Modified Kaatsu Training: Adaptations and Subject Perceptions

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ABSTRACT

WEATHERHOLT, A., M. BEEKLEY, S. GREER, M. URTEL, and A. MIKESKY. Modified Kaatsu Training: Adaptations and Subject Perceptions. Med. Sci. Sports Exerc., Vol. 45, No. 5, pp. 952–961, 2013. Purpose: Although Kaatsu training involves low training loads, high perceived exertion and pain scores suggest that potential benefits may be offset by poor adherence or tolerance, particularly if applied in untrained or clinical populations. The purpose of this study was to investigate muscle adaptations, perceived exertion ratings, perceived sensations, and exercise adherence to a modified Kaatsu training protocol involving upper arm exercise. Methods: Forty subjects ages 18–30 yr were assigned to exercise (EX) or nonexercise control (CON) groups. The EX group performed three sets of 15 repetitions of unilateral biceps and triceps exercises, three times per week for 8 wk while wearing a pneumatic cuff to restrict blood flow on one arm (CUFF) and nothing on the other (NCUFF). The CON group did not exercise but wore the cuff on one arm for a comparable amount of time. Results: Strength, girth, tomography scans along with RPE, and sensations during workouts were assessed. Perceived exertion and sensations were assessed during workouts using visual analog scales. Results: Biceps curl and triceps extension strength along with arm size increased during the 8-wk period when compared with the CON group. Compliance was 85.4% and 97% for the EX and CON groups, respectively. EX subjects completed 85.4% of their workouts, whereas controls attended 90.4% of their sessions. The prominent sensations reported in the CUFF arm were pressure and aching. Conclusions: The Kaatsu training used in this study yielded moderate exertion ratings and low-pressure sensations, increased muscle size and strength, and was well tolerated, thereby lending support to Kaatsu training’s potential as a training modality for untrained or clinical populations. Key Words: BLOOD FLOW RESTRICTION, MUSCLE HYPERTROPHY, RESISTANCE TRAINING, MUSCLE STRENGTH, PERCEIVED EXERTION, OCCLUSION

It is generally accepted that conventional resistance exercise involving high mechanical loading (i.e., ~70% of maximal strength) induces increases in muscle size and strength (8). Of late, an alternative to conventional heavy resistance training has begun to garner interest. It involves lifting light loads (20%–50% of maximal strength) while restricting blood flow to the exercising muscles through use of specially designed pneumatic cuffs (29). The intellectual property of using blood flow restriction during exercise and the special pneumatic equipment used has recently received copyright and patent protection here in the United States and internationally (Steven Munatones, personal communication, Kaatsu USA) and as a result will be called Kaatsu training throughout this article. Peer-reviewed studies, many of which have come out of Japan (30), have shown that Kaatsu training elicits increases in both muscle strength and mass comparable with that of conventional resistance training and in a shorter time span (i.e., days vs weeks) (29). The use of low training loads is a very enticing characteristic of Kaatsu training for a multitude of reasons. One is due to the Kaatsu training’s potential application in various clinical populations that may not be able to tolerate the high loading of conventional resistance training but could benefit greatly from the positive adaptations provided by it.

However, as noted in a review of the literature, there are many unanswered questions regarding Kaatsu training, its applicability for clinical use, and how best to prescribe it (24). Numerous training protocols have been reported in published studies with frequencies of exercise ranging from 3 d wk−1 to twice daily (3,4,15,24), loads ranging from 20% to 50% of maximal strength (4,16,33,34,36), a multitude of set and repetition combinations (3,4,15,16,24,33,34,36), and a range of restriction pressures (i.e., 100–300 mm Hg) (4,33,36,37,40). On the basis of the authors’ personal experiences following training protocols reported in previous research studies, Kaatsu
training elicits high levels of perceived exertion requiring substantial motivation, disquieting sensations while the cuffs are inflated, and significant delayed onset muscle soreness after initial training bouts. Three previously published blood flow restriction training studies involving athletes or subjects with experience in resistance training reported high levels of perceived exertion and pain (22,26,37). On the basis of our experiences and the findings of previous studies, it seems Kaatsu training would be less than desirable for use in certain clinical populations, particularly those unaccustomed to resistance exercise. If Kaatsu training is to be used by older adults or other clinical populations unfamiliar in many instances with resistance training, it seems prudent to gain insight into Kaatsu programs that have been modified to potentially make it more tolerable.

Finally, many of the previous studies have involved small N’s (six or fewer exercise subjects) (29,34), were of short duration (less than 4 wk) (1,3,6,17), and have not involved experimental designs using both intra- and intersubject controls. The purpose of this study was to examine changes in muscle strength and size, to assess levels of perceived exertion, to describe sensations experienced during training, and to report adherence/compliance rates of a modified Kaatsu training program using an experimental design that improves on earlier studies (i.e., larger sample size, longer training period, and intra- and intersubject controls). We hypothesized that the modified Kaatsu training program would increase muscle size and strength and elicit tolerable levels of perceived exertion and sensation.

METHODS

Subjects. The Indiana University–Purdue University Indianapolis and the University of Indianapolis institutional review boards approved the methods used for this study, and all subjects provided signed informed consent. Forty healthy college students ages 18–30 yr were recruited via word of mouth and campus postings to participate in this study. Potential subjects who regularly resistance trained or had resistance trained within 8 wk of volunteering for this project were excluded. Figure 1 provides a graphic overview of the experimental design. Twenty-five of the subjects were Indiana University–Purdue University Indianapolis students (13 men and 12 women, mean ± SD age = 22.4 ± 2.7 yr) and were assigned to the exercise (EX) group. Fifteen were University of Indianapolis students (4 men and 11 women, mean ± SD age = 20.4 ± 1.4 yr) and were assigned to the control/nonexercise (CON) group. The EX group performed upper arm resistance exercises (i.e., unilateral biceps curl and unilateral triceps extension) with a blood flow restricting cuff on one arm (CUFF) and no cuff on the other (NCUFF). The determination of which arm was cuffed was randomized. The CON group did not participate in any resistance training but wore a restrictive arm cuff on one of their arms for the same length of time as subjects in the EX group. As with the EX group, the determination of which arm was cuffed was randomly assigned.

Testing procedures. Girth and skinfold measurements were taken on both arms before, during, and after the 8-wk experimental period. Girth measurements were taken using a Gullick tape, and skinfold measures were taken using a Lange skinfold caliper. The sites for the measurements were determined as follows: the distance between the acromion process and the olecranon process was measured. Using a surgical marking pen, a small dot was made at the halfway point on the posterior aspect of the arm. Two girth measures were taken at the level of the dot with the arm relaxed and hanging at the subject’s side. If the measures were off by more than 3 mm, a third measure was taken. The two closest values were averaged and used to represent upper arm girth. Two skinfold measures were also taken at the same level as the girth measurements. The first measure was taken at the dot on the posterior aspect of the arm. The second measure was taken on the anterior aspect of the arm. The anterior location was on the same horizontal plane as the posterior mark. Two skinfold measures were performed at each mark. If the measures varied by more than 1 mm, a third measure was taken. The two closest measures were averaged and used to represent the skinfold thickness at the sites. All girth and skinfold measures were performed by the same experienced technician for all subjects.

The one-repetition maximum (1RM) was measured for the unilateral biceps curl (Fig. 2A) and the unilateral triceps extension (Fig. 2B) exercises and used to represent the strength of the elbow flexors and extensors, respectively. To minimize learning effects, at least 1 wk before baseline 1RM data collection, each subject scheduled a session in which they practiced the exercises and went through the testing process. On the strength testing days, subjects were allowed to warm-up their upper arm muscles by performing the exercises with light loading that they could easily perform 10 repetitions with. After a 2-min rest, the subjects performed a second set with a heavier weight estimated to be approximately 50% of their 1RM. After another 2 min of rest, subjects began their first 1RM attempt. If they completed their first 1RM attempt, more weight was added until they failed to lift the weight. A 2-min rest was given between each 1RM attempt. If the subject failed to lift the weight on their first attempt, they rested for 2 min and made another attempt with a lighter weight. In all cases, the 1RM was determined within three to five attempts. Strength testing was performed before, during (every 2 wk), and after the 8-wk experimental period.

Peripheral quantitative computed tomography (pQCT) was used to measure muscle cross-sectional area (mCSA) of the upper arms. Computed tomographic scans were performed using a Stratec XCT 2000 machine (Stratec Medizintechnik GmbH, Pforzheim, Germany) equipped with Stratec software version 5.40B. Two scans at midshaft humerus were taken before and after the 8-wk experimental period to assess mCSA of both the upper arms. The site for
Midshaft humerus was determined using a sliding anthropometer and defined as half the distance between the acromion process and the olecranon process. Using a surgical marking pen, a small dot was made at the halfway point on the posterior aspect of the arm. Subjects were informed to remove all metal objects and to lie in a supine position on a table next to the machine with the elbow extended and the shoulder laterally abducted at 90°. The arm was centered within the gantry of the machine and held in position using support pads and Velcro strapping. Subjects were asked to remain still while the pQCT scanned the arm. Single tomographic slices (thickness = 2.3 mm, voxel size = 600 μm, scan speed = 12 mm·s⁻¹) of the upper arm were taken, and the procedure was repeated on the contralateral upper arm such that each individual had two pQCT scans during pretesting and two during posttesting sessions.

For the determination of cross-sectional areas, the midshaft humerus tomographic slices were analyzed using contour mode 3 (threshold = -200 mg·cm⁻³) and peel mode 2 (threshold = -200 mg·cm⁻³) to differentiate soft tissues (i.e., skin, subcutaneous fat, and muscle). Bone was subsequently segregated from muscle using cortical mode 1 (threshold = 711 mg·cm⁻³). The pQCT images were manually traced three times, and the averages were used to represent mCSA. The technician running the pQCT analysis was blinded to the group designation of the subjects to remove any potential for bias. A recent study using the same pQCT scanner reported that the magnitude of variability of repeated mCSA measures was less than 1.5% of the total cross-sectional area measured (32).

RPE were assessed immediately after performing each set using a modified Borg RPE scale that provided color,
Each subject in the EX and CON groups reported to the laboratory three times per week for the 8-wk experimental period. The EX group performed progressive resistance training at an intensity of 20% of their predetermined 1RM for three sets of 15 repetitions. The 1RM was reassessed every 2 wk, and the training weight adjusted accordingly throughout the experimental period. A warm-up preceded training and involved performing 10 repetitions of unweighted arm movements mimicking the elbow flexor and extensor exercises. To train the elbow flexors and extensors, unilateral biceps curls and triceps extensions were performed using a cable pulley system with an attached stirrup handle (Figs. 2A and 2B). Subjects performed the exercises at a standard cadence of approximately 1 s up (i.e., the concentric phase) and 2 s down (i.e., the eccentric phase). One minute of rest was allowed between sets. Subjects in the EX group performed the exercises in the following sequence for every workout session: arm curl (CUFF), arm curl (NCUFF), elbow extension (NCUFF), and elbow extension (CUFF). The CON group subjects were instructed to report to the laboratory but did not perform any resistance exercises. Instead, they watched videos or studied while they wore the restrictive cuff (see next section) on one arm for the same length of time as the EX subjects.

Blood flow restriction. A specially designed pneumatic cuff (30 mm width; Kaatsu International, Tokyo, Japan) was used to restrict blood flow. The pneumatic cuff was placed on only one arm (randomly assigned) of the subjects in the EX and CON groups. The deflated cuff was placed on the proximal aspect of the upper arm at the level of the insertion of the deltoid muscle (see Figs. 2A and 2B) and then attached to the Kaatsu master control unit (Kaatsu International) that houses an air compressor and pressure gauge. Once attached to the control unit, the tightness of the cuff around the arm was adjusted until the desired “tightness pressure” was achieved. Once the cuff was adjusted to the proper tightness pressure, the arm cuff was inflated to 90 mm Hg for 30 s, deflated for 10 s, and then increased 30 mm Hg for another 30 s and so on until the desired cuff training pressure for that day was achieved. During the course of the experimental period, the tightness pressures and training pressures used were progressively increased (Table 1) for both the EX and the CON subjects. The EX subjects wore the cuff for the entire time it took to perform the three sets of 15 repetitions, which took approximately 5 min for each exercise. The CON subjects wore the cuff without exercising for a comparable amount of time. After completion of the three sets or the timed control condition, the cuff was depressurized and removed from the arm.

Statistical analysis. All analyses were performed using statistical software (IBM SPSS 19; IBM, Chicago, IL). An alpha level of $P \leq 0.05$ was considered statistically significant. The descriptive statistics for the EX and the CON groups are presented as mean ± SD. All other data are presented as mean ± SEM. To account for potential baseline differences, an ANCOVA was used to detect differences between the EX and the CON groups followed by a Fisher’s protected least squares differences post hoc analysis when significance was achieved. Repeated-measures analysis of variance was used when comparing longitudinal data for strength, girth, skinfolds, perceived exertions, and sensations within the exercise group, followed by a Sidak post hoc analysis when significance was achieved.

RESULTS

Of the 25 EX (13 men and 12 women) and 15 CON (4 men and 11 women) subjects that started the study, 20 EX (10 men and 10 women) and 14 CON (4 men and 10 women) subjects completed the posttesting. Of the five subjects in the EX group who dropped out, one quit before any data were collected because of scheduling issues, three quit after starting the program because of time conflicts, and
one was forced to quit because of illness (i.e., mononucleosis). The subject that dropped out in the CON group quit because of time conflicts. Thus, 85.4% of the EX subjects and 97% of the CON subjects finished the pre- and posttesting. Of the 24 training workouts or control sessions that were to be attended during the 8-wk experimental period, the EX group completed an average 20.5 workouts (range 13–23), whereas the CON group attended an average 21.7 sessions (range 19–24 sessions); thus, adherence was 85.4% and 90.4% for the EX and CON groups, respectively.

The RPE scores reported by the EX subjects when performing the biceps curl and triceps extension with their CUFF arm were significantly higher than when exercising their NCUFF arm throughout the 8-wk experimental period (P = 0.000). In regard to changes in RPE in the CUFF arm from week to week, it was observed that RPE did not significantly change from previous weeks until week 6, when the cuff tightness pressure achieved 30 mm Hg and the training pressure was 180 mm Hg. After week 6, the cuff tightness pressure and the training pressure remained constant, and RPE did not differ significantly from week 6 to week 8. Figure 3A shows the average RPE for weeks 6 to 8 for the

<table>
<thead>
<tr>
<th>Week</th>
<th>Cuff Tightness Pressure (mm Hg)</th>
<th>Cuff Inflation Pressure (mm Hg)</th>
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<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>90</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>90</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>120</td>
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<tr>
<td>4</td>
<td>30</td>
<td>120</td>
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<tr>
<td>5</td>
<td>30</td>
<td>150</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>180</td>
</tr>
<tr>
<td>7</td>
<td>30</td>
<td>180</td>
</tr>
<tr>
<td>8</td>
<td>30</td>
<td>180</td>
</tr>
</tbody>
</table>

FIGURE 3—A, Visual analog scale used to assess perceived exertion after each set of the exercises performed. B, Visual analog scales used to assess perceived sensations of pressure, burning, aching, and pins/needles before each exercise set. N & X = average rating for weeks 6-8 for NCUFF and CUFF arms, respectively.
CUFF and NCUFF arms. In regard to changes in RPE from set to set within a workout, the RPE scores increased progressively from set 1 through set 3 of each exercise. During weeks 6 to 8, the RPE scores averaged 3.2 ± 1.0 for set 1, 5.1 ± 1.8 for set 2, and 7.0 ± 2.5 for set 3. The perceived exertion scores reported during the same period when exercise NCFU arm averaged 1.5 ± 0.3, 2.4 ± 0.3, and 3.3 ± 0.4 for set 1 through set 3, respectively. RPE were not assessed for the CON subjects because they did not perform any exercise.

Figure 3B shows the RPS for the four variables (i.e., pressure, burning, aching, and pins/needles) experienced during weeks 6 to 8 when the pressures were highest. As with RPE, the RPS increased progressively from set 1 to set 3 within workouts and during the weeks as cuff tightening and training pressures increased. The RPS scores became significantly different from the previous weeks when the cuff tightening pressure reached 30 mm Hg and the training pressure reached 120 mm Hg in week 4 (P = 0.009, F = 8.57). The RPS scores continued to increase significantly until week 6. From weeks 6 to 8, the average weekly RPS did not increase significantly.

Table 2 shows the pre- and posttraining values for strength, arm girth, skinfolds, and cross-sectional area of the upper arm. Biceps curl and triceps extension strength increased significantly from pre- to posttraining within the EX group for both the CUFF (13.5% and 15.4%, respectively) and NCFU (15.0% and 9.8%, respectively) arms. However, the biceps and triceps strength increases for the CUFF arm were not significantly different than those for the NCFU arm. When compared with the CON group, the biceps strength increases in the CUFF and NCFU arms of the EX group were significantly greater (P = 0.011; P = 0.006, respectively). For triceps strength, only the CUFF arm of the EX group showed a significant increase when compared with the CON group (P = 0.011). Table 3 shows the longitudinal strength data for the CUFF and NCFU arms of the EX group. Biceps curl strength did not significantly increase from baseline level until week 6 (P = 0.001), whereas triceps extension strength did not significantly increase from baseline until week 8 (P = 0.023). Longitudinal strength data for the CON group are not shown because there were no changes in strength during the 8 wk.

The CUFF and NCUFF arm girths (see Table 2) increased significantly (P = 0.000; P = 0.001) in the EX subjects compared with the CON subjects during the 8-wk experimental period. However, no significant differences were found when within-group comparisons were made between the CUFF and the NCFU arms of the EX group. Longitudinal analysis revealed that arm girths became significantly larger compared with baseline (i.e., week 0) at week 6 (P = 0.038). Analysis of the longitudinal data for skinfold measures did not show any significant changes during the 8 wk. Similar to the girth results, CUFF and NCFU arm mCSA increased in the EX group compared with the CON group (P = 0.008; P = 0.000, respectively); however, no significant differences in mCSA were detected between arms within the EX group.

**DISCUSSION**

Our personal experiences with Kaatsu training and previous reports (22,35,36) indicate that exercise with blood flow restriction can be perceived as strenuous despite the use of low loads. Typically, Kaatsu training programs involve the use of a fatigue-inducing first set of 30 repetitions followed by three sets of 15 repetitions for a total of 75 repetitions per exercise (24). This is a high repetition volume, particularly for most clinical populations and/or individuals with no resistance training history, and not likely to be well tolerated. As a result, we modified the program by removing the initial fatigue-inducing set of 30 repetitions, thus decreasing the repetition volume from 75 to 45 repetitions (i.e., three sets of 15 repetitions). We chose upper arm exercise because in our experience, Kaatsu arm training perceptually is more taxing and painful than leg exercise and as such would be a good model for investigating exercise adherence and perceptions. In addition, most Kaatsu studies have involved the legs, so relatively little has been reported involving arm exercise and/or RPE and training-associated sensations. The modified, upper arm Kaatsu training protocol used in this study elicited ratings ranging from “very weak” to “moderate” for sensations (see Fig. 3B) and moderate for RPE (see Fig. 3A). These RPS and RPE levels were not achieved until approximately week 6 of the training protocol, during which

**TABLE 2. Control and exercise group pre- and posttraining values for strength, skinfolds, girth, and mCSA.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control Group ARM</th>
<th>Exercise Group ARM</th>
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<tbody>
<tr>
<td></td>
<td>No Cuff</td>
<td>Cuff</td>
</tr>
<tr>
<td>Biceps curl strength (kg)</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td></td>
<td>20.1 ± 2.8</td>
<td>20.6 ± 2.6</td>
</tr>
<tr>
<td>Triceps extension strength (kg)</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td></td>
<td>19.8 ± 2.0</td>
<td>20.1 ± 1.8</td>
</tr>
<tr>
<td>Arm skinfolds (mm)*</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td></td>
<td>28.2 ± 3.1</td>
<td>29.3 ± 3.1</td>
</tr>
<tr>
<td>Arm girth (cm)</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td></td>
<td>29.5 ± 2.9</td>
<td>29.2 ± 2.9</td>
</tr>
<tr>
<td>mCSA (mm²)</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td></td>
<td>3397.5 ± 309.7</td>
<td>3405.0 ± 316.4</td>
</tr>
</tbody>
</table>

*Represents the sum of the anterior and posterior skinfold measures.

**ANCOVA** detected significant difference with CON arm (P < 0.05).

**Significantly different from pretraining strength measures (P < 0.05).**

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**KAATSU TRAINING: ADAPTATIONS AND PERCEPTIONS**

Medicine & Science in Sports & Exercise

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TABLE 3. Longitudinal strength and girth data for the exercise (EX) group.

<table>
<thead>
<tr>
<th></th>
<th>Biceps Curl</th>
<th>Triceps Extension</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>No-Cuff Arm</td>
<td>Cuff Arm</td>
</tr>
<tr>
<td>Strength (kg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 0</td>
<td>22.7 ± 2.4</td>
<td>23.0 ± 2.3</td>
</tr>
<tr>
<td>Week 2</td>
<td>24.3 ± 2.5</td>
<td>23.2 ± 2.2</td>
</tr>
<tr>
<td>Week 4</td>
<td>24.9 ± 2.7</td>
<td>24.5 ± 2.4</td>
</tr>
<tr>
<td>Week 6</td>
<td>25.7 ± 2.3*</td>
<td>25.4 ± 2.2*</td>
</tr>
<tr>
<td>Week 8</td>
<td>26.1 ± 2.5*</td>
<td>26.1 ± 2.3*</td>
</tr>
<tr>
<td>Arm girth (cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 0</td>
<td>22.7 ± 2.4</td>
<td>23.0 ± 2.3</td>
</tr>
<tr>
<td>Week 2</td>
<td>24.3 ± 2.5</td>
<td>23.2 ± 2.2</td>
</tr>
<tr>
<td>Week 4</td>
<td>24.9 ± 2.7</td>
<td>24.5 ± 2.4</td>
</tr>
<tr>
<td>Week 6</td>
<td>25.7 ± 2.3*</td>
<td>25.4 ± 2.2*</td>
</tr>
<tr>
<td>Week 8</td>
<td>26.1 ± 2.5*</td>
<td>26.1 ± 2.3*</td>
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*Significantly different from week 0 ($P < 0.05$).

The “very weak” to “moderate” RPE and RPS ratings of the modified Kaatsu arm training protocol appeared to positively affect the subjects’ high compliance and exercise adherence rates (i.e., 85% for both measures). Research shows that exercise intensity influences our affective responses to exercise (38). In other words, people who push past their comfort zones during exercise are less likely to adhere to an exercise regime than those who stay within their comfort zones (38). Given that none of the subjects dropped out due to adverse events or sensations and that adherence was higher than the 66%–82% adherence typically reported for general exercise (26), the Kaatsu training protocol used for this study was well tolerated. For Kaatsu training to be used as a clinical intervention, it must be tolerable by subject populations not accustomed to high exertion and its associated discomforts. Our study demonstrates that Kaatsu training involving three sets of 15 repetitions with a load equivalent to 20% of maximal strength elicits weak to moderate exertion and sensation levels and is well tolerated by young, nonresistance trained adults. Although promising, the generalizability of our findings into actual clinical populations warrants further investigation.

Although we observed significant increases in muscle strength and cross-sectional area after 8 wk of Kaatsu training, our observed changes were not as significant as other Kaatsu training studies. Probably, the main reason for this difference is the conservative approach we took to structuring the Kaatsu training program. Previous Kaatsu studies have used a range of pressures (i.e., 100–300 mm Hg) (4,33,36,37), training frequencies (i.e., twice daily to 3 d wk$^{-1}$) (3,4,15,24), training durations (i.e., 4–10 wk), sets (i.e., 3–4 sets [3,4,15,16,24,33,34,36]), repetitions (i.e., 15–30 per set) (3,4,15,16,24,33,34,36), exercise intensities (i.e., 20%–50% of 1RM) (4,16,33,34,36), exercises (i.e., squat, knee extension, chest press, etc.) (4,17,24,33,39), and training modalities (i.e., weight lifting, walking, cycling, etc.) (2,4,5,17,24,33,39). On the basis of the authors’ personal experiences with Kaatsu training and using various acute program variables (i.e., pressures, sets, reps, load, etc.) reported in other Kaatsu training studies, we designed a Kaatsu program that was less intense, yet maintained the potential to be effective. The Kaatsu upper arm training protocol that was used for the EX group in our study involved three sets of 15 repetitions at 20% of 1RM performed three times per week for 8 wk. The conservative nature of our Kaatsu training protocol most likely explains why some of the previous Kaatsu training studies found greater increases in mCSA (i.e., >6%) (4,33,35) compared with our study (i.e., ~4%).

Another explanation for the smaller increases in muscle mass reported in our study may be due to the ramped protocol we used for cuff tightness and inflation pressures (see Table 1). On the basis of the RPE data for our EX subjects, RPE values on the CUFF arm were not significantly higher...
Third, the initial belt tightness and inflation pressures used in the first 5 wk may not have been high enough to elicit a strong stimulus for strength and muscle cross-sectional changes. If we speculate based on the RPE data, then it is possible that the subjects experienced only 3 wk of adequate training stimulus, which in turn could explain our smaller reported increases.

Our experimental design using both internal (CUFF vs NCUFF arms) and external (EX group vs CON group) controls enabled a couple of interesting observations. First, it appears that the Kaatsu training elicited a neural cross-education effect. In other words, the Kaatsu trained arm (i.e., CUFF arm) appears to have influenced the strength in the non-Kaatsu trained arm (i.e., NCUFF arm). We know this to be the case because the NCUFF arm was training with a load (i.e., 20% of maximal strength) that is generally accepted as being too low to cause strength increases. It could be argued that the strength increase in the NCUFF arm was due to a learning effect because our subjects were untrained in regard to resistance training. However, this is unlikely because all subjects underwent an exercise familiarization session before we collected baseline strength measures. Furthermore, our longitudinal strength data for the NCUFF arm (see Fig. 2) do not show an early, rapid strength increase, which would be apparent if the strength gain was due to a learning effect. Instead, the NCUFF strength gains increased during the course of the 8-wk training period. Although the underlying mechanisms for cross education are not well understood, it is believed that the intense training of one arm can cause improved muscle activation in the contralateral untrained arm. This phenomenon has been demonstrated in other training studies (7,23,27), including Kaatsu training (27,31), and knowledge of it has been used in rehabilitation to prevent strength losses in injured muscles that cannot be exercised (21,25,28,31). What makes the finding of a cross-education effect in this study unique is that to the authors' knowledge, all previous reports of neural cross education have involved much heavier loads (i.e., ≥50% of maximal strength) (14) than those used in this study (i.e., 20% of maximal strength). This finding has significant clinical relevance and warrants further investigation.

The second interesting finding is that the Kaatsu training appears to have a systemic effect and is not limited to the local muscles in which the blood flow has been restricted. This supports observations of earlier Kaatsu studies suggesting a systemic effect (27,35). Although the underlying mechanisms explaining the systemic effect are unclear, Kaatsu training elicits the release of certain anabolic hormones. For example, growth hormone release is increased in response to conventional heavy resistance training and Kaatsu training. Growth hormone release has been shown to influence protein regulation and muscle growth (27,35). In Kaatsu training, it is speculated that metabolites (i.e., ions, lactate, etc.) may accumulate because of blood flow restriction in turn stimulating metaboreceptors that trigger the release of the growth hormone despite the use of light loads (18,29). This release of growth hormone may have a systemic effect, thus causing an increase in muscle size in the NCUFF arm also (27,35). Therefore, our data suggest that Kaatsu training elicits a systemic as well as localized effect on muscle, the extent to which warrants further investigation.

There were several strengths to the current study. First, both internal and external controls were used in the experimental design. The use of internal controls enabled us to explore the potential systemic effects of Kaatsu training. Second, the study had one of the larger sample sizes compared with other Kaatsu studies (i.e., n > 15). Third, the pQCT mCSA measurements were performed by a technician blinded as to group assignment. Fourth, we assessed the RPE and RPS levels during the course of the experimental period. These data provide insight into the level of exertion and the specific sensations experienced during Kaatsu training, which are important to researchers and future practitioners given the novelty of Kaatsu training in the United States. Finally, the ramped Kaatsu belt tightness and inflation pressure protocol enabled a format for assessing the changing RPE and RPS levels associated with Kaatsu training over time.

Although the current study possesses several strengths, it also has limitations. One weakness was that we did not measure blood flow at the various levels of initial cuff tightness and training pressures used during the weeks of training. The inclusion of blood flow measures could have shed some insight into the degree of blood flow restriction required to promote a training stimulus. The specific RPS instrument that was used in this current study has never been tested for psychometric properties. However, it is a modified version of scales that have been used to rate pain (10,20), and the visual analog scaling that our instrument is based upon has been tested for psychometric properties (10–12,19,20). Another limitation is that our sample population involved healthy, 18- to 30-yr-old college students, which makes its generalization to other actual clinical populations questionable.

In summary, the modified Kaatsu training of the upper-arm muscles elicited increases in strength, arm girth, and mCSA when compared with a nonexercise control group. However, no differences were found when comparing the same measures between the cuffed and the noncuffed arms within the exercise group. This finding suggests that there was both a neural cross-education effect regarding strength gains and a systemic effect of Kaatsu training on muscle hypertrophy. Moderate RPE levels indicate that the upper arm Kaatsu training was well tolerated by young adults who were untrained in regard to resistance training. The tolerance to Kaatsu training was further substantiated by the study's adherence and compliance rates. Finally, on the basis of the RPS data, the highest-rated sensation by subjects was "pressure," which progressed in intensity from set 1 to set 3. On the basis of these findings, the modified Kaatsu training protocol used in this study has significant potential to serve as a...
viable alternative to conventional heavy resistance training and offers benefits that could positively affect numerous clinical populations.

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