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EFFECTS OF BLOOD FLOW RESTRICTION TRAINING ON HANDGRIP STRENGTH AND MUSCULAR VOLUME OF YOUNG WOMEN

Daniel Zanardini Fernandes, MSc[1,2]
Vinicius Müller Reis Weber, MSc[2,3]
Marcos Paulo Amaral da Silva, BSc[1]
Natã Gomes de Lima Stavinski, BSc[1]
Lucas Eduardo Campos de Oliveira, BSc[1]
Eduardo Henrique Casoto Tracz, BSc[1]
Sandra Aires Ferreira, PhD[2]
Danilo Fernandes da Silva, PhD[1,4]
Marcos Roberto Queiroga, PhD[1,2]

ABSTRACT

Background: High-intensity training methods are generally recommended to increase muscle mass and strength, with training loads of 60-70% 1RM for novice and 80-100% 1RM for advanced individuals. Blood flow restriction training, despite using lower intensities (30-50% 1RM), can provide similar improvements in muscle mass and strength. However, studies commonly investigate the effects of blood flow restriction training in large muscular groups, whereas there are few studies that investigated those effects in smaller muscle groups, such as the muscles involved in grasping (e.g, wrist flexors; finger flexors). Clinically, smaller muscular groups should also be considered in intervention programs, given that repetitive stress, such as repeated strain injuries, affects upper limbs and may lead to chronic pain and incapacity for work. The purpose of the present study was to examine the effects of blood flow restriction training in strength and anthropometric indicators of muscular volume in young women.

Hypothesis: The effect of blood flow restriction training in handgrip strength (HGS) and muscular volume of young women can be similar to traditional training, even with lower loads.

Methods: Twenty-eight university students, 18 to 25 years of age, were randomly assigned into two groups, blood flow restriction training (BFR, n = 14) and traditional training (TRAD, n = 14). The anthropometric measures and maximum handgrip strength (MHGS) test were performed before and after the intervention. The participants did three weekly sessions of dynamic concentric contraction exercises on a dynamometer for four weeks (12 sessions). Each session had a time length of five minutes and the intensity was established from a percentage of MHGS at 30-35% in the first week, 40-45% in the second and 50-55% in third/fourth weeks. Three sets of 15-25 handgrip repetitions were performed until a failure with a 30 seconds rest for BFR training and three sets of 8-12 repetitions with one-minute rest for TRAD training.

Results: A significant increase was found in the arm muscle circumference (20.6 ± 2.2 vs 21.6 ± 1.7cm) and right MHGS (32.7 ± 4.5 vs 34.3 ± 4.1 kgf) and left MHGS (28.0 ± 5.5 vs 30.9 ± 4.1 kgf) for the BFR training, and the left MHGS (27.6 ± 5.0 vs 31.0 ± 6.1 kgf) for the TRAD training.

Conclusion: Dynamometer training with blood flow restriction, performed with low to moderate loads, was more effective than the traditional training in increasing HGS and muscle volume in young women.

Level of evidence: 2b

Keywords: Blood flow restriction training, movement system, muscle strength, Resistance training, women, upper extremity

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[1] Group of Study and Research in Experimental Physiology and Applied to Physical Activity (LAFEAF), Department of Physical Education, Midwestern Paraná State University, Guarapuava, PR, Brazil.
[2] Associate Post-Graduate Program in Physical Education UEL/ UEM.
[3] Laboratory of Physical Activity and Health, Center of Physical Education and Sports, State University of Londrina, Londrina, Paraná, Brazil.
[4] School of Human Kinetics, Faculty of Health Sciences, University of Ottawa, Ottawa, Ontario, Canada.

The authors report no conflicts of interest.

CORRESPONDING AUTHOR
Daniel Zanardini Fernandes
Department of Physical Education, State University of Midwest (UNICENTRO)
Rua Simeão Carmargo Varela de Sá,
Number: 03, Zip Code: 85040-080
Phone: +55 (42) 3421-3000
FAX: +55 (42) 3621-1090
E-mail: danizafe@gmail.com

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INTRODUCTION

High-intensity training methods are generally recommended to increase muscle mass and strength.[1,2] Such training is recommended for adults, young, and elderly people, since it contributes to the maintenance of daily activities, prevents osteoporosis, sarcopenia, back pain and other pathological conditions such as insulin resistance and Type 2 diabetes.[3,4]

Evidence from the American College of Sports Medicine (ACSM) suggests that high-intensity training methods with training loads of 60-70% 1RM for novice individuals and 80-100% 1RM for advanced individuals should be used to improve strength and muscle mass.[2,5] However, this is often impractical for some populations, such as osteoarthritis patients, individuals who are undergoing rehabilitation and asymptomatic populations who need to develop muscle strength.[6] There is a need for resistance training methods that can be safely applied to certain populations with physical limitations, while improving strength and muscle mass without increasing the risk of injury or exacerbating preexisting disorders.

It is suggested that blood flow restriction training (BFR), despite using low to moderate intensity loads (30% to 50% of 1RM),[7] promotes an increase in mass (hypertrophy) and strength.[8,9] However, this training approach has not shown an impact on muscular power.[9] The improvements in muscle mass and strength were previously noticed in both clinical[9] and athletic[10] populations. Vascular function has also been shown to improve.[11] BFR is a training method that usually consists in partially (e.g., 160 mmHg) or totally (e.g., 300 mmHg) restricting the limb blood flow during exercise using an inflatable cuff placed at the most proximal portion of the limb. The flow restriction determination is based on the resting systolic blood pressure and causes arterial blood inflow to be reduced and largely occludes venous return.[6,12,13] The mechanisms by which the physiological changes occur are not completely known; however, they seem to be associated with hypoxia and muscular acidosis, which produces a rapid and intense fatigue due to the lower oxygenation and high stimulation of metaboreceptors. The poor oxygen environment may also increase Type II muscle fiber recruitment in order to maintain the intensity of contraction, which can lead to the strength gains previously reported.[7,14] Commonly, studies investigating the effects of BFR training on muscle strength and hypertrophy use exercises for large muscle groups, such as the quadriceps.[14–16] In this regard, investigations exploring the effects of BFR training on smaller muscle groups, such as finger or wrist flexors, are limited. Most of the diseases related to repetitive stress, such as repeated strain injuries, affects upper limbs and may lead to chronic pain and incapacity for work[17]. Consequently, there is a need to explore potential interventions to improve upper limb strength and minimize the negative effects of traditional high intensity strength training. Maximum handgrip strength (MHGS) is commonly used as an outcome parameter in clinical practice,[18] is associated with obesity[19] and is a predictor of all-cause mortality.[20,21] The purpose of the present study was to determine the difference between BFR training and a traditional training regimen on MHGS and anthropometric indicators of muscular volume in young women.

METHODS

Participants

The sample consisted of 28 female university students. Included subjects were female, untrained (i.e., not engaged in an exercise training program for at least six months), right-handed and aged between 18-25 years old. These criteria were followed for three main reasons: 1) since the BFR training using handgrip strength had not been tested before, the authors attempted to first test it in clinically healthy participants; 2) given that the untrained (i.e. first starting the training program or coming from long periods without regular exercise) and health population represents a large portion of those interested in resistance training, the authors anticipated that the results would have a larger practical application; 3) to maximize sample homogeneity[22] with regards to characteristics (e.g., sex, age, training level/participation) that could influence our results. The exclusion criteria were: participants who presented with a history of injury/surgery in the upper limbs, had previous or current cardiac disease, were not able to attend the training sessions and were left-handed dominant. All participants were previously informed about the procedures to which they would be submitted. No financial incentive was provided, neither any other source of incentive. Volunteers signed an informed consent form, as determined by the National Health Council on Research Involving Humans Subjects and the Declaration of Helsinki. The project was approved by the Research Ethics Committee of the Midwestern Paraná State University (UNICENTRO) (nº 2048694/2017).

Procedures and data collection

The research was described in undergraduate courses of the Health Sciences Sector of the Midwestern Parana State University campus. The researchers visited the classes to introduce the objectives and to inform the inclusion and exclusion criteria for participating in the study. One week later, 30 interested participants attended the laboratory to confirm participation. In this visit, participants were randomly assigned by a computer random number generator to one of the training groups, blood flow restriction training group (BFR; n = 15) or traditional group (TRAD; n = 15).

All participants underwent anthropometric and handgrip strength measurements before and after the series of training session (48 hours after). In the pre-training assessment, participants scheduled the days and times for the strength training sessions following the procedures of each intervention group. In both pre- and post-training visits, participants performed anthropometric measurements and the MHGS test.

Experimental design of the intervention

Interventions were planned according to the recommendation of the ACSM, following the principles of *Frequency* (sessions/week), *Intensity* (how difficult the exercise is), *Time* (how long the exercise session took), *Type* (what kind of exercise it is), *Volume* (the total amount of exercise that was completed), and *Progression* (how the program was altered), known as the FITT-VP principles of the exercise prescription.[6]

The frequency was controlled for the sessions at 3 times per week. The intervention duration was four weeks (for a total of 12 sessions). The BFR and TRAD training participants previously scheduled a time of the day (8-12 a.m. or 1:30-8 p.m.) for the individual sessions of handgrip strength exercises. The baseline LHGS and RGHS were used to define the intensity of the training sessions for TRAD and BFR (intervention period) as described below.

Training for the BFR Group

Participants performed a three minutes warm-up, which consisted of performing 30% of 1RM of MGHS contractions for one minute and thirty seconds and resting (i.e., passive recovery) for the remaining time. For vascular occlusion, the ClinicArm WCS® manometer (WCS®, Cardiomed, Brazil) was used with the arm sleeve placed at the most proximal portion of the upper limb. In the warm-up, the arm sleeve was inflated and the safety valve locked at 60mmHg, and during the training it was locked at 160mmHg for each arm throughout the study.[23] Then, the participants in the occlusion group performed the training protocol, which consisted of three sets of 15-25 repetitions until failure with intensity between 35% and 55% (Table 1) in both hands, with a 30 second

Table 1. *Distribution of loads for BFR and TRAD according to acronym FITT-VP**

Group	Week	F	I	T^1	T	V	P
BFR	1º	3	30-35%	5 min	Resistance	15 min	Intensity
	2º		40-45%				Intensity
	3º		50-55%				Intensity
	4º		50-55%				
TRAD	1º	3	65-70%	5 min	Resistance	15 min	Intensity
	2º		70-75%				Intensity
	3º		80-85%				Intensity
	4º		80-85%				

BFR= blood flow restriction training group; TRAD= traditional training group; min=minutes; F= frequency (times per week); I= Intensity (% Maximum handgrip strength test, from pre assessment value); T^1= time (duration); T= Type (aerobic, resistance, neuromuscular, neuromotor, flexibility); V= Volume (F x T^1); P= Progression

*FITT-VP, according to ACSM (2018)

rest between each series. Each repetition lasted approximately one second in the concentric contraction and one second in the eccentric contraction. Participant was seated, arm at the side of the body with the elbow flexed at 90° holding the dynamometer resting on the thigh. The training was performed individually in each arm, always starting with the left arm, and after the end of the three sets, the exercise in the right arm began. There was a minute rest in the transition. The parameters for BFR training group can be found in Table 1.

Training for the TRAD Group

The training protocol was based on the general strength training recommendations of the ACSM.[6] After the three-minute warm-up, which consisted of performing 30% 1RM contractions for one minute and thirty seconds and resting (i.e., passive recovery) for the remaining time, participants performed the training protocol. The training for the group without occlusion consisted of three sets of 8-12 repetitions until failure, with one-minute rest between each series. Each repetition lasted approximately one second in the concentric contraction and one second in the eccentric contraction. Participants positioned exactly the same as the BFR group. The training was performed individually in each arm always starting with the left arm. After the end of the three sets, the exercise in the right arm started. There was a one-minute rest in the transition. The parameters for TRAD training group can be found in Table 1.

Anthropometric measurements

Measurements of body mass, height, arm and forearm circumference, and thickness of skinfold were obtained in order to estimate body fat before and after the intervention period. The body mass obtained using an 100 g anthropometric scale (Welmy®, W300, Santa Barbará d'Oeste, SP, Brazil) and height was verified using a wooden stadiometer with a scale of 0.1 cm.[24] From these measurements, the body mass index (BMI) (kg/m²) was calculated. The arm (AC) and forearm (FC) circumference were taken at the marked level of the mid-acromial-radial level and at the maximum girth of the forearm, respectively.[25] For the circumference measures, the authors used an inextensible metric tape (Mabis®, Gulik model, Japan) on the right body side. Arm muscle circumference (AMC) was calculated according to the formula proposed by Gurney and Jellife[26] (AMC = AC (cm) – [π * tricipital skinfold (cm)]) and adopted as measures of muscle volume. Body composition was determined by the anthropometric method of thickness of the skinfold, verified by CESCORF® compass, in the tricipital, subscapular, supra-iliac and medial leg regions. Body density was determined by the regression equations developed by Petroski[27] and the percentage of fat was calculated by previously proposed equation.[28]

Handgrip strength test

The right (RHGS) and left (LHGS) handgrip strength were determined using a manual dynamometer (Crown®, Filizola, São Paulo, Brazil) with a capacity of 50 kgF, shortly after checking the anthropometric measurements and body composition. Before the test, all participants were instructed on the operation of the equipment and the procedures for carrying out the measurement protocol. Two practice attempts were used for familiarization. For each test, three maximal trials (approximately two seconds each trial) were standardized, with a one-minute recovery interval between each trial. As a standard procedure, the participant was seated in a chair with the elbow flexed to an angle of 90°, tested hand holding the dynamometer and the other hand resting on the thigh.[29] The dynamometer grip adjustment was individualized for the participant so that only the last four distal phalanges exerted strength on the drawbar. From this position, the participant was directed to perform a maximum contraction. Then, the dynamometer was transferred to the other hand, in which the same procedure was adopted. To avoid a fatigue effect,[29] the recorded measure comprised the best trial for each hand, in kgF.

Data Analysis

Statistical analysis was carried out using SPSS program version 25.0 (Chicago, IL, USA), with a significance level of $P < 0.05$. The normality of the data was tested by the Shapiro-Wilk test. Values were presented on mean and standard deviation, for the nonparametric values median and interquartile range [IQR], when necessary. The results on the performance of the handgrip test, pre and post-intervention, were analyzed by ANOVA (mixed of repeated

Table 2. *Age and anthropometric characteristics of participants in BFR and TRAD groups, compared using t test for independent samples; $p < 0.05$*

Variables	All (n=28)	BFR (n=14)	TRAD (n=14)	*p*
Age (years)	20.1±1.4	20.1±1.6	20.2±1.1	0.790
Body mass (kg)	61.4±7.7	60.6±8.6	62.3±6.9	0.583
Height (cm)	162.8±5.3	162.2±6.3	163.4±4.3	0.547
BMI (kg/m²)	23.2±3.2	23.1±3.6	23.3±2.7	0.849
% Fat	24.1±4.2	23.8±4.7	24.4±3.6	0.737

BFR= blood flow restriction training group; TRAD= traditional training group; BMI= body mass index;

measurements) or Student's t-test for dependent and independent samples. The effect size (ES) (mean posttest - pretest mean/pretest and posttest mean standard deviation) was calculated to determine the magnitude of the intervention effects, considering the training groups with restriction to blood flow (BFR) and traditional training (TRAD). The ES was classified as small (0.2 to 0.49), medium (0.5 to ≤0.79) and large (≥0.8).[30] The variation between the variables (circumferences, and handgrip strength) were also calculated ((post – pre/pre) * 100) and expressed as Δ%. The differences in Δ% were compared by the Mann-Whitney U test and the Eta Squared was calculated for effect size between groups and classified as the same as the ES[30]

RESULTS

Two participants (one from each group) were unable to attend the training sessions and were excluded, resulting in a sample of 28 participants (BFR; n = 14 and TRAD; n = 14). The characteristics of the groups are shown in Table 2. There were no significant differences for any of the variables analyzed, showing the homogeneity among groups.

Table 3 presents the results of the anthropometric and performance variables in the MHGS test before and after the conventional training intervention (TRAD) and with blood flow restriction (BFR). The BFR group significantly increased arm circumference, muscle volume and grip strength, as represented by

Table 3. *Development of circumference measurements and hand pressure strength in young women before and after BFR and TRAD*

Groups	Variables	Pre	Post	*p*	ES**
BFR	AC (cm)	26.3±2.8	27.3±2.7	0.029*	0.37
	FC (cm)	23.1±1.2	22.9±1.1	0.466	-0.19
	AMC (cm)	20.6±2.2	21.6±1.7	0.027*	0.46
	RHGS (kgf)	32.7±4.5	34.3±4.1	0.001*	0.37
	LHGS (kgf)	28.0±5.5	30.9±4.1	0.001*	0.60
TRAD	AC (cm)	27.0±2.2	27.1±2.5	0.917	0.04
	FC (cm)	22.7±1.4	22.9±1.3	0.089	0.15
	AMC (cm)	20.9±1.4	20.8±1.6	0.776	0.05
	RHGS (kgf)	30.4±6.0	32.9±5.8	0.087	0.42
	LHGS (kgf)	27.6±5.0	31.0±6.1	0.003*	0.62

BFR= blood flow restriction training group; TRAD= traditional training group; AC= arm circumference; AMC= arm muscle circumference; FC= forearm circumference; RHGS= right handgrip strength; LGHS= left handgrip strength; RMSSD= Root mean square of the successive differences between consecutive RR intervals; ES= effect size.

*statistically significant difference at $p<0.05$.

**The ES magnitude was classified according to Cohen (1988) as: small (≤0.2) moderate (≤0.5) and large (≤0.8). Values presented in mean ± SD; t-test for dependent samples.

the higher AC, AMC and the right (RHGS) and left (LHGS) handgrip strength. These results resulted in an average ES for AC (0.37), AMC (0.46) and RHGS (0.37), also, a large ES for LHGS (0.60).

For the TRAD group there was a significant improvement of strength only for the left hand, with ES that varied from weak to (0.15), and moderate to strong for right hand strength (0.42) and left hand (0.62), respectively. Other variables showed a lower magnitude of effect from the intervention (Table 3).

Table 4 shows the comparison of the change values between BFR and TRAD. The values of AC, RHGS and LHGS were very similar between the groups. However, although not statistically significant (both were approaching statistically significant values), AC and AMC were slightly higher, with a marginal difference ($p = 0.053$; ES = 0.13 and $p = 0.056$; ES = 0.14) for the BFR group.

DISCUSSION

The objective of the present study was to determine the difference between BFR and traditional training on MHGS and anthropometric indicators of muscular volume in young women. The results demonstrated a significant increase of volume in the right arm, and mass grasp strength bilaterally in the BFR group and mass grasp strength only in the left hand for the TRAD group.

Interestingly, the magnitude of the effects of the intervention on handgrip strength was similar in both groups, but with a greater effect on training the left hand than the right hand. In other words, both handgrip strength training (BFR and TRAD) promoted greater effect in the limb with the lower pre-intervention strength level (Table 3).

Table 4. *Comparison of magnitude variation between the training protocols. Values presented in median*

	Δ% BFR	**Δ% TRAD**	***p***	**Eta Squared**
AC (cm)	1.8 [-0.2 – 6.0]	-0.3 [-2.0 – 1.5]	0.053	0.13
FC (cm)	0.2 [-2.5 – 1.8]	1.5 [-0.6 – 2.5]	0.232	0.05
AMC (cm)	2.0 [-0.1 – 8.8]	-0.1 [-2.6 – 2.6]	0.056	0.14
RHGS (kgf)	5.0 [0.0 – 6.8]	5.1 [-2.5 – 15.1]	0.945	<0.01
LHGS (kgf)	8.7 [2.6 – 24.2]	14.9 [5.6 – 20.8]	0.550	0.01

BFR= blood flow restriction training group; TRAD= traditional training group; **Δ%**= Relative variation between pre and post measures. AC= arm circumference, FC= forearm circumference, AMC= arm muscle circumference; RHGS= right handgrip strength, LHGS= left handgrip strength;

The findings of the present study are in accordance with the literature, in which, a similar strength gain between BFR and TRAD has been observed in several populations (e.g, healthy young and middle-aged men; injured adults), even at different intensities.[16,31–34] However, the information about ES suggests that high intensity training is slightly more efficient for strength gain when compared to flow restriction training.[8,35,36] This may be justified by the greater recruitment of motor units in high-intensity training in relation to training in low-intensity blood flow restriction.[37]

The tendency toward a greater AC ($p = 0.053$; ES = 0.13) and AMC ($p = 0.056$; ES = 0.14) delta change in the BFR group compared to the traditional training group can be justified by the adaptations that these fibers suffered. Some studies show that metabolic changes, which occur in the target muscles and near to the occluded part, play an important role in volume and strength gains.[38,39] Additionally, the effect of occlusion in the region distal to the restriction causes a bigger accumulation of metabolic byproducts.[40]

Several mechanisms have been proposed to explain gains in muscle volume and strength from blood flow restriction to muscles. Among the mechanisms, the accumulation of metabolites and reactive oxygen species, the elevation of anabolic hormones (e.g., human growth hormone) and the activation of tracts related to muscle remodeling and angiogenesis have all been suggested.[40–43]

Regarding the significant increase in muscle strength in the non-dominant hand, AC, and AMC, it may be justified by the fact that the BFR is able to generate adaptations in distant limbs or muscles near the occluded part.[44] In addition, greater use of the dominant hand for daily tasks may decrease the effectiveness of resistance training under different contexts because initial strength gains are mostly responses to neural changes and, since the dominant hand is more commonly used (especially for powerful grasping tasks), the increase may be relevant only after the hypertrophy process has occurred.[45] It has been proposed recently that strength gains with BFR would be a consequence of muscle hypertrophy rather than neural adaptations, which is usually associated with traditional training.[46] In this sense, it is worth mentioning that in the present study, the BFR group presented increased strength and AMC (muscle volume), after 12 sessions of dynamic concentric exercises of low to moderate intensity, lasting five minutes per session, which may be important.

The results of the current study revealed an improvement of 5.0% in RHGS and 8.7% in LHGS in the BFR group. In the TRAD group, the increase was of 5.1% for RHGS and 14.9% for LHGS. Research has shown that BFR demonstrates a positive effect on hypertrophy, muscle strength and volume.[47–49] Yasuda et al.[50] demonstrated that six weeks of BFR in the bench press exercise, using 30% 1 RM, increased the triceps strength by 8.3% and the pectoralis major by 8.3%. Nevertheless, in a group with no blood flow restriction (75% 1 RM) there were higher increases in training with low load (BFR), both for the triceps (8.6%) and the pectoralis major (17.6%). In the study by Takarada et al.,[51] using a similar methodology to the present study, the researchers found an increase in muscle strength of elbow flexors of 18.4% for BFR and 22.6% for no vascular occlusion in elderly people. In addition, in another group that trained with 50% of 1 RM (without vascular occlusion), muscle strength increased by 1.4%. Another study that used an intra-subject design (one leg vs. the other) and compared BFR training (>250mmHg) with traditional training (40% of maximal voluntary contraction) found an increase in strength of 9% after two weeks and 26% after four weeks for the occluded leg, while for the non-occluded leg there were no significant gains.[52] Moreover, a recent meta-analysis concluded that the benefits in muscular volume and strength are greater when the low-intensity training is performed in combination with BFR, given that the traditional training requires higher intensities.[53] These results suggest that resistance training of low to moderate intensity, without occlusion, does not alter the magnitude of muscle strength in the same way as BFR.[51,53]

Among the limitations of this study, the relatively short intervention time (30 days or 12 sessions) should be highlighted. However, even with this scenario, there was a significant increase in LHGS in both groups and RHGS in the BFR group. Additionally, the BFR group presented an increase in arm muscle volume. Still as a limitation, the use of a manual dynamometer to perform the exercises restricted the possibility of some direct comparisons with the literature. However, the use of the dynamometer allowed more precision in the prescription and monitoring of the training load. Furthermore, the fact that arm circumference measurements were only verified on the right side limits the possible comparisons between limbs regarding muscle volume gains and their effects on strength gains. Although, several studies evaluating muscle volume/hypertrophy have used only one side to perform the measurements.[49–51] Future research using direct methods to evaluate the muscular volume is needed, as well as studies with different populations. Once that we studied young healthy individuals, our results cannot be applied to injured populations or those with pain.

CONCLUSION

BFR performed with low to moderate intensity loads was more effective in increasing handgrip strength and muscle forearm volume in healthy young women as compared to the traditional training. This study provides evidence that BFR can be an upper extremity muscle strength training tool, is relatively easy to administer, and did not have any adverse effects. More research is needed investigating the use of BFR in rehabilitation and clinical practice of healthcare professionals.

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