

• 论 著 •

高频超声及弹性技术评价冈上肌腱修补术后 康复效果的应用研究

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[摘要] 目的 探讨高频超声及弹性成像技术随访冈上肌腱修补术后康复效果的应用价值。方法 收集因单纯冈上肌腱撕裂在河北医科大学第三医院肩肘专科行关节镜下肩袖修补术的患者39名,回顾分析术后1个月、3个月、6个月高频超声及弹性成像技术测量冈上肌腱厚度、宽度及剪切波速度(shear wave velocity, SWV)的结果,同时收集患者的视觉模拟评分法(visual analog scale, VAS)评分、Constant-Murley肩关节评分。比较术后不同时期冈上肌腱超声指标的变化,分析超声指标与VAS评分的相关性,并依据Constant-Murley评分70为界,分析各超声指标对康复效果的判断效能。结果 术后各时期两两比较,患侧冈上肌腱宽度差异均无统计学意义($P > 0.05$);术后1个月与3个月、1个月与6个月患侧冈上肌腱厚度差异有统计学意义($P < 0.05$),术后3个月与6个月患侧冈上肌腱厚度差异无统计学意义($P > 0.05$);术后1个月与3个月、3个月与6个月、1个月与6个月患侧冈上肌腱SWV值差异有统计学意义($P < 0.05$)。术后1个月患侧与健侧冈上肌腱厚度及SWV值差异有统计学意义($P < 0.05$),宽度差异无统计学意义($P > 0.05$);术后3个月及6个月患侧与健侧冈上肌腱SWV值差异均有统计学意义($P < 0.05$),厚度及宽度差异均无统计学意义($P > 0.05$)。Spearman相关性分析显示SWV值与肩关节VAS评分呈中等正相关($r_s = 0.791, P < 0.001$),而厚度及宽度与肩关节VAS评分无显著相关性。依据Constant-Murley评分70为界,SWV值的曲线下面积为0.781,厚度及宽度曲线下面积为0.531、0.466。结论 高频超声及弹性成像技术能够实时评估患者冈上肌腱术后形态及硬度的变化情况,其中SWV在评价VAS及判断功能康复效果方面具有一定的参考价值,有助于临床医师及康复医师制定合适的康复计划。

[关键词] 肩损伤;高频超声;弹性成像 doi:10.3969/j.issn.1007-3205.2024.12.012

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Application of high-frequency ultrasound and elastography technology in evaluating the rehabilitation effect after supraspinatus tendon repair

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[Abstract] **Objective** To explore the application value of high-frequency ultrasound and elastography technology in following up the rehabilitation effect after supraspinatus tendon repair. **Methods** A total of 39 patients who underwent arthroscopic rotator cuff repair due to simple supraspinatus tendon tear in the Department of Shoulder and Elbow, the Third Hospital of Hebei Medical University were enrolled. The results of high-frequency ultrasound and elastography technology measuring the thickness, width and shear wave velocity (SWV) of the supraspinatus tendon at 1 month, 3 months and 6 months after surgery were retrospectively analyzed. The visual analog scale (VAS) score and Constant-Murley shoulder joint score of the patients were

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also collected. The changes of ultrasound indicators of supraspinatus tendon at different periods after surgery were compared, the correlation between ultrasound indicators and VAS scores was analyzed, and the judgment efficiency of each ultrasound indicator for the rehabilitation effect was analyzed based on the Constant-Murley score of 70. **Results** When comparing each other at each postoperative period, there was no significant difference in the width of the supraspinatus tendon on the affected side ($P > 0.05$), while there was a significant difference in the thickness of the supraspinatus tendon on the affected side between 1 month and 3 months after surgery, and between 1 month and 6 months after surgery ($P < 0.05$). There was no significant difference in the thickness of the supraspinatus tendon on the affected side between 3 months and 6 months after surgery ($P > 0.05$). The difference in SWV value of supraspinatus tendon on the affected side was significant between 1 month and 3 months after surgery, between 3 months and 6 months after surgery, and between 1 month and 6 months after surgery ($P < 0.05$). The difference in thickness and SWV value of the supraspinatus tendon between the affected side and the healthy side was significant at 1 month after surgery ($P < 0.05$), but the difference in width was not significant ($P > 0.05$). At 3 months and 6 months after surgery, the difference in SWV value of the supraspinatus tendon between the affected side and the healthy side was significant ($P < 0.05$), but there was no significant difference in the thickness and width ($P > 0.05$). Spearman correlation analysis showed that the SWV value had a moderate positive correlation with the VAS score of the shoulder joint ($r_s = 0.591, P < 0.001$), while the thickness and width had no significant correlation with the VAS score of the shoulder joint. Based on the Constant-Murley score of 70, the area under the curve (AUC) of the SWV value was 0.781, and the AUC of the thickness and width was 0.531 and 0.466 respectively. **Conclusion** High-frequency ultrasound and elastography technology can evaluate the changes in postoperative morphology and stiffness of patients' supraspinatus tendon in a timely manner. SWV has certain reference value in evaluating VAS and judging the effect of functional rehabilitation, which is helpful to clinicians and rehabilitation physicians to develop an appropriate rehabilitation plan.

[Key words] shoulder injuries; high-frequency ultrasound; elastography

肩袖由肩关节周围的冈上肌、冈下肌、肩胛下肌、小圆肌的肌腱形成,是维持肩关节稳定性的重要结构,肩袖损伤是导致肩关节疼痛、肩关节活动受限及功能障碍的常见病因^[1-2]。肩关节镜下肩袖修补术以及合适的术后康复计划能够提高肩袖损伤患者的肩关节活动度,减轻疼痛,但有相当数量的患者在术后康复中由于错误手法或不当的康复时机的影响,容易出现再撕裂。因此术后及时且准确地评估患者肩袖愈合情况,对康复计划作出合适的调整,能够对患者的预后产生积极的影响。本研究通过应用高频超声及弹性成像技术对肩关节冈上肌腱撕裂行修补术的患者进行术后随访,回顾分析超声指标及临床数据,探讨高频超声及弹性成像技术在肌腱术后随访中的应用价值,并对单一肌腱损伤的患者进行分析,旨在更准确地判断超声指标对肩袖修补术后肌腱愈合情况的随访价值。

1 资料与方法

1.1 一般资料 收集 2023 年 2—6 月因肩袖撕裂(肩关节镜证实仅有冈上肌腱撕裂)在河北医科大学第三医院肩肘专科行关节镜下肩袖修补术的患者 39 例,为排除因手术技术差异造成的影响,入组仅由同一位高年资医师完成的手术患者。纳入标准:①符合肩袖撕裂诊断标准;②具备关节镜下肩袖修补术指征,并行冈上肌腱修补术;③同意本研究并签署知情同意书;④已于术后 1 个月、3 个月、6 个月完整进行 3 次术后临床及超声随访。排除标准:①术中同时行除冈上肌腱以外的肌腱修补或固定操作;②术后通过超声、MRI 随访表明再撕裂者;③合并其他伴发或并发疾病,并可能对研究造成影响;④无法配合完成康复随访者;⑤存在患肢神经、肌功能缺陷者;⑥其他研究者判定不适合纳入研究的情况。

1.2 超声检查方法 采用 Siemens Acuson S3000 (Siemens Medical Solution, Mountain View, California)彩色多普勒超声诊断仪,线阵探头,频率4~9 MHz,进行高频超声及弹性成像技术检查,厚度及宽度单位为 mm,SWV 单位为 m/s,量程为0~10 m/s。在肩袖修补术后的第1、3、6个月,患者取改良 Crass 体位,行肩关节常规二维超声检查,在冈上肌腱长轴切面垂直测量肌腱最大厚度,在短轴切面通过肱二头肌长头腱(the tendon of long head of biceps brachii,BT)及冈下肌腱定位,并垂直肌纤维长轴测量冈上肌腱最大宽度。冈上肌腱的剪切波速度(shear wave velocity,SWV)测量:在探头与皮肤间放置足量耦合剂,尽量减少探头施压并获得冈上肌腱长轴切面,测量点在冈上肌腱肱骨大结节附着点内侧1 cm处,超声探头与肌腱纤维走行方向一致进行取样,手动选择在感兴趣区中放置2~3个1 mm×1 mm的取样框,测量SWV的平均值。分别测量患侧与健侧冈上肌腱厚度、宽度及SWV值,重复测量3次,取平均值进行记录分析,见图1~3。

1.3 临床视觉模拟评分法(visual analog scale, VAS)评分、Constant-Murley 肩关节评分 每次随访进行VAS评分、Constant-Murley 肩关节评分并记录。

1.4 统计学方法 应用 SPSS 25.0 统计软件分析数据。符合正态分布的计量资料比较采用 *t* 检验,单因素方差分析和 SNK-*q* 检验,不符合正态分布的计量资料采用秩和检验。应用受试者工作特征曲线及曲线下面积评估不同参数的预测价值。 $P < 0.05$ 为差异有统计学意义。



图1 冈上肌腱厚度测量
Figure 1 Measurement of the thickness of supraspinatus tendon

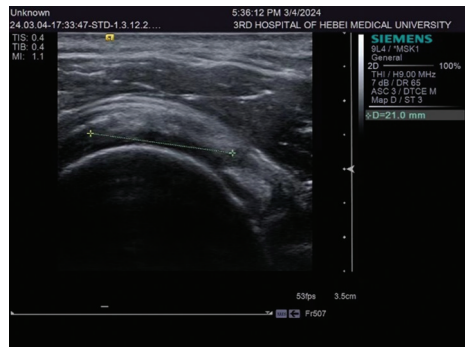


图2 冈上肌腱宽度度测量
Figure 2 Measurement of the width of supraspinatus tendon

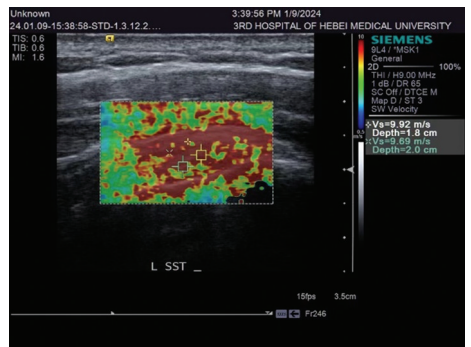


图3 冈上肌腱 SWV 值测量
Figure 3 Measurement of SWV value of supraspinatus tendon

2 结 果

2.1 临床特征 收集单纯冈上肌腱损伤的患者共39例,均经肩关节镜证实。其中男性11例,女性28例,左肩损伤14例,右肩损伤25例,年龄19~65岁,平均(51.5±5.5)岁。

2.2 患侧冈上肌腱厚度、宽度、SWV 值术后不同时期比较 术后1个月、3个月与6个月患侧冈上肌腱宽度差异均无统计学意义($P > 0.05$);术后1个月与3个月、1个月与6个月患侧冈上肌腱厚度差异均有统计学意义($P > 0.05$),术后3个月与6个月患侧冈上肌腱厚度差异无统计学意义($P > 0.05$);术后1个月与3个月、3个月与6个月、1个月与6个月比较患侧冈上肌腱SWV值差异均有统计学意义($P > 0.05$),患侧冈上肌腱SWV值随时间增加逐渐下降,见表1、图4。

2.3 术后患侧与健侧冈上肌腱厚度、宽度及SWV 值比较 术后1个月患者患侧冈上肌腱厚度及SWV值较健侧增加,差异有统计学意义($P < 0.05$),患侧与健侧冈上肌腱宽度差异无统计学意义,见表2、图5~6。

术后3个月患者患侧冈上肌腱SWV较健侧增加,差异有统计学意义($P < 0.05$),患侧与健侧的冈上肌腱厚度及宽度差异无统计学意义($P > 0.05$),

见表3、图7。

术后6个月患者患侧与健侧冈上肌腱SWV值较健侧增加,差异有统计学意义($P < 0.05$),患侧与健侧的冈上肌腱厚度及宽度差异无统计学意义($P > 0.05$),见表4、图8。

表1 术后患侧冈上肌腱厚度、宽度、SWV值不同时期比较

Table 1 Comparison of thickness, width and SWV of supraspinatus tendon on the affected side at different periods after surgery ($n = 39, \bar{x} \pm s$)

时期	厚度(mm)	宽度(mm)	SWV(m/s)
术后1个月	5.52±0.51	20.26±1.45	8.75±0.99
术后3个月	5.22±0.50*	20.17±1.25	7.53±1.10*
术后6个月	5.12±0.33*	20.21±1.10	6.20±1.09*#
F值	7.734	0.049	53.114
P值	0.001	0.952	<0.001

* P值<0.05与术后1个月比较 # P值<0.05与术后3个月比较(SNK-q检验)

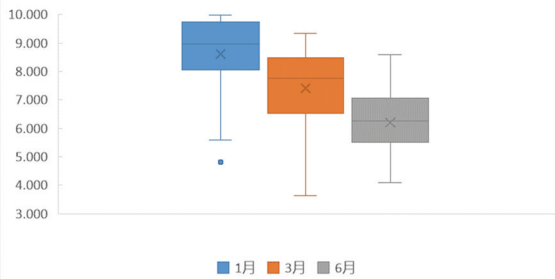


图4 术后1、3、6个月患侧冈上肌腱SWV值
Figure 4 SWV value of supraspinatus tendon at 1, 3 and 6 months after surgery

表2 术后1个月患侧与健侧冈上肌腱厚度、宽度及SWV值比较

Table 2 Comparison of thickness, width and SWV value of supraspinatus tendon between the affected side and the healthy side at 1 month after surgery ($n = 39, \bar{x} \pm s$)

侧别	厚度(mm)	宽度(mm)	SWV(m/s)
患侧	5.52±0.510	20.26±1.45	8.75±0.99
健侧	5.23±0.53	20.50±1.02	5.84±1.12
t值	2.939	0.842	6.701
P值	0.004	0.403	<0.001

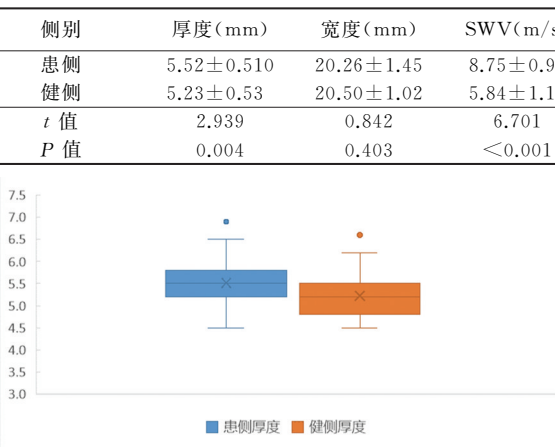


图5 术后1个月患侧与健侧冈上肌腱厚度
Figure 5 The thickness of supraspinatus tendon between the affected side and the healthy side at 1 months after surgery

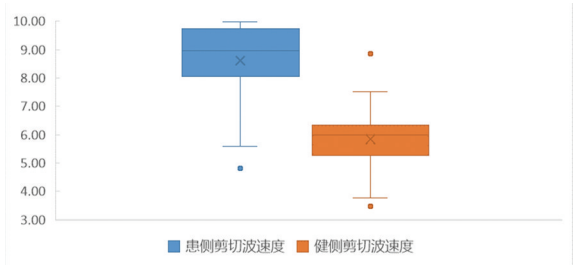


图6 术后1个月患侧与健侧冈上肌腱SWV值
Figure 6 The SWV value of supraspinatus tendon between the affected side and the healthy side at 1 months after surgery

表3 术后3个月患侧与健侧冈上肌腱厚度、宽度及SWV值比较

Table 3 Comparison of thickness, width and SWV value of supraspinatus tendon between the affected side and the healthy side at 3 months after surgery ($n = 39, \bar{x} \pm s$)

侧别	厚度(mm)	宽度(mm)	SWV(m/s)
患侧	5.22±0.50	20.17±1.25	7.53±1.10
健侧	5.20±0.51	20.48±0.98	5.89±1.04
t值	0.180	1.202	4.662
P值	0.858	0.233	<0.001

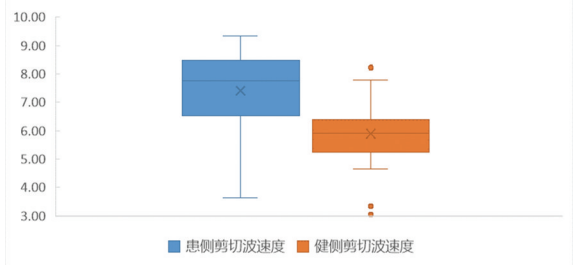


图7 术后3个月患侧与健侧冈上肌腱SWV值
Figure 7 SWV value of supraspinatus tendon on the affected side and healthy side at 3 months after surgery

2.4 患侧肩关节VAS评分在术后不同时间比较
患侧肩关节VAS评分随时间增加而呈下降趋势,见图9。Spearman相关性分析显示厚度、宽度及SWV值与VAS评分的相关性均较低。SWV值与肩关节VAS评分呈中等正相关($r_s = 0.791$),而厚度($r_s = 0.102$)及宽度($r_s = -0.021$)与肩关节VAS评分无显著相关性,见表5。

2.5 冈上肌腱厚度、宽度、SWV值的受试者工作特征曲线
以Constant-Murley肩关节评分70分为判定标准,绘制受试者工作特征曲线,SWV值曲线下面积为0.781,厚度及宽度曲线下面积为0.531、0.466,见图10。

表4 术后6个月患侧与健侧冈上肌腱厚度、宽度及SWV值比较

Table 4 Comparison of thickness, width and SWV value of supraspinatus tendon between affected side and healthy side at 6 months after surgery

(n = 39, $\bar{x} \pm s$)

侧别	厚度(mm)	宽度(mm)	SWV(m/s)
患侧	5.12±0.33	20.21±1.10	6.20±1.09
健侧	5.31±0.48	20.47±0.86	5.71±0.84
t 值	1.238	1.173	2.224
P 值	0.216	0.245	0.029

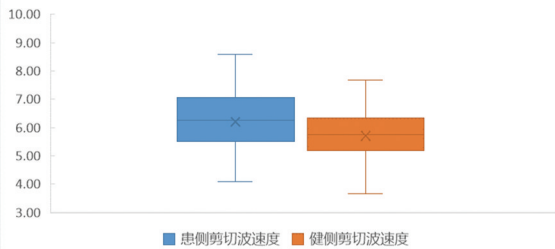


图8 术后6个月患侧与健侧冈上肌腱SWV值
Figure 8 SWV value of supraspinatus tendon on the affected side and the healthy side at 6 months after surgery

表5 术后患侧冈上肌腱厚度、宽度、SWV值与肩关节VAS评分相关性分析

Table 5 Correlation analysis between thickness, width, SWV value of supraspinatus tendon and VAS score of shoulder joint after surgery

指标	VAS 评分	
	r 值	P 值
厚度	0.102	0.274
宽度	-0.021	0.824
SWV	0.791	<0.001

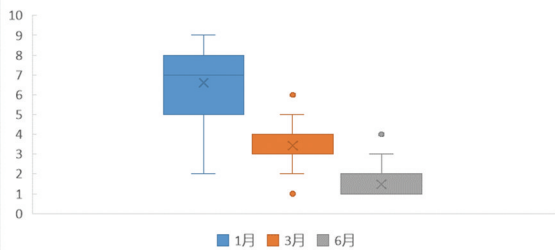


图9 术后1、3、6个月患侧肩关节VAS评分
Figure 9 VAS score of supraspinatus tendon at 1, 3 and 6 months after surgery

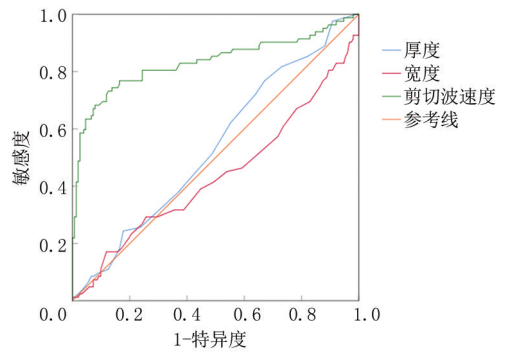


图10 冈上肌腱厚度、宽度、SWV值的ROC曲线

Figure 10 ROC curve of thickness, width and SWV values of supraspinatus tendon

3 讨论

肩袖损伤是导致肩部疼痛及肩关节功能障碍最常见的原因之一,其发病率为5%~39%^[3]。肩袖损伤的发病原因众多,肩关节镜下肩袖修补术是治疗的主要方法。随着关节镜下肩袖损伤修复手术技术和设备的改进,患者预后有所改善,但未愈合或肩袖再撕裂的发生率仍然很高,大多数肩袖再撕裂常发生在手术后的前6个月内^[10-12]。可能对肌腱愈合产生不利影响的因素包括年龄较大、巨大撕裂、肌腱萎缩和脂肪浸润等。部分研究报道提到,不同的康复动作也会对肩袖的愈合情况及肌腱硬度产生影响^[13-14]。肌骨超声是肩袖损伤修补术后随访的主要影像学方法,目前文献^[14-16]报道多于术后随访中只测量冈上肌腱的横截面积或者冈上肌腱的SWV值或杨氏模量值,而同时测量冈上肌腱的形态及弹性成像数据的较少。本研究综合前期学者研究的基础上,综合评价冈上肌腱的形态及弹性成像超声指标,通过肌腱康复期连续动态观察,了解到肌腱愈合情况,旨在为临床医生选择康复计划提供支持。本研究显示,术后1个月,患侧冈上肌腱的厚度较对侧明显增厚,SWV值较对侧增大,说明冈上肌腱仍处于术后反应期,肌腱软组织仍然充血水肿,而断裂后的冈上肌腱通过手术再次连接于大结节足印区后,冈上肌腱张力增加,导致SWV值增大,也就是冈上肌腱硬度增加。术后3个月及6个月,冈上肌腱的厚度慢慢减小,逐渐与健侧厚度一致,表明冈上肌腱水肿消退并逐渐愈合。冈上肌腱的SWV值也随着时间逐渐下降,虽然在术后6个月时总体与健侧仍有差异,但差异显著减小,表明冈上肌腱内的纤维软组织生长、延长并逐步附着到肱骨大结节相应的足印区。

先前研究^[17]表明术后愈合情况与肩袖撕裂的

大小有关,Itoigawa等^[18]的研究结果也印证了其相关性,可能是由于巨大撕裂后,通过肩关节镜修复固定肌腱于肱骨大结节时,巨大撕裂的肌腱受到拉伸更多。本研究结果表明部分巨大撕裂的患者术后超声随访时患侧冈上肌腱SWV值较健侧及同时期手术的其他患者的SWV值增大,与以上研究相印证。

术后1、3、6个月时,患者患侧的冈上肌腱宽度与健侧相比差异无统计学意义,同样术后不同时间对比,患者患侧的冈上肌腱宽度也同样没有明显的改变,表明冈上肌腱的宽度受手术及术后康复动作的影响较小。这可能是由于筛选的患者均是冈上肌腱受损,而肩袖周围剩余肌腱未损伤,导致肱二头肌长头腱与冈下肌腱之间的空间相对稳定,通过关节镜修复后,冈上肌腱附着的宽度也并未发生太明显的变化。因此,未来统计其他类型的患者时,需要注意多处肌腱损伤的患者经过肩袖修补术后,周围有相互影响的肌腱宽度是如何变化的。

然而,术后1个月与3个月、3个月与6个月、1个月与6个月患者患侧的冈上肌腱厚度相比较时,术后3个月与6个月差异无统计学意义,但是患者患侧的冈上肌腱在术后3个月、6个月时的厚度较1个月时明显减小,表明冈上肌腱的充血水肿逐步消退,这与Gerber等^[19]的动物实验及Itoigawa等^[18]的人类实验相似,肌及肌腱内的线粒体、肌纤维和肌原纤维体积在手术后1个月时逐步减少,然后在术后3~7个月内部分恢复正常水平。何勇等^[14]研究显示冈上肌腱的横截面积在导引训练康复或者常规康复时,均随着康复时间增大。本研究没有测量冈上肌腱的横截面积,是由于通过描记法测量的冈上肌腱面积受操作者的主观意识影响过大,较难识别术后1个月时冈上肌腱与周围软组织的边界。

在本研究中,术后1个月与3个月、3个月与6个月、1个月与6个月患者患侧的冈上肌腱SWV值相比较时,患者患侧的冈上肌腱张力及硬度随着康复的进行,逐渐下降,在术后6个月时,与健侧的差异逐渐减小,在接下来也可以收集术后12个月或者更常见的数据进行比较。有研究^[20]表明,性别和年龄影响着肌、肌腱的杨氏模量值,杨氏模量值随着年龄的增大而增大,而女性的肌、肌腱剪切模量值往往高于男性。Seth等^[21]、Seo等^[22]及Hou等^[23]研究结果表明,撕裂后患侧冈上肌腱的SWV低于健侧冈上肌腱,同时冈上肌腱受脂肪含量增加和肌萎缩的影响,其SWV将会降低。

同时Seth等^[21]研究还表示,术后1个月时冈上肌腱的高杨氏模量值提示可能会发生再撕裂的风

险将大于较低杨氏模量值的冈上肌腱,在术后随访中,表明冈上肌腱杨氏模量值突然减小可预测肩袖撕裂复发。因此,术后进行检查时,在进行超声检查的同时,测量冈上肌腱的SWV值变得相当重要,能同时警示、提醒临床医生及患者术后发生再撕裂的可能。临床工作中,临床医师通常会对患者进行Constant-Murley肩关节评分,以评估后得到的分数70分为界限判定是否需要就诊,如果高于70分则提示患者可以进行非手术治疗,如果进一步恶化再进行下一步的诊治。以Constant-Murley肩关节评分70分为界限绘制关于冈上肌腱厚度、宽度、SWV值的ROC曲线,得到SWV值的AUC为0.781,厚度及宽度的AUC为0.531、0.466,结果表明利用冈上肌腱的SWV值判断肩关节功能具有一定的诊断价值,而冈上肌腱的宽度诊断价值较低,导致其诊断价值较低的原因可能是周围肱二头肌长头腱及冈下肌腱尚完好,对冈上肌腱宽度的变化有一定限制作用。

虽然Bouillard等^[24]表明,肌硬度比肌活动更能准确地估计肌力量。但在临床工作中,需要结合VAS评分、Constant-Murley肩关节评分、高频超声以及其他检查来判断患者肩袖愈合情况,以此制定适合每一位患者的康复计划。

本研究的局限性,样本量较少,有待扩大样本量进一步研究;研究对象仅为冈上肌腱,并没有对肩袖周围的全部肌腱作系统研究以及全面评估,但是通过排除修复其他肌腱的患者,也在一定程度上保证了研究的准确性。

综上所述,高频超声可以实时获得患者冈上肌腱术后形态的变化情况,以了解冈上肌腱是否充血水肿、是否发生了再撕裂。同时,本研究显示冈上肌腱在肩袖修补术后不同时间的SWV值有明显改变,且随着时间的增加,SWV值不断减小,随后与正常冈上肌腱的SWV值趋于相同,表明冈上肌腱的硬度由硬逐渐趋于正常。证明弹性成像技术不仅能够预测冈上肌腱术后再撕裂的风险,同样也能够准确判断冈上肌腱的术后愈合情况,在临床医师及康复医师为患者制定合适的康复计划提供强有力的帮助。未来,通过研究肩袖多个肌腱损伤术后的形态及SWV值的变化情况,发挥高频超声及弹性成像技术的更大作用。

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