

Shear wave elastography of the scalene muscles in healthy adults

A preliminary study

Mohamed A. Bedewi, MD, PhD^{a,*}, Bader Abdullah Alhariqi, MD^a, Nasser M. Aldossary, MD^a, Ayman H. Gaballah, MD^b, Kholoud J. Sandougah, MD^c

Abstract

The aim of the study is to evaluate the reliability of shear wave elastography to assess the anterior and middle scalene muscles in healthy adult subjects.

The study included 60 scalene muscles in 15 healthy subjects. High-resolution ultrasound and shear wave elastography were used to evaluate the anterior scalene and the middle scalene muscles. Stiffness values were measured.

The mean shear elastic modulus showed the following values, right anterior scalene muscle 18.83 ± 5.32 kPa, left anterior scalene muscle 21.71 ± 4.8 kPa, right middle scalene muscle 12.84 ± 5.2 kPa, left middle scalene muscle 19.76 ± 5.30 kPa. Positive correlation was noted between the left middle scalene muscle and body mass index ($P = .004$). No difference in elasticity was noted between the right and left anterior scalene muscles; however, significant difference was noted between the right and left middle scalene muscles ($P = .002$).

The results obtained in our study could be a reference point for future research considering different scalene muscle pathologies.

Abbreviations: BMI = body mass index, SWE = shear wave elastography.

Keywords: elastography, muscle, scalene, shear wave, ultrasound

1. Introduction

The scalene muscles are located lateral to the cervical spine and deep to the sternocleidomastoid muscle.^[1] Anatomical variation is common among the scalene muscles. To assess function of the

scalene muscles, electromyography is usually used, other tools include ultrasonography and magnetic resonance imaging. The anterior and middle scalene muscles connect the first 2 ribs to the vertebrae. Both muscles form the space for passage of the brachial plexus (fissura scalenorum). The middle scalene muscle arises from the transverse processes of the posterior tubercles of C2-C7. It is supplied by the anterior rami of C3-C8. The anterior scalene muscle originates from the transverse processes of the anterior tubercles of C3-C6. It is supplied by the anterior rami of C5 and C6. Both muscles help flexion of the cervical spine and act as accessory muscles of respiration when the cervical spine is stationary. In addition to its importance in surgeries of thoracic outlet syndrome, scalene muscles are important in cases of neck pain.^[1,2] Shear wave elastography (SWE) is an emerging imaging technique that depicts tissue stiffness.^[3] Recent research suggests that combination of ultrasound elastography and conventional ultrasound gives more precise results than ultrasound alone in certain areas.^[4] SWE could assess both pathologic and physiologic behaviors of muscles. This is due to its accuracy, user-friendliness, wide availability, in addition to quantitative results.^[5] In SWE, the transducer induces a pulse, which propagates through soft tissues in a shear manner and presents measurements in kilopascals (kPa, Young modulus). The shear wave velocity correlates positively with the stiffness of the examined tissue, being low in soft tissues and high in stiff tissues. SWE is nowadays used in evaluating liver fibrosis, thyroid diseases, and breast lesions. Its use for muscles, nerves, tendons, and ligaments is also evolving.^[6-12] SWE can be used for quantification of the mechanical properties of muscles in different age groups. SWE can assess various muscular disorders such as muscular dystrophies, Parkinson disease, and spasticity resulting from stroke.^[13]

Establishment of normal reference values for muscle stiffness by a safe noninvasive imaging tool is important for the

Editor: César Calvo Lobo.

All data generated or analyzed during the study are available from the first and corresponding author.

This study was approved the institutional review board of the college of medicine in Prince Sattam Bin Abdulaziz university (PSAU/ COM/RC/IRB/p/70).

Consent was obtained from all study participants.

The authors have no conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

^a Department of Internal Medicine, College of Medicine, Prince Sattam Bin Abdulaziz University, Al-Kharj, Kingdom of Saudi Arabia, ^b Department of Radiology, University of Missouri, Columbia, MO, USA, ^c Department of Medicine, College of Medicine, Al Imam Mohammed Ibn Saud Islamic University, Riyadh, Kingdom of Saudi Arabia.

* Correspondence: Mohamed A. Bedewi, College of Medicine, Prince Sattam bin Abdulaziz University, P.O. Box 173, Al-kharj 11942, Kingdom of Saudi Arabia (e-mail: mohamedbedewi@yahoo.com).

Copyright © 2021 the Author(s). Published by Wolters Kluwer Health, Inc. This is an open access article distributed under the terms of the Creative Commons Attribution-Non Commercial License 4.0 (CCBY-NC), where it is permissible to download, share, remix, transform, and buildup the work provided it is properly cited. The work cannot be used commercially without permission from the journal.

How to cite this article: Bedewi MA, Alhariqi BA, Aldossary NM, Gaballah AH, Sandougah KJ. Shear wave elastography of the scalene muscles in healthy adults: a preliminary study. *Medicine* 2021;100:32(e26891).

Received: 5 February 2021 / Received in final form: 10 July 2021 / Accepted: 19 July 2021

<http://dx.doi.org/10.1097/MD.00000000000026891>

assessment of disease activity, progression, and response to treatment in several pathologies.^[13–16] Among these disorders is the myofascial pain syndrome which is considered one of the most common musculoskeletal conditions.^[17] In addition, assessment of the stiffness of the scalene muscles could have direct impact on the management of cases of tight scalene muscles causing thoracic outlet syndrome.^[18] The aim of the study is to evaluate the reliability of shear wave elastography to assess the anterior and middle scalene muscles in healthy adult subjects.

2. Methods

2.1. Participants

This is a cross-sectional observational study. We recruited normal healthy subjects from the employee of a university hospital. The sample size was estimated to be $n=25$, only 15 of them applied the criteria for reliability. Sixty muscles were evaluated in healthy adult subjects. After institutional review board approval (PSAU/ COM/ RC/IRB/p/69), participants of the study were recruited between March 2020 and May 2020, and written consent was obtained. Inclusion criteria included healthy subjects, males or females (age range 24–26). Exclusion criteria were: history of neck pain, neck surgery, and trauma. For each participant, data including sex, age, weight, BMI, and height were recorded.

2.2. Technique

Ultrasound examinations were performed by an L18–4, M HZ linear-array transducer (EPIQ Elite SW 5.0.1, Ultrasound system: Philips, Bothell). A radiologist (M.A.B, 19 years of experience) performed all examinations. To image the scalene muscles, the subject was placed in a supine position and the ultrasound transducer was placed just lateral to the thyroid lobe. The nerve roots of the brachial plexus were seen as oval hypo-echoic structures between the anterior and middle scalene muscles (Figs. 1 and 2). Each subject was scanned 3 times with the

removal of the transducer from the skin after each measurement. Large amount of gel was used with light touch of the probe to decrease pressure effect on the skin. To increase the reliability of the reported stiffness values, a confidence map was used to mask areas below a specified confidence level. After identifying the scalene muscles, the “elasticity” mode was activated and the probe was held stationary for 5 seconds with a 2 mm diameter region of interest (ROI) circle placed 3 mm away from the upper surface of the muscle. After viewing the color map, real-time shear wave images were recorded with color-coding. The readings consisted of median elasticity (MED), maximum elasticity (MAX), and average elasticity (AVG) and were reported in kPa. The color scale was mapped to a 0kPa to 200 kPa range. The spectrum of scale colors ranges from blue for softer tissues through red for stiffer tissues (Fig. 1).

2.3. Statistical analysis

Statistical analysis was performed using Statistical Package for the Social Sciences (SPSS) version 21 software (SPSS Inc, Chicago, IL). Data were presented as mean \pm standard deviation (SD) and range. A nonparametric test (Mann–Whitney test) was used to assess the difference between mean elasticity of the anterior and middle scalene muscles. The correlations between the mean elasticity bilaterally and age, weight, height, and BMI were calculated by Pearson correlation coefficient test. The sample size was estimated to be 25 prior to the start of the study, but fewer subjects fulfilled the optimal measurement criteria and signed informed consent. A P value $\leq .05$ was considered statistically significant. The intra-observer reliability calculation was analyzed by the 2-way random effect and expressed by the overall intraclass correlation coefficient.

3. Results

The study included 60 muscles in 15 healthy adult subjects, with a mean age of 32.2 ± 6.66 [range 24–46], mean height 158.4 ± 6.49

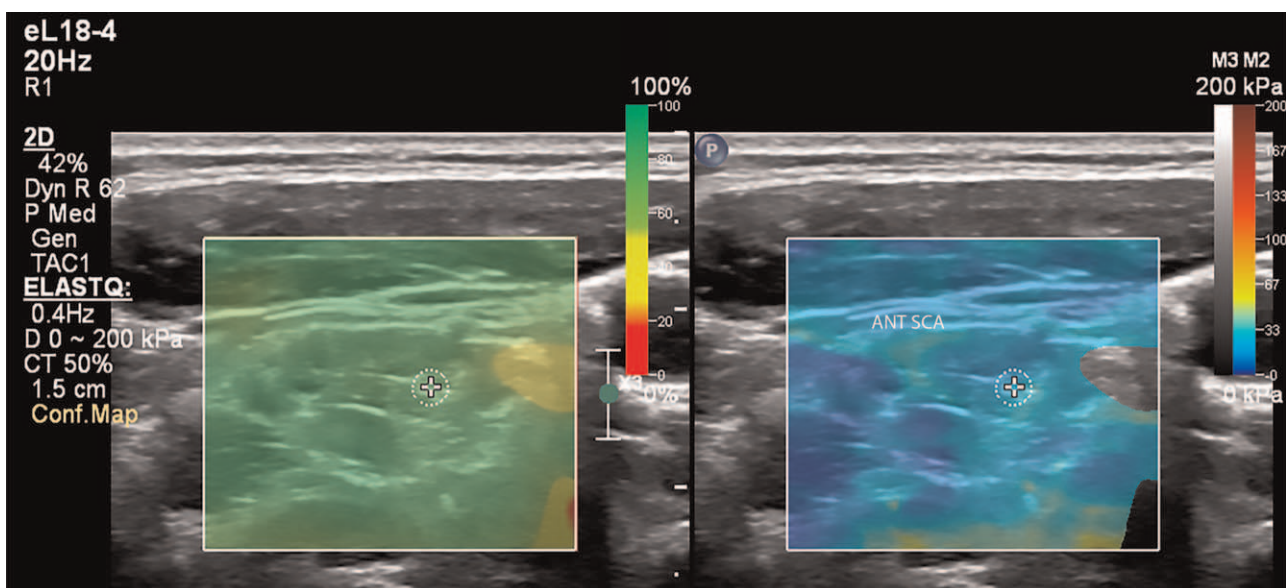


Figure 1. Short-axis view shear wave elastography of the anterior scalene muscle, with confidence map on the left, color map scale on the right, for measurement of stiffness in kPa. ANT SCA = anterior scalene muscle.

Table 1
The demographic characteristics of study participants (mean ± standard deviation).

	(n = 15)	Range
Age (yr)	32.2 ± 6.66	24–46
Weight (kg)	58.43 ± 10.28	44–84
Height (cm)	158.4 ± 6.49	150–169
BMI	23.23 ± 3.30	19–31

BMI = body mass index.

Table 2
Correlations between age, weight, height, and BMI, with CSA, and elastic modulus of the anterior and middle scalene muscles.

	R AS	R MS	R AS	L MS
Age	0.163	−0.253	−0.193	0.427
Sig	0.562	0.362	0.490	0.112
Weight/kg	0.286	−0.171	−0.114	0.441
Sig	0.302	0.541	0.685	0.100
Height/cm	0.099	0.060	0.006	−0.197
Sig	0.726	0.833	0.983	0.481
BMI	0.297	−0.256	−0.148	0.691*
Sig	0.283	0.358	0.600	0.004

AS = anterior scalene muscle, BMI = body mass index, L = left, MS = middle scalene muscle, R = right, Sig = significance.
 * Significance (P = .004).

[range 150–169], mean weight 58.4 ± 10.28 [range 44–84], mean BMI 23.23 ± 3.30 [range 19–31]. The mean shear elastic moduli were as follows: right anterior scalene muscle 18.83 ± 5.32 kPa, left anterior scalene muscle 21.71 ± 4.8 kPa, right middle scalene muscle 12.84 ± 5.2 kPa, left middle scalene muscle 19.76 ± 5.30 kPa. Table 1 shows the demographic characteristics of study participants. Table 2 shows correlation between demographic factors and elasticity of the anterior and middle scalene muscles.

The intra-observer reliability calculations resulted in an overall intra-class correlation coefficient of 0.80. Age, height, and weight showed no correlation with the elasticity of both muscles. Positive correlation was noted between the left middle scalene muscle and BMI (P = .004). No difference in elasticity was noted between the right and left anterior scalene muscles; however, significant difference was noted between the right and left middle scalene muscles (P = .002).

4. Discussion

We studied the anterior and middle scalene muscles in healthy adult subjects by SWE. The relationship between elasticity and height, weight, body mass index, gender were also studied. Numerous studies were conducted using SWE for different muscles in healthy subjects, and some muscle pathologies. These studies revealed informative but heterogeneous results.¹⁷ The mean stiffness of the scalene muscles in our study was as follows: right anterior scalene muscle 18.83 ± 5.32 kPa, left anterior scalene muscle 21.71 ± 4.8 kPa, right middle scalene muscle 12.84 ± 5.2 kPa, left middle scalene muscle 19.76 ± 5.30 kPa. Kuo et al studied neck muscles in 20 healthy adult volunteers by SWE. The mean and standard deviation were as follows: The scalene anterior (1.12 ± 0.17 m/s), trapezius (2.09 ± 0.45 m/s), levator scapulae (1.21 ± 0.30 m/s), sternocleidomastoid (0.97 ± 0.10 m/s).¹⁴ Dieterich et al measured the average stiffness of some extensor neck muscle (semispinalis capitis, splenius capitis, trapezius, semispinalis cervicis, and multifidus). The stiffness in different locations ranged from 8.6 to 13.3 kPa. Interestingly, this study revealed similar stiffness between people with and without chronic neck pain despite sensation of increased sensation of stiffness in those people with neck pain.¹⁹ Herman et al studied the SWE of the normal soft tissues of the neck. He revealed a mean stiffness of the masseter to be 10.0 ± 4.3 kPa, and for the sternocleidomastoid muscle to be 11.0 ± 3.4 kPa.²⁰ Arda et al reported the mean stiffness of the masseter muscle to be 10.4 ± 3.7 kPa. He also reported higher values for the gastrocnemius muscle (11.1 ± 4.1 kPa) and for the supraspinatus muscle (31. ±

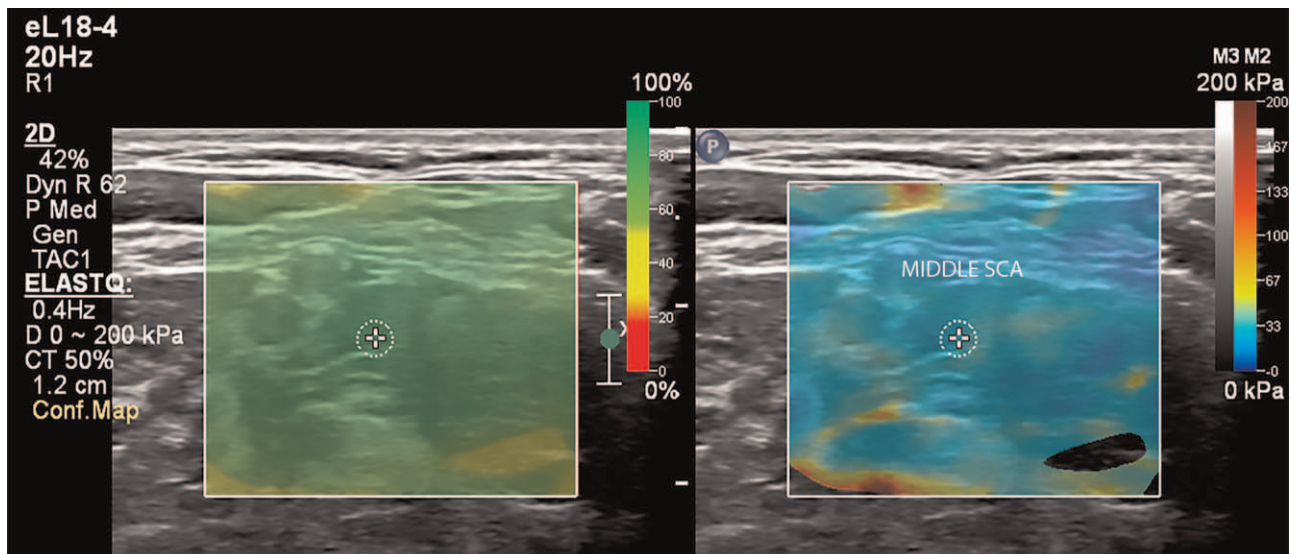


Figure 2. Short-axis view shear wave elastography of the middle scalene muscle, with confidence map on the left, color map scale on the right, for measurement of stiffness in kPa. MIDDLE SCA = middle scalene muscle.

13 kPa).^[21] In comparison with the published research for the neck musculature, our results are comparatively higher, except for the right middle scalene muscle. This could be attributed to the use of different ultrasound systems. Another reason could be the use of meter/second as a parameter for stiffness measurement instead of kPa which could yield difference in results. Understanding practice guidelines is important to enhance reproducibility. There is diversity in the elasticity measurements of various muscles between different studies ranging in the resting state between 3.1 kPa and 42.8.^[21] Several factors could contribute to these differences. First, the arrangement of various components of fibrils, muscular fibers, collagen fibers and elastic fibers. As a result, the stiffness in complex multiorientation fibers is therefore considered a difficult task.^[22] Second, measurement with different limb positions and postures yields different elasticity measurements.^[23,24] Third, muscle state at the time of examination whether it is in the “resting state” or “contracted” is also important.^[25] Fourth, due to the anisotropic nature of orientation muscle fibers, the angle between the transducer axis and the muscle fibers is sensitive in determining the shear wave velocity.^[26] This study has several limitations. First, the sample size was small, with only 15 subjects fulfilling the criteria for optimal elastographic measurements. This could limit the reliability and statistical significance of our results. Second, is lack of comparison to pathological tissues. Future studies should be conducted with larger sample size, with a variety of pathological conditions. In conclusion, the results obtained in our study could be a reference point for future research considering different scalene muscle pathologies.

Acknowledgments

The authors are grateful to the deanship of scientific research at Prince Sattam bin Abdulaziz University.

Author contributions

Conceptualization: Mohamed Abdelmohsen Bedewi, Ayman H Gaballah.

Data curation: Mohamed Abdelmohsen Bedewi.

Formal analysis: Mohamed Abdelmohsen Bedewi.

Funding acquisition: Mohamed Abdelmohsen Bedewi.

Investigation: Mohamed Abdelmohsen Bedewi.

Methodology: Mohamed Abdelmohsen Bedewi.

Project administration: Mohamed Abdelmohsen Bedewi, Kholoud J Sandougah.

Resources: Mohamed Abdelmohsen Bedewi, Kholoud J Sandougah.

Supervision: Mohamed Abdelmohsen Bedewi, Bader Abdullah Alhariqi, Nasser M Aldossary.

Validation: Mohamed Abdelmohsen Bedewi, Ayman H Gaballah.

Visualization: Mohamed Abdelmohsen Bedewi.

Writing – original draft: Mohamed Abdelmohsen Bedewi.

Writing – review & editing: Mohamed Abdelmohsen Bedewi.

References

- Bordoni B, Varacallo M. *Anatomy, Head and Neck, Scalenus Muscle*. Treasure Island (FL): StatPearls Publishing; 2020.
- Georgakopoulos B, Lasrado S. *Anatomy, Head and Neck, Inter-scalene Triangle*. Treasure Island (FL): StatPearls Publishing; 2020.
- Koppenhaver S, Kniss J, Lilley D, et al. Reliability of ultrasound shear-wave elastography in assessing low back musculature elasticity in asymptomatic individuals. *J Electromyogr Kinesiol* 2018;39:49–57.
- Herman J, Hermanová Z, Salzman R, Vomáčka J, Stárek I. [Ultrasound elastography and its use in the head and neck imaging]. *Cas Lek Cesk* 2015;154:222–6.
- Klauser AS, Miyamoto H, Bellmann-Weiler R, Feuchtner GM, Wick MC, Jaschke WR. Sonoelastography: musculoskeletal applications. *Radiology* 2014;272:622–33.
- Creze M, Nordez A, Soubeyrand M, Rocher L, Maître X, Bellin MF. Shear wave sonoelastography of skeletal muscle: basic principles, biomechanical concepts, clinical applications, and future perspectives. *Skelet Radiol* 2018;47:457–71.
- Ryu JA, Jeong WK. Current status of musculoskeletal application of shear wave elastography. *Ultrasonography* 2017;36:185–97.
- Taljanovic MS, Gimber LH, Becker GW, et al. Shear-wave elastography: basic physics and musculoskeletal applications. *Radiographics* 2017;37:855–70.
- Winn N, Lalam R, Cassar-Pullicino V. Sonoelastography in the musculoskeletal system: current role and future directions. *World J Radiol* 2016;8:868–79.
- Davis LC, Baumer TG, Bey MJ, Holsbeek MV. Clinical utilization of shear wave elastography in the musculoskeletal system. *Ultrasonography* 2019;38:2–12.
- Paluch E, Nawrocka-Laskus E, Wiczorek J, Mruk B, Frel M, Walecki J. Use of ultrasound elastography in the assessment of the musculoskeletal system. *Pol J Radiol* 2016;81:240–6.
- Hobson-Webb LD. Emerging technologies in neuromuscular ultrasound. *Muscle Nerve* 2020;61:719–25.
- Phan A, Lee J, Gao J. Ultrasound shear wave elastography in assessment of skeletal muscle stiffness in senior volunteers. *Clin Imaging* 2019;58:22–6.
- Kuo WH, Jian DW, Wang TG, Wang YC. Neck muscle stiffness quantified by sonoelastography is correlated with body mass index and chronic neck pain symptoms. *Ultrasound Med Biol* 2013;39:1356–61.
- Chang PH, Chen YJ, Chang KV, Wu WT, Özçakar L. Ultrasound measurements of superficial and deep masticatory muscles in various postures: reliability and influencers. *Sci Rep* 2020;10:14357.
- Chiu YH, Chang KV, Chen IJ, Wu WT, Özçakar L. Utility of sonoelastography for the evaluation of rotator cuff tendon and pertinent disorders: a systematic review and meta-analysis. *Eur Radiol* 2020;30:6663–72.
- Calvo-Lobo C, Diez-Vega I, Martínez-Pascual B, et al. Tensiomyography, sonoelastography, and mechanosensitivity differences between active, latent, and control low back myofascial trigger points: a cross-sectional study. *Medicine (Baltimore)* 2017;96:e6287.
- Sell JJ, Rael JR, Orrison WW. Rotational vertebral insufficiency as a component of thoracic outlet syndrome resulting in transient blindness. *Case report. J Neurosurg* 1994;81:617–9.
- Dieterich AV, Yavuz UŞ, Petzke F, Nordez A, Falla D. Neck muscle stiffness measured with shear wave elastography in women with chronic nonspecific neck pain. *J Orthop Sports Phys Ther* 2020;50:179–88.
- Herman J, Sedlackova Z, Vachutka J, Furst T, Salzman R, Vomacka J. Shear wave elastography parameters of normal soft tissues of the neck. *Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub* 2017;161:320–5.
- Arda K, Ciledag N, Aktas E, Aribas BK, Köse K. Quantitative assessment of normal soft-tissue elasticity using shear-wave ultrasound elastography. *AJR Am J Roentgenol* 2011;197:532–6.
- Lv F, Tang J, Luo Y, et al. Muscle crush injury of extremity: quantitative elastography with supersonic shear imaging. *Ultrasound Med Biol* 2012;38:795–802.
- Eby S, Zhao H, Song P, et al. Quantitative evaluation of passive muscle stiffness in chronic stroke. *Am J Phys Med Rehabil* 2016;95:899–910.
- Gao J, He W, Du LJ, et al. Quantitative ultrasound imaging to assess biceps brachii muscle in chronic post-stroke spasticity: preliminary observation. *Ultrasound Med Biol* 2018;44:1931–40.
- Shinohara M, Sabra K, Gennissou JL, Fink M, Tanter M. Real-time visualization of muscle stiffness distribution with ultrasound shear wave imaging during muscle contraction. *Muscle Nerve* 2010;42:438–41.
- Wang M, Byram B, Palmeri M, Rouze N, Nightingale K. Imaging transverse isotropic properties of muscle by monitoring acoustic radiation force induced shear waves using a 2-D matrix ultrasound array. *IEEE Trans Med Imaging* 2013;32:1671–84.