OPEN

PRS GLOBAL OPEN

ORIGINAL ARTICLE

Hand

A1 Pulley Tenderness as a Modification to Tenderness along the Flexor Sheath in Diagnosing Pyogenic Flexor Tenosynovitis

Robert C. Siska, MD*
Amelia L. Davidson, BS†
Cassandra R. Driscoll, MD*
Donald T. Browne, MD*
Jacob C. Maus, MD*
Shamit S. Prabhu, MS†
Megan A. Rudolph, MD*
Michael A. Schneider, MD‡
Christopher M. Runyan, MD*
Michael Reynolds, MD*

Background: Pyogenic flexor tenosynovitis (PFT) is frequently diagnosed by physical examination according to the Kanavel signs. This study proposes a modification of the Kanavel sign "tenderness over the course of the flexor sheath" by including palpation of the A1 pulley to increase specificity for diagnosis.

Methods: A retrospective review was performed over 8 months for patients in the emergency department who received a consult to hand surgery to rule out PFT. Two cohorts, nonPFT infections and PFT infections, were studied for the presence or absence of the four Kanavel signs, as well as tenderness specifically over the A1 pulley on the affected digit(s) or T1 pulley of the thumb.

Results: There were a total of 33 patients in the two cohorts (21 nonPFT, 12 PFT) with statistically significant differences with regard to the presence of all the Kanavel signs. A1 pulley tenderness had the greatest odds ratio, positive predictive value, specificity, and accuracy when compared with all Kanavel signs. When used in conjunction with each Kanavel sign, there was an increase in specificity in all four signs. Receiver operating characteristic analysis revealed increased area under the curve with A1 pulley tenderness added, indicating improved ability to classify hand infections as PFT versus nonPFT.

Conclusion: Although the classic Kanavel signs have shown reliable clinical utility, this study finds that tenderness at the A1 pulley can be a useful specification of "tenderness over the course of the flexor sheath" to help with the diagnosis of PFT.
(Plast Reconstr Surg Glob Open 2022;10:e4165; doi: 10.1097/GOX.0000000000004165; Published online 2 March 2022.)

INTRODUCTION

Pyogenic flexor tenosynovitis (PFT), an infection of the flexor tendon sheath, has an estimated prevalence of 2.5%–9.4% of all hand infections.[1,2] Because delayed intervention can result in tendon damage, necrosis, and worsening infection that can lead to severe motion deformities or amputations, emergency medicine and primary care physicians frequently consult hand surgeons out of concern for this diagnosis.[3] Although early infections can be treated with antibiotics, PFT often requires surgical intervention with incision and drainage of the tendon sheath in the operating room.[4]

Inflammation and swelling in the sheath can be seen on MRI and ultrasound imaging, but PFT remains a clinical diagnosis that is classically described and characterized by the presence of Kanavel signs.[5,6] In his 1912 publication, Dr. Allen B. Kanavel described the following three clinical signs as manifestations of PFT: "exquisite tenderness over the course of the tendon sheath; a resting flexion posture of the finger; and pain with passive extension of the finger."[5,7] Kanavel also mentioned uniform swelling of digits with PFT, which is now accepted as the fourth Kanavel sign in contemporary writings and clinical practice.[5,8]

The four Kanavel signs are the most widely used testing criteria for PFT, but numerous studies have found significant variations in the presence and absence of Kanavel signs.[9,10] Dailiana et al reported that only 54% of patients with PFT presented with all four signs, but all patients had flexor sheath tenderness and pain with passive extension.[9] In contrast, Pang et al concluded that

*From the *Department of Plastic and Reconstructive Surgery, Atrium Health Wake Forest Baptist, Winston-Salem, N.C.; †Wake Forest University School of Medicine, Winston-Salem, N.C.; and ‡Department of Emergency Medicine, Advent Hospital System, Daytona Beach, Fla.*

Received for publication December 14, 2021; accepted January 4, 2022.

DOI: 10.1097/GOX.0000000000004165

Disclosure: *The authors have no financial interest to declare in relation to the content of this article.*

uniform swelling was the most commonly observed sign, present in 97% of patients with PFT, with only 72% of Pang's patients having pain with passive extension, 69% having resting flexion, and 64% having tenderness along the flexor sheath.[10] Kennedy et al calculated sensitivities, specificities, and positive predictive value (PPV) for the Kanavel signs and determined an 88% PPV for flexor tenosynovitis if the patient exhibited the following: (1) tenderness of the flexor sheath, (2) pain with passive extension, and (3) duration of symptoms less than 5 days.[5] Neviaser suggested that the inability to make contact between the digit and the palm was an additional sign of PFT, and that pain with passive extension of the digit was the most reliable early Kanavel sign.[6] These studies collectively demonstrate that when used as independent criteria on their own, none of the Kanavel signs seem to have a high specificity for PFT.

In Nadine Semer's publication *Practical Plastic Surgery for Nonsurgeons*, she suggests that the primary area of tenderness to palpation in PFT is over the A1 pulley, making it the most sensitive sign of PFT.[11] She writes that tenderness in this area "may help to differentiate it from other infectious processes involving the finger." Upon our subsequent review of the literature, we observed that tenderness to palpation specifically over the A1 pulley portion of the flexor tendon sheath had not yet been validated as a clinical sign in diagnosing PFT. While it may be included in the existing examination for tenderness over the course of the tendon sheath, we hypothesized that many physicians may not include this specification as the soft tissue over the A1 pulley may be considered the palm of the hand and not a part of the finger by hand surgery trainees or by nonsurgeons. We therefore decided to examine the effectiveness of including A1 pulley tenderness in the PFT examination as a specification of tenderness over the course of the tendon sheath.

METHODS

A retrospective chart review was performed after obtaining approval from the Wake Forest Health Sciences institutional review board [Atrium Health Wake Forest Baptist (formerly known as Wake Forest Baptist Health), approval no. IRB00073857.]. This study included patients for whom the plastic surgery department (hand surgery) was consulted from the emergency department out of concern for PFT over an 8-month period from June 1, 2020 to February 28, 2021. A physical examination was conducted for each patient by one of the four plastic surgery residents/registrars (postgraduate year four or above) for the presence or absence of the four Kanavel signs, and for the presence or absence of tenderness to palpation specifically over the A1 pulley portion of the sheath on the affected digit(s). This examination was taught and verified by the senior author so that the documentation and the examination were consistent between examiners. The T1 pulley of the thumb was used as a surrogate structure to the A1 pulley when examining the thumb. The sign of "exquisite pain along the flexor sheath" was positive if palpation elicited tenderness along the sheath at one or more locations, which could include (but did not require) tenderness over the A1 or T1 pulley. Palpation volar to the metacarpal phalangeal (MCP) joint in the distal volar palm was considered the location for the A1/T1 pulleys. All of the patients with suspected PFT, or those with high clinical suspicion aided by assessment of WBC and vital signs, were managed with incision/drainage and irrigation of the tendon sheath in the operating room. Flexor tenosynovitis was defined as direct visualization and documentation by an attending plastic surgeon of purulent fluid within the flexor tendon sheath. All fluid isolates from the tendon sheaths of patients in our study were cultured.

Takeaways

Question: Does the addition of A1/T1 pulley tenderness on physical examination as a specific modification to "tenderness along the flexor sheath" improve the specificity or sensitivity of this Kanavel sign with regard to the diagnosis of pyogenic flexor tenosynovitis?

Findings: Only palpating the A1 or T1 pulley region on a finger rather than the entire volar flexor sheath does appear to increase specificity with regard to diagnosing pyogenic flexor tenosynovitis.

Meaning: Examination of the A1/T1 pulleys should be added to the four classic Kanavel signs when examining a patient for pyogenic flexor tenosynovitis.

RESULTS

Demographics

Our study yielded 33 patients who were classified into one of the two groups, those with the PFT diagnosis (12 patients) and those without the PFT diagnosis (21 patients) who instead had an alternative hand infection diagnosis. Infections other than PFT included eight with an abscess, five with cellulitis, six with felons (one of which was associated osteomyelitis), one with an infected mucous cyst, and one patient with a paronychia. Kanavel signs were significantly different between the two groups, but no other factors such as age, biological sex, or affected digit(s) demonstrated a statistically significant difference (Table 1).

Demographics and Kanavel Signs

Descriptive statistics for the two cohorts of the 33 patients were completed using Student *t* test for continuous variables and Fisher exact test for binomial variables. Contingency tables were additionally created for the presence or absence of each Kanavel sign and A1 pulley tenderness. Patients who had multiple affected fingers had the same Kanavel signs/A1 pulley examination on each digit, and thus were counted once for the purposes of data analysis. With the large prevalence of PFT in the study set (36%, 95% CI: 22%–53%) compared with the population prevalence (2.5%–9.4%),[1,2] all tests had adequate effect

Table 1. Demographic Data for 33 Patients (PFT Group: n = 12; nonPFT Group: n = 21) Included in the Study

	Group		
	NonPFT	PFT	*P*
Age	41	42.33	0.8269*
Men/women	10/11	8/4	0.4688†
Tenderness to palpation on flexor sheath	13/21 (62%)	12/12 (100%)	0.0005†
Pain with passive extension	11/21 (52%)	12/12 (100%)	0.0021†
Flexed posture of the digit	12/21 (57%)	10/12 (83%)	0.0328†
Fusiform swelling in digit	11/21 (52%)	8/12 (67%)	0.4688†
A1 pulley tenderness	3/21 (14%)	11/12 (92%)	<0.0001†

*Independent samples *T*-test.
†Fisher exact test.

Table 2. Culture Results for the PFT (n = 12) Patients after Incision and Drainage Procedure*

Cultured Organisms	N
No growth	4
MSSA	2
MRSA	3
Group Strep A	2
Beta-hemolytic strep	1
Strep dysgalactiae	1
Total	13

*One of the patients yielded two growth results.

sizes despite the small data set. Because of the higher prevalence of PFT in our patient population, analysis of factors related to this disease had a greater chance of being detected in this population compared with national prevalence. Odds ratios, PPVs, sensitivities, and specificities were all calculated. For those that had a zero value for a group subset, a modified Haldane-Anscombe correction was applied. Additionally, a multivariate regression with Bonferroni correction was performed to model the predictive value of adding A1 pulley tenderness into the Kanavel signs.

Culture Data

A total of 13 different cultures were obtained in the 12 patients who had PFT (one patient had a polymicrobial infection and two different organisms cultured) (Table 2). The four patients diagnosed with PFT intraoperatively who had no growth in their cultures received empiric, broad-spectrum IV antibiotics before cultures were obtained. Methicillin-resistant *Staphylococcus aureus* was the most common organism cultured from the PFT cohort.

Sensitivity and Specificity of Kanavel Signs with Regard to Flexor Tenosynovitis

The Kanavel signs showed a range of sensitivity from 66.7% to 100% and specificity from 52.4% to 61.9% for detection of PFT (Table 3). The sensitivity and specificity for A1 pulley tenderness was 91.7% and 85.7%, respectively. PPVs ranged from 44.4% for uniform swelling to 78.6% for A1 pulley tenderness (Table 3). Accuracy, the likelihood that a patient with a certain sign would receive the correct diagnosis, was lowest in uniform swelling at 57.6 and highest with A1 pulley tenderness at 87.9 with all other signs falling between these values. Six patients had tenderness over the flexor sheath distally without having tenderness over the more proximal A1 pulley; these included two abscesses, two cellulitis, one osteomyelitis with felon, and one PFT diagnosis. There were no subjects in our study who had A1 pulley tenderness without also having "tenderness over the course of the flexor sheath" that was detected more distally on the examination. Three patients who were taken to the operating room out of concern for PFT were found to have a different diagnosis (two volar finger abscesses and one felon).

Multivariate Regression

Two of the signs, tenderness over the course of the flexor sheath and pain with passive extension, produced quasicomplete separation because they were present in all patients with PFT, and they were therefore removed from the analysis (the binomial nature and limited study subjects did not allow for corrections in these separations).[12] By combining the other two Kanavel signs and adding in appropriate confounds, the Kanavel signs alone had a negative predictive potential of 75.0% and a PPV of 53.9% (Table 4). By adding A1 pulley tenderness, the new clinical algorithm had an increased negative predictive value of 94.7% and a PPV of 78.6%, in which including A1 pulley tenderness was considered a significant difference ($P = 0.0027$, Table 5). Receiver operating characteristic (ROC) analysis from the logistic regression yielded an area under the curve of 0.7361 with the two Kanavel signs and an area under the curve of 0.9167 when A1 pulley tenderness was added.

Table 3. Contingency Table Results for each Kanavel Sign Based on the Presence or Absence, with Diagnosis of PFT or nonPFT

	Odds Ratio	PPV (%)	Sensitivity (%)	Specificity (%)	Accuracy
Tenderness along sheath	**39.71**	**60.00** (46.51, 72.13)	**100.00** (73.54, 100)	**61.9** (38.44, 81.89)	**75.76** (57.74, 88.91)
Tenderness on passive extension	**27.38**	**54.55** (43.38, 65.27)	**100.00** (73.54, 100)	**52.38** (29.78, 74.29)	**69.7** (51.29, 84.41)
Fusiform swelling in digit	**2.20***	**44.44** (30.49, 59.34)	**66.67** (34.89, 90.08)	**52.38** (29.78, 74.29)	**57.58** (39.22, 74.52)
Finger flexed in resting position	**6.67**	**52.63** (38.95, 65.93)	**83.33** (51.59, 97.91)	**57.14** (34.02, 78.18)	**66.67** (48.17, 82.04)
A1 pulley tenderness	**66.00**	**78.57** (55.92, 91.38)	**91.67** (61.52, 99.79)	**85.71** (63.66, 96.95)	**87.88** (71.80, 96.60)

*95% CI crossed 1.0.
Bolded numbers represent average values with 95% CI in parenthesis below.

Table 4. Logistic Regression Results Considering Prediction of PFT Diagnosis by the Presence of Established Kanavel Signs

Multivariate Predictor	Regression Coefficient	Standard Error	*P*	Adjusted Odds Ratio	95% CI
Age	0.01517	0.02754	0.5818	0.6950	0.05773, 6.937
Gender (women)	−0.6116	0.8666	0.4803	0.5425	0.08978, 2.903
Fusiform swelling in entirety of digit	0.3657	1.015	0.7186	1.442	0.2105, 13.27
Resting in flexed position	−2.109	1.113	0.0581	0.1214	0.009736, 0.8915
Area under the curve	0.7361	0.08676	0.0260		
Negative predictive value	75.00%				
Positive predictive value	53.85%				

Diagnosis ~ Age+Gender+Fusiform_Swelling+Flexed_Position

Table 5. Logistic Regression Results Considering Prediction of PFT Diagnosis by the Presence of Established Kanavel Signs and the Addition of A1 Pulley Tenderness

Multivariate Predictor	Regression Coefficient	Standard Error	*P*	Adjusted Odds Ratio	95% CI	VIF
Age	0.03634	0.04289	0.3968	1.037	0.9561, 1.136	1.079
Gender (women)	−0.8812	1.269	0.4875	0.4143	0.02670, 5.046	1.100
Fusiform swelling in entirety of digit	−0.6113	1.398	0.6619	0.5426	0.03318, 11.86	1.521
Resting in flexed position	−0.1088	1.682	0.9484	0.8969	0.02487, 32.59	1.949
A1 pulley tenderness	−4.318	1.440	0.0027	0.01333	0.0003695, 0.1428	1.351
Area under the curve	0.9167	0.06929	<0.0001			
Negative predictive value	94.74%					
Positive predictive value	78.57%					

Diagnosis as the outcome variable with age, gender, fusiform swelling, flexed position, and A1 pulley tenderness as control variables.

DISCUSSION

The flexor tendon sheath consists of a synovial portion and a retinacular (pulley) portion.[13] The synovial portion is a closed tube consisting of a visceral layer, or epitenon, and an outer parietal layer that converges with the retinacular pulley system.[13,14] Figure 1 demonstrates the five annular pulleys and three cruciform pulleys that overly the synovial sheath in a segmented fashion to improve tendon/finger excursion.[13,14] The synovial portion is a closed space with a poor vascular supply, which makes it an ideal environment for unchecked bacterial growth.[9] When bacteria enters the space between the parietal and visceral layers, pressure builds from the infection, leading to pain with movement of the tendon.[8]

The unique anatomy of the A1 pulley of the flexor sheath could account for the consistency of A1 tenderness as a specification to tenderness over the course of the flexor sheath in PFT. The entrance to the flexor sheath, the A1 pulley, is an anatomical bottle-neck compared with the much broader adjacent A2 pulley.[14] Because of its relative narrowness, one could suspect that A1 is subjected to greater contact with the underlying tendon, resulting in exacerbated pain in this location when there is infection. Furthermore, A1 is the point of maximal tendon excursion within the sheath, and thus pain and inflammation secondary to displacement of the tendon with movement or with manual compression may be greater at A1 relative to the other pulleys. This greater degree of excursion has previously been implicated in the pathogenesis of stenosing tenosynovitis.[15]

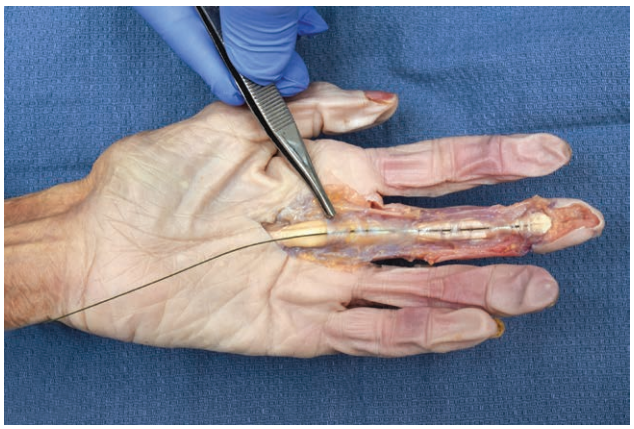

Fig. 1. Cadaver dissection demonstrating the flexor sheath with the pulley system (forceps pointing to the A1 pulley).

Our initial hypothesis that A1 and T1 pulley tenderness would have a higher sensitivity than the other Kanavel signs was not supported by our data. Although it did have a high sensitivity, we found that the greatest strength of A1 pulley tenderness as an examination finding was its relatively high specificity of 85.7% when compared with the other Kanavel signs (Table 3). Including A1 pulley tenderness also increased both the positive and negative predictive values when they were calculated in addition to uniform swelling and flexed position ($P < 0.0001$) (Table 5). The ROC analysis visually demonstrates this through the increase in area under the curve with the addition of A1 pulley tenderness (Fig. 2). Based on our analysis, the addition of A1 pulley tenderness could reliably aid in medical decision-making for providers evaluating patients with suspected PFT.

Both the sensitivities and specificities of this study were similar overall to the findings calculated by Kennedy et al.[5] A major difference between our study and that of Kennedy et al was that their study included all incoming finger infections referred to hand surgery over a 5-year period, versus our inclusion criteria of consultations specifically out of concern for PFT during the 8 months. We did, however, find the following similar results: Flexed posture and uniform swelling were present less frequently than the other two Kanavel

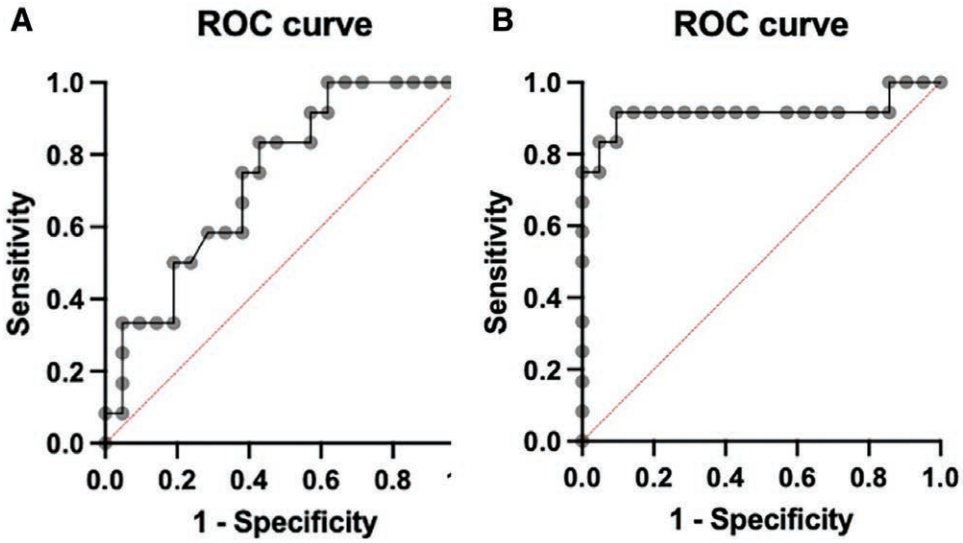

Fig. 2. ROC curves for Kanavel signs both without and with A1 pulley tenderness considered. A, ROC curve with two of the Kanavel signs, fusiform swelling, and resting flexed position. B, ROC curve with two of the Kanavel signs, fusiform swelling, and resting flexed position, combined with A1 pulley tenderness. The other two signs, pain with passive extension and tenderness along sheath, were not included due to quasi-complete separation and unmeaningful ROC curve formation.

signs in patients with culture-positive PFT and were also less likely to differentiate PFT from other finger infections.

Our data demonstrate that tenderness over the course of the flexor sheath and pain with passive extension are extremely sensitive markers for PFT, but are often encountered in nonPFT hand infections as well. The Kanavel signs can be difficult to perform in isolation as the hand physical examination is nuanced; for example, palpating the flexor tendon sheath without creating passive extension can be challenging. When examining pain with passive extension, we often stabilize the proximal and distal interphalangeal joints with one hand while extending the finger tip with our other hand so as to isolate pain passive extension from other referred pain to the adjacent soft tissue. Similarly, through singular palpation of the A1 pulley, we feel that one can more easily localize the pain and provide a more definitive finding to suggest PFT. This could prove a useful examination maneuver to help with the decision to move to the operating room.

Limitations of this study include its retrospective nature, possible diagnostic inconsistencies as discussed above, and the potential bias, given the use of A1 pulley tenderness as part of our examination to look for PFT before this study data were analyzed. Additionally, there were four different surgeons examining the patients for data collection, and the interobserver reliability of the signs has not been addressed, nor has their predictive value been validated in previous studies.[5] We attempted to minimize bias by instituting a standardized examination among all physician examiners, but we acknowledge that there is inherent subjectivity and an inherent degree of bias in all physical examinations. Furthermore, the addition of A1 pulley tenderness is not a perfect method for PFT diagnosis. An abscess or cellulitis around an MCP joint might cause a positive A1 pain sign, as this happened three times in our study in patients without PFT. Studies with a larger population, or conducted over a longer period of time, would be helpful to better support and clarify the role of A1/T1 pulley tenderness as a modification to the sign of tenderness over the course of the flexor sheath when diagnosing PFT.

CONCLUSIONS

Although the Kanavel signs have clinical utility, tenderness over the A1 pulley is a useful specification to the sign of "tenderness over the course of the flexor sheath," as it alone has a higher specificity and PPV than each of the classic Kanavel signs.

Amelia Davidson, BS
475 Vine Street
Winston-Salem, NC 27101
E-mail: aldavids@wakehealth.edu

ACKNOWLEDGEMENT

These individuals are acknowledged for their partial involvement in the study, whether it be the organization, data collection, or data analysis: Nadine B. Semer, MD, FACS; Jungwon Park, MD, PhD; Thomas N. Steele, MD; Betsey Wilson; Lisa R. David, MD, MBA, FACS; Greg Russell, MS; and Caleb Suggs, BS.

REFERENCES

1. Glass KD. Factors related to the resolution of treated hand infections. *J Hand Surg Am.* 1982;7:388–394.
2. Weinzweig N, Gonzalez M. Surgical infections of the hand and upper extremity: a county hospital experience. *Ann Plast Surg.* 2002;49:621–627.

3. Stern PJ, Staneck JL, McDonough JJ, et al. Established hand infections: a controlled, prospective study. *J Hand Surg Am.* 1983;8(5 Pt 1):553–559.
4. Giladi AM, Malay S, Chung KC. A systematic review of the management of acute pyogenic flexor tenosynovitis. *J Hand Surg Eur Vol.* 2015;40:720–728.
5. Kennedy CD, Lauder AS, Pribaz JR, et al. Differentiation between pyogenic flexor tenosynovitis and other finger infections. *Hand (N Y).* 2017;12:585–590.
6. Neviaser R, Gunther S. Tenosynovial infections in the hand: diagnosis and management. *Instr Course Lect.* 1980;29: 108–128.
7. Kanavel A. The symptoms, signs, and diagnosis of tenosynovitis and fascial-space abscesses. In: *Infections of the Hand.* 1st ed. Philadelphia, Pa.: Lea & Febiger; 1912:201–226.
8. Osterman M, Draeger R, Stern P. Acute hand infections. *J Hand Surg Am.* 2014;39:1628–1635; quiz 1635.
9. Dailiana ZH, Rigopoulos N, Varitimidis S, et al. Purulent flexor tenosynovitis: factors influencing the functional outcome. *J Hand Surg Eur Vol.* 2008;33:280–285.
10. Pang HN, Teoh LC, Yam AK, et al. Factors affecting the prognosis of pyogenic flexor tenosynovitis. *J Bone Joint Surg Am.* 2007;89:1742–1748.
11. Semer NB. Chapter 37: Specific types of hand infections. In: *Practical Plastic Surgery for Nonsurgeons.* Philadelphia, Pa.: Henley & Belfus, Inc.; 2001:347–354.
12. Lu X. Correcting the quasi-complete separation issue in logistic regression models. *SAS Institute Papers.* Paper 10220–12016.
13. Cohen MJ, Kaplan L. Histology and ultrastructure of the human flexor tendon sheath. *J Hand Surg Am.* 1987;12:25–29.
14. Doyle JR. Anatomy of the finger flexor tendon sheath and pulley system. *J Hand Surg Am.* 1988;13:473–484.
15. Draeger RW, Bynum DK Jr. Flexor tendon sheath infections of the hand. *J Am Acad Orthop Surg.* 2012;20:373–382.