Interlibrary Loans and Journal Article Requests

Notice Warning Concerning Copyright Restrictions:

The copyright law of the United States (Title 17, United States Code) governs the making of photocopies or other reproductions of copyrighted materials.

Under certain conditions specified in the law, libraries and archives are authorized to furnish a photocopy or other reproduction. One specified condition is that the photocopy or reproduction is not to be *"used for any purpose other than private study, scholarship, or research."* If a user makes a request for, or later uses, a photocopy or reproduction for purposes in excess of "fair use," that user may be liable for copyright infringement.

Upon receipt of this reproduction of the publication you have requested, you understand that the publication may be protected by copyright law. You also understand that you are expected to comply with copyright law and to limit your use to one for private study, scholarship, or research and not to systematically reproduce or in any way make available multiple copies of the publication.

The Stephen B. Thacker CDC Library reserves the right to refuse to accept a copying order if, in its judgment, fulfillment of the order would involve violation of copyright law.

Terms and Conditions for items sent by e-mail:

The contents of the attached document may be protected by copyright law. The CDC copyright policy outlines the responsibilities and guidance related to the reproduction of copyrighted materials at CDC. If the document is protected by copyright law, the following restrictions apply:

- You may print only one paper copy, from which you may not make further copies, except as maybe allowed by law.
- You may not make further electronic copies or convert the file into any other format.
- You may not cut and paste or otherwise alter the text.

Pinch force and forearm-muscle load during routine colonoscopy: a pilot study

Amandeep K. Shergill, MD, Krishna R. Asundi, PhD, Alan Barr, MS, Janak N. Shah, MD, James C. Ryan, MD, Kenneth R. McQuaid, MD, David Rempel, MD, MPH

San Francisco, California, USA

Background and Objective: Overuse injuries of the hand, wrist, forearm, and shoulder are common among endoscopists and may be from repetitive pinching and gripping forces or awkward posturing. In this pilot study, we evaluated distal upper-extremity musculoskeletal load during colonoscopy (1) to confirm the feasibility of performing ergonomic measurements in endoscopists and (2) to identify tasks that may contribute to overuse injuries.

Design and Subjects: Three experienced gastroenterologists were evaluated during 3 colonoscopies each.

Setting: Veterans Affairs Medical Center, San Francisco, California.

Main Outcome Measurement: Right-thumb pinch force using a thumb-force sensor and bilateral forearm-muscle activity using electromyography.

Results: The mean duration of the 9 colonoscopies was 19.5 minutes. The highest mean (SD) right-thumb peak pinch forces occurred during left (10.4 [4.1] N) and right (10.1 [4.5] N) colon insertion, which exceeded the injury threshold of 10 N. Mean peak forearm-muscle activity was also greatest during left and right colon insertion. Activity of the left abductor pollicis longus, left extensor carpi radialis, and right extensor carpi radialis exceeded the American Conference of Industrial Hygienists (ACGIH) hand activity level (HAL) action limit. The left extensor carpi radialis was at the ACGIH HAL threshold limit.

Limitations: The small sample size, no force measurement for the left thumb, and all the gastroenterologists were men.

Conclusion: The pinch forces and forearm-muscle loads applied during routine colonoscopy may pose a risk for overuse injuries at the elbow and wrist.

Almost 60% of endoscopists surveyed have suffered some musculoskeletal complaint related to endoscopy, and a higher endoscopy volume is associated with a higher likelihood of overuse injuries, such as wrist tendinopathies, epicondylitis, carpal tunnel syndrome, and shoulder or cervical muscle strains.[1] These injuries may present as hand numbness or as pain in the hand, wrist, elbow, neck, or back, and are related to high-force pinching or rapid forceful gripping motions, direct pressure, and prolonged, awkward postures.[1-4] Endoscopy involves repeated pinching or gripping of the endoscope and can involve awkward hand, wrist, elbow, shoulder, and neck postures, all of which may be risk factors for overuse injuries.[4,5]

The aim of this pilot study was to evaluate the pinch force and forearm-muscle activity among experienced gastroenterologists during routine endoscopy to (1) confirm the feasibility of performing ergonomic measurements in endoscopists and (2) to identify the tasks that may contribute to the risk for overuse injuries. Our long-term goals are to identify modifications in endoscopic techniques and endoscope design that can decrease risk factors and prevent overuse injuries among endoscopists.

Abbreviations: ACGIH, American Conference of Industrial Hygienists; APDF, amplitude probability distribution function; APL, abductor pollicis longus; ECR, extensor carpi radialis; EMG, electromyography; FDS, flexor digitorum superficialis; HAL, hand activity level; HAL-TLV, hand activity level threshold limit value; MVC, maximum voluntary contraction; MVE, maximum voluntary electrical activity.

DISCLOSURE: *The authors report that there are no disclosures relevant to this publication.*

0016-5107/$36.00
doi:10.1016/j.gie.2008.09.030

MATERIALS AND METHODS

Population

Three experienced endoscopists (>5 years of practice) from the San Francisco Veterans Affairs Medical Center

participated. The endoscopists, as well as the patients undergoing colonoscopy, provided informed consent, approved by the investigational review boards of the University of California, San Francisco, and the San Francisco Veterans Affairs Medical Center.

Outcome measures

Right-thumb force. The right-thumb pinch force was recorded by using a tactile pad (10 × 30 × 1 mm) (Pressure Profile Systems, Los Angeles, Calif) that was placed on the volar aspect of the distal phalanx of the right thumb and secured with a latex thumb glove. The thumb pad was calibrated by pressing down on the colonoscope insertion tube with the instrumented thumb, while the downward force was measured with a 6-axis load cell (error range ±0.1 N; ATI Industrial Automation, Apex, NC). During colonoscopy, thumb-force data from the pad were collected at 100 Hz and were recorded to a personal computer by using Labview Software version 6.0 (National Instruments, Austin, Tex).

Right-forearm and left-forearm activity. Muscle activity was recorded in the forearm from 5 muscle groups by using surface electromyography (EMG): the right and left extensor carpi radialis (ECR), the right and left flexor digitorum superficialis (FDS), and the left abductor pollicis longus (APL). Self-adhesive silver/silver chloride snap electrodes (active diameter of 10 mm and a center-to-center distance of 20 mm) were placed by using recommended anatomical landmarks,[6] and a ground electrode was placed over the lateral epicondyle. EMG activity from the 5 muscle groups was sampled at 1500 Hz by using a TeleMyo 2400T telemetric EMG system (Noraxon USA Inc, Scottsdale, Ariz). The EMG data was normalized to the maximum voluntary electrical activity (MVE) obtained by having the endoscopist perform a 5-second isometric maximum voluntary contraction (MVC) for each muscle.

Procedures

Each gastroenterologist performed 3 colonoscopies while under observation by another colleague. The left colon (rectum to the splenic flexure) and the right colon (splenic flexure to the cecum) insertion times and withdrawal times (excluding retroflexion) were recorded.

Data analysis

Thumb-force data were passed through a sixth order low-pass Butterworth filter with a 5 Hz cutoff frequency. Forearm EMG signals were rectified by using a root mean square conversion with a 50-ms time window. A 1-second moving average was used to smooth MVE data. EMG activity for each muscle was normalized to each endoscopist's MVC for the 5 muscle groups. Summary measures of the right-thumb force and the right and left forearm EMG data were calculated for left and right colon insertion and withdrawal. Both force and EMG data are reported as amplitude probability distribution functions (APDF) to reduce noise.[7]

Our results focus on the mean peak thumb pinch forces and forearm EMG activity, because these are most predictive of an overuse injury. APDF90 is a summary measure of mean peak force, ie, 90% of recorded data are below this value, and 10% are above. An APDF90 threshold of 10 N was used to evaluate the risk of right-thumb injury.[8,9] Threshold values for mean peak forearm-muscle activity were established by the American Conference of Industrial Hygienists (ACGIH) hand activity level threshold limit value (HAL-TLV).[10]

All data are presented as mean (SD). Summary measurements were compared between colonoscopy phases by using repeated measures analysis of variance (SAS v8; SAS Institute Inc, Cary, NC) and were adjusted for multiple comparisons per hand (2 muscles right hand, 3 muscles left hand) by using a Bonferroni correction. Significant findings were followed up with the Tukey test to adjust for multiple comparisons. A $P < .05$ was considered significant.

Capsule Summary

What is already known on this topic

- Overuse injuries of the hand, wrist, forearm, and shoulder are common among endoscopists and may be because of repetitive pinching and gripping or awkward posturing.

What this study adds to our knowledge

- Measurement of right-thumb pinch force and bilateral forearm-muscle activity as 3 endoscopists each completed 3 routine colonoscopies revealed that the procedure may lead to overuse injuries at the elbow and the wrist.

RESULTS

All the endoscopists were men, mean (SD) age 44.7 ± 8.4 years, with a mean (SD) of 12 ± 8.0 years of experience. Their mean height was 175 ± 12 cm and weight was 79.4 ± 14.2 kg. Endoscopist no. 1 is left handed; endoscopist nos. 2 and 3 are right handed. All endoscopists held and manipulated the control dials with the left hand and inserted and guided the insertion of the colonoscope with the right hand. A variable stiffness colonoscope (CFQ-180; Olympus America, Center Valley, Pa) was used for all colonoscopies.

The mean (SD) duration of the 9 colonoscopies was 19.5 ± 6.5 minutes. The mean (SD) times for the 3 phases of colonoscopy, left colon insertion, right colon insertion, and withdrawal were as follows: 3.7 ± 1.3 minutes, 3.8 ± 2.2 minutes, and 11.5 ± 3.3 minutes, respectively.

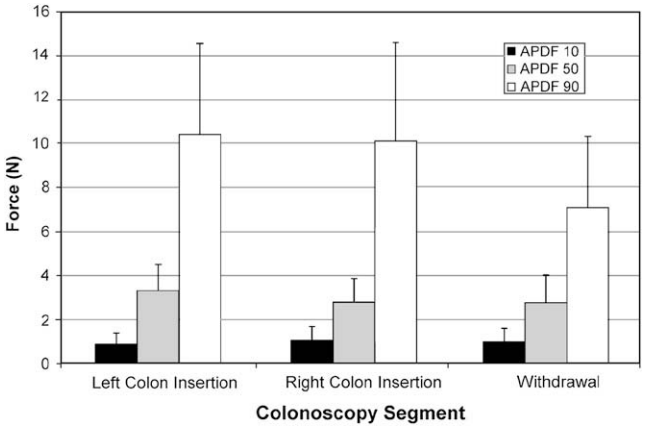

Figure 1. Summary measurements of right-thumb pinch forces during each segment of colonoscopy, represented as APDF in newtons. Illustrated are the mean static (APDF10), median (APDF50), and peak (APDF90) pinch forces. No significant differences were found among colonoscopy segments.

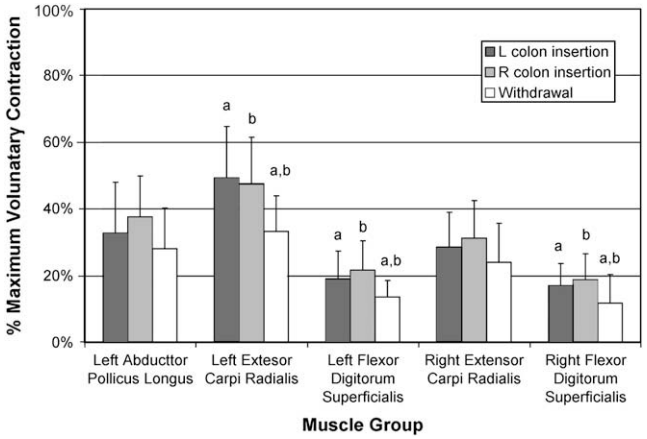

Figure 2. Summary measures of mean peak (APDF90) forearm EMG measurements, as the percentage of maximum voluntary contraction (strength) for 3 colonoscopy segments: left colon insertion, right colon insertion, and withdrawal. Common *superscripts* identify significant differences on the Tukey follow-up test.

Endoscopist no. 1 described the first colonoscopy as ''insertion to the cecum without difficulty'' but described the second and third colonoscopies as ''insertion to the cecum with a moderate amount of difficulty.'' Endoscopist nos. 2 and 3 described all 3 colonoscopies as ''insertion to the cecum without difficulty.'' A mean of 1.6 (range 0-3) small polyps were found per examination and were removed with excisional biopsies. Because only surface EMG was used (as opposed to intramuscular EMG), no pain was experienced by the endoscopists during the study.

The mean peak (SD) (APDF90) right-thumb pinch forces measured during left colon and right colon insertion were 10.4 ± 4.1 N and 10.1 ± 4.5 N, respectively (Fig. 1). The differences between colonoscopy segments were not significant ($P = .29$). The mean percentage of maximum right-thumb pinch force that was reached for each endoscopist was 46%, 32%, and 18.5% during left colon insertion, and 35%, 42%, and 16% during right colon insertion.

The right forearm-muscle EMG activity levels demonstrated the highest muscle loads during insertion. The right FDS APDF90 was significantly higher for both left colon and right colon insertion than during withdrawal (repeated measures $P = 002$; Tukey pairwise comparisons in Fig. 2); however, these APDF90 levels were below the ACGIH HAL-TLV action limit of 30% MVC during all segments of colonoscopy. In contrast, the APDF90 of the right ECR was 31% MVC during right colon insertion, which exceeds the ACGIH HAL-TLV action limit. No significant differences between segments were detected (repeated measures $P = .096$; Fig. 2).

A similar pattern was observed for the left forearm. Mean peak left ECR activity was 49% and 48% of MVC during left and right colon insertion, respectively; these values approach the ACGIH HAL-TLV threshold limit of 50% of MVC. Both were significantly higher than muscle activity during withdrawal (repeated measures $P < .001$; Tukey pairwise comparisons in Fig. 2). Similarly, the left FDS APDF90 was significantly higher during both left colon and right colon insertion than withdrawal (repeated measures $P < .0001$; Tukey pairwise comparisons in Fig. 2); however, the APDF90 for all segments of colonoscopy was less than the ACGIH HAL-TLV action limit of 30% MVC. The APDF90 of the left APL EMG was 33% of MVC during left colon insertion and 38% of MVC during right colon insertion, which are both greater than the ACGHI HAL-TLV action limit of 30% MVC. There were no differences between colonoscopy segments in the left APL APDF90 ($P = .93$).

DISCUSSION

This is the first study, to our knowledge, to estimate hand forces and muscle loads among endoscopists performing colonoscopy. We found that mean peak pinch forces of the right thumb were greatest during insertion of the colonoscope into the left and right colon. For evaluation of the right-thumb mean peak pinch forces, we used a threshold value of 10 N, a threshold that, when repeatedly exceeded, is associated with increased risk of musculoskeletal injury of the thumb and wrist.[8,9] Our pilot study demonstrated that the right-thumb mean peak pinch forces during colonoscopy can exceed this 10 N threshold. This high force value may be from the torque applied during insertion or the force required to reduce or overcome loops in the colonoscope while attempting to reach the cecum.

For both hands, the highest forces for forearm-muscle activity also occurred during insertion. We evaluated forearm-muscle activity by using the ACGIH HAL-TLV,[10] a tool that uses mean peak force values and HAL to estimate

TABLE 1. Muscle groups examined and potential injuries

Muscle	Action	Subtask during colonoscopy	Potential injury	Study results: At or exceeds ACGIH HAL-TLV action limit*	Study results: At or exceeds ACGIH HAL-TLV threshold limit†
Left APL	Abduction and extension of thumb	Manipulating dials of colonoscope	DeQuervain's tenosynovitis	Yes	No
Left ECR	Wrist extension and abduction	Stabilizing control section of colonoscope	Second and third extensor compartment tenosynovitis at the wrist and epicondylitis (tennis elbow)	Yes	Yes
Left FDS	Flexion of the digits of the hand	Grasping control section of colonoscope	Carpal tunnel syndrome	No	No
Right ECR	Wrist extension and abduction	Torquing colonoscope insertion tube	Second and third extensor compartment tenosynovitis at the wrist and epicondylitis (tennis elbow)	Yes	No
Right FDS	Flexion of the digits of the hand	Grasping colonoscope insertion tube	Carpal tunnel syndrome	No	No

*Action limit, HAL: for colonoscopy, defined as APDF $\geq$30% maximum voluntary contraction; if forces exceed the action limit, then the task should be modified to reduce the risk of repetitive strain injury.
†Threshold limit, HAL: for colonoscopy, defined as APDF $\geq$50% maximum voluntary contraction; if forces exceed the threshold limit, then the task should be changed, given the high risk of repetitive strain injury.

the risk of musculoskeletal disorders related to jobs that are performed for 4 or more hours daily. The ACGIH-HAL describes the HAL or rate of hand motion with a scale of 0 to 10; it also uses APDF90 normalized to the strength of the individual subject's muscle group that is being evaluated (maximum voluntary contraction). The ACGIH recommends interventions for jobs that exceed specified action limits and threshold limits. Colonoscopy falls into a HAL of 4, ie, hand activity that is slow, with steady motion or exertions, but with frequent brief pauses. For a HAL of 4, the action limit is an APDF90 level of >30% of MVC. In our study, this action limit is exceeded by the left APL, as well as the right and left ECR. The ACGIH recommends that intervention with surveillance and general controls be initiated for activities that exceed the action limit. The threshold limit is an APDF90 >50% or more of MVC. In our study, this threshold limit is approached by the left ECR. The ACGIH recommends that jobs that exceed the threshold limit should be modified to reduce the applied hand force, given the high risk of injury.[10] The study findings by muscle group and the risk of injury as determined by the HAL-TLV are summarized in Table 1. The muscle groups and potential injuries are illustrated in Figure 3.

This pilot study demonstrated that the pinch forces and forearm-muscle activity applied during colonoscopy can be quantified and may pose a risk for overuse injuries at the elbow and the wrist. Because high hand forces in combination with awkward wrist postures are applied during colonoscopy, it will be useful in future studies to evaluate their combined effects upon the risk of musculoskeletal injury. Given the increasing demand for colonoscopies in the United States and their attendant risk of long-term disability for endoscopists, the ergonomics of colonoscopy is an important issue that merits further study.

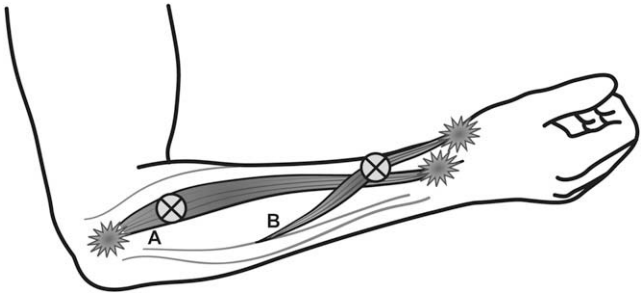

Figure 3. The site of injury (*) and the site of electrode placement (⊗). Extensor carpi radialis (*A*)(injury: lateral epicondylitis, second and third compartment tenosynovitis). Abductor pollicis longus (*B*) (injury: DeQuervain's tenosynovitis).

REFERENCES

1. Buschbacher R. Overuse syndromes among endoscopists. Endoscopy 1994;26:539-44.
2. Liberman AS, Shrier I, Gordon PH. Injuries sustained by colorectal surgeons performing colonoscopy. Surg Endosc 2005;19:1606-9.

3. Cappell MS. Colonoscopist's thumb: DeQuervains's syndrome (tenosynovitis of the left thumb) associated with overuse during endoscopy. Gastrointest Endosc 2006;64:841-3.
4. Rempel DM, Harrison RJ, Barnhart S. Work-related cumulative trauma disorders of the upper extremity. JAMA 1992;267:838-42.
5. van Tulder M, Malmivaara A, Koes B. Repetitive strain injury. Lancet 2007;369:1815-22.
6. Perotto AE. Anatomical guide for the electromyographer. 4th ed. Springfield (Ill): Charles C. Thomas; 2005.
7. Jonsson B. Quantitative electromyographic evaluation of muscular load during work. Scand J Rehabil Med Suppl 1978;6:69-74.
8. Roquelaure Y, Mechali S, Dano C, et al. Occupational and personal risk factors for carpal tunnel syndrome in industrial workers. Scand J Work Environ Health 1997;23:364-9.
9. Silverstein BA, Fine LJ, Armstrong TJ. Hand wrist cumulative trauma disorders in industry. Br J Ind Med 1986;43:779-84.
10. American Conference of Governmental Industrial Hygienists (ACGIH). ACGIH 2008 TLVs and BEIs, based on the documentation of the threshold limit values for chemical substances and physical agents. Cincinnati: ACGIH; 2008. p. 189.

Received February 6, 2008. Accepted September 18, 2008.

Current affiliations: San Francisco Veterans Affairs Medical Center (A.K.S., J.N.S., J.C.R., K.R.M.), San Francisco, California, Department of Medicine, Division of Gastroenterology (A.K.S., J.N.S., J.C.R., K.R.M.), University of California San Francisco, San Francisco, California, Department of Medicine, Division of Occupational Medicine (A.B., D.R.), University of California San Francisco, San Francisco, California, Department of Bioengineering (A.B., D.R.), University of California Berkeley, Berkeley, California, Department of Environmental Health (K.R.A.), Harvard School of Public Health, Boston, Massachusetts, USA.

Presented at Digestive Disease Week, May 20-23, 2007 Washington, DC (Gastrointest Endosc 2007;65:AB315).

Reprint requests: Amandeep Shergill, MD, UCSF, Division of Gastroenterology, VA Medical Center, 4150 Clement St, Bldg 203 (111B1), San Francisco, CA 94121.

If you want to chat with an author of this article, you may contact him at amandeep.shergill@ucsf.edu.