (1, 5)
Sacroiliac joint pain	7 (6, 7)	3 (3, 4)	1 (0, 2)
Dysfunction	6 (6, 7)	4 (1, 5)	1 (0, 2)
Facet joint pain	7 (6, 7)	2 (2, 3)	1 (1, 1)
Myofascial pain	6 (5, 7)	2 (1, 3)	1 (0, 1)
Nonconclusive	6 (5, 7)	3 (2, 4)	0 (0, 1)

*Values are median (95% confidence interval).

FIGURE 3. Distribution of the low back pain intensity scores in the 9 diagnostic categories in 934 chiropractic patients at (A) baseline, (B) 2-week follow-up, and (C) 3-month follow-up. Abbreviation: SI, sacroiliac.

at 1-year follow-up (TABLE 4). The proportion of patients with back-related visits to secondary care ranged from 3% (95% CI: 0%, 9%) for patients in the facet joint pain category to 56% (95% CI: 21%, 86%) for patients in the NRI category (TABLE 4). Six patients had back surgery during the 1-year follow-up. One of these patients was in the NRI category and 4

were in the disc-related categories. We found only minor differences between the categories (FIGURES 2 through 4). Thus, the Petersen classification explained very little of the variance on its own ($R^2 = 0.00\text{--}0.05$) and performed much worse than a set of known clinical predictors (age, sex, duration of pain, LBP in the last year, SBT, and patient's recovery ex-

pectations; $R^2 = 0.11\text{--}0.19$) (TABLE 2). Consequently, it did not add considerably to the explained variance of the set of known predictors, even though it was statistically significant for activity limitation at 2-week and 3-month follow-ups.

DISCUSSION

THE PETERSEN CLASSIFICATION HAS limited value in predicting outcomes for patients with LBP in chiropractic practice. It was statistically significantly associated with both short-term outcomes and 1-year trajectories of LBP intensity; however, aside from the NRI category, the group differences were small and the classification explained little of the variation in outcomes. We cannot exclude that category-specific treatment has contributed to mask baseline differences in prognosis. Other studies have found that patients in the reducible disc categories responded significantly better to treatment when randomized to appropriate centralizing exercises compared to other treatments or exercises.²⁶ In our study, 47% to 84% of patients in the disc categories received centralizing exercises, compared to less than 7% in the other categories, and patients in the myofascial category received more stretching and soft tissue treatment than the others. This could indicate that potential differences in prognosis between some diagnostic categories were evened out by effective targeted treatment. When added to a set of known clinical predictors, the classification improved the prediction of activity limitation, suggesting that the clinical examination provided an independent, but small, amount of information about the condition that the other measured covariates did not.

The observed differences between categories confirmed previous findings that the NRI category was substantially different from the nonspecific LBP category, and the myofascial category tended to have the best and the nonreducible disc category the worst prognosis of the non-

TABLE 2	THE PROGNOSTIC CAPACITY OF THE DIAGNOSTIC CLASSIFICATION, A SET OF KNOWN CLINICAL PREDICTORS, AND A COMBINATION OF THE TWO*					
	Diagnostic Classification (Model A)		Set of Known Predictors (Model B) [†]		Set of Known Predictors Plus Diagnostic Classification (Model C) [‡]	
	2 wk	3 mo	2 wk	3 mo	2 wk	3 mo
Activity limitation	0.041§	0.051§	0.470§	0.193§	0.158¶	0.219¶
LBP intensity	0.015§	0.004§	0.109§	0.155§	0.105¶	0.171¶
1-year LBP trajectories	0.011§		0.183§		0.186¶	
Abbreviation: LBP, low back pain.						
*Values are reported as adjusted R ² in relation to the 3 outcomes.						
†Set of known predictors: STarT Back Tool, age, sex, duration of pain, LBP in the last year, and patient's recovery expectations.						
‡P value for likelihood ratio test comparing model B and model C.						
§P<.001.						
¶P<.05.						
¶P>.1.						

TABLE 3	PROPORTION OF PATIENTS WITH AN ACTIVITY LIMITATION PROPORTIONAL SCORE OF 8 OR LESS AT 2-WEEK AND 3-MONTH FOLLOW-UPS				
	2 wk*		3 mo [†]		
	n	Percent [‡]	n	Percent [‡]	
All patients	776 [§]	25 (22, 28)	735 [‡]	50 (46, 53)	
Reducible disc	172	24 (19, 31)	169	47 (40, 55)	
Partly reducible disc	192	23 (17, 29)	188	51 (44, 58)	
Nonreducible disc	44	20 (11, 36)	37	46 (30, 63)	
Nerve root involvement	14	14 (3, 48)	14	7 (1, 44)	
Sacroiliac joint pain	73	21 (13, 32)	64	42 (30, 55)	
Dysfunction	30	23 (11, 43)	29	48 (30, 67)	
Facet joint pain	150	30 (23, 38)	144	57 (49, 65)	
Myofascial pain	26	50 (30, 70)	23	70 (47, 86)	
Nonconclusive	57	26 (16, 40)	51	53 (39, 67)	
*P<.01. P value for the association between the diagnostic classification and activity limitation at 2-week follow-up.					
[†] P<.001. P value for the association between the diagnostic classification and activity limitation at 3-month follow-up.					
[‡] Values in parentheses are 95% confidence interval.					
[§] 18 patients missed the diagnostic classification.					
[‡] 16 patients missed the diagnostic classification.					

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specific LBP categories.^{1,23,37,40,41} Kongsted et al²² found this to be true also for patients with LBP referred to secondary care, as patients with NRI had poorer outcomes on all measures compared with patients with nonspecific LBP.

In a subpopulation, the number of treatments was lower in the categories with the best outcomes, and vice versa. For example, patients in the myofascial pain category had the fewest and second fewest number of visits to primary and secondary care, respectively, and reported the least pain and activity limitation

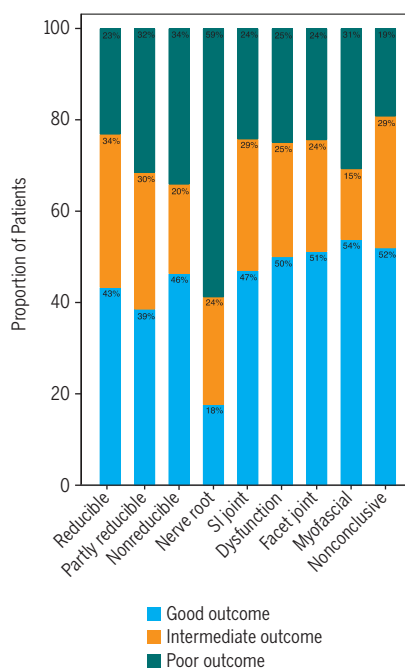
at both 2-week and 3-month follow-ups, whereas patients in the NRI category had poorer outcomes on all measures and consulted primary care almost twice as frequently as those in the other categories. However, as it seemed that some diagnostic categories triggered differences in treatment approaches, they may also have triggered differences in treatment intensity and referral to secondary care facilities, thereby affecting the outcome.

We pragmatically studied the classification as applied in usual clinical practice by a large number of clinicians with very

little extra training, likely reflecting the way it is utilized in everyday chiropractic practice. The geographical dispersion of the participating chiropractors ensured a broad representation of Danish chiropractic patients. It is possible, however, that the results would have been different had the participating chiropractors had more training in the examination algorithm, as the hierarchical thinking of this protocol was new to most of them.

We introduced the extra category “partly reducible disc” because it is our impression that clinicians treat patients with modifiable pain (ie, pain that does centralize, but not to the degree that fulfills the criteria for the reducible disc category) in a manner similar to that of patients in the reducible disc category. We were therefore reluctant to merge the “partly reducible disc” category with the “nonreducible disc” category. Based on the results of this study, the reducible and partly reducible disc categories seem to be similar in their associations with outcomes. However, in terms of care, patients in the partly reducible disc category were more similar to those in the nonreducible disc category, utilizing about 25% more health care visits than patients in the reducible disc category. In terms of prediction, the introduction of the partly reducible disc category may thus have confused the results of the disc categories.

Despite the relatively large cohort, the numbers of patients in the nonmechanical disc, postural syndrome, adherent nerve root, stenosis, adverse neural tension, and abnormal pain syndrome categories were too low to describe them sufficiently. This does not mean that they could not be relevant when present. Surprisingly, we did not find any patients in the abnormal pain syndrome category. This category has been quite prevalent in other studies where these tests have been the primary focus of the study.^{9,18} In our study, the tests for abnormal pain syndrome were the last tests in a long examination algorithm; thus, if both abnormal pain syndrome and another diagnosis



Outcome Trajectories*

	Good Outcome	Intermediate Outcome	Poor Outcome
Reducible disc	43 (36, 51)	34 (27, 41)	23 (17, 30)
Partly reducible disc	39 (32, 46)	30 (24, 37)	32 (25, 39)
Nonreducible disc	46 (31, 62)	20 (10, 35)	34 (21, 50)
Nerve root involvement	18 (5, 46)	24 (8, 52)	59 (33, 81)
Sacroiliac joint pain	47 (35, 59)	29 (19, 41)	24 (15, 36)
Dysfunction	50 (31, 69)	25 (12, 45)	25 (12, 45)
Facet joint pain	51 (42, 60)	24 (18, 33)	24 (18, 33)
Myofascial pain	54 (34, 73)	15 (5, 36)	31 (15, 52)
Nonconclusive	52 (38, 65)	29 (18, 43)	19 (10, 33)

*Values are proportion (95% confidence interval).

FIGURE 4. Distribution of the 3 low back pain trajectory groups (good, intermediate, and poor outcome) within the 9 diagnostic categories, based on 934 chiropractic patients. Abbreviation: SI, sacroiliac.

co-occurred, then the abnormal pain syndrome would not be reported. It may also be that chiropractors in Denmark attract a different population of patients.²⁸

We cannot exclude that nonresponse may be related to the individual outcomes. However, our nonresponder analyses indicated no relationship between the nonresponse and the diagnostic classification, and it is therefore unlikely that loss to follow-up affected the prognostic differences between the categories.

Based on the results of this study and those of previous studies, it is important to identify patients with NRI, as these patients have a different prognosis from patients with nonspecific LBP.^{22,23} Otherwise, our results suggest that the Petersen classification is not helpful in subgrouping patients with different types of back pain for prognostic purposes, a result that lends support to existing evidence that diagnoses based on clinical tests are not helpful in establishing patient prognosis.¹¹ Further, 6 out of 14 categories were rarely represented in a cohort of 934 patients, and the chiropractors disagreed or partly disagreed with the primary diagnosis in one third of the sample, which raises the question of whether the clas-

sification algorithm in its current form is useful in chiropractic practice.

CONCLUSION

THE PETERSEN CLASSIFICATION HAS limited value in predicting outcomes for patients with LBP receiving usual care in chiropractic practice. We did not investigate whether the classification might be helpful in guiding the choice of treatment, but for informing prognosis, clinicians should rely on other information shown to be predictive for patients with LBP. However, identifying patients with NRI is important, as these patients have a prognosis different from that of patients with nonspecific LBP. ●

KEY POINTS

FINDINGS: Subgrouping patients according to the Petersen classification is not helpful in predicting the future course of patients with low back pain in chiropractic practice. Patients with signs of nerve root involvement have a worse prognosis than patients with nonspecific low back pain.

IMPLICATIONS: If the examination is used to inform prognosis, then only the neu-

rological examination seems relevant. Future prognostic research should include examination findings about potential nerve root involvement.

CAUTION: Several categories were not or only sparsely represented in this population. Results might be different in other cohorts.

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TABLE 4

NUMBER OF HEALTH CARE VISITS IN THE
9 DIAGNOSTIC CATEGORIES AT 1-YEAR
FOLLOW-UP IN 444* PATIENTS IN THE REGION
OF SOUTHERN DENMARK

	Visits to Chiropractor [†]	Visits to General Practitioner [†]	Total Visits to Primary Care [‡]	Back-Related Visits to Secondary Care [§]
Reducible disc (n = 114)	6 (2-16.5)	4 (1-13.5)	11 (3.5-29)	9 (4, 16)
Partly reducible disc (n = 112)	6 (2-13.4)	5 (0-17)	14 (5-27.7)	13 (8, 21)
Nonreducible disc (n = 37)	5 (2-10.4)	6 (0.8-24.2)	13 (4.8-32.6)	14 (5, 29)
Nerve root involvement (n = 9)	8 (2-15)	11 (1-19)	21 (7-34)	56 (21, 86)
Sacroiliac joint pain (n = 32)	6.5 (2-15)	4.5 (0-20.8)	11 (6.3-36.8)	19 (7, 36)
Dysfunction (n = 18)	4.5 (2-16)	7 (1.8-14.5)	14 (5.9-28.2)	11 (1, 35)
Facet joint pain (n = 77)	6.4 (1.8-10.2)	5 (1-15.2)	11 (4.8-25.2)	3 (0, 9)
Myofascial pain (n = 18)	4.5 (1-14.4)	4 (0-17.3)	10 (3.8-31.3)	6 (0, 27)
Nonconclusive (n = 12)	4 (0.9-18.6)	5.5 (0-20.1)	11.5 (1.9-29.9)	17 (2, 48)

*15 patients missed the diagnostic classification.

[†]Values are median (10th-90th percentile).

[‡]Including visits to physical therapists.

[§]Values are proportion (95% confidence interval).

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APPENDIX A

CRITERIA FOR DIAGNOSTIC CATEGORIES

Diagnostic Categories	Criteria
1. Nerve root involvement	• Dominant pain below gluteal fold • Positive straight leg raise test • Reflex and/or muscle weakness corresponding to dermatomal distribution of the leg pain
2a. Reducible disc	• LBP with or without leg pain • AROM painfully limited in at least 1 direction • Centralization* on end-range testing
2b. Partly reducible disc	• LBP with or without leg pain, plus • AROM painfully limited in at least 1 direction, plus • Centralization* on end-range testing but the pain does not centralize 1 full region,[†] or • Centralization* of pain immediately after end-range testing but, after resuming a weight-bearing position, the pain returns to pretest intensity • Most distal pain is reduced but does not disappear
2c. Nonreducible disc	• LBP with or without leg pain, plus • AROM painfully limited in at least 1 direction, plus • No centralization* or improvement in pain intensity after test • Peripheralization[‡] in at least 1 direction on end-range testing
2d. Nonmechanical	• LBP with or without leg pain, plus • Increased pain intensity after testing in all directions • No improvement in AROM, and • Dominant pain above S1, but does not fulfill criteria for facet joint pain, or • Antalgic posture, or • Symptoms change side on testing in lateral bending or rotation
3. Adherent nerve root	• Dominant pain below gluteal fold • Does not fulfill criteria for categories 1 or 2a through 2d • Reduced ROM in flexion with referral of pain to the leg, but only in end range (on/off type of pain) • No pain in flexion in the lying position • No change after end-range testing
4. Stenosis	• Dominant pain below gluteal fold • Does not fulfill criteria for categories 1, 2a through 2d, or 3 • Symptoms diminish when sitting and worsen when walking • Walking distance increases when the back is in flexion
5. Sacroiliac joint pain	• LBP with or without leg pain, plus • Does not fulfill criteria for categories 1, 2a through 2d, 3, or 4 • A minimum of 3/5 positive sacroiliac joint tests[§]
6. Facet joint pain	• Local LBP • Does not fulfill criteria for categories 1, 2a through 2d, or 3 through 5 • Pain on combined extension/rotation, and • At least 2 of the following: - Best position: sitting - Best activity: walking - Paraspinal onset of pain - Age >50 y
7. Dysfunction	• LBP with or without leg pain, plus • Does not fulfill criteria for categories 1, 2a through 2d, or 3 through 6 • AROM is limited in at least 1 direction with turn-on/turn-off pain in end range
8. Postural syndrome	• Local LBP only when staying in the same position for some time • Normal and pain-free AROM • No provocation of symptoms during or after end-range testing • Longer duration of static test in at least 1 direction provokes pain

Table continues on page A2.

APPENDIX A

Diagnostic Categories	Criteria
9. Myofascial pain	- LBP with or without leg pain, plus - Does not fulfill criteria for categories 1, 2a through 2d, or 3 through 8 - Reproduction/worsening of patient's presenting pain on muscle palpation - May be used in combination with categories 1 through 8 or alone
10. Abnormal nerve tension	- LBP with or without leg pain, plus - Does not fulfill criteria for categories 1, 2a through 2d, or 3 through 8 - Positive anterior test[†] (minimum of 2 steps of the test provoke patient's known pain) - Pain only when tissue is stretched - May be used in combination with categories 1 through 8 or alone
11. Abnormal pain syndrome	- Minimum 3 of the following: - Widespread pain - LBP on axial compression or simulated rotation - Straight leg raise test improves on distraction - Muscle weakness or sensory loss in nonanatomical distribution - Overreaction on examination - May be used in combination with categories 1 through 8 or alone
Nonconclusive	Does not fulfill criteria for any category

Abbreviations: AROM, active range of motion; LBP, low back pain; ROM, range of motion.

*The most distal pain recedes toward the low back, or abolition of local LBP.

[†]One full region is from foot to calf, from calf to thigh, or from thigh to buttock/low back.

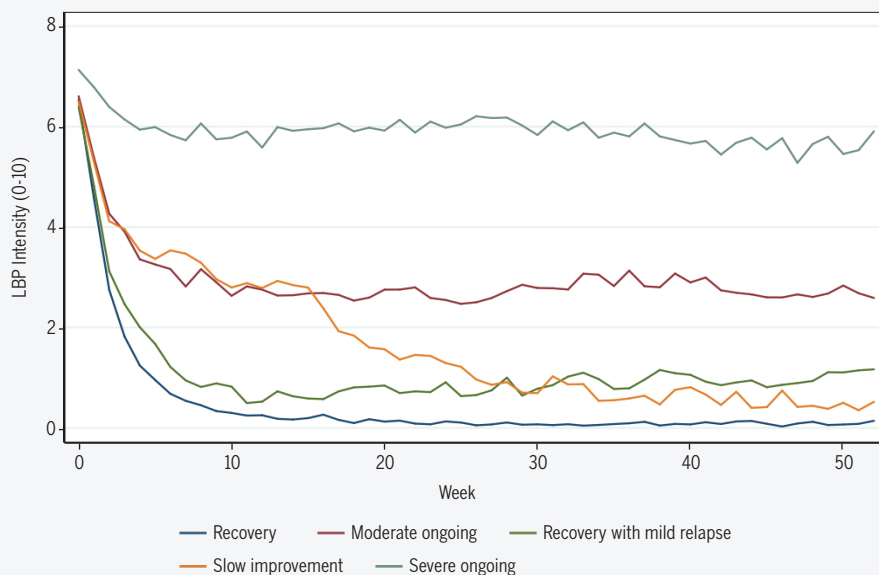
[‡]Movement of the pain farther from the midline of the low back toward the periphery or significant worsening of the most peripheral symptoms.

[§]Thigh thrust/P4, Gaenslen test, distraction/separation test, compression test, sacral thrust.

[‡]Step 1: patient sitting—straight leg raise until pain or until extreme position/as far as the patient tolerates. Step 2: add dorsiflexion of foot. Step 3: add flexion of the head. Minimum of 2 steps must be positive.

APPENDIX B

LOW BACK PAIN INTENSITY TRAJECTORIES PREVIOUSLY IDENTIFIED BY LATENT CLASS ANALYSIS



Abbreviation: LBP, low back pain.

APPENDIX C

DROPOUT ANALYSES: ACTIVITY LIMITATION AND LOW BACK PAIN INTENSITY AT 3-MONTH FOLLOW-UP*

	Responders (n = 782) [†]	Nonresponders (n = 152) [‡]	P Value
Mean ± SD age, y	44 ± 12	39 ± 11	<.001
Sex (female)	46 (42, 49)	40 (33, 48)	.20
Physical workload			.01
Sitting	24 (21, 27)	21 (15, 28)	
Sitting/walking	36 (33, 40)	25 (18, 33)	
Light physical work	20 (17, 23)	24 (18, 32)	
Heavy physical work	19 (17, 23)	30 (23, 38)	
Sick leave			.37
No days off work within previous month	79 (75, 81)	75 (67, 82)	
Educational level			.06
No qualification	8 (6, 10)	15 (10, 22)	
Vocational training	26 (23, 29)	29 (22, 37)	
Higher education for <3 y	16 (14, 19)	14 (9, 21)	
Higher education for 3-4 y	35 (32, 39)	29 (22, 37)	
Higher education for >4 y	15 (13, 18)	13 (8, 19)	
Duration of pain			.03
0-2 wk	63 (59, 66)	62 (54, 70)	
2-4 wk	14 (12, 17)	11 (7, 17)	
1-3 mo	11 (9, 14)	7 (4, 12)	
>3 mo	12 (10, 15)	20 (14, 27)	
Previous LBP episodes			.10
0 episodes	16 (13, 18)	20 (14, 27)	
1-3 episodes	36 (33, 40)	28 (21, 36)	
>3 episodes	48 (44, 52)	52 (44, 61)	
LBP in the last year			.24
≤30 d	75 (72, 78)	71 (62, 78)	
>30 d	25 (22, 28)	29 (22, 38)	
LBP intensity (NPRS, 0-10) [§]	7 (3-9)	7 (3-9)	.48
Leg pain intensity (NPRS, 0-10) [§]	2 (0-7)	2 (0-7)	.19
Recovery expectations [§]			.02
0 (no chance) to 10 (high chance)	9 (4-10)	9 (2-10)	
Depressive symptoms [§]			.02
MDI, sum score (maximum, 47)	6 (1-18)	8 (1-22)	
FABQ physical activity subscale sum score [§]	13 (5-20)	13 (6-21)	.10
FABQ work subscale sum score [§]	11 (3-25)	15 (3-28)	<.01
STarT Back Tool			.24
Low risk	55 (52, 59)	47 (39, 56)	
Medium risk	37 (34, 41)	44 (35, 52)	
High risk	8 (6, 10)	9 (5, 15)	
Activity limitation [§]			.88
RMDQ proportional score (0-100)	57 (17-83)	52 (17-83)	

Table continues on page A5.

APPENDIX C

	Responders (n = 782) [†]	Nonresponders (n = 152) [‡]	P Value
Self-perceived general health [§]			.19
EQ-5D VAS (0-100)	70 (35-90)	70 (31-90)	

Abbreviations: EQ-5D, EuroQol-5 Dimensions; FABQ, Fear-Avoidance Beliefs Questionnaire; LBP, low back pain; MDI, Major Depression Inventory; NPRS, numeric pain-rating scale; RMDQ, Roland-Morris Disability Questionnaire; VAS, visual analog scale.

*Values are proportion (95% confidence interval) unless otherwise indicated.

[†]Responded to at least 1 outcome measure (activity limitation, low back pain intensity) at 3-month follow-up.

[‡]Responded to neither of the 2 outcome measures (activity limitation, low back pain intensity) at 3-month follow-up.

[§]Values are median (10th-90th percentile).

DROPOUT ANALYSES: PATIENTS ALLOCATED TO AN LBP TRAJECTORY COMPARED WITH PATIENTS NOT ALLOCATED TO AN LBP TRAJECTORY*

	Patients With LBP Trajectory (n = 724)	Patients Without LBP Trajectory (n = 210)	P Value
Mean $\pm$ SD age, y	43 $\pm$ 11	44 $\pm$ 13	.54
Sex (female)	45 (41, 48)	45 (39, 52)	.90
Physical workload			.46
Sitting	23 (20, 27)	24 (19, 31)	
Sitting/walking	36 (32, 39)	30 (24, 37)	
Light physical work	20 (17, 23)	22 (17, 28)	
Heavy physical work	21 (18, 24)	24 (18, 31)	
Sick leave			.62
No days off work within previous month	78 (75, 81)	77 (70, 82)	
Educational level			.41
No qualification	9 (7, 11)	8 (5, 13)	
Vocational training	26 (23, 29)	27 (21, 34)	
Higher education for <3 y	16 (13, 18)	16 (12, 22)	
Higher education for 3-4 y	36 (32, 39)	30 (24, 36)	
Higher education for >4 y	14 (12, 17)	19 (14, 25)	
Duration of pain			.75
0-2 wk	63 (59, 66)	61 (55, 69)	
2-4 wk	14 (11, 16)	13 (9, 18)	
1-3 mo	11 (9, 13)	10 (6, 14)	
>3 mo	13 (10, 15)	16 (11, 21)	
Previous LBP episodes			.39
0 episodes	17 (15, 20)	14 (9, 19)	
1-3 episodes	35 (32, 39)	35 (28, 41)	
>3 episodes	48 (44, 52)	52 (45, 59)	
LBP in the last year			.94
$\leq$ 30 d	74 (71, 78)	74 (68, 80)	
>30 d	26 (23, 29)	26 (20, 32)	
LBP intensity (NPRS, 0-10) [†]	7 (4-9)	7 (3-9)	.61
Leg pain intensity (NPRS, 0-10) [†]	2 (0-7)	1 (0-7)	.76
Recovery expectations [†]			.28
0 (no chance) to 10 (high chance)	9 (4-10)	9 (3-10)	
Depressive symptoms [†]			.16
MDI, sum score (maximum, 47)	6 (1-18)	7 (1-19)	
FABQ physical activity subscale sum score [†]	13 (6-20)	13 (6-20)	.99

Table continues on page A6.

[RESEARCH REPORT]

APPENDIX C

	Patients With LBP Trajectory (n = 724)	Patients Without LBP Trajectory (n = 210)	P Value
FABQ work subscale sum score [†]	11 (3-26)	12 (3-27)	.87
StarT Back Tool			.33
Low risk	55 (51, 59)	49 (42, 56)	
Medium risk	37 (33, 41)	42 (35, 50)	
High risk	8 (6, 10)	9 (5, 14)	
Activity limitation [†]			.50
RMDQ proportional score (0-100)	53 (17-83)	52 (13-83)	
Self-perceived general health [†]			.76
EQ-5D VAS (0-100)	70 (35-90)	70 (32-90)	

Abbreviations: EQ-5D, EuroQol-5 Dimensions; FABQ, Fear-Avoidance Beliefs Questionnaire; LBP, low back pain; MDI, Major Depression Inventory; NPRS, numeric pain-rating scale; RMDQ, Roland-Morris Disability Questionnaire; VAS, visual analog scale.

**Values are proportion (95% confidence interval) unless otherwise indicated.*

[†]Values are median (10th-90th percentile).

APPENDIX D

TREATMENT IN THE 9 CATEGORIES*

	All Patients	Reducible Disc	Partly Reducible Disc	Nonreducible Disc	Nerve Root Involvement	Sacroiliac Joint Pain	Dysfunction	Facet Joint Pain	Myofascial Pain	Nonconclusive
Manipulation	94 (92, 95)	93 (89, 96)	95 (92, 97)	98 (88, 100)	71 (43, 88)	93 (85, 97)	96 (83, 99)	98 (95, 99)	90 (72, 97)	88 (77, 94)
Mobilization	13 (11, 15)	10 (6, 14)	12 (8, 17)	16 (8, 28)	47 (24, 72)	14 (8, 24)	9 (3, 22)	11 (7, 17)	10 (3, 28)	18 (10, 31)
STT	69 (66, 72)	63 (57, 70)	65 (59, 71)	66 (52, 77)	47 (24, 72)	77 (67, 85)	84 (70, 93)	76 (69, 82)	93 (75, 98)	68 (55, 79)
LUS	1 (1, 2)	3 (1, 6)	0 (0, 3)	2 (0, 12)	0	1 (0, 1)	0	1 (0, 5)	0	0
Postural advice	9 (8, 11)	10 (7, 15)	6 (4, 10)	16 (8, 28)	12 (3, 41)	12 (6, 21)	13 (6, 27)	8 (5, 14)	3 (0, 22)	12 (6, 23)
Advice about CPMLA	84 (81, 86)	86 (81, 90)	90 (85, 93)	91 (80, 96)	100	87 (78, 93)	82 (68, 91)	80 (73, 85)	77 (57, 89)	65 (52, 76)
Information about the condition	72 (69, 75)	75 (69, 81)	75 (69, 80)	76 (63, 85)	100	70 (59, 79)	80 (65, 90)	67 (60, 74)	73 (54, 87)	52 (39, 64)
Centralizing exercises	48 (44, 51)	83 (76, 88)	84 (78, 88)	47 (34, 60)	76 (48, 92)	6 (2, 14)	4 (1, 17)	4 (2, 8)	3 (0, 22)	20 (12, 32)
Strength exercises	14 (12, 16)	17 (12, 22)	14 (10, 19)	12 (6, 24)	6 (1, 37)	17 (10, 26)	9 (3, 22)	12 (8, 18)	10 (3, 28)	8 (3, 19)
Stabilization exercises	35 (32, 38)	40 (33, 46)	42 (35, 48)	45 (32, 58)	41 (19, 67)	31 (22, 42)	36 (23, 51)	31 (25, 39)	23 (11, 43)	8 (3, 19)
Stretching exercises	19 (17, 22)	16 (12, 22)	16 (12, 21)	21 (12, 33)	6 (1, 37)	26 (18, 37)	24 (14, 40)	20 (15, 27)	47 (29, 65)	8 (3, 19)
Other	1 (1, 2)	2 (1, 5)	0 (0, 3)	0	0	1 (0, 8)	0	2 (1, 5)	13 (5, 32)	0
Referred to OHCP	1 (1, 3)	1 (0, 4)	0 (0, 3)	3 (1, 13)	6 (1, 37)	2 (1, 9)	2 (0, 15)	1 (0, 5)	3 (0, 22)	2 (0, 11)
No treatments	1 (0, 1)	0	0 (0, 3)	0	0	1 (0, 8)	0	1 (0, 4)	0	3 (1, 13)

Abbreviations: CPMLA, cryotherapy, pain medication, level of activity; LUS, laser, ultrasound, shockwave; OHCP, other health care provider; STT, soft tissue treatment.

*Values are proportion (95% confidence interval).

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Additive Effect of Therapeutic Ultrasound in the Treatment of Plantar Fasciitis: A Randomized Controlled Trial



The plantar fascia is a thick, nonelastic, multilayered connective tissue crossing the plantar part of the foot.²⁴ Plantar fasciitis is the main cause of pain in the plantar surface of the heel. It has been estimated that this problem is involved in approximately 11% to 15%

of all foot pain complaints requiring medical attention.²⁵ Other names for this condition include painful heel syndrome, heel spur, runner's heel, subcalcaneal pain, calcaneodynia, and calcaneal periostitis.³⁷

In the United States, more than 2 million people are treated for plantar fasciitis every year. It is estimated that approximately 10% of the US population will experience plantar fasciitis, regardless of sex, age, ethnicity, or level of activity.

This phenomenon is seen in active people, such as runners and military personnel; however, it also appears in the general population, especially in women aged 40 to 60 years.^{6,37}

Plantar fasciitis can be a painful and exhausting condition, frustrating for both the patient and the physical therapist. The most common signs for identifying plantar fasciitis are pain and tenderness in the medial tubercle of the heel bone, as well as an increase in pain when taking first steps in the morning and pain in prolonged weight bearing.³⁰

Conservative treatment options for plantar fasciitis include joint and soft tissue manipulations, transcutaneous electrical nerve stimulation, patient training, taping, night splints, stretching, ice, heat, muscle strengthening, and insoles. In addition, shockwave therapy, injections, medications, and even surgical interventions are used in the event that conservative treatments prove ineffective. At present, researchers have not determined the most effective combination of treatments for plantar fasciitis due to the dearth of high-quality research in this area.¹⁷

In 2003, a systematic review¹¹ of 19 randomized clinical trials (RCTs) evaluated the effectiveness of treatments for plantar heel pain, of which 7 compared

• **BACKGROUND:** Plantar fasciitis is the chief cause of pain in the plantar surface of the heel. Therapeutic ultrasound is one of the most common conservative treatment modalities used by physical therapists worldwide, despite scarce evidence of its efficacy in treating plantar fasciitis.

• **OBJECTIVE:** To evaluate the additive effect of therapeutic ultrasound in the treatment of plantar fasciitis in terms of pain, function, and quality of life.

• **METHODS:** In this prospective, randomized, double-blind, placebo-controlled clinical trial, 54 patients with plantar fasciitis, aged 24 to 80 years, who met the inclusion criteria were randomized into an active intervention and a control group. Individuals in the active intervention group were treated with self-performed stretching of the plantar fascia and calf muscles and with therapeutic ultrasound. Individuals in the control group were treated with the same stretching exercises and sham ultrasound. Both groups received 8 treatments, twice weekly. Outcome measures included

a numeric pain-rating scale, the computerized adaptive test for the foot and ankle, and an algometric test.

• **RESULTS:** Both groups showed statistically significant improvement in all outcome measures ($P < .001$, both groups). At the completion of the study, no statistically significant differences were found between the groups in any of the outcomes.

• **CONCLUSION:** The addition of therapeutic ultrasound did not improve the efficacy of conservative treatment for plantar fasciitis. Therefore, the authors recommend excluding therapeutic ultrasound from the treatment of plantar fasciitis and agree with results of previous studies that stretching may be an effective treatment for healing plantar fasciitis.

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• **KEY WORDS:** heel pain, physical therapy, therapeutic ultrasound, treatment

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active treatment with placebo or no treatment at all. Treatments included insoles, heel pads, corticosteroid injections, night pads, and shockwaves. The authors¹¹ found limited evidence of effectiveness using the reviewed interventions. Treatments used to reduce heel pain seemed to produce only marginal gains over no treatment and control therapies such as stretching. All RCTs included in the review had methodological problems with the study design or small sample sizes.¹¹

In 2014, a systematic review¹² that included 26 trials (23 of them controlled clinical trials) assessed subjects who especially experienced pain in the morning with a visual analog scale or numeric scales (used as the main outcome measure). Interventions included shockwave therapy, stretching and manual treatments, therapeutic ultrasound, laser, taping, acupuncture, electrical stimulations, insoles, magnetotherapy, and elastic taping. Of the 23 controlled clinical trials, 14 compared the active treatments (monotherapy or combination of several treatment techniques) to a single treatment or placebo. The authors¹² concluded that a combination of several treatment techniques appeared to be more effective than monotherapy. However, due to the heterogeneity of techniques, the different number of sessions, and the diverse duration of treatments, it was impossible to perform a quantitative statistical analysis.¹²

One of the most widely used electrical devices among physical therapists in Israel and worldwide is therapeutic ultrasound.^{26,36,41,42,44} Therapeutic ultrasound raises tissue temperature and metabolism, softens the tissues, increases blood circulation, increases the chemical activity of the tissues, increases the permeability of the cell membranes, and modulates the molecular structures and the rate of pulsation and protein production—all potentially affecting the speed of tissue recovery.³⁹ Yet there is insufficient high-quality scientific evidence to support the clinical use of therapeutic ultrasound in treating musculoskeletal problems.⁴²

Only 2 studies have examined the efficacy of ultrasound in the treatment of plantar fasciitis. One compared active therapeutic ultrasound with sham ultrasound treatment,¹⁰ and the second supplemented calf muscle stretching in both groups.⁴³ Both studies found that the addition of active therapeutic ultrasound therapy had no advantage over sham treatment in cases of plantar fasciitis. However, the methodology in both studies was problematic. In the first study, researchers used ultrasound parameters of 0.5 W/cm², 3 MHz, and a pulse ratio of 1:4 for 8 minutes.¹⁰ These parameters may not have allowed the ultrasound waves to deliver energy to the target tissues. The plantar fascia, according to the authors' examination, lies at a depth of greater than 2 cm; therefore, the frequency and intensity of the ultrasound should be much higher.³⁵ In addition, pulsed ultrasound, used especially on chronically ill patients, may also be unsuitable because it prevents the raising of tissue temperature, thus reducing the thermal effect of treatment.²

In the second study, the researchers employed parameters of 2 W/cm², 1 MHz, and a continuous wave⁴⁶; however, the technique for placing the ultrasound transducer was static, which is not a commonly used technique and may increase the chances of producing pain and causing a detrimental effect in nearby tissues. The ultrasound was applied for 3 minutes at each painful point, which may be insufficient. Further, the number of subjects in both studies was low, making their statistical power questionable. In addition, both studies included each foot separately in the randomization of patients with bilateral plantar fasciitis, which could have interfered with the blinding in cases where each foot received different treatments.

In conclusion, high-quality RCTs are needed to assess the efficacy of the additive effect of therapeutic ultrasound in the treatment of plantar fasciitis. The aim of the present study was to evaluate the additive effect of therapeutic ultrasound in treating plantar fasciitis in terms of

pain, function, and quality of life. The authors hypothesized that therapeutic ultrasound, employing parameters that increase heat in the target tissue (continuous wave, 1.8 W/cm², and a frequency of 1 MHz), and stretching exercises would significantly improve pain, function, and quality of life in patients with plantar fasciitis, more than stretching and sham therapeutic ultrasound.

METHODS

Design and Setting

THIS STUDY, AN INTERVENTIONAL, prospective, double-blind randomized controlled trial, was performed at the Maccabi Healthcare Services physical therapy clinics in Rehovot, Ashdod, and Ashkelon, Israel.

Sample

Recruitment took place from June 2015 through May 2017. The study included patients who were registered at the Maccabi Healthcare Services; were diagnosed with plantar fasciitis, plantar heel pain, calcaneal spur, foot pain, or heel pain syndrome; and were referred for physical therapy by an orthopaedist or general practitioner.

Inclusion criteria were being 18 years of age or older and reporting a primary complaint of pain at the bottom of the heel, with the following clinical features^{3,8,28}: (1) a gradual development of pain (with no trauma), (2) pain generated by carrying weight or by local pressure, (3) an increase in pain in the morning upon taking a few steps or after prolonged non-weight bearing, and (4) symptoms decreasing with slight levels of activity, such as walking. Additional criteria were a numeric pain-rating scale (NPRS) score for morning pain of greater than 3 (to prevent the floor effect), sensitivity or swelling in the proximal planetary region of the fascia, or medial plantar tuberosity of the calcaneal bone.

Exclusion criteria included peripheral neuropathy, calcaneal cysts or tumors, calcaneal fractures or stress fractures,

use of steroids during the past 6 months, foot surgery performed the year prior, infection or diabetic foot, tarsal tunnel syndrome (TTS), fat-pad syndrome, pregnancy, and unavailability in the coming month.

The study was approved by the Helsinki Ethical Committee of Maccabi Healthcare Services, Bait Balev Nursing Home, Bat Yam, Israel. All patients signed an informed-consent form prior to participation, and the rights of the participants were protected. The study was registered at ClinicalTrials.gov (registration number NCT02679326).

Sample-Size Estimation

Because 2 previous studies were underpowered,^{10,46} the researchers decided to commence recruitment with 60 subjects (30 in each group), and possibly refine sample-size calculations after mid-term data analysis. Using PS: Power and Sample Size Calculation Version 3.0 (William D. Dupont and Walton D. Plummer, Jr.), the authors performed sample-size calculations based on the following parameters: a 2-sided test, power of 0.8, and $\alpha = .05$. The main outcome measure was the NPRS for morning pain. The researchers chose to apply the mean difference of 2 (representing the clinically important difference on the NPRS).¹⁴ In mid-term statistics, the standard deviation of the NPRS was 2.48, thus establishing the need for 25 subjects in each group. Due to the possibility of dropouts, 54 participants were recruited. Trial registration at ClinicalTrials.gov was prematurely closed with 51 participants having completed the study, not accounting for the final 3 participants, for whom data collection was not yet completed.

Allocation

The allocation of patients to the active intervention and control groups was performed using a 10-patient block randomization software program (mahmoodsaghaei.tripod.com/Softwares/randalloc.html). The results of the randomization were recorded, placed in

sealed envelopes, and kept in the office of the director of the physical therapy clinics. After signing an informed-consent form and meeting the inclusion criteria, patients were assigned to a specific group by the head of the physical therapy institutions in Rehovot, Ashdod, or Ashkelon.

Outcome Measures

Baseline evaluation included demographic data collection, medical history, and a physical examination. Demographic data included age, sex, weight, height, and body mass index (weight in kilograms divided by height in meters squared), the affected side (the more symptomatic side when the condition was bilateral), duration of the condition, and physical activity (participating or not, and how many hours each week) (TABLE 1).

Physical examination included palpation performed for local heat or swelling and for local pain at the medial calcaneal tuberosity. Participants with clinical symptoms of pain in the middle of the heel, aggravated when walking on hard surfaces or with a history of heel blow, were excluded for suspicion of fat-pad syndrome.⁴³ In the differential diagnosis of TTS, 3 signs were used to exclude the pathology: the presence of numbness or burning pain, a positive Tinel sign, and a positive neurodynamic test. The Tinel sign was found to be positive in TTS and medial plantar nerve entrapment by Schon and Baxter in 1990.³⁹ The modified straight leg raise test with dorsiflexion/eversion was found to be a valuable tool to differentiate plantar heel pain of neural origin from plantar fasciitis. As none

TABLE 1

DEMOGRAPHIC AND BASELINE CHARACTERISTICS OF THE GROUPS*

Variable	Active Ultrasound (n = 28)	Sham Ultrasound (n = 26)
Age, y	50.93 ± 12.87	52.58 ± 12.36
BMI, kg/m ²	28.95 ± 4.10	29.81 ± 4.42
NPRS (0-10) in the morning	6.57 ± 2.04	7.04 ± 2.01
NPRS (0-10) during the day	5.63 ± 2.39	5.46 ± 2.21
Foot and ankle CAT (initial, 0-100)	51.79 ± 10.30	48.81 ± 10.00
Alometry, kg	4.97 ± 1.67	5.25 ± 1.67
Weekly sports activities, h	3.29 ± 2.08	3.85 ± 2.26
Duration of symptoms, %		
<3 mo	25.0	26.9
>3 mo	75.0	73.1
Side of pain, %		
Right	32.2	23.1
Left	46.4	57.7
Both	21.4	19.2
Sex, %		
Female	78.6	53.8
Male	21.4	46.2
Daily activity/work level, % [†]		
1	14.3	19.2
2	42.9	46.2
3	35.7	19.2
4	7.1	15.4

Abbreviations: BMI, body mass index; CAT, computerized adaptive test; NPRS, numeric pain-rating scale.

*Values are mean ± SD unless otherwise indicated.

[†]Levels: 1, predominantly sitting; 2, sitting and walking short distances; 3, quite active: walking long distances and prolonged standing; 4, predominantly walking and standing.

of these tests can provide an accurate answer, participants with at least 1 positive test for TTS were excluded.

Outcome measures were the levels of pain during the first few steps in the morning and during the day (rated by the NPRS), pressure pain threshold, and perceived functional level (foot and ankle computerized adaptive test [CAT]). The main outcome was morning pain rated by the NPRS. Patients were asked to assess the intensity of pain when taking their first steps in the morning on a scale from 0 to 10, with 0 as no pain and 10 as unbearable pain. The NPRS is not age dependent, contains a low risk for error, a high face validity, and high convergent and criterion validity compared to other pain scales.^{16,23} The NPRS is considered a gold standard for self-assessment of pain and is a reliable and accurate tool.²⁹ A 2-point decrease or a 30% reduction in NPRS score represents a significant clinical change.^{5,14}

The second outcome measure was the average pain felt during the day as measured by the NPRS. The third outcome measure was the foot and ankle CAT, which assessed the perceived functional level of the patient. This test was incorporated into the report because, in many studies, the state of overall functioning and health-related quality of life is considered the gold standard of treatment outcomes.¹⁸

The foot and ankle CAT consists of a computerized adaptive questionnaire that collects patient results using a computer to adjust questions to the patient by matching the difficulty of each question to the patient's ability. The participant stops answering the questions when he or she has answered 3 consecutive questions corresponding to a certain functional level. Hart et al²⁰ observed that after an average of 6.6 questions, the questions ceased. The advantage of the adjusted questionnaire is the fewer number of questions asked and the reduced time needed to complete the questionnaire.

The foot and ankle CAT is derived from the Lower Extremity Functional Scale questionnaire,²⁰ consisting of 18 ques-

tions that represent functional activities such as "walking between rooms." The patient is asked to rate his or her ability to perform each activity on a 5-point scale ranging from 0 ("very difficult or unable to perform the action") to 5 ("no difficulty"). The total score of the questionnaire ranges from 0 to 100, with a higher score indicating better function. The CAT has shown good construct validity²⁰ and identification validity.¹⁹ An average change of 8 points or greater in functional status is viewed as a significant clinical change.⁴⁵

To assess pressure pain threshold, algometry was used to measure the minimum pressure required to produce pain. A disc was placed vertically on a pressure pain point. The examiner then increased the intensity of the pressure until initial pain occurred (when the feeling of stress became painful). The score was calculated as the average score of 3 continuous measurements. The algometer enables an objective assessment of pain and complements the NPRS, which is a subjective tool. The algometry test was found to be valid and reliable when measurements were repeated (interrater, intrarater) on healthy people.¹⁵ High reliability was found for algometer testing in an average calculation between 3 repeated measures (intraclass correlation coefficient = 0.91; 95% confidence interval: 0.82, 0.97).⁴ The algometer measurement was performed twice during the study, first during the initial evaluation and then at the final evaluation.

Intervention

Stretching Many studies have suggested that stretching the triceps surae muscles is an essential part of plantar fasciitis treatment.^{31,33} The purpose of stretching is to release the tension created in the plantar fascia or stiffness of the Achilles tendon, both of which connect to the calcaneus bone.⁴³ Both groups in the present study received a verbal explanation and printed pages with images and instructions on how to perform stretching of the plantar fascia and triceps surae. Stretching exercises used in this study were

based on previous studies^{13,32} that found those exercises effective for pain reduction and functional improvement.

The authors chose a regimen of twice daily (once before walking in the morning and once during the day, after sitting for a long period or at the end of the day), 5 repetitions of 20 seconds each. Subjects executed these exercises during their first treatment session, supervised by a physical therapist. The plantar fascia stretch was performed with the patient seated. Two stretching exercises of the triceps surae were conducted against a wall (once with a straight knee and once with a bent knee) twice a day, 5 sets of 20 seconds static at a time.

Therapeutic Ultrasound Because the researchers found no publications on depth of the plantar fascia, they assessed the depth of the plantar fascia connection to the medial calcaneal tuberosity prior to the current study by examining 10 computed tomography (CT) scans of normal feet (5 of males and 5 of females), and found that the average depth of the plantar fascia was 2.1 ± 0.2 cm (range, 1.80-2.40 cm; mean standard error, 0.06). The test was performed at the Barzilay Hospital by a researcher experienced in CT evaluation (L.K.), together with a board-certified radiologist, using anonymized CT scans from the archive.

In addition to stretching, participants in the study group were treated with 8 minutes of therapeutic ultrasound at a frequency of 1 MHz and continuous current at a pulse intensity of 1.8 W/cm^2 (when the sensitivity level was too high and the procedure hurt the patient, the therapist reduced the intensity). The selection of the parameters was based on previous studies^{10,46} and on the recommendations of the ultrasound dose calculations website (<http://www.electrotherapy.org/modality/ultrasound-dose-calculation>). The authors also used an online calculator for ultrasound dosage (<http://www.sonodose.dk/SONODOSE-lite/SONODOSE-lite.htm>).

Because previous studies^{10,46} have showed no effect of ultrasound, the

researchers intended to maximize therapeutic effects (both thermic and nonthermic) in the target tissue. To maximize the thermic effect, the authors chose the continuous mode, which is also in accord with the common recommendation for chronic conditions. According to the recommendations of both sites, in lesions deeper than 2 cm, use of 1-MHz frequency is recommended. When the targeted tissue is at an average depth of 2.1 cm in mixed tissues (eg, skin, fat pad) and taking into account the thickness of the plantar fascia,¹ 1.8 W/cm² was the optimal power to reach the therapeutic intensity (in the site of the lesion) of 1 W/cm². The treatment time of 8 minutes is slightly longer than recommended by the online calculator, and by the researchers' clinical practice (5 minutes), but was chosen because of its use in a previous study¹⁰ and because the authors wanted to use the highest possible parameters.

In addition to stretching, the control group was treated with 8 minutes of negligible-intensity ultrasound. Parameters were a frequency of 3 MHz, pulse intensity of 0.1 W/cm², and a duty cycle of 1:4 (pulsed). With these parameters, the ultrasound energy did not penetrate beyond a few millimeters and did not reach the target tissue. Both groups received 8 treatments, twice a week for 4 weeks. During the study period, the therapists recorded all occurrences of adverse events reported by the patients.

Throughout the study, the examiner was blinded to patient allocation and the patient to the treatment group to which he or she belonged (double blinded). After a physical therapist examined the patient, different physical therapists at the institute treated the patient. At the beginning of the study, all physical therapists were instructed on how to perform the ultrasound treatment and the stretching techniques. Patients were treated by different physical therapists to avoid overloading the institute's schedule. The therapist was not blinded to the type of treatment provided to the patient. Physical therapists were instructed to register

every adverse event and to immediately report it to the research coordinator. At the end of the study, no adverse events were reported.

Statistical Analysis

Statistical analysis was performed using SPSS Version 21 for Windows (IBM Corporation, Armonk, NY). The demographic and baseline characteristics between groups were compared by the 1-way analysis of variance (ANOVA) for parametric variables and the chi-square test for nonparametric variables. The outcome measures were compared using the mixed ANOVA to identify the main effect of time and the group-by-time interaction. All statistics were conducted using per-protocol and intention-to-treat analyses. The threshold for statistical significance for all tests (2-sided analyses) was $P < .05$. As no difference was found in any outcome measures, intention-to-treat analysis was not performed. The effect size was calculated using Cohen's d .⁷

RESULTS

OF 145 PATIENTS WITH PLANTAR FASCIITIS who were interviewed by telephone, 84 did not meet the inclusion criteria due to language difficulties or refusal to participate in the study. The remaining 61 who met the inclusion criteria were invited to the clinic. Of these, 7 refused to participate in the study or were found unsuitable, leaving 54 patients (18 men, 36 women; age range, 24–80 years; mean $\pm$ SD age, 51.72 ± 12.53 years) who met the inclusion criteria and were enrolled.

Fifty patients completed the study, after 3 dropped out from the active intervention group (1 unavailable, 2 unwilling to continue) and 1 from the control group (dissatisfied) (FIGURE). No differences in baseline characteristics were found between those who dropped out and those who completed the study, except that the dropouts were younger (39.75 ± 13.53 versus 52.68 ± 12.09 years), scored higher on the functional foot and ankle CAT

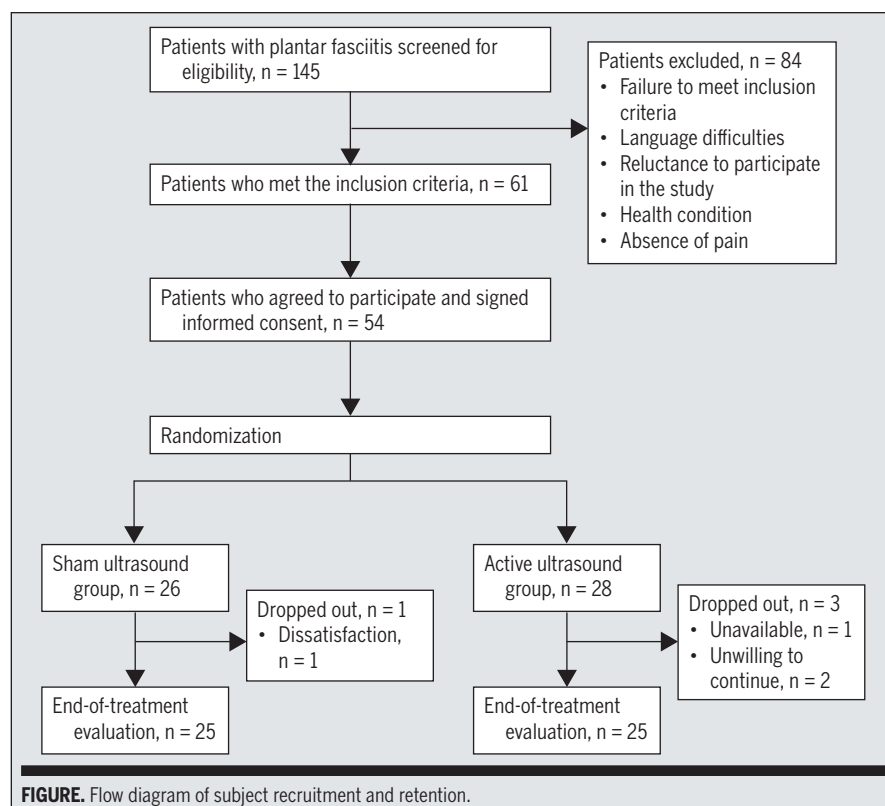


FIGURE. Flow diagram of subject recruitment and retention.

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(62.50 ± 3.87 versus 49.38 ± 9.90), and completed more hours of sports activity during the week (8.00 ± 0.01 versus 3.15 ± 1.77). Most patients (n = 40) had plantar fasciitis for greater than 3 months, 13 had this condition between 3 weeks and 3 months, and 1 for less than 3 weeks.

Twenty-two patients attended all 8 sessions (14 from the active ultrasound group and 8 from the sham ultrasound group), 14 patients attended 7 sessions (4 from the active ultrasound group and 10 from the sham ultrasound group), 9 other patients attended 6 sessions (3 from the active ultrasound group and 6 from the sham ultrasound group), and 5 attended fewer than 5 sessions (4 from the active ultrasound group and 1 from the sham ultrasound group). The main reason for not attending was unavailability. No statistically significant differences were found between the groups in the number of attended treatments ($F_1 = 0.6, P = .81$; active ultrasound group mean ± SD, 7.04 ± 1.34; sham ultrasound group mean ± SD, 6.96 ± 0.98).

When comparing the baseline characteristics between groups (TABLE 1), the mean NPRS score during the first steps in the morning was high in both groups (mean ± SD, 6.57 ± 2.04 in the active ultrasound group and 7.04 ± 2.01 in the

sham ultrasound group). Body mass index of both groups showed that the majority of participants were overweight (28.95 ± 4.10 kg/m² in the active ultrasound group and 29.81 ± 4.42 kg/m² in the sham ultrasound group). No differences were found between the groups in any baseline characteristics.

In the mixed ANOVA (per-protocol analysis) (TABLE 2), no significant difference was found in the group-by-time interaction for all 4 outcome measures. But the effect of time was significant ($P < .001$ in each outcome measure), indicating that both groups significantly improved during the study. For example, in the NPRS score for morning pain, 17 participants in the active ultrasound group and 19 participants in the sham ultrasound group improved more than the minimal detectable clinical difference. However, no difference in improvement was seen between the active versus the sham ultrasound groups. When comparing the need for further treatment between the 2 groups, 10 of 25 (40%) in the active ultrasound group, versus

12 of 25 (48%) in the sham ultrasound group, had to continue treatment, with no statistically significant difference between groups ($\chi^2_1 = 0.33, P = .57$). Because intention-to-treat analyses showed similar results, the authors have not presented them.

DISCUSSION

THIS PROSPECTIVE, DOUBLE-BLIND RCT found that there was no additive effect of therapeutic ultrasound on the treatment of plantar fasciitis in terms of pain, function, and quality of life. These findings are in agreement with previous researchers^{10,46} who found that therapeutic ultrasound was ineffective in treating this condition. The advantages of the present study over previous investigations were (1) the choice of adequate parameters of therapeutic ultrasound intervention (the ultrasound parameters were selected to allow the ultrasound waves to deliver enough energy to the target tissues at a depth of 2.1 ± 0.3 cm), (2) adequate statistical power (50 patients [25 in each group] were included to provide sufficient statistical power to reject the null hypothesis), and (3) study design (the RCT was double blinded, and only the leg with the more

TABLE 2

SUMMARY OF FINDINGS FOR GROUP-BY-TIME INTERACTION

Variable/Group	Baseline	4 wk	Mean Difference Between Groups*	Group-by-Time Interaction	Main Effect of Time
NPRS (0-10) in the morning			0.01 (-1.07, 1.09)	$F_1 = 0.47, P = .50$, Cohen $d = 0.24$	$F_1 = 63.63, P < .001$
Active ultrasound	6.76 ± 2.03	3.66 ± 2.91			
Sham ultrasound	7.04 ± 2.05	3.36 ± 2.60			
NPRS (0-10) during the day			0.58 (-0.42, 1.58)	$F_1 = 1.81, P = .19$, Cohen $d = 0.44$	$F_1 = 54.60, P < .001$
Active ultrasound	5.71 ± 2.18	3.60 ± 2.44			
Sham ultrasound	5.60 ± 2.14	2.56 ± 1.69			
Foot and ankle CAT (0-100)			1.44 (-3.61, 6.49)	$F_1 = 0.10, P = .75$, Cohen $d = -0.10$	$F_1 = 65.49, P < .001$
Active ultrasound	50.36 ± 9.92	62.92 ± 9.99			
Sham ultrasound	48.40 ± 9.99	62.00 ± 12.17			
Alometry, kg			0.11 (-0.82, 1.04)	$F_1 = 0.52, P = .48$, Cohen $d = 0.20$	$F_1 = 16.33, P < .001$
Active ultrasound	4.95 ± 1.63	6.22 ± 2.07			
Sham ultrasound	5.25 ± 1.70	6.14 ± 2.09			

Abbreviations: CAT, computerized adaptive test; NPRS, numeric pain-rating scale.

*Values in parentheses are 95% confidence interval.

severe symptoms was included in the randomization in patients who experienced pain in both heels). Considering these results, with the reinforcement of the previous studies,^{10,46} the authors conclude that therapeutic ultrasound should be excluded from the complex treatment of plantar fasciitis.

On the other hand, when comparing the beginning and the end of the study, statistically significant improvement in all outcome measures was found (TABLE 2). This improvement can be attributed to the spontaneous change over time or, more likely, to the execution of the stretches, which is consistent with the results of studies that examined the effectiveness of stretching in patients with plantar fasciitis.^{13,21,22,27-29,32,33} Results similar to these, in terms of pain improvement over time, can be found in a study that examined the effectiveness of stretching in one of its groups, with the other groups using 1 of 4 different shoe inserts.³¹ Another study examined stretching as one of its therapeutic techniques⁶; however, because many therapeutic techniques were simultaneously employed, it is not possible to know which technique helped improve the symptoms.

The results of the present study are also similar to those of Saban et al,³⁸ who found improvement in their 2 groups (stretching and therapeutic ultrasound versus stretching, deep massage, and nervous system movement) on the outcomes of pain felt with the first steps in the morning and the foot and ankle CAT between the beginning and the end of the study. The results of the current study are also consistent with Shashua et al's study,⁴⁰ in which the control group received stretching together with ultrasound therapy (at 1.5 W/cm², 1 MHz, and 50% pulsed for 5 minutes). These researchers found a statistically significant improvement after 8 treatments and continued improvement at a 6-week follow-up.⁴⁰

A secondary outcome measure in the present study was the pressure pain threshold. The results showed a statistically significant improvement in both

groups between the beginning and the end of the study, but no difference between the 2 groups. It is important to note that the patients who enrolled in the study were in different stages of the disease (from several weeks to several months in duration), and some had more diffuse pain. As a result, in this study, the authors focused on the medial calcaneal tuberosity area.⁹

The results of the algometric test were inconsistent with an algometric test performed in Shashua et al's study⁴⁰ that showed no difference in the algometric outcome at the beginning and end of the study in both groups.⁴⁰ This difference may be explained by the fact that in the study by Shashua et al,⁴⁰ the location of the pressure point varied between patients and perhaps between tests of the same patients. In the study by Shashua et al,⁴⁰ the pressure point was chosen according to the subjective report of the patient on the location of the most sensitive area at the time of evaluation. In the present study, the pressure point was relatively constant (medial calcaneal tuberosity).

Limitations

This study did not include a control group receiving no treatment; therefore, it cannot be ruled out that the improvement seen in both groups was due to the natural history of recovery. In addition, contact between the ultrasound transducer and treatment area may have an effect due to local massage, and it is possible that some of the improvements in both groups may be attributed to this. However, taking into consideration that no evidence exists that massage of the heel area, especially the very light massage produced by the ultrasound transducer, can benefit patients with plantar fasciitis, this effect seems unlikely.

CONCLUSION

PLANTAR FASCIITIS PATHOLOGY IS painful, persistent, debilitating, and difficult to treat.^{22,34} Contrary to this

study's hypothesis, the addition of active therapeutic ultrasound therapy does not improve the efficacy of plantar fasciitis treatment. The authors therefore recommend excluding active therapeutic ultrasound when treating plantar fasciitis. ●

KEY POINTS

FINDINGS: The inclusion of active ultrasound (1 MHz, 1.8 W/cm², continuous for 8 minutes) was not superior to sham ultrasound when added to stretching exercises in the treatment of plantar fasciitis. A combination of stretching exercises and the addition of active or sham therapeutic ultrasound was effective in decreasing pain and improving the function of patients with plantar fasciitis.

IMPLICATIONS: Inclusion of active ultrasound is not recommended in the standard physical therapy treatment of plantar fasciitis.

CAUTION: It is possible that a "massage" performed by an ultrasound transducer as the sham treatment had some therapeutic effect. Also, the placebo effect of ultrasound can be an integral part of the therapeutic effect.

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A Time to Reflect on Motor Control in Musculoskeletal Physical Therapy

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Motor control is a popular concept within physical therapy practice and has received a significant amount of attention over the last 25 years. It has been implicitly conceived and understood by clinicians and researchers throughout this time, yet appears to differ considerably with respect to its definition and translation into clinical practice.

The field of motor control research encompasses a number of areas, including physics, engineering, statistics, and behavioral and cognitive science, as well as physiology, neuroscience, and medicine.²⁶ Within these fields, the concept of motor control appears to be explicitly well understood, but contextually only makes sense from each individual perspective. Under close examination within musculoskeletal physical therapy practice, motor control is a complex, broad, and ambiguous concept. This is likely due to the contributions of the varied fields that draw together to help with the management of patients with musculoskeletal conditions. Complex questions, such as whether pain is a cause or a consequence of altered adaptive or maladaptive motor control strategies, still pervade the musculoskeletal literature and influence motor control treatment approaches.

The purpose of this Viewpoint is to outline the history of motor control

and its use in musculoskeletal physical therapy practice and to highlight the consequences of its interpretation and variation in its use. Attention is given to understanding the concept of motor control and its misrepresentation through the use of surrogate terms. A number of comparable definitions are cited in the literature; however, this ambiguity has given rise to surrogate terms, such as *neuromuscular control*, *neuromotor control*, and *core stability*, which may cause confusion in clinical practice, education, and research. How the concept of motor control may be applied in practice to resolve ambiguity and recommendations for the direction of future research are made.

Motor Control in Musculoskeletal Practice

Motor control theories and principles, including motor learning, have emerged to promote health, well-being, physical performance, and development within musculoskeletal practice. Motor control

has been broadly described as “an area of science exploring how the nervous system interacts with the rest of the body and the environment in order to produce purposeful, coordinated movement.”¹⁵ However, the origins of motor control exercises in physical therapy low back pain literature paint a slightly different picture. The field of clinical biomechanics has dominated the low back pain literature since the late 1970s, when White and Panjabi’s³⁰ work led to a number of assumptions that still appear to exist today. During this time, the focus of understanding low back pain was on the structural integrity of the spine with respect to its stability and function, using in vitro models that suggested that the spine was inherently unstable.²³ As a consequence, therapeutic strategies to enhance the stability of the spine and the ability of the spine to adapt under physiologic load emerged as a focus of motor control strategies. These were subsequently applied to other areas of the body.

Motor Control: A Broad, Complex Concept From a Biomechanical Frame of Reference

Panjabi’s²³ model of spinal stability, the most cited antecedent model, is based on the theoretical interactions between

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active (muscular) and passive (articular/ligamentous) stabilizers through a control (nervous) system to meet the demands of spinal stability, with a distinct lack of theoretical linking between them.

This spinal-stability model suggests that causes of symptoms are due to biomechanical instability, tissue damage, or structural change and are not in keeping with a contemporary understanding of musculoskeletal practice that values a multidimensional perspective.²² Panjabi's model²³ draws from Anders Bergmark's² influential biomechanical theory, which delineated the function of the deep and superficial muscles of the body as being distinctively different and potentially relevant in clinical practice. The combination of models contributed to the rise of motor control strategies to theoretically improve painful conditions by isolating movement strategies to target muscles that may contribute to instability. These motor control strategies have been linearly described as the rehabilitation strategy to retrain the deep stability muscles, with the vague notion of progressing to larger and more functional movements. This may, in fact, be simply a graded exposure

program with respect to load and movement within safe environments among a myriad of contextually nonspecific factors. Such approaches lack the cognitive, behavioral, emotional, lifestyle, cultural, and contextual understanding that whole-person approaches to health care espouse.²² This is despite greater theoretical and explanatory models superseding the biomechanical stability model, such as pain adaptation theory,¹² movement variability,¹⁹ and development of first-person neuroscience in the context of pain.²⁹

Variation of the Clinical Application of Motor Control in Musculoskeletal Clinical Practice

Many clinical approaches developed from different theoretical models, premises, and measurements have used motor control treatment strategies for musculoskeletal conditions (TABLE). This raises the following questions:

1. When describing a patient as having "altered" or "poor" motor control, what does that mean and in what context?
2. When therapists describe motor control exercises, what does that mean

and when does a movement exercise become a motor control exercise?

3. If motor control exercises constrain aspects of specific movement strategies (eg, control), do they run the risk of facilitating poorer outcomes such as fear avoidance?²⁸

Conceptual Clarification

One way to understand motor control is to examine it at a conceptual level. Concepts have been described as the building blocks of theory³ and theory development,¹⁸ and are embedded through our use of language and how we clinically practice. Concepts that are vague or not well understood have the potential of creating ambiguity, with unforeseen consequences that may negatively impact knowledge translation, patient-centered care, clinical education, and, ultimately, patient-related outcomes. It is therefore advantageous that both the development and clarification of concepts within the evidence base facilitate a richer understanding and, therefore, application of them. Ironically, despite the implicit importance of conceptual clarity in fields of research and clinical practice,

TABLE

EXAMPLES OF THE USE OF THE CONCEPT OF MOTOR CONTROL WITHIN MUSCULOSKELETAL PHYSICAL THERAPY PRACTICE

Study	Antecedent Theory	Premise	Measurement of Motor Control	Patient Group
Janda ¹³	Muscle imbalance theory	Muscle length and tension relationships to posture, muscle activity, and function	Muscle length tests and clinical observations of static postures and dynamic movements	Whole body
Richardson and Jull ²⁴	Bergmark's ² biomechanical principles (differentiation between deep and superficial muscles)	Inhibition of deep stabilizing muscles and overactive superficial muscles cause aberrant load and tissue sensitivity	Pressure gauge biofeedback while completing an isometric contraction of the lumbar spine, later applied to the craniocervical neck flexion test	Low back pain and, later, neck pain
Sahrmann ²⁷	Kinesiopathological model	Abnormal movement variation leading to pathological tissue changes	Movement impairment clinical tests using postural, static muscle length, and dynamic movement tests	Whole body
O'Sullivan ²⁰	Biopsychosocial model and Panjabi ²³ model of spinal stability	Adaptive and maladaptive motor patterns classified into direction-specific control impairment classification	Clinical examination and history taking to determine adaptive versus maladaptive movement behaviors	Low back pain
McGill ¹⁶	Clinical biomechanical movement and loading principles	Load, shear, and movement intolerances	Provocative tests used to evaluate current tolerances to load and capacity	Low back pain
Hides and Stanton ⁹	Panjabi ²³ model of spinal stability and Bergmark's ² biomechanical principles (differentiation between deep and superficial muscles)	Repetitive dominance of limb causing asymmetrical trunk muscular hypertrophy, altering force production, active and passive stability, and subsequent injury	Cross-sectional area and symmetry of deep abdominal muscles as visualized with magnetic resonance imaging or ultrasound in the clinic	Low back pain and lower extremity injury ³¹

there is still debate among philosophers and researchers regarding the definition and function that underpin the concepts themselves.²⁵

Future work with regard to conceptual analysis and Delphi studies on the concept of motor control as used in musculoskeletal practice may provide further insight to address these concerns.

The Language of Motor Control: Core Stability—a Source of Confusion and Potential Deleterious Outcome

The surrogate terms of a concept can cause a lack of clarity and confusion if they depart significantly from the concept's linguistic use and meaning.⁵ *Neuromuscular control* and *neuromotor control* contain similar linguistic characteristics in that they refer to the nervous and muscular systems alongside the control of movement. However, the term *core stability* lacks a clear linguistic relationship with movement. The term *core stability* emerged through the use of stabilization exercises of the trunk. The use of stabilization exercises in this context has exclusively been identified from within the musculoskeletal literature in the management of low back pain.^{10,11}

McNeill¹⁷ cautioned against using the term *core stability*, as it was “imprecise and open to interpretation,” and went on to describe core stability as a subset of motor control, suggesting that it required further clarity and perhaps should be abandoned. O’Sullivan²¹ is critical of both the terms *stabilization* and *core stability* with respect to the management of chronic nonspecific low back pain, stating that the biomedical explanation of lack of stability of the spine may cause “fear, abnormal body focus and reinforces pain-related movement and avoidance behaviours, hypervigilance, catastrophising, pain and disability fuelling the vicious cycle of pain.” If this were the case with spine-related pain, then it would be reasonable to suggest the same in peripheral joint regions, as discussed eloquently by Jull.¹⁴ Additionally, the relationship between the use of language, a person’s

understanding, and subsequent meaning in the literature appears to be very clear. Language can indeed have a harmful effect, as studies have identified deleterious consequences in patients experiencing musculoskeletal pain.^{1,4,6,7}

Interpretation From Research Into the Clinic: Lessons Learned?

The research literature has a tendency to measure aspects of the concept of motor control and then to conclude that, if any effect is found, then it is due to the concept itself rather than a change in the attribute. Numerous examples identify attributes of motor control, such as muscle force production, muscle timing, and joint position sense, then identify an outcome after an intervention. The observed outcome is then ambiguously reported as being a change in motor control rather than simply a change in the attribute, such as valgus during a single-leg squat motion or reduced movement variability. An example is the seminal paper by Hodges and Richardson,¹¹ which reported that relative delays in the measurements of transversus abdominis muscle contraction occurred in individuals with low back pain when lifting an arm repeatedly. The conclusion of the paper was that this indicated a “deficit of motor control” and that it was “hypothesised to result in inefficient stabilisation of the spine.” The unforeseen consequences are that such descriptions are then observed in clinical practice, both conceptually and literally. Looking back, efforts in clinical practice became more about attempting to feel and retrain the contraction of the deep abdominal muscles, which took precedence over other areas of clinical practice when treating these groups of patients.

The use of the term *motor control* within practice is often used in a specific way (eg, knee valgus or hip internal rotation during a step-down task), but is described broadly as a poor motor control strategy; describing the movement strategy rather than the vague term *motor control* could simply ameliorate this.

Perhaps it is of more value to describe the changes in the attribute, or set of attributes, of movement than to suggest that motor control itself changes. This practical approach may improve knowledge translation and resolve ambiguity.

Developing New Theoretical Constructs

With developments in cognitive and pain neuroscience and a greater understanding of the complexities involved between pain and rehabilitation, the physical therapy profession may benefit from its continued vigilance against biomedical oversimplifications. The future applications of motor control require a broad and integrated representation of theoretical constructs that outline multiple mechanisms, consequences, and alterations in movement function in relation to the context of pain and suffering, with a fusion of biological, biographical, psychological, social, and cultural paradigms.

Promising theories from cognitive neuroscience may solve some of the challenges of motor control by stepping away from traditional concepts of input, output, feed forward, optimum, and comparator modeling and toward predictive coding⁸ under a unifying theory of biological function.

Key Points

- Motor control has enormous potential for developing our understanding of the assessment, treatment, and management of the patients in our care. However, a significant amount of work is required to develop our understanding at the conceptual level to inform further research and implementation in clinical practice.
- Concepts in musculoskeletal practice that are vague run the risk of unresolved ambiguity in language and our collective understanding. The concept of motor control suffers from ambiguity due to its size and scope, and may benefit from future analysis and completion of a Delphi study within the context of musculoskeletal physical therapy practice.

- In the meantime, being explicit when describing movement strategies through defining their attributes is likely to reduce ambiguity and improve understanding in clinical practice, education, and research. ●

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Psychological and Functional Readiness for Sport Following Advanced Group Training in Patients With Anterior Cruciate Ligament Reconstruction

Anterior cruciate ligament (ACL) injury is one of the most common knee injuries,³² occurring at a rate of approximately 250 000 to 300 000 annually in the United States.⁴⁷ A large number of patients with ACL injury choose to undergo anterior cruciate ligament reconstruction (ACLR)⁴⁹ to restore sufficient knee stability to allow a return to their preinjury level of function.⁸ Patients generally have high expectations for returning to preinjury activities after ACLR,¹⁵ and return-to-sport participation con-

tributes significantly to patient satisfaction following ACLR.²⁴

Disappointingly, many patients fail to return to sport following ACLR, with a meta-analysis showing that at 4-year

follow-up, only 63% of patients had returned to sports at their preinjury level and only 44% had returned to competitive sport.⁶ For those patients with ACLR who do return to sport, risk of ACL graft reinjury or contralateral ACL injury is high.^{7,42,53,54} Inconsistency in meeting the goal of a successful return to preinjury sports after ACLR without reinjury may indicate inadequate rehabilitation.

Poor psychological readiness for returning to sport has been identified as a factor that may prohibit return to sport after injury³ and one that can exist even when physical impairments are resolved.^{25,30,46} Components of poor psychological readiness for returning to sport include increased fear of reinjury^{4,16,25} and decreased confidence (self-efficacy) related to athletic ability or performing sport-specific tasks.²¹ Most clinical settings do not routinely evaluate or address psychological readiness for sport during ACLR rehabilitation,² even though it has been identified as the strongest factor associated with returning to preinjury activity in this population.³

Advanced rehabilitation following ACLR is advocated to fully prepare patients for the return to sports.³⁹ Plyometric training is one common intervention used in advanced ACLR rehabilitation,¹

● **BACKGROUND:** Decreased psychological readiness for sport may contribute to poor return-to-sport rates after anterior cruciate ligament reconstruction (ACLR). Though advanced rehabilitation is used to improve functional readiness for sport after ACLR, the effect of advanced rehabilitation on psychological readiness is unknown.

● **OBJECTIVE:** To examine changes in psychological and functional measures and readiness for sport based on these measures in patients with ACLR following advanced group training.

● **METHODS:** In this retrospective cohort study, patients with primary ACLR enrolled in a 5-week group training program after completing traditional physical therapy. Data collection pretraining and posttraining included demographic information, the Anterior Cruciate Ligament-Return to Sport after Injury (ACL-RSI) scale, and single-leg hop testing (single, triple, crossover triple, and timed hops). Readiness for sport was based on criteria for the ACL-RSI scale score (low threshold, 56 points or greater; high threshold, 75 points or greater) and hop tests (90% or greater limb symmetry).

● **RESULTS:** Fifty-eight patients (21 male) participated. Mean ACL-RSI scale scores, mean hop test limb symmetry, and the proportion of patients meeting ACL-RSI and hop test readiness-for-sport criteria significantly improved from pretraining to posttraining. Posttraining ACL-RSI scale scores were correlated with single hop ($r = 0.269$) and triple hop ($r = 0.275$) limb symmetry, yet changes in the measures were not significantly correlated. After training, only 53.4% (lower ACL-RSI threshold) or 37.9% (higher ACL-RSI threshold) of the sample met both psychological and functional readiness criteria.

● **CONCLUSION:** Advanced group training following ACLR improved psychological and functional outcomes; however, further, individualized intervention may be needed to address residual deficiencies in some patients.

● **LEVEL OF EVIDENCE:** Therapy, level 2b. *J Orthop Sports Phys Ther* 2018;48(11):864-872. Epub 12 Jun 2018. doi:10.2519/jospt.2018.8041

● **KEY WORDS:** ACL, hop testing, return to sport

¹TRIA Orthopaedic Center, Bloomington, MN. This study was approved with a waiver of informed consent by the Institutional Review Board at the University of Minnesota. No grant support was used to complete this study. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. Address correspondence to Dr Adam Meierbachtol, TRIA Orthopaedic Center, 8100 Northland Drive, Bloomington, MN 55431. E-mail: adam.meierbachtol@tria.com • Copyright ©2018 *Journal of Orthopaedic & Sports Physical Therapy*®

as it encompasses sport-specific tasks (eg, running, jumping, and cutting).^{10,39} Plyometric training after ACLR has shown positive effects on vertical jump height and self-reported knee function,⁹ performance measures such as limb symmetry on single-leg hop tests,³⁴ and movement-pattern quality.¹³ Interventions to improve neuromuscular control have also been advocated to improve function⁴⁵ and minimize reinjury risk³⁸ following ACLR.

While most rehabilitation following ACLR is performed individually, group training programs have shown improved hop test distance in uninjured athletes³⁷ and improved limb symmetry in patients who underwent ACLR.³⁴ Most studies on advanced ACLR rehabilitation have focused on changes in function, not psychological outlook. One study reported improved self-efficacy, but not decreased fear of reinjury, after an introduction to plyometric training in ACLR rehabilitation.⁹ However, advanced plyometric training techniques were not used in that study due to the early postsurgical time frame.

The purpose of this study was to examine changes in psychological and functional measures, as well as readiness for sport based on these measures, in patients with ACLR following advanced group training. The authors hypothesized that psychological and functional measures would improve and a greater proportion of patients would demonstrate readiness for sport following the advanced group training program.

METHODS

Study Overview

THIS WAS A RETROSPECTIVE PRE-POST intervention study. Chart reviews were performed on patients who met study inclusion criteria. Data collection included demographic information, questionnaire responses, and single-leg hop testing scores obtained before and after participation in the advanced group training program.

Participants

Patients with a primary ACLR who voluntarily enrolled in an advanced group training program between July 2015 and February 2017 were eligible for participation. Prior to enrollment, all patients had completed traditional physical therapy consistent with published protocols.⁵⁵ Briefly, this included phase-based rehabilitation progressions focused on restoration of knee range of motion, gait normalization, increasing lower extremity strength, perturbation and dynamic proprioception, completion of a walk-to-jog program, and, finally, plyometrics and agility.

To be eligible for enrollment, patients had to be at least 5 months post surgery and to exhibit minimal pain with activity, trace or less effusion, full knee range of motion, and a combination of reasonable lower extremity mechanics during a drop vertical jump and hop test limb symmetry of greater than 75% to minimize injury risk. In addition, all patients had to express a desire to return to sports that involve cutting and pivoting. Exclusion criteria were previous ipsilateral or contralateral ACLR, multiligament reconstruction, concomitant meniscus repair, time from surgery to the start of the advanced training program of greater than 1 year, or reconstruction with allograft tissue. Patients with allograft reconstruction were excluded, as they comprised a small number (5/100) of eligible patients and homogeneity in the study sample was desired. This study was approved with a waiver of informed consent by the Institutional Review Board at the University of Minnesota.

Demographic Variables

Demographic variables were age at the time of surgery, sex, autograft source, number of physical therapy visits attended prior to study enrollment, number of months from surgery to the start of advanced group training, number of days from pretesting to posttesting, and number of group training sessions attended.

Advanced Group Training Program

The basis for the advanced group training program has been described previously.³⁶ The program consists of 2 training sessions per week for 5 weeks (10 total sessions), held in a group format, with a maximum of 8 participants who start and finish the program collectively. The focus of the program is on plyometric exercises, with additional lower extremity and core-strengthening exercises and agility drills (**APPENDIX**, available at www.jospt.org).

Each training session lasted 2 hours and started with a dynamic warm-up, followed by the specified exercises, and ended with a cool-down. The group training format allowed for additional rehabilitation to patients who may have exhausted their insurance benefits and provided an environment where participants could challenge each other. Exercises were progressed as specified, unless individual modifications were deemed necessary to ensure patient safety. The program is staffed with 1 physical therapist and 1 certified athletic trainer to allow adequate corrective feedback on movement patterns.

Outcomes

The psychological measure was the 12-item Anterior Cruciate Ligament-Return to Sport after Injury (ACL-RSI) scale.⁵² Items cover the domains of emotions, confidence in performance, and risk appraisal, which are thought to be psychological responses associated with resumption of sport following athletic injury. Items are scored from 0 to 100 points, and the total is divided by 12, giving a score range from 0 (a completely negative psychological outlook) to 100 (a completely positive psychological outlook). The scale has been shown to have acceptable reliability, validity, and test-retest reliability.^{26,52} Furthermore, questionnaire scores have been shown to predict athletes who return to the preinjury level of sport after ACLR.^{5,28,35}

The functional measure was a single-leg hop test battery consisting of the single hop for distance, triple hop for distance,

crossover triple hop for distance, and 6-m timed hop.⁴⁰ Patients performed 3 trials of each hop test on the nonsurgical limb, followed by the surgical limb, and the best performance on each side for each hop test was recorded. Limb symmetry was calculated as (surgical limb performance/nonsurgical limb performance) $\times$ 100 for distance measures and (nonsurgical limb performance/surgical limb performance) $\times$ 100 for the timed measure. This hop testing battery has been shown to be reliable and valid in patients following ACLR⁴⁴ and is recommended to assess functional readiness to return to sports following ACLR.^{20,27,51}

Statistical Analysis

Sample-size estimation was based on detecting a significant pretraining-to-posttraining change in the 2 outcomes, ACL-RSI scale score and hop test limb symmetry. Pilot data from 15 subjects were used for the calculation, and limb symmetry scores were pooled across the 4 hop tests. Using an online sample-size calculator (<http://biomath.info/power/prt.htm>), the sample size necessary to attain 80% power at a 5% significance level was $n = 9$ for the ACL-RSI scale score and $n = 47$ for the pooled limb symmetry score. Thus, the minimal sample size was set at 47 patients.

Statistical analysis was performed with SPSS Statistics Version 24 (IBM Corporation, Armonk, NY). Descriptive statistics were generated for demographic variables, ACL-RSI scale score, and limb symmetry for each hop test. Data were visually inspected and analyzed for normality with the Shapiro-Wilk test. Statistical significance was set at $P < .05$ for all analyses.

Paired-samples t tests analyzed the pretraining-to-posttraining change in ACL-RSI scale score and hop test limb symmetry. Effect sizes determined the magnitude of the change. The Pearson correlation coefficient was used to determine the association between the change (posttraining score minus pretraining value) in ACL-RSI scale score and hop

test limb symmetry scores, and between the posttraining ACL-RSI scale score and hop test limb symmetry scores.

Patients were categorized into “ready” or “not ready” groups based on criteria of readiness for sport. Previous studies have identified the following ACL-RSI scale scores that predict successful return to sport: 56 points at 4 months post surgery,⁵ 67 points at 6.5 months post surgery,¹⁹ 72 points at 12 months post surgery,²⁸ and 76 points at 14 months post surgery.³⁵ Though the ACL-RSI scale score threshold appears to increase with time from surgery, a definitive threshold has not yet been established.

Therefore, categorization of patients as psychologically ready was based on ACL-RSI scale scores of 56 points or greater (lower threshold) and 75 points or greater (higher threshold). Categorization of patients as functionally ready was based on a limb symmetry score of greater than or equal to 90% on all 4 hop tests, which agrees with previous recommendations for return to sport after ACLR.^{19,20,27,50} The proportion of patients categorized as ready on both ACL-RSI scale and hop test criteria, one of the criteria, or neither criterion was computed at pretraining, posttraining, and for the change from pretraining to posttraining. The McNemar test analyzed the pretraining-to-posttraining change in the propor-

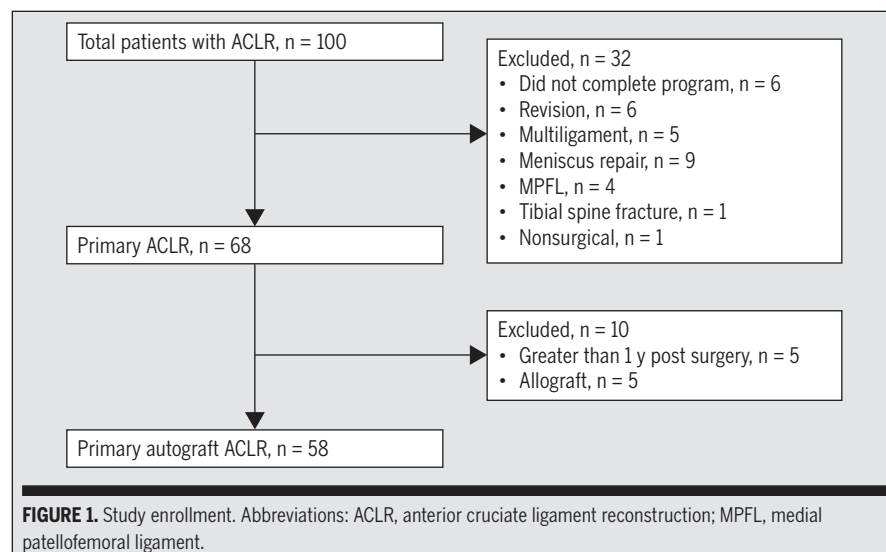
tion of patients categorized as ready on the ACL-RSI scale and hop test measures separately, as well as the proportion of patients categorized as ready on ACL-RSI scale and hop test measures combined.

RESULTS

OF 100 PATIENTS WITH ACLR WHO participated in the advanced group training program during the study period, 58 patients met all study criteria (FIGURE 1). Demographic variables for the study sample can be viewed in TABLE 1. The study sample comprised 64% female participants, and the program was started at a mean of 8.1 months after surgery.

The ACL-RSI scale and hop test limb symmetry scores significantly improved from pretraining to posttraining (TABLE 2) (all, $P < .01$). The mean increase in ACL-RSI scale score was 17.8 points, which exceeds the standard error of the measurement for the measure.⁴⁸ Mean hop test limb symmetry scores ranged from 88.3% to 91.2% at pretraining, and from 92.6% to 94.7% at posttraining. The effect size for the change in ACL-RSI scale score ($d = 1.04$) was greater than the effect size for the change in limb symmetry for any of the hop tests (range, $d = 0.36$ - 0.59).

TABLE 3 shows the correlations between ACL-RSI scale score and hop test limb



symmetry scores. No significant correlation was found between the ACL-RSI scale and hop test limb symmetry change scores. However, significant positive correlations were found at posttraining between ACL-RSI scale score and single hop ($r = 0.269$, $P = .041$) and triple hop ($r = 0.275$, $P = .036$) limb symmetry scores.

Readiness for sport categorization at pretraining and posttraining for ACL-RSI and hop test limb symmetry criteria individually is shown in **FIGURES 2 and 3**. Regardless of the ACL-RSI threshold used, the proportion of patients categorized as psychologically ready increased from pretraining to posttraining (**FIGURES 2A and 2B**, respectively; $P < .001$). More specifically, using either of the ACL-RSI

thresholds, 21 patients (36.2%) changed from not ready to ready following training, while no patients regressed in status.

The proportion of patients categorized as functionally ready, based on hop test limb symmetry, also significantly increased from pretraining to posttraining (**FIGURE 3**) ($P = .003$). Following training, 20 patients (34.5%) improved from not ready to ready, while 1 patient regressed in status (met all hop test criteria at pretraining but did not meet triple hop and crossover triple hop criteria at posttraining). The number of patients who achieved 90% or greater limb symmetry on each hop test at posttraining was 46 of 58 (79.3%) for the single hop, 42 of 58 (72.4%) for the triple hop, 43 of 58

(74.1%) for the crossover triple hop, and 44 of 58 (75.9%) for the timed hop.

Readiness-for-sport categorization at pretraining and posttraining, based on ACL-RSI scale and hop test limb symmetry criteria combined, is shown in **FIGURE 4**. Using the lower ACL-RSI scale threshold, the proportion of patients classified as ready increased from 6.9% at pretraining (**FIGURE 4A**) to 53.4% at posttraining (**FIGURE 4B**) ($P < .001$). Using the higher ACL-RSI scale threshold, the proportion of patients classified as ready increased from 5.2% at pretraining (**FIGURE 4C**) to 37.9% at posttraining (**FIGURE 4D**) ($P < .001$).

The proportion of patients who changed from the not ready to the ready categorization following training, with consideration of both ACL-RSI scale and hop test limb symmetry criteria, is shown in **FIGURE 5**. Using the lower ACL-RSI scale threshold, 10.3% (6/58) changed status on both criteria at posttraining, while 32.8% (19/58) did not change status on either criterion at posttraining (**FIGURE 5A**). Of these, 4/58 (6.9%) had already met both criteria. Using the higher ACL-RSI scale threshold, 13.8% (8/58) changed status on both criteria at posttraining, while 36.2% (21/58) did not change status on either criterion at posttraining (**FIGURE 5B**). Of these, 3/58 (5.2%) had already met both criteria.

DISCUSSION

THIS STUDY EXAMINED CHANGES in psychological and functional measures, as well as readiness for sport based on these measures, in patients with ACLR following participation in an advanced group training program. As hypothesized, significant improvements were found in both ACL-RSI scale and hop test limb symmetry scores at posttraining, and the percentage of patients who demonstrated readiness to return to sport on each measure significantly increased from pretraining to posttraining. However, there was no correlation between the amount of change on ACL-RSI scale

TABLE 1

DEMOGRAPHICS OF STUDY SAMPLE*

Variable	Value
Age at time of surgery, y	21.2 ± 7.8
Sex, n	
Female	37
Male	21
Autograft source, n	
Patellar tendon	44
Hamstring	14
Pretraining physical therapy visits, n	23.5 ± 7.0
Time from surgery to start of training, mo	8.1 ± 1.8
Time from pretraining to posttraining, d	40.5 ± 1.6
Training sessions attended, n	9.4

*Values are mean or mean ± SD unless otherwise indicated.

TABLE 2

PRETRAINING AND POSTTRAINING VALUES FOR THE ACL-RSI SCALE AND HOP TEST LIMB SYMMETRY MEASURES

Outcome	Pretraining*	Posttraining*	Effect Size, <i>d</i>
ACL-RSI scale, points	60.1 ± 19.3	77.9 ± 14.7	1.04 [†]
Single hop LSI, %	89.7 ± 8.7	94.2 ± 6.6	0.58 [†]
Triple hop LSI, %	88.3 ± 8.1	92.6 ± 6.5	0.59 [†]
Crossover triple hop LSI, %	89.6 ± 9.4	93.0 ± 9.2	0.36 [†]
Timed hop LSI, %	91.2 ± 8.8	94.7 ± 7.6	0.43 [†]

Abbreviations: ACL-RSI, Anterior Cruciate Ligament-Return to Sport after Injury; LSI, limb symmetry index.

*Values are mean ± SD.

[†] $P < .01$.

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and hop test limb symmetry scores, and only the single and triple hop limb symmetry scores were significantly correlated with ACL-RSI scale score following training. Despite improvements from pretraining to posttraining, when using the lower and higher ACL-RSI scale thresholds, respectively, only 53.4% and 37.9% of the sample met criteria for psychological and functional readiness for sport following training. These findings support the potential for advanced group training to provide psychological and functional benefit to patients with ACLR; however, should ongoing deficits persist, additional, individualized intervention may be necessary to ensure complete readiness for sport.

The ACL-RSI scale scores increased after advanced group training, indicating better psychological readiness for

sport. This finding corroborates previous work showing increased self-efficacy after plyometric training during ACLR rehabilitation, although in that study fear of reinjury did not significantly change.⁹ Furthermore, the group mean ACL-RSI scale score at posttraining (77.9 points) is higher than that reported for patients with primary ACLR at 1 year post surgery (65.4²⁸ and 65.0²⁹ points). Thus, the findings of this study add to the understanding of the potential for meaningful psychological improvement following completion of advanced ACLR rehabilitation.

Limb symmetry on the single-leg hop tests also improved following training, supporting the researchers' previous work.³⁴ The mean increase ranged from 3.4% to 4.5% across the hop tests, and the effect size was much smaller than the effect size for ACL-RSI scale score. At face value, this appears to indicate that the advanced group training program had greater psychological than functional benefit in this sample.

However, there was a ceiling effect for the potential change in hop testing limb

symmetry, as patients were required to achieve a minimum of 75% limb symmetry prior to enrolling in the advanced group training program. This study inclusion criterion was intended to ensure sufficient strength for patient safety during the advanced group training program, but it also reduced the capacity for change on the hop tests. Conversely, there was no psychological requirement for program enrollment, nor were patients given specific psychological intervention prior to enrollment. Despite the relatively small improvement on hop tests, the mean limb symmetry index for each hop test exceeded 90% at posttraining, which is consistent with the current threshold recommended for return to sport.^{19,20,27,51}

Overall, the proportion of patients who met ACL-RSI scale and hop test limb symmetry readiness-for-sport criteria increased after training, which supports the efficacy of advanced rehabilitation to prepare patients with ACLR for a return to sport. The clinical picture was different when using the lower and higher ACL-RSI scale thresholds. Using the lower

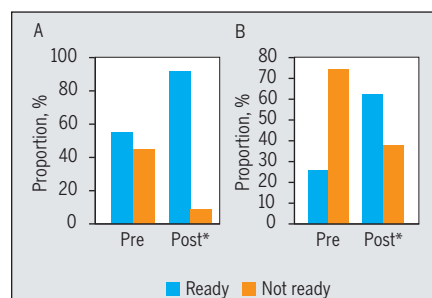


FIGURE 2. Proportion of patients categorized as "ready" or "not ready" for return to sport at pretraining and at posttraining, based on ACL-RSI scale criteria. (A) Classification using a threshold of 56 points or greater on the ACL-RSI scale. (B) Classification using a threshold of 75 points or greater on the ACL-RSI scale. Abbreviation: ACL-RSI, Anterior Cruciate Ligament-Return to Sport after Injury. * $P < .001$.

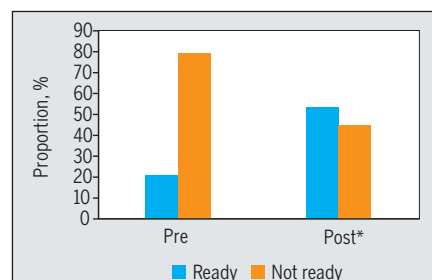


FIGURE 3. Proportion of patients categorized as "ready" or "not ready" for return to sport at pretraining and at posttraining, based on hop test limb symmetry index criteria. * $P \leq .05$.

TABLE 3

CORRELATION BETWEEN ACL-RSI SCALE SCORES AND HOP TEST LIMB SYMMETRY AT POSTTRAINING AND CHANGE FROM PRETRAINING TO POSTTRAINING*

	ACL-RSI Scale Score	
	Posttraining	Change
Single hop LSI		
Posttraining	0.27 [†]	
Change		-0.04
Triple hop LSI		
Posttraining	0.28 [†]	
Change		0.07
Crossover triple hop LSI		
Posttraining	0.14	
Change		0.18
Timed hop LSI		
Posttraining	0.23	
Change		-0.07

Abbreviations: ACL-RSI, Anterior Cruciate Ligament-Return to Sport after Injury; LSI, limb symmetry index.

*Values are r.

[†] $P < .05$.

ACL-RSI scale threshold, 91.3% of patients were categorized as psychologically ready for sport after training, while using the higher ACL-RSI scale threshold, only 62.1% of patients were categorized as psychologically ready for sport after training. The differences in categorization depending on the ACL-RSI scale threshold used demonstrate the need for future work to define an appropriate ACL-RSI scale threshold to use in return-to-sport decision making.

Only 53.4% were categorized as psychologically and functionally ready for sport after training. No correlation was found between the change in ACL-RSI scale score and hop test limb symmetry, and only weak correlations were found between ACL-RSI scale score and single hop and triple hop limb symmetry at posttraining. Although the result suggests relative independence of these measures, the authors urge caution with this interpretation. The study entrance criterion of 75% hop test limb symmetry reduced variability in the measure, which could have limited the potential for finding an association between the change in hop test limb symmetry and ACL-RSI scale score. Further research is necessary to fully understand the association between psychological and functional improvement.

Considering both ACL-RSI scale and hop test limb symmetry criteria together, only 53.4% (using the lower ACL-RSI scale threshold) or 37.9% (using the

higher ACL-RSI scale threshold) were categorized as ready to return to sport at posttraining. Other patients were categorized as ready to return to sport on individual measures, and this may have important clinical ramifications. For example, those who met the ACL-RSI scale criterion but not the hop test limb symmetry criterion may have adequate psychological outlook to return to sport but increased reinjury risk due to functional deficits. Conversely, patients who met the hop test limb symmetry criterion but not the ACL-RSI scale criterion could be at risk for cessation of sport due to psychological limitation.

The authors found that about a quarter of the sample improved on the ACL-RSI scale criterion and another quarter improved on the hop test limb symmetry criterion, but about 40% showed no change on either criterion. These results highlight the potential for an individual response to advanced ACLR rehabilitation and the need to consider both psychological and functional status in return-to-sport decision making.⁵¹

Previous studies have focused on education^{17,41} or cognitive-behavioral techniques (eg, goal setting,^{14,22} imagery,^{31,33} self-talk,⁴³ relaxation,^{12,23} and graded exposure^{18,56}) as interventions to improve psychological outlook after injury. However, a recent systematic review found limited evidence for the efficacy of psychosocial interventions to improve functional recovery following ACLR.¹¹

The advanced group training program included exercise progressions with increasing physical demand, without specifically targeting psychological outlook. The exercise progressions are similar in principle to a graded exposure, whereby patients are progressively exposed to situations that cause fear,¹⁸ and this might have facilitated the psychological improvements seen at posttraining. However, patients were not specifically queried about the tasks or situations that caused fear or lack of confidence, and this might have limited psychological improvement in some patients. Future work could incorporate exercises that target patient concerns related to fear of reinjury or lack of confidence, possibly in combination with other psychologically based interventions, to enhance the psychological response.

Importantly, this study used a group format for advanced ACLR rehabilitation. This may be advantageous to improving psychological readiness, as it allows for further supervised rehabilitation while minimizing cost, and may also increase the support patients feel because they are exercising with others who are in similar postoperative situations. One negative aspect of the group format is that interventions were not individualized; however, this agrees with the conclusion that intervention focused on individual deficits may

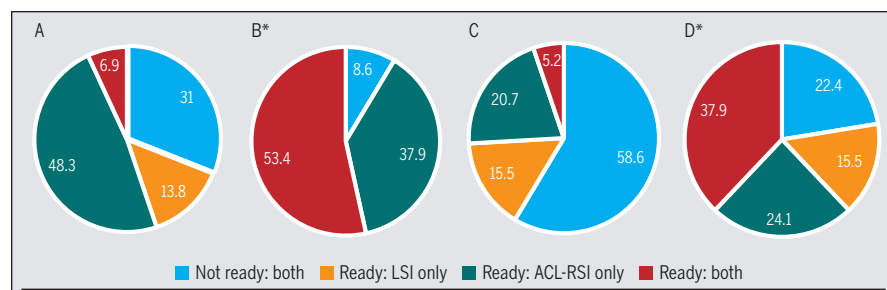


FIGURE 4. Proportion of patients categorized as “ready” or “not ready” for return to sport at pretraining and at posttraining, based on combined ACL-RSI scale and hop test LSI criteria. (A) Pretraining and (B) posttraining results using an ACL-RSI scale threshold of 56 points or greater. (C) Pretraining and (D) posttraining results using an ACL-RSI scale threshold of 75 points or greater. Abbreviations: ACL-RSI, Anterior Cruciate Ligament-Return to Sport after Injury; LSI, limb symmetry index. * $P < .001$.

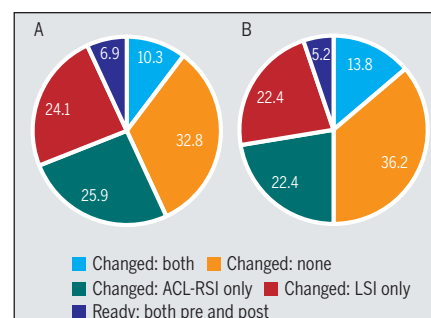


FIGURE 5. Proportion of patients who changed from the “not ready” to the “ready” categorization from pretraining to posttraining, based on ACL-RSI scale and hop test LSI return-to-sport criteria. (A) The low ACL-RSI scale threshold of 56 points or greater was used. (B) The high ACL-RSI scale threshold of 75 points or greater was used. Abbreviations: ACL-RSI, Anterior Cruciate Ligament-Return to Sport after Injury; LSI, limb symmetry index.

be necessary to ensure complete readiness for sport should deficits persist following group training.

The main strength of this study is the focus on psychological change following completion of an advanced group training program, as this is a novel contribution to the literature. Past studies have reported psychological deficits after ACLR without describing the rehabilitation program.^{16,25,35}

The main study limitation is the lack of a control group. Without a control group, it is unknown to what extent, if any, the posttraining psychological and functional improvements were due to the passage of time. Also, this study is subject to selection bias, as patients self-elected to participate in the advanced group training program. It is therefore possible that pretraining scores and improvements following the advanced group training program do not generalize to the entire ACLR population, particularly as patients in this study expressed motivation to return to sport. This study did not include muscle strength testing, so it is possible that residual weakness (particularly quadriceps weakness) would need to be addressed for better functional outcome. Finally, the criteria used to categorize psychological and functional readiness for return to sport were defined by the study and may be different from those used in other clinical settings.

CONCLUSION

IMPROVED PSYCHOLOGICAL AND FUNCTIONAL status was observed in patients with ACLR following the completion of an advanced group training program. Moreover, a greater proportion of patients showed psychological and functional readiness for returning to sport at posttraining. However, psychological and functional improvements were not correlated, and the measures were only weakly correlated at posttraining.

Using different ACL-RSI scale thresholds substantially alters readiness-for-sport categorization. Regardless of the

psychological criterion used, nearly 50% of patients continued to demonstrate failure to achieve either psychological or functional readiness thresholds, or both, following training. Thus, additional intervention may be necessary in some patients to address remaining deficits to optimize successful return to sports. ●

KEY POINTS

FINDINGS: Both psychological and functional readiness for sport improved following an advanced group training program in patients with anterior cruciate ligament reconstruction. However, nearly half of the patients demonstrated residual psychological and/or functional deficits.

IMPLICATIONS: Advanced group training can help improve both psychological and functional readiness for sport after anterior cruciate ligament reconstruction, which may facilitate a return to preinjury sports participation. Some patients who demonstrate ongoing deficits may require additional, individually based physical and/or psychological intervention.

CAUTION: Patients voluntarily enrolled in the advanced group training program and may have a different psychological outlook from that of others who did not enroll. Also, it is unknown to what extent the psychological and functional improvements were due to the passage of time.

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APPENDIX

ADVANCED PLYOMETRIC-BASED TRAINING PROGRAM*

	Week 1	Week 2	Week 3	Week 4	Week 5
Plyometrics					
Lateral jump (4 × 20)	DL lateral jump and hold slow	DL lateral jumps, fast	SL lateral jumps, slow	SL lateral hops, fast	SL figure-of-eight hops
SL anterior jump (3 times down and back)	Step hold	Hop hold	Hops forward	Triple hop	Triple crossover hop
SL lateral jump (2 × 10)	SL lateral Airex hop	SL lateral BOSU ball hop	SL lateral BOSU ball with ball catch	SL BOSU-ball X-hop	SL BOSU-ball X-hop with ball catch
Tuck jump (3 × 10)	Single tuck jump	Double tuck jump	Repeated tuck jump	Side-to-side tuck jump	Side-to-side barrier tuck jump
Lunge jump (2 × 10)	Lunge jump	Scissor jump	Lunge jump, unilateral weight	Scissor jump, unilateral weight	Scissor jumps with ball cross
SL rotatory jump (2 × 12)	SL 90° turn	SL 90° turn on Airex	SL 90° turn with ball catch	SL 180° turn on Airex	SL 180° turn on Airex with ball catch
Strength					
Prone trunk (2 × 20)	BOSU-ball superman	BOSU-ball superman with alternate arm/leg lifts	BOSU-ball swimmers	Plank with alternate leg lifts	Plank with opposite shoulder/hip extension
Kneeling trunk (3 × 60 s)	BOSU-ball double knee hold	BOSU-ball single knee hold	DL kneel on exercise ball	DL kneel on exercise ball with partner push	DL kneel on exercise ball with ball catch
Lunge (3 × 10)	Front lunge	Walking lunge	Walking lunge, unilateral weight	Walking lunge with plate crossover	Walking lunge with shoulder press
Hamstring (2 × 20)	DL BOSU-ball bridge	SL BOSU-ball bridge	SL BOSU-ball bridge with ball	Exercise ball hamstring curl	Russian hamstring
Lateral trunk (2 × 30)	Side plank	Side-plank dips	Rolling Ts	Side-plank threaders	Side-plank dips with leg movement
Flexor trunk (2 × 20)	Double crunch	Double crunch with twist	Russian twist	Double crunch with Mediball on BOSU ball	Double crunch with Mediball on BOSU ball
Extensor trunk (2 × 20)	Back hyperextension on stability ball	Back hyperextension with Mediball reach on exercise ball	Back hyperextension with dumbbell fly on exercise ball	Back hyperextension with Mediball twist on exercise ball	Back hyperextension with overhead Mediball catch on exercise ball
Agility					
Foot speed	Ladder drills	Ladder drills	Ladder drills	Ladder drills	Ladder drills
Cutting	Decelerations	Step cut at 45° and 90°	Run cut at 45° and 90°	Sprint cut at 45° and 90°	M, W, L pattern cone drills
Reaction	Side shuffle with SL stop	Mirror drill	Reaction cone light drills	Partner direction change	Reaction ball

Abbreviations: DL, double leg; SL, single leg.

**The training program was progressed over the 5-week period from DL, a stable surface, and slow movements to SL, an unstable surface, and quick movements. External perturbations were incorporated with Airex pads and BOSU balls to further increase the difficulty of maintaining knee stability.*

Detection of Knee Power Deficits Following Anterior Cruciate Ligament Reconstruction Using Wearable Sensors

Following anterior cruciate ligament (ACL) reconstructive surgery, individuals continue to present with altered sagittal plane knee loading patterns for 6 to 24 months as they progress to participation in higher levels of physical activities and sports.^{14,16,22,27} The presence of altered loading strategies during this period is of particular concern, as they are related to an increased risk of reinjury. A recent prospective study found that 23% of athletes who exhibited asymmetrical knee loading at the time they returned to sport sustained a

second ACL injury.¹⁸ These data suggest that clinical identification and amelioration of asymmetrical sagittal plane knee loading may be particularly important

following anterior cruciate ligament reconstruction (ACLR).

Biomechanically, asymmetrical sagittal knee loading following ACLR is characterized by decreases in knee extensor moments and power absorption in the reconstructed knee compared to non-surgical and healthy control knees during dynamic tasks that require eccentric control or deceleration.^{7,15,21,23,24,27} Deficits in knee power during running, hopping, and cutting tasks are of particular concern, as dynamic activities and sports that involve energetic maneuvers demand high levels of power absorption at the knee.^{3,4,12,28} At approximately 5 months post surgery, as individuals begin running, deficits in knee power absorption and knee angular velocity are as large as 37% and 21%, respectively.²¹ While this may not be surprising given the demands of running, similar deficits are also present at this time during a less demanding, dynamic single-limb loading (SLL) task.²¹ Similar impairments are also observed during running at 3 years post surgery, indicating that deficits in knee power absorption may persist long term if not addressed.⁵

Difficulty detecting these deficits clinically may underlie their persistence. Joint power is calculated using 3-D, marker-based motion-analysis systems that

● **BACKGROUND:** Following anterior cruciate ligament reconstruction (ACLR), individuals present with significant knee power absorption deficits during deceleration of dynamic tasks. An inability to quantify these deficits clinically may underlie their persistence. Recent studies suggest that segment angular velocities measured with wearable inertial sensors have the potential to provide valuable information about knee power during a single-limb loading (SLL) task. However, the diagnostic accuracy of these measures and procedures needs to be established before translating this information to clinical practice.

● **OBJECTIVE:** To determine the diagnostic accuracy of using inertial-sensor thigh angular velocities to detect asymmetrical knee loading during a dynamic SLL task in individuals following ACLR.

● **METHODS:** In this controlled laboratory study, 21 individuals following ACLR performed 3 trials of SLL on each limb. Sagittal plane peak knee power absorption was calculated for each limb (reconstructed and nonsurgical) during deceleration. Between-limb ratios (reconstructed/nonsurgi-

cal limb) were calculated for knee power using marker-based motion analysis, and thigh angular velocity was extracted from inertial sensors. Sensitivity and specificity of thigh angular velocity ratios in diagnosing asymmetrical knee loading (knee power deficits greater than 15%) were determined using receiver operating characteristic curve analysis.

● **RESULTS:** Thigh angular velocity ratios detected asymmetrical knee loading when performing SLL with high sensitivity (81%) and specificity (100%).

● **CONCLUSION:** These findings support the use of cost-effective wearable sensors to objectively quantify movement clinically in this population of individuals following ACLR. This study establishes procedures for the clinical quantification of dynamic knee loading deficits. *J Orthop Sports Phys Ther* 2018;48(11):895-902. Epub 11 Jul 2018. doi:10.2519/jospt.2018.7995

● **KEY WORDS:** anterior cruciate ligament reconstruction, knee power, limb asymmetries, rehabilitation, wearable sensors

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combine high-speed motion and ground reaction force data to calculate joint kinematics and kinetics. However, these analyses are complex, expensive, and time consuming, and thus are impractical in the clinic. Moreover, large knee loading deficits (43%) often coincide with smaller deficits in knee angles (approximately 10°) during dynamic movements that take place quickly (less than 200 milliseconds).¹⁷ This makes detection of concurrent kinematic deficits difficult clinically, as assessment of movement quality is typically made subjectively with visual observation.

More recently, wearable inertial sensors capable of collecting kinematic data (linear acceleration and angular velocity) at high capture rates (greater than 120 Hz) in multiple planes have been used to quantify human motion.^{6,9,19} Findings from these studies suggest that inertial data are sensitive enough to detect movement impairments in populations with orthopaedic impairments.¹⁹ Specifically, thigh angular velocity measured using inertial sensors is strongly related to knee power absorption calculated using a 3-D, marker-based motion-analysis system during an SLL task in individuals following ACLR.²⁰

While these findings suggest that inertial sensors have the potential to provide valuable information about knee power, the relationship was not considered in the context of between-limb deficits. Quantification of movement impairments often relies on comparison to the other limb, represented by a symmetry ratio. It is not known whether measures of thigh angular velocity during this task are sensitive enough to discriminate between symmetrical and asymmetrical loading deficits.

Further analyses are needed to determine the diagnostic accuracy of these measures and procedures before translating these methods to clinical practice. Therefore, the aim of this study was to determine the discriminative accuracy in diagnosing asymmetrical knee loading with thigh angular velocity ratios during an SLL task. Using the typical clinical

benchmark of symmetry, a between-limb ratio of 0.85 to 0.90,^{11,13,25} it was hypothesized that thigh angular velocity measurements extracted from inertial sensors would detect asymmetrical knee power with high sensitivity and specificity.

METHODS

Participants

INDIVIDUALS WHO HAD PRIMARY UNILATERAL ACLR and had recently initiated running progression exercises as part of their rehabilitation were recruited from 3 nearby physical therapy clinics to participate in this study. Participants were excluded from the study if they (1) were not cleared by their physical therapist (not a member of the research team) to perform the functional activities (ie, running, walking, hopping), (2) had evidence of concurrent pathology or morphology that could cause pain or discomfort during physical activity, and (3) exhibited any physical, cognitive, or other condition that might impair the individual's ability to perform the tasks proposed in this study.

All procedures were explained to each participant, and written informed consent was obtained as approved by the Institutional Review Board at the University of Southern California Health Sciences Campus. Parental consent was obtained for all participants under the age of 18 years.

Procedures

Testing took place in the Human Performance Laboratory of the Division of Biokinesiology and Physical Therapy at the University of Southern California, located at the Competitive Athletic Training Zone, Pasadena, CA. Participants' age, height, weight, tibia length, dominant limb (defined as the leg the participant would use to kick a ball), knee medical history, and physical activity prior to injury were recorded.

Prior to performing the SLL test, participants were asked to warm up on a stationary bike for 5 minutes. Reflective

markers were placed on the first and fifth metatarsals, the distal end of second toes, medial and lateral malleoli, medial and lateral epicondyles of femurs, greater trochanters, posterior superior iliac spines, iliac crests, and the L5-S1 junction. In addition, tracking marker clusters, reflective markers attached to rigid plates, were secured bilaterally on participant thighs, lower legs, and the heels of their shoe by the same examiner. All markers were removed after a static calibration trial was collected, except the rigid plates, pelvis markers, and distal toe markers, which remained on during testing.

Inertial sensors were placed on the mid-lateral thighs, with the *x*-axis aligned superior inferiorly with the greater trochanter and bilaterally with the lateral epicondyle of the femur. For testing, the position of the inertial sensors coincided with the position of the tracking marker clusters, and the sensors were affixed around the thighs on the rigid plates firmly using elastic Velcro (VIL Ltd, London, UK) straps and tape (FIGURE 1).

Kinematic data and ground reaction force data were collected using a marker-based, 11-camera motion-capture system (Qualisys AB, Gothenburg, Sweden) at 250 Hz and AMTI force platforms (Advanced Mechanical Technology, Inc, Watertown, MA) at 1500 Hz, or a 14-camera motion-capture system (BTS SpA, Milan, Italy) at 340 Hz and force platforms (BTS SpA) at 1360 Hz. Two motion-capture systems were used due to a transition to a new motion-capture system during the study.

Inertial data were collected, using 2 inertial sensors equipped with triaxial accelerometers, gyroscopes, and magnetometers (Opal; APDM, Inc, Portland, OR), concurrently with kinematic and ground reaction force data and time synchronized. The primary variable of interest from the inertial sensors, angular velocity, was measured using the gyroscope. While direct measurements from the accelerometer and magnetometer were not used for analysis, they remained active throughout data collection

to increase the accuracy of the gyroscope measurements using APDM's proprietary algorithm.

Angular velocities were recorded at 128 Hz using Motion Studio software (APDM, Inc) and wirelessly streamed from both sensors directly to the computer using the "robust synchronized streaming" mode. During this mode of data collection, information was streamed from multiple synchronized sensors directly to the computer. Data were buffered on the sensors to prevent data loss in the case of wireless interruptions.

SLL Test

During testing, participants performed a dynamic SLL task on each limb as described previously.²¹ For this task, participants were instructed to stand on both feet on a single platform in front of a target (FIGURE 2). Tape was placed on the ground on an adjacent force platform as a target. The distance to the edge of the target force plate was normalized to each individual as a distance equal to his or her tibia's length.

Participants were instructed to leap forward to the target location onto a single limb, lower themselves as far as they could, and then return to the starting force plate on 2 limbs in 1 continuous, fluid movement. The goal of the task was to go as low as possible and return to the starting position without pausing. For each trial, participants were asked to perform 3 consecutive repetitions at a self-selected pace. Participants alternated between limbs during SLL trials, beginning with the nonsurgical limb.

A trial was considered acceptable when it contained the presence of a distinct flight phase, maintenance of balance throughout the task, complete foot placement on the target force platform, and continuous movement throughout the stance phase and between repetitions. The presence of a flight phase, verified using force platform data, was considered a criterion for a successful trial to avoid instances of double-limb support. Practice trials were allowed for

individuals to become familiar with the task. Participants performed 3 trials on each limb.

Data Analysis

In combination with force data, reconstructed 3-D marker coordinates (Track

Manager; Qualisys AB and SMART-D; BTS SpA) were used to calculate joint kinematics, kinetics, and energetics (Visual3D Version 4.8; C-Motion, Inc, Germantown, MD). Coordinate data were low-pass filtered using a fourth-order, zero-lag Butterworth filter with a 12-Hz

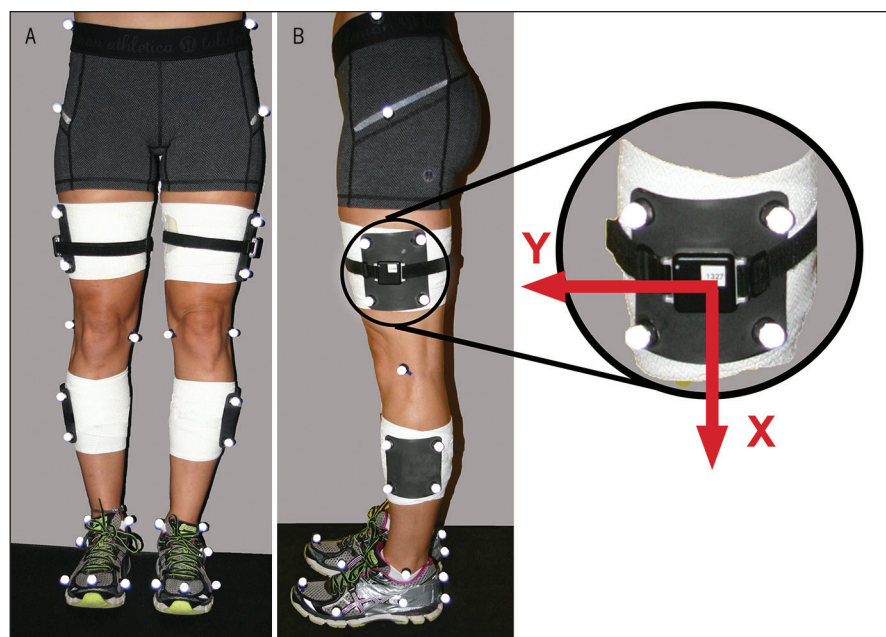


FIGURE 1. Orientation and location of inertial sensors and markers on the lower extremity during testing from the (A) anterior and (B) lateral views. Orientation of inertial-sensor axes is depicted on the right with red arrows.

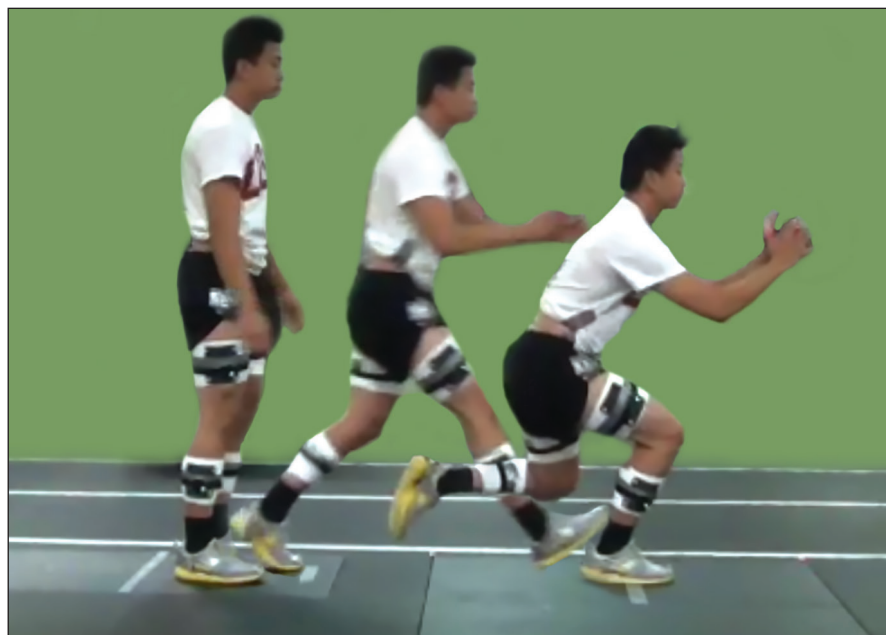


FIGURE 2. Single-limb loading test.

cutoff. Kinematics, anthropometrics, and ground reaction forces were used in standard inverse dynamic equations to calculate internal net joint moments.

Net joint power was calculated as the product of joint moment and joint angular velocity. All kinetic and energetic data were normalized to body mass. Data obtained from Visual3D were exported and analyzed using a customized MATLAB program (Version R2014b; The MathWorks, Inc, Natick, MA).

Signals from the inertial sensors placed on the thighs measured thigh angular velocity. Angular velocities, a direct output from the gyroscope, around the z -axis (x - y plane) of the sensor were chosen to represent sagittal plane movement (FIGURE 2). To coincide with the coordinate data, angular velocities were low-pass filtered using a fourth-order, zero-lag Butterworth filter with a 12-Hz cutoff. Customized MATLAB programs were used to identify variables of interest extracted from the inertial sensors.

All dependent variables were identified during the deceleration phase using outputs from the marker-based system. Deceleration was defined as the time between foot strike and peak knee flexion. Foot strike was identified from the force-plate measurements when the vertical ground reaction force was greater than 30 N. Peak knee power absorption was calculated using the marker-based motion-capture system. Peak thigh angular velocities were identified using measurements from inertial sensors. Knee power symmetry ratios were calculated by dividing peak knee power absorption in the reconstructed limb by nonsurgical values. Similarly, thigh angular velocity symmetry ratios were calculated by dividing peak thigh angular velocities in the reconstructed limb by nonsurgical-limb values.

A ratio of 1 indicated that the reconstructed and nonsurgical limbs were equal in value. A ratio less than 1 indicated that the reconstructed limb had smaller values than the nonsurgical limb. The average symmetry ratios of 3 trials (middle repetition of each trial) were used for analysis.

Statistical Analysis

To determine the relationship between knee power and thigh angular velocity symmetry ratios, a linear regression was performed, using the peak knee power absorption ratios extracted from marker-based motion capture and the peak thigh angular velocity ratios measured using inertial sensors. Diagnostic accuracy was examined by determining the area under the receiver operating characteristic (ROC) curve (AUC), sensitivity, specificity, positive and negative predictive values, and likelihood ratios in diagnosing asymmetrical knee loading (between-limb knee power ratio less than 85%) with thigh angular velocity ratios.

To determine the optimal threshold of thigh angular velocity symmetry ratio for diagnosis of knee loading asymmetries, ROC curve analysis was performed. The AUC and 95% confidence intervals (CIs) were calculated to represent the probability that thigh angular velocity ratios can discriminate between symmetrical and asymmetrical knee power.

Asymmetrical knee power was defined as a deficit in knee power absorption of greater than 15% in the reconstructed limb when compared to the nonsurgical limb, or a knee power symmetry ratio of less than 0.85. The AUC values ranged from 0 to 1, with an AUC of 1 indicating 100% probability that a given thigh angular velocity ratio could discriminate between symmetrical and asymmetrical knee power. In the case of a significant AUC, a cutoff point of thigh angular velocity symmetry ratio for distinguishing between individuals with and without asymmetrical knee power at the highest sensitivity and specificity was identified. To facilitate interpretation and utilization of the SLL test clinically, positive predictive and negative predictive values and positive and negative likelihood ratios were calculated to characterize the value of thigh angular velocity measurements for quantifying asymmetrical loading in individuals following ACLR.

A likelihood nomogram was used to determine the probability that an indi-

vidual similar to the participants of the present study would have asymmetrical loading using the established thigh angular velocity ratio threshold.¹⁰ Statistical analyses were performed using PASW Version 18 (IBM Corporation, Armonk, NY), with a significance level of $P < .05$.

RESULTS

TWENTY-ONE INDIVIDUALS (MEAN $\pm$ SD age, 28.8 ± 11.2 years; 12 female, 9 male; height, 170.9 ± 9.9 cm; mass, 69.7 ± 13.1 kg) who had primary unilateral ACLR (11 right and 10 left) using a bone-patellar tendon-bone autograft ($n = 10$), allograft ($n = 8$), or hamstring autograft ($n = 3$) approximately 5.1 ± 1.5 months prior to testing participated. All individuals reported that they were recreationally active prior to their injury (evaluated using the Cincinnati Knee Rating System questionnaire).² *Recreational athlete* was defined as level 1 or 2 on the Cincinnati Knee Rating System.

At the time of participation, individuals were actively attending physical therapy and had initiated a progressive program to resume running within 2 months from the time of testing. Seven participants had prior ACL injuries; more specifically, 2 participants had prior ACL surgery on the same limb approximately 4 and 30 years prior to the current injury and surgery, 2 participants had prior ACL surgery on the opposite limb approximately 3 and 4 years prior to the current injury and surgery, and 3 participants had partial tears of their same ACL with no surgery 2, 8, and 15 years prior to the current injury and surgery.

Knee power ratios ranged from 0.15 to 1.25 (mean $\pm$ SD, 0.62 ± 0.29). Thigh angular velocity ratios ranged from 0.21 to 1.22 (mean $\pm$ SD, 0.73 ± 0.24). Thigh angular velocity ratios ($P < .001$, $R^2 = 0.664$) explained 66.4% of the variance in knee power ratios (FIGURE 3). Thigh angular velocity symmetry ratios were positively correlated with knee power symmetry ratios, indicating that larger

angular velocity ratios are related to greater knee power ratios.

Of 21 participants, 16 were categorized as having asymmetrical knee power (knee power ratio less than 0.85). The ROC curve analysis revealed a significant AUC (0.90; 95% CI: 0.77, 1.00; $P = .008$) for the use of thigh angular velocity ratios to discriminate between asymmetrical and symmetrical knee power.

Thigh angular velocity symmetry ratios less than or equal to 0.811 classified an individual performing the SLL task with asymmetrical knee power with 81.2% sensitivity and 100% specificity. The positive predictive value was 100% and the negative predictive value was 62.5%. The positive likelihood ratio was infinite and the negative likelihood ratio was 0.188. Overall, 76.2% of the participants in this study had asymmetrical knee power. Using the overall prevalence rate of asymmetry in this study (76.2%) as the estimated pretest probability, along with the calculated likelihood ratios, the researchers determined that the posttest probability for having asymmetrical knee loading for a participant with a thigh angular velocity ratio less than or equal to 0.811 was greater than 99.9% (FIGURE 4), and for a participant with a thigh angular velocity ratio greater than 0.811 was 38% (FIGURE 4).

DISCUSSION

THIS STUDY SUPPORTS THE USE OF thigh angular velocities extracted from inertial sensors for clinical detection of knee power asymmetries in individuals following ACLR using the described testing procedure. The ROC curve analysis determined that thigh angular velocity symmetry ratios are able to discriminate between asymmetrical and symmetrical knee power with high specificity (100%) and sensitivity (81.2%).

For these data, 100% specificity indicates that the inertial-sensor measurements resulted in no false positives, meaning that all participants who had symmetrical knee power based on the

gold standard (marker-based motion capture) were identified as having symmetrical knee power using inertial sensors. Further, 81.2% sensitivity indicates that inertial-sensor measurements resulted in a few false negatives, meaning that of all participants who had asymmetrical knee power as indicated by the gold standard, 81% (13/16) of them were identified as having asymmetrical knee power using inertial-sensor measurements. Three of the 16 were considered symmetrical using inertial sensors when the gold standard test deemed them asymmetrical.

A between-limb ratio in thigh angular velocity of 0.811 was determined to be the critical cutoff for determining asymmetry in knee power that is greater than 15%. In the context of the population tested, clinical interpretation of these data suggests that this test can serve as a good diagnostic tool for identifying knee loading asymmetries using the described testing procedures and an SLL task.

The positive predictive value of 100% indicates that all of the participants diagnosed with asymmetrical loading using thigh angular velocity ratios were

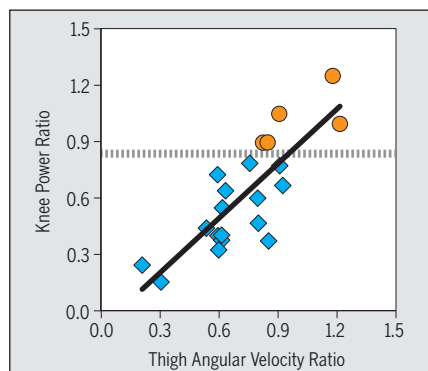


FIGURE 3. The relationship between thigh angular velocity ratios extracted from inertial sensors and knee power symmetry ratios calculated from marker-based motion capture. A ratio of 1.0 indicates that the surgical limb (after anterior cruciate ligament reconstruction) equals the nonsurgical limb. A ratio less than 1.0 indicates that the surgical limb is less than the nonsurgical limb. The dashed line represents a knee power ratio of 0.85, the cutoff point for diagnosing asymmetrical knee loading. Depicted are participants diagnosed as asymmetrical (squares) and symmetrical (circles) using the knee power ratio ($y = 0.96x - 0.09$; $R^2 = 0.66$, $P < .001$).

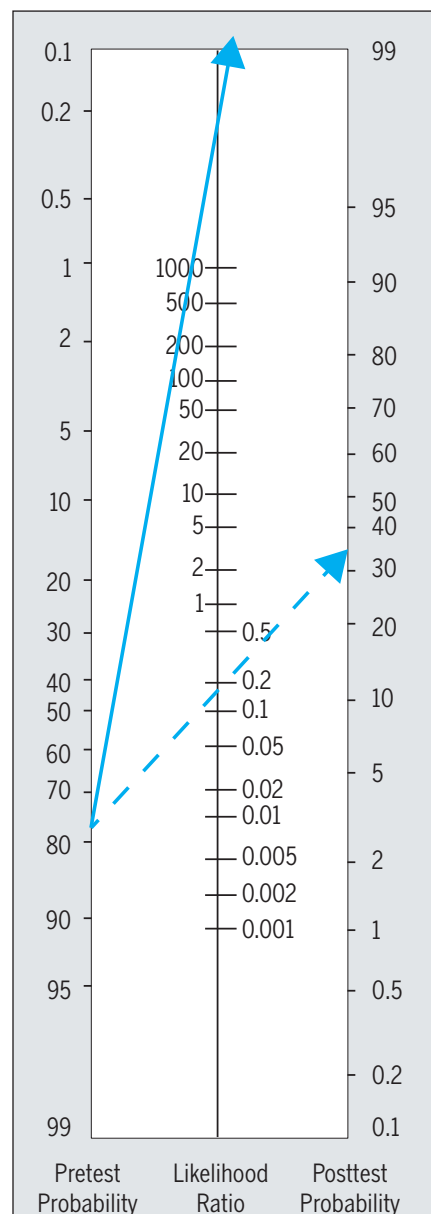


FIGURE 4. A likelihood ratio nomogram. The pretest probability of asymmetrical knee loading in individuals following anterior cruciate ligament reconstruction was estimated at 76%. The positive likelihood ratio of infinite for thigh angular velocity during the single-limb loading test is indicated, along with the posttest probability of greater than 99.9% (solid line). The negative likelihood ratio of 0.18 for thigh angular velocity during the single-limb loading test is indicated, along with the posttest probability of 38% (dashed line). This nomogram illustrates the usefulness of thigh angular velocity ratios to effectively diagnose asymmetrical or symmetrical knee loading. Adapted with permission from Fagan.⁸ ©Massachusetts Medical Society

confirmed as asymmetrical with knee power measurements. The negative predictive value indicates that 62.5% of the participants with symmetrical knee loading using thigh angular velocity measurements were symmetrical in knee power. Furthermore, given that the positive likelihood ratio was calculated as infinite, posttest probability analysis indicates that if an individual has a between-limb thigh angular velocity ratio derived from inertial sensors less than or equal to 0.81, indicating asymmetry, then the individual is highly likely to have asymmetrical knee power and, subsequently, less power in the reconstructed knee (FIGURE 4). With a negative likelihood ratio of 0.188, the posttest probability analysis indicates that if an individual has a between-limb angular velocity ratio greater than 0.81, indicating symmetry, then there is only a 38% probability that the individual actually has asymmetrical knee power (FIGURE 4).

These findings are promising, as they demonstrate a strong potential for using inertial-sensor measurements to quantify knee loading asymmetries in the clinic. However, caution should be taken when using the results of this test for clinical decision making, given the 38% probability that this test may not capture knee power asymmetry. Moreover, clinicians should consider the results of this test only in the context of other clinical benchmarks when making decisions for return to play. As inertial-sensor technology continues to advance, the ability to detect asymmetries without complex analyses continues to improve.^{9,19,26}

The implications of these findings are exciting, as they establish procedures for examining dynamic knee loading in the clinic using inertial sensors. While previous studies determined that segment angular velocities measured with inertial sensors can provide objective information regarding movement quality^{19,20} in individuals following ACLR, this is the first study to translate these findings for use in a clinical setting. The strong relationship between thigh angular velocity and knee power absorption is driven by

the fact that power is the product of knee angular velocity and net joint moment. Further work is needed to determine the strength of predicting knee extensor moments using outputs from inertial measurement units.

A need for more objective information regarding joint mechanics in clinical decision making is underscored by the inability of current functional testing to quantify mechanical deficits.^{1,17} Interpretation of current functional assessments, including distance hopped or time to task completion, provides no specific assessment of knee joint function. Furthermore, completion of such tasks can be accomplished with compensatory patterns that increase the demands on the hip and ankle to accomplish the overall goal.^{17,23} The current testing procedure provides information specific to the knee during a functional SLL task.

The procedures established in this study are particularly suited to detect the early dynamic loading deficits present when patients are progressing to running.²¹ Identification of decreased knee power and angular velocity may be most important at this time, as running is typically one of the first dynamic tasks introduced during rehabilitation. The SLL task used in the current study is appropriate for assessment of dynamic loading deficits at this point because it requires rapid deceleration and high knee angular velocities, but with much smaller demands with respect to the magnitude of loading when compared to running.²¹ The previously established relationship between knee power asymmetries during this single-limb task and running suggests that there may be some value in using this test to determine readiness to initiate running.

While only the clinical accuracy of identifying knee power asymmetries larger than 15% was established, the strong relationship between angular velocity and power ratios suggests that the angular velocity ratio may be able to provide a reasonable estimation of knee power ratio using the prediction equation (FIGURE

3). Findings from this study indicate that the SLL task and internal sensors can be used together to detect dynamic knee loading asymmetries, specifically knee power absorption, with high sensitivity and specificity in individuals following ACLR.

Study Limitations

The current study has several limitations. The participants included in this study represent a relatively small sample size of somewhat homogeneous patients, and this study included relatively few people with true negatives (symmetrical knee power). The current testing paradigm can only be applied to individuals 4 to 6 months post surgery who are progressing to running. Further work is needed to establish the diagnostic accuracy of such testing in a greater number of individuals during other phases of rehabilitation with more symmetrical knee power.

Moreover, it cannot be assumed that these analyses translate broadly to tasks other than the SLL task and the procedures described here. Future studies are needed to determine the value of such analyses across other dynamic tasks, such as running, cutting, or landing. Inertial sensors used in this study, while less expensive than traditional motion capture, still require a computer and expertise to operate. As clinician-friendly technology develops, similar testing paradigms may be used to further establish diagnostic accuracy in quantifying dynamic knee loading asymmetries.

It is also important to note that inertial sensors in this study were placed on marker clusters; therefore, when translating this testing paradigm to the clinic, similar procedures should be used, and further work is needed to establish validity of measurements without the marker cluster plates. While the current study suggests a mechanism for identifying knee power asymmetries following ACLR, future studies identifying therapeutic interventions aimed at improving these loading deficits are needed.

CONCLUSION

INERTIAL-SENSOR MEASUREMENTS CAN detect dynamic knee loading asymmetries in individuals following ACLR with high sensitivity and specificity, specifically during the SLL task used in this study. Clinical quantification of dynamic knee loading asymmetries may help direct rehabilitation programs to mitigate the persistence of dynamic knee loading deficits. These findings set the foundation for using inertial sensors to quantify movement in the clinic in individuals following ACLR and in the absence of marker-based motion analysis. ●

KEY POINTS

FINDINGS: Inertial-sensor measurements can detect dynamic knee loading asymmetries in individuals following anterior cruciate ligament reconstruction with high sensitivity and specificity.

IMPLICATIONS: Inertial sensors may be used for quantification of dynamic knee loading asymmetries in the clinic and may help direct rehabilitation programs to mitigate the persistence of dynamic knee loading deficits.

CAUTION: The results of this study can only be applied to individuals 4 to 6 months following anterior cruciate ligament reconstruction who are beginning to run again after surgery. Further work is needed to establish the diagnostic accuracy of such testing during other dynamic tasks and time points following surgery to allow for a broader application of these technologies.

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The Utilization of Formal Physical Therapy After Shoulder Arthroplasty

Physical rehabilitation has traditionally been thought to be a critical part of recovery after shoulder surgery. Although formal comparative studies have not been performed, structured programs by professional therapists may help to guide patients through the various recovery periods, speed up their recovery, and improve functional outcomes. A recent study performed by Arshi et al¹ described the utili-

zation and costs of postoperative physical rehabilitation after rotator cuff repair, comparing patients with private insurance and those with Medicare. Their re-

sults indicated that a significant number of patients who underwent rotator cuff repair did not utilize physical rehabilitation postoperatively, but, of those who used physical rehabilitation, utilization rates were higher in the private insurance population compared to those with Medicare. The authors point out that, although postoperative physical rehabilitation is widely considered very important to recovery, frequency and overall length of utilization vary widely. There is a growing belief among orthopaedic providers that how much formal physical rehabilitation a patient receives is influenced by the patient's insurance and its willingness to pay for various postoperative therapies.

Regarding shoulder arthroplasty, there remains a lack of information regarding the role of physical rehabilitation in the primary and revision settings. To our knowledge, there are no studies providing information about the current state of usage of formal physical rehabilitation after shoulder arthroplasty. A recent study by Mulieri et al¹⁴ challenged the need for formal physical rehabilitation after anatomic total shoulder arthroplasty (TSA), finding that a home-based, physician-guided therapy program provided similar results with lower costs. Despite this, there remain few studies examining the role of physical rehabilitation, utilization rates, and variables that influence the utilization of physical rehabilitation after shoulder arthroplasty.

• **BACKGROUND:** It is widely believed that structured rehabilitation programs by professional therapists help guide patients through the various recovery periods after shoulder arthroplasty, speeding up their recovery and improving their final functional gains. However, to our knowledge, there are no studies providing information about the current state of physical rehabilitation use after shoulder arthroplasty.

• **OBJECTIVES:** To describe the variation in physical rehabilitation utilization after total shoulder arthroplasty (TSA) and reverse shoulder arthroplasty (RSA), and to identify differences in utilization based on type of insurance (private versus public), sex, age, and region of the country.

• **METHODS:** This epidemiological retrospective database study utilized a commercially available database, PearlDiver, with longitudinal patient tracking linking all patients' Current Procedural Terminology and International Classification of Diseases-Ninth Revision codes to their specific records to analyze patterns of physical rehabilitation usage after TSA and RSA in the United States. Two main patient populations were analyzed within the PearlDiver database, the Humana private insurance population and the Medicare insurance population. The period analyzed was 2010 to 2015.

• **RESULTS:** There was significantly higher utilization of physical rehabilitation in the Humana

population when compared to the Medicare population ($P < .001$, Cramer's $V = 0.270$). In the Humana population, 36% of patients had 5 or fewer physical rehabilitation visits in the 6 months following their operation, while in the Medicare population, 56% of patients had 5 or fewer physical rehabilitation visits in the same period. Those with TSA had a higher utilization rate than those with RSA in the Humana ($P < .001$, $V = 0.104$; TSA, 31% had 5 or fewer physical rehabilitation visits; RSA, 40% had 5 or fewer physical rehabilitation visits within 6 months) and Medicare populations ($P < .001$, $V = 0.135$; TSA, 51% had 5 or fewer physical rehabilitation visits; RSA, 61% had 5 or fewer physical rehabilitation visits within 6 months).

• **CONCLUSION:** Postoperative utilization of physical rehabilitation after anatomic TSA and RSA is markedly higher in privately insured patients than in patients with Medicare, regardless of age, sex, diagnosis, or region of country. These findings have important implications, from the individual patient's experience and outcomes to system-wide resource utilization.

• **LEVEL OF EVIDENCE:** Economic and decision analyses, level 4. *J Orthop Sports Phys Ther* 2018;48(11):856-863. Epub 8 May 2018. doi:10.2519/jospt.2018.8176

• **KEY WORDS:** physical therapy, reverse total shoulder, surgical rehabilitation, total shoulder

¹Boston Shoulder Institute, Brigham and Women's Hospital, Boston, MA. ²Arthrex, Inc, Naples, FL. This study was exempt from Institutional Review Board review because it utilized a Health Insurance Portability and Accountability Act-compliant, commercially available database with no identifiable private information available on patients. There was no external funding for this study. Dr Higgins was a staff member at Brigham and Women's Hospital during the course of the study and peer-review process. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. Address correspondence to Dr Laurence D. Higgins, Arthrex, Inc, 1370 Creekside Boulevard, Naples, FL 34108-1945. E-mail: Laurence.Higgins@Arthrex.com • Copyright ©2018 *Journal of Orthopaedic & Sports Physical Therapy*®

The purpose of this study was to assess the variation in usage of formal physical rehabilitation in patients with private insurance and those with Medicare. The usage of the term *formal* indicates that we cannot track the usage of self-directed or “at-home” physical rehabilitation following surgery. Our hypothesis was that utilization would be standardized, with no differences between factors, including insurance type, geographical region, age of patient, sex of patient, type of surgery (reverse shoulder arthroplasty [RSA] versus anatomic TSA), and diagnosis.

METHODS

WE PERFORMED A REVIEW OF THE PearlDiver patient record database (PearlDiver Inc, Colorado Springs, CO), focusing on all patients who underwent an anatomic TSA or RSA. The PearlDiver database is a commercially available database with insurance records of orthopaedic patients, including 20.9 million covered lives in Humana (Humana Inc, Louisville, KY) and a 5% sampling file of the Medicare population. Both Humana and the Medicare 5% sampling file (of the 51 million covered lives in Medicare) contain all inpatient, outpatient, and physician office records. This Health Insurance Portability and Accountability Act of 1996-compliant database can be searched by Current Procedural Terminology (CPT) codes and International Classification of Diseases-Ninth Revision (ICD-9) procedure and diagnosis codes. Longitudinal patient tracking is available in the PearlDiver database, and every patient's CPT and ICD-9 codes are linked. Two main patient populations were analyzed within the PearlDiver database, the Humana private insurance population and the Medicare insurance population.

Patient, Procedure, and Rehabilitation Query

For our study, both database populations were searched for individuals who had undergone either anatomic TSA as ICD-

9 procedure code 8180 or RSA as ICD-9 procedure code 8188. Patients were eligible for inclusion in the study only if they were active in the database for at least 1 year following the shoulder replacement, to ensure that patients did not switch insurance. We used procedures from 2010 to 2015. These dates were chosen because RSA became its own code in 2010 and 2015 was the last year in which ICD-9 codes were regularly used. Therefore, to be included, patients must have undergone a TSA or RSA between 2010 and 2015, using an ICD-9 procedure code. Since the transition to the International Classification of Diseases-10th Revision (ICD-10) began in October 2015, there are patients who underwent these surgeries in 2015 and were coded with an ICD-10 code. These patients are not included in this study. The distinction between different implant types (reverse versus total) is important to account for variations that naturally arise due to different patient pathologies in postoperative protocols, as the procedures are not interchangeable. Factors we collected in addition to procedure type and number of physical rehabilitation visits included sex, age, diagnosis, and region of the country. Sex was reported as male and female, and age was reported as 5-year intervals (standard in database). Regions of the country were categorized into Midwest, Northeast, South, and West per the US Census Bureau definition of these regions. Data were unavailable for analysis when there were fewer than 11 patients in a subset, as PearlDiver is unable to give specific numbers when a patient subset has fewer than 11 patients, per the Health Insurance Portability and Accountability Act of 1996 compliance to protect patient privacy. This is the established database standard. Preoperative diagnosis was evaluated as a factor, as different diagnoses might lead to significantly different postoperative protocols and therefore could significantly influence physical rehabilitation utilization. Diagnoses for RSA included osteoarthritis, rotator cuff pathology, fracture, and

other, while those for TSA were broken down into osteoarthritis, fracture, and other. Different diagnoses were queried for RSA versus TSA due to the differing indications for the surgeries. The “other” category of diagnosis included any variable without sufficient numbers to be its own category, including inflammatory arthritis, posttraumatic etiology, septic arthritis, tumor, pathological dislocation, infection, avascular necrosis, and instability. We first isolated every diagnosis category separately, but combined all of those with insufficient numbers in the database into the “other” category.

Physical rehabilitation visits were tracked for the 6 months immediately following patients' replacement surgeries, starting with tracking on day 1 after surgery. The follow-up period extends 6 months after the surgery and therefore extends into 2016 for some included patients. Because the physical rehabilitation visits were tracked with CPT codes, the switch to ICD-10 did not affect this tracking. There was no information on physician prescriptions for physical rehabilitation, specific physician rehabilitation protocols, or the frequency of home physical rehabilitation programs. Physical rehabilitation visits were identified by having one of any of an exhaustive list of physical rehabilitation visit codes. The list of physical rehabilitation codes was reviewed by 2 physical therapists to ensure that all appropriate CPT codes were included. The term *physical rehabilitation* is used instead of *physical therapy* because other providers, such as occupational therapists, may use these CPT codes. Therefore, the authors feel it is most accurate to describe these visits broadly, as physical rehabilitation visits. Any day in the record that a patient had 1 or more of the physical rehabilitation CPT codes billed was counted as 1 visit. The physical rehabilitation utilization groups were broken down into 5-visit intervals to make it easy to comprehend and analyze postoperative rehabilitation visits. The best interval size was based on the expert opinion of 2 board-certified orthopaedic

surgeons, the first and senior authors, as the best way to group clinically relevant numbers of postoperative visits.

All CPT and ICD-9 codes used in searching the PearlDiver database for this study are summarized in **APPENDIX A** (available at www.jospt.org).

Statistical Analysis

Descriptive statistics were utilized, categorizing physical rehabilitation visits in specific groups for the analysis. A chi-square test of independence was utilized to compare the distribution of physical rehabilitation visits, into the categories of 0 physical rehabilitation visits, 1 to 5 visits, 6 to 10 visits, 11 to 15 visits, 16 to 20 visits, 21 to 25 visits, 26 to 30 visits, and greater than 30 visits within 6 months after the patient's shoulder replacement, between specific groups or by certain variables. The null hypothesis was that the distribution of physical rehabilitation visits would be independent of the variable being compared. The primary categorization compared was type of insurance: Humana (private insurance) versus Medicare (public insurance). Type of replacement (TSA versus RSA), sex, age, category of diagnosis, and region of the country were also investigated to see whether the distribution of physical rehabilitation visits depended on these categorizations. The alpha level was set at .05, and therefore a *P* value of less than .05 was considered statistically significant.

Cramer's *V* is a measure of the strength of association for the chi-square test of independence. In terms of this test, it measures how meaningful the differences are between the samples being compared; the Cramer's *V* value is reported for all significant chi-square test of independence results. Cramer's *V* is calculated by the square root of the chi-square value over the number of observations (*n*) for that cohort. As the chi-square test of independence is sensitive to sample size, it is especially important to include a measure of the strength of association/effect size.¹² Cramer's *V* is generalizable

across contingency tables of varying size; in other words, Cramer's *V* allows us to compare the strength of association from one variable to another when sample sizes are different. Cramer's *V* values and their classification as insubstantial, small, medium, or large are displayed in **TABLE 1**.¹⁰ It is important to note that if Cramer's *V* is less than 0.10, then the difference between the samples is insubstantial.

RESULTS

Patient Population and Demographics

IN TOTAL, THE STUDY INCLUDED 16 507 patients who had undergone either a TSA or RSA and were active in the database at least 1 year after their operation. The breakdown of operations and demographics is summarized in **TABLE 2**. Physical rehabilitation utilization was

TABLE 1

CRAMER'S *V* AND EFFECT SIZE

Cramer's <i>V</i> Value	Effect Size
<0.10	Insubstantial
0.10-0.29	Small
0.30-0.49	Medium
≥0.50	Large

TABLE 2

DEMOGRAPHICS*

Variable	Humana		Medicare	
	TSA	RSA	TSA	RSA
All patients	5041 (48)	5374 (52)	3268 (54)	2824 (46)
Sex				
Male	2233 (44)	1908 (36)	1353 (41)	952 (34)
Female	2808 (56)	3466 (64)	1915 (59)	1872 (66)
Region				
Midwest	1524 (30)	1486 (28)	949 (29)	863 (31)
Northeast	143 (3)	145 (3)	463 (14)	325 (12)
South	2732 (54)	3141 (59)	1235 (38)	1154 (41)
West	642 (13)	592 (11)	621 (19)	482 (17)
Age, y				
<65	930 (18)	598 (11)	318 (10)	210 (7)
65-69	1197 (24)	974 (18)	850 (26)	484 (17)
70-74	1377 (27)	1388 (26)	823 (25)	669 (24)
75-79	923 (18)	1264 (24)	721 (22)	698 (25)
80-84	457 (9)	784 (15)	416 (13)	509 (18)
≥85	157 (3)	366 (7)	140 (4)	254 (9)
Diagnosis [†]				
Osteoarthritis	4817	3781	2839	1308
Rotator cuff	NA	1678	NA	560
Fracture	104	927	60	336
Other	147	370	375	654

Abbreviations: NA, not applicable; RSA, reverse shoulder arthroplasty; TSA, total shoulder arthroplasty. *Values are *n* or *n* (percent).

[†]Diagnoses do not add up to the total number of patients because there are some patients who have 2 primary diagnoses on the day of surgery.

analyzed for the 6 months after TSA or RSA and broken down by insurance type, sex, region of country, age, and diagnosis (APPENDICES B and C, available at www.jospt.org). In general, the Humana cohort had higher overall physical rehabilitation utilization than did the Medicare population across all factors.

Insurance Type

The Humana patient population had a significantly higher overall rate of postoperative physical rehabilitation utilization when compared to the Medicare population ($P<.001$, Cramer's $V = 0.270$) (FIGURES 1A through 1C). The Humana and Medicare populations had a similar percentage of patients with 0 visits (23% and 22%, respectively), but the Medicare population had a strikingly larger percentage of patients with only 1 to 5 visits (34% in Medicare versus 12% in Humana). The Humana population had a higher percentage of patients in all visit categories above 1 to 5 visits (FIGURE 1A).

Type of Replacement

Those with TSA had a higher physical rehabilitation utilization rate than those with RSA in the Humana ($P<.001$, $V = 0.104$) and Medicare populations ($P<.001$, $V = 0.135$) (FIGURE 2). FIGURES 2A and 2B highlight that a significantly larger percentage of patients with RSA had 0 visits following surgery in both the

Humana and Medicare populations (27% in Humana and 27% in Medicare) compared to those with TSA (19% in Humana and 17% in Medicare).

Sex

Differences in the distribution of physical rehabilitation visits between sexes were found to be of insubstantial strength ($V<0.100$ in all cases).

Region

One variable that had impact on postoperative physical rehabilitation utilization was region of the country. When comparing across all 4 regions (Midwest, Northeast, South, West), larger magnitudes of difference were seen in physical rehabilitation utilization in the Medicare popu-

lation than in the Humana population (Medicare RSA: $P<.001$, $V = 0.183$; Medicare TSA: $P<.001$, $V = 0.190$; Humana RSA: $P<.001$, $V = 0.112$; Humana TSA: $P<.001$, $V = 0.098$). The differences of the greatest magnitudes in distributions were between the Midwest and the Northeast (TSA, $V = 0.189$; RSA, $V = 0.196$) and the Midwest and the West (TSA, $V = 0.192$; RSA, $V = 0.196$) in both the TSA and RSA Medicare populations, with the Midwest having significantly less physical rehabilitation utilization, which is best demonstrated by 69% of patients in the Midwest undergoing only 5 or fewer physical rehabilitation visits, compared to only 54% of patients in the Northeast and 53% of patients in the West within the Medicare population (FIGURES 3A and 3B).

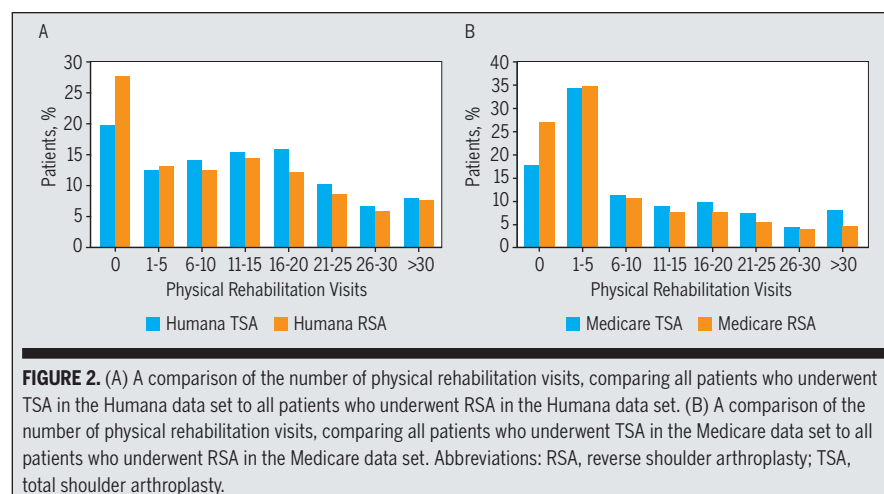


FIGURE 2. (A) A comparison of the number of physical rehabilitation visits, comparing all patients who underwent TSA in the Humana data set to all patients who underwent RSA in the Humana data set. (B) A comparison of the number of physical rehabilitation visits, comparing all patients who underwent TSA in the Medicare data set to all patients who underwent RSA in the Medicare data set. Abbreviations: RSA, reverse shoulder arthroplasty; TSA, total shoulder arthroplasty.

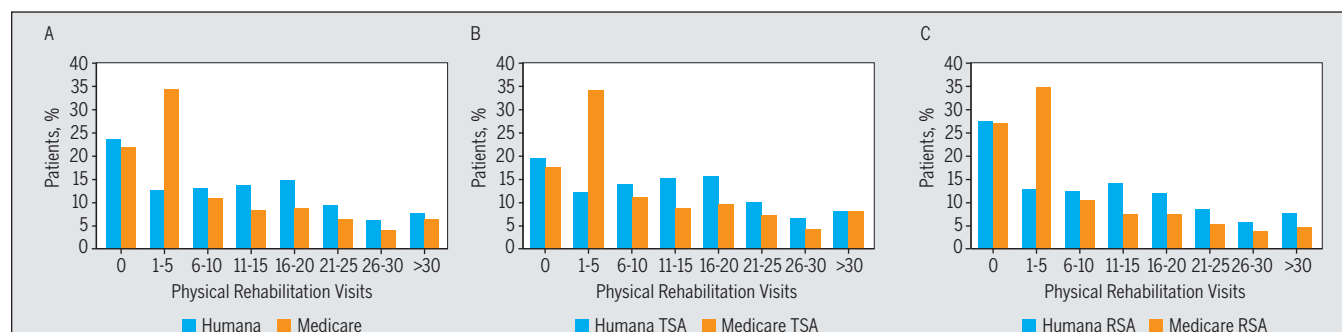


FIGURE 1. (A) A comparison of the number of physical rehabilitation visits, comparing all patients who underwent TSA or RSA in the Humana data set to all patients who underwent TSA or RSA in the Medicare data set. (B) A comparison of the number of physical rehabilitation visits, comparing all patients who underwent TSA in the Humana data set to all patients who underwent TSA in the Medicare data set. (C) A comparison of the number of physical rehabilitation visits, comparing all patients who underwent RSA in the Humana data set to all patients who underwent RSA in the Medicare data set. Abbreviations: RSA, reverse shoulder arthroplasty; TSA, total shoulder arthroplasty.

Age

With regard to age in the TSA Medicare population, patients who were younger than 65 years of age had lower utilization rates when compared to those 65 to 69 years ($P < .001$, $V = 0.198$), 70 to 74 years ($P < .001$, $V = 0.193$), and 75 to 79 years ($P < .001$, $V = 0.180$) of age. Furthermore, patients older than 80 years of age also had lower utilization rates when compared to patients who were 65 to 69 years ($P < .001$, $V = 0.155$), 70 to 74 years ($P < .001$, $V = 0.146$), and 75 to 79 years ($P = .004$, $V = 0.129$) of age. Similar observations were seen in the TSA Humana population, but the Cramer's V correlations were much lower, as the differences between age groups were much less pronounced and did not have meaningful magnitudes overall. In the RSA Humana population, the trend was similar to that in the TSA population. The differences seen between ages in the RSA Humana population, like the TSA Humana population, were very weak overall. There were no significant differences in comparing the groups of 65 to 69, 70 to 74, and 75 to 79 years of age in any of the populations (TSA Medicare, $P = .864$; RSA Medicare, $P = .918$; TSA Humana, $P = .782$; RSA Humana, $P = .196$).

Diagnosis

Diagnosis alone did not have a significant impact on physical rehabilitation utilization rates. However, when separating

those with osteoarthritis, there was still a higher utilization in those with Humana insurance ($P < .001$, $V = 0.264$) (FIGURE 4) and those who underwent a TSA compared to an RSA (Medicare: $P < .001$, $V = 0.116$; Humana: $P < .001$, $V = 0.098$). The strength of the differences (the TSA population having less physical rehabilitation utilization) was meaningful in the Medicare population, but not in the Humana population. Furthermore, within the RSAs performed for rotator cuff pathologies, there was a higher utilization in the Humana population compared to Medicare ($P < .001$, $V = 0.259$), and the difference was of similar strength to the difference in utilization between the overall Humana and Medicare study populations ($V = 0.259$ for RSA for rotator cuff pathology, $V = 0.270$ for overall study population).

DISCUSSION

THE NUMBER OF TSAs PERFORMED IN the United States has risen at an exponential rate, increasing 246% from 1999 to 2008,¹¹ a rate that is almost double the rise in total knee arthroplasty (135%) over the same period.¹³ This prevalence of shoulder arthroplasties is projected to continue to rise at a similar rate in the future.⁵ The marked variability in health care utilization within the United States is a problem, as it is a large driver behind the increasing costs and variability in outcomes after various

procedures.^{6,9} Despite the idea that physical rehabilitation is part of the postoperative protocol endorsed by most surgeons, there is very little information on the utilization rates of physical rehabilitation after RSA or TSA. Therefore, the purpose of this study was to assess the variation in usage of physical rehabilitation after shoulder arthroplasty, examining the effects of many factors on the utilization of formal physical rehabilitation.

The results of this study suggest that there was marked variation in the use of formal physical rehabilitation after shoulder arthroplasty. Utilization rates were higher in the Humana than in the Medicare population after both anatomic TSA and RSA. Although insurance status exhibited the most striking differences, patients with anatomic TSA had higher rates of postoperative physical rehabilitation utilization than patients with RSA within both insurance samples. Interestingly, even when looking at the subset of patients for whom arthritis was the preoperative diagnosis associated with replacement in both RSA and TSA, patients with TSA still had higher utilization rates of postoperative physical rehabilitation. The other factor that impacted postoperative physical rehabilitation utilization was geographical region, as patients in the Midwest had lower rates than those in the West and Northeast. Sex and diagnosis did not impact utilization. Differences in physical rehabilitation utilization were

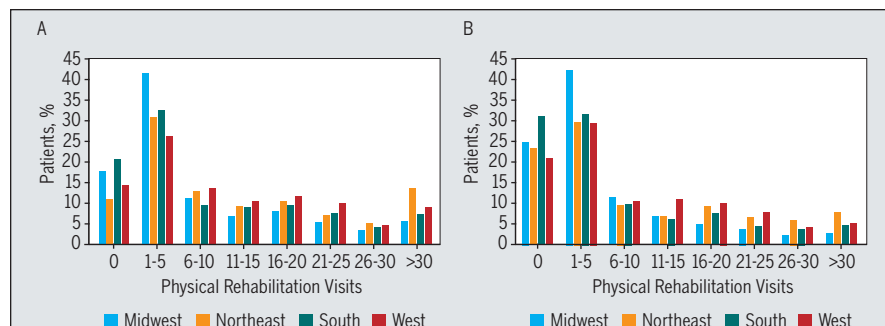


FIGURE 3. (A) A comparison of the number of physical rehabilitation visits, comparing all patients in 4 different regions (Midwest, Northeast, South, and West) who underwent total shoulder arthroplasty. (B) A comparison of the number of physical rehabilitation visits, comparing all patients in 4 different regions (Midwest, Northeast, South, and West) who underwent reverse shoulder arthroplasty.

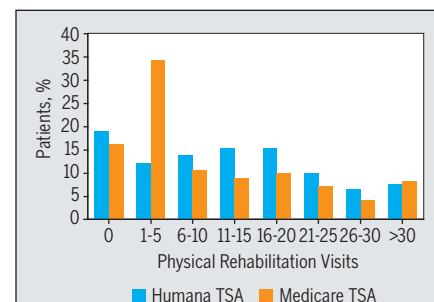


FIGURE 4. A comparison of the number of physical rehabilitation visits, comparing all patients who underwent TSA for the primary diagnosis of osteoarthritis in the Humana data set to all patients who underwent TSA for the same diagnosis in the Medicare data set. Abbreviation: TSA, total shoulder arthroplasty.

significant between those younger than 65 years or older than 80 years and the age groups of 65 to 69, 70 to 74, and 75 to 79 years of age; however, these differences only had a remarkable effect size in the TSA Medicare population.

Studies have estimated that over 65 000 shoulder arthroplasties were performed within the United States in 2011,⁸ a rise of over 250% from 1999,¹¹ with estimates for a continued and potentially even greater rise into the future.⁵ Formal postoperative rehabilitation remains the standard of care in most surgeons' practices, yet the number of visits varies tremendously between providers, hospitals, and patients. Understanding the role of formal rehabilitation gives the basis to begin developing a more standardized and streamlined approach, which would potentially provide significantly more cost-effective care to patients across the spectrum.^{6,9} The findings in this study demonstrate that variations are not solely dependent on specific practice locations, but that insurance status and type of arthroplasty (TSA versus RSA) also play a role in the amount of postoperative physical rehabilitation a patient receives. These variations will be critical to understand and consider as future studies evaluate the role of physical rehabilitation.

Like the findings of Arshi et al¹ in physical rehabilitation usage after rotator cuff surgery, the private Humana population had a significantly higher physical rehabilitation utilization rate than the Medicare population. These differences were likely not due to demographics, as the 2 insurance populations had comparable age, sex, and diagnosis. The only notable difference was that the Medicare population had a higher percentage of patients from the Northeast. But, given the regional variation we identified, this would not have contributed to lower utilization in the Medicare population (**TABLE 2**). Furthermore, there were higher utilization rates in the Humana population when subgrouping by each of these factors in both patients with RSA and those with TSA (**APPENDICES B and C**). These

findings confirm that a patient's insurance status plays a critical role in both the patient's and surgeon's postoperative decision-making thought process, potentially having an important impact on future attempts at protocol standardization.

One interesting finding in this study was the increased utilization after TSA compared to RSA. Furthermore, this difference was seen in both Humana and Medicare populations, as well as in those with a diagnosis of osteoarthritis. Although this study was not designed to answer the reasons underlying these differences, there are multiple possible explanations for this difference. It is possible that both patients and surgeons have more aggressive expectations after TSA regarding motion and ultimate shoulder function, given the historical notion that RSA is a salvage procedure. However, many recent studies have demonstrated very good motion and shoulder function in specific patient populations after RSA,^{4,7,15,17} potentially challenging the idea that rehabilitation goals after TSA should exceed those after RSA. Another possible explanation could be the assumption that patients undergoing TSA are generally younger and/or healthier than those undergoing RSA, possibly leading to a higher rate of physical rehabilitation utilization. Younger and/or healthier patients may have a higher rate of formal physical rehabilitation utilization for multiple reasons. For example, they are less likely to be homebound or have trouble getting to and from appointments, they are more likely to have aggressive goals about regaining motion and strength, and they are less likely to be injured or have complications from more aggressive physical rehabilitation programs. However, the median age for the TSA and RSA populations was comparable in the Humana (70-74 years in each) and Medicare (70-74 years in TSA versus 75-79 years in RSA) populations. Furthermore, in our study, younger patients (younger than 65 years of age) actually had lower utilization rates, while there were no differences when compar-

ing age groups within the age range of 65 to 79 years.

An unexpected finding in the study was the regional variability, with lower utilization rates in the Midwest region of the United States when compared to the Northeast and the West. It is difficult to explain this finding without more specific analyses into surgeon and patient views on postoperative rehabilitation within this and the other regions, as well as into any regional differences in functional outcomes. There is a body of research in the literature about significant regional variation in surgical rates and the multitude of influences that might cause this; however, further discussion is beyond the scope of this work.^{2,3,16,18} However, the other factors we examined, including sex and diagnosis, did not impact physical rehabilitation utilization. The lower utilization rates in patients younger than 65 years and older than 80 years of age in the Medicare subgroup are likely multifactorial, with factors such as implied health and associated activity level playing a part in the decision to undergo formal physical rehabilitation. Alternatively, the minimal differences between patients 65 to 79 years of age, as well as between all age groups in the Humana population, demonstrated that for the most part, surgeons and patients do not consider a patient's age, and potentially their implied activity level, as a primary determining factor in the need for formal rehabilitation.

The possibility of patient-directed rehabilitation at home having equivalent outcomes to formal office-based physical rehabilitation was brought to the forefront after Mulieri et al¹⁴ demonstrated equivalent outcomes after TSA when comparing the 2 therapy programs. Future investigation into the impact of rehabilitation on functional outcomes and complications after shoulder arthroplasty is critical to direct future efforts to standardize postoperative recovery protocols. In these analyses, it will be important to consider and further investigate the etiologies behind differences based

on insurance status, procedure type, and regional variations. This has the potential to not only impact individual patient outcomes and experiences but also have a systemwide impact on resource utilization, as well as on time and cost optimization.

These conclusions should only be considered in light of certain limitations. The nature of a large database prevents a comprehensive, detailed analysis of specific variables or outcomes, as would be possible in smaller, retrospective, single-institution reviews. Furthermore, the database is searched using CPT codes and ICD-9 codes, which means it is reliant on the accuracy of coding for its conclusions. Additionally, as differentiating physical rehabilitation visits related to the arthroplasty from potentially unrelated visits is not possible, we used a 6-month postoperative cutoff, with the goal being to isolate visits that were related to the shoulder arthroplasty. We cannot be completely sure, however, that every visit analyzed here was related to this operative procedure. As stated in the Methods section, there is no information on physician prescriptions for physical rehabilitation, and we are not able to assess socioeconomic levels and the effect that ability to pay has upon participation in physical rehabilitation. Finally, the database does not provide information on functional outcomes, making postoperative outcome analysis difficult. However, the advantage of this study design involves the large, multicenter database that spans multiple regions of the United States, with a great diversity of centers, surgeons, and patients included in the analysis. The 16 507 patients included in this study represent a sample size that very few other studies on shoulder arthroplasty can include and help to ensure that the findings are not influenced by outliers.

CONCLUSION

POSTOPERATIVE UTILIZATION OF physical rehabilitation after TSA and RSA is markedly higher in pa-

tients with private insurance than in patients with Medicare, regardless of age, sex, diagnosis, or region of country. Physical rehabilitation utilization was also increased in patients undergoing anatomic TSA compared to RSA, while it was decreased in patients living in the Midwest region of the United States when compared to the Northeast and West regions. Physical rehabilitation usage had only slight differences among age groups, and did not significantly vary between sex and diagnosis. These variations in physical rehabilitation utilization rates are important to consider during future evaluations attempting to elicit the role of rehabilitation after shoulder arthroplasty. These findings have important implications, from the individual patient's experience and outcomes to systemwide resource utilization. ●

KEY POINTS

FINDINGS: There was significantly higher utilization of physical rehabilitation in the 6 months after total shoulder arthroplasty and reverse shoulder arthroplasty in the Humana insurance population when compared to the Medicare insurance population. There was also significant variation between regions of the country in utilization of physical rehabilitation in the 6 months after total shoulder arthroplasty and reverse shoulder arthroplasty.

IMPLICATIONS: These variations in physical rehabilitation utilization rates are important to consider during future evaluations attempting to elicit the role of rehabilitation after shoulder arthroplasty. These findings have important implications, from the individual patient's experience and outcomes to systemwide resource utilization.

CAUTION: The database used for this study is searched using Current Procedural Terminology codes and International Classification of Diseases-Ninth Revision codes, which means it is reliant on the accuracy of coding for its conclusions. Additionally, we were not able to assess socioeconomic levels with this database,

and therefore cannot isolate the effect that ability to pay has upon participation in formal physical rehabilitation.

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[RESEARCH REPORT]

APPENDIX A

CODES UTILIZED

	Code
Total shoulder arthroplasty procedure	ICD-9 procedure code 8180
Reverse shoulder arthroplasty procedure	ICD-9 procedure code 8188
Physical therapy codes (all CPT codes)	97001, 97002, 97010, 97011, 97012, 97013, 97014, 97015, 97016, 97017, 97018, 97019, 97020, 97021, 97022, 97023, 97024, 97025, 97026, 97027, 97028, 97032, 97035, 97039, 97110, 97112, 97113, 97140, 97530, 97535
Osteoarthritis diagnosis (all ICD-9 diagnosis codes)	71511, 71521, 71531, 71591
Rotator cuff pathology diagnosis (all ICD-9 diagnosis codes)	72610, 72613, 72761, 8404
Fracture diagnosis (all ICD-9 diagnosis codes)	81200, 81201, 81202, 81203, 81209, 81210, 81211, 81212, 81213, 81219, 81220, 81230, 82309
Other (all ICD-9 diagnosis codes)	7140, 71931, 7144, 71111, 71121, 71131, 71621, 71631, 73311, 71821, 71101, 71141, 71151, 71161, 71171, 71181, 71191, 9123, 71601, 73001, 73011, 73021, 73031, 73081, 73091, 73349, 73341, 71611, 71831, 83100, 83109, 83110, 83119, 71801, 73071, 71871, 7260, 92300, 92309, 92700, 92709

Abbreviations: CPT, Current Procedural Terminology; ICD-9, International Classification of Diseases-Ninth Revision.

APPENDIX B

PHYSICAL REHABILITATION USAGE BREAKDOWN (REVERSE SHOULDER ARTHROPLASTY)*

Variable	0 Visits		1-5 Visits		6-10 Visits		11-15 Visits		16-20 Visits		21-25 Visits		26-30 Visits		>30 Visits	
	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H
Sex																
Male	25	26	35	13	10	14	8	15	7	11	7	8	3	5	5	7
Female	28	28	34	13	11	11	7	13	8	12	4	9	4	6	4	8
Region																
Midwest	25	25	42	15	12	13	7	16	5	12	4	9	2	5	3	6
Northeast	23	27	30	14	10	8	7	6	9	11	7	10	6	8	8	15
South	31	29	32	12	10	12	6	13	8	12	4	8	4	6	5	9
West	21	25	30	15	11	14	11	17	10	13	8	8	4	5	5	4
Age, y																
<65	37	32	35	16	10	13	<5	10	6	10	<5	7	<5	6	<5	7
65-69	25	24	35	12	10	11	9	15	7	12	5	10	5	6	5	9
70-74	25	24	35	13	12	13	6	15	7	12	5	9	5	6	5	9
75-79	25	27	34	11	10	13	7	15	9	14	6	8	4	6	5	6
≥80	28	32	34	14	10	11	9	13	7	10	5	7	2	5	4	7
Diagnosis																
Osteoarthritis	24	26	35	13	11	13	9	15	9	12	5	9	4	6	4	7
Rotator cuff	25	29	34	12	13	12	7	15	6	12	7	9	4	6	4	6
Fracture	32	27	34	12	8	10	6	13	6	11	4	9	5	7	4	11
Other	31	34	34	14	10	12	6	10	7	10	4	7	3	4	5	9

Abbreviations: H, Humana; M, Medicare.

*Values are percent.

APPENDIX C

PHYSICAL REHABILITATION USAGE BREAKDOWN (TOTAL SHOULDER ARTHROPLASTY)*

Variable	0 Visits		1-5 Visits		6-10 Visits		11-15 Visits		16-20 Visits		21-25 Visits		26-30 Visits		>30 Visits	
	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H
Sex																
Male	15	18	33	12	11	13	9	16	10	16	8	10	5	7	9	7
Female	19	20	34	12	11	15	8	14	9	15	7	10	4	6	7	8
Region																
Midwest	18	17	42	13	11	15	7	16	8	17	5	9	4	6	6	7
Northeast	11	16	31	17	13	9	9	13	10	13	7	15	5	8	14	8
South	21	22	32	11	9	13	9	14	10	15	7	11	4	7	7	8
West	14	16	26	14	14	17	11	18	12	15	10	7	5	6	9	7
Age, y																
<65	26	22	39	15	11	12	7	14	8	15	3	9	2	7	3	6
65-69	14	18	33	11	11	15	8	16	11	15	8	10	5	7	9	8
70-74	15	17	31	12	12	14	11	15	11	16	8	11	4	7	9	9
75-79	17	19	33	10	11	14	8	15	9	17	8	10	5	7	9	9
≥80	23	23	37	14	10	14	8	15	8	14	5	8	3	5	6	6
Diagnosis																
Osteoarthritis	16	19	34	12	11	14	9	15	10	15	7	10	4	7	8	8
Fracture	30	26	35	13	18	...	...	12	...	18	...	...	...	...	...	...
Other	25	26	31	10	14	14	7	12	8	13	7	8	4	8	5	10

Abbreviations: H, Humana; M, Medicare.

*Values are percent.