Biomechanical evaluation of braces used for the treatment of epicondylitis

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The purpose of the study was to investigate the biomechanical effects of different types of braces that are used in the treatment of patients with epicondylitis radialis. Vibration and acceleration of the forearm and the elbow were measured with sensors taped to defined anatomic points on the skin surface. The impact-induced vibration of the racket-arm system was analyzed while the subjects were playing tennis. Different designed brace systems were investigated with respect to acceleration amplitudes and acceleration integrals. Clasp-based brace systems showed a slight reduction of acceleration amplitudes (−6%) and acceleration integrals (−8%). Braces with pads at the lateral epicondyle reduced acceleration amplitudes by 20% and acceleration integrals by 22%. Braces with pads placed at the forearm showed the highest reduction of acceleration amplitudes (−46%) and acceleration integrals (−42%). Overload of the wrist extensors, which is considered to be a major pathogenic factor in lateral epicondylitis, can be reduced by braces. There is a significant difference in the effects among different biomechanical principles of braces. (J Shoulder Elbow Surg 2002;11:265-70.)

An overuse of the wrist extensors is mentioned by many authors as a major factor in the development of lateral epicondylitis.[8-10,17,18,22] In tennis it has been shown that force and flexibility deficiencies in the forearm muscles and lack of movement accuracy lead to increased load at the lateral epicondyle.[1] These factors are also correlated to the incidence of lateral epicondylitis.[18,20,21]

Most braces on the market for the treatment of patients with epicondylitis claim to reduce load at the lateral epicondyle. There are clasp-based braces (Fig-ure 1), which compress very locally at the insertion of the wrist extensor tendons. In acute epicondylitis particularly, these braces are often not tolerated by the patient, because local compression at the insertion can be painful. Another type of brace applies compression over an area of several square centimeters with a silicone pad (Figure 2). A third type of brace was investigated with a high-viscosity fluid pad placed at the forearm over the extensor muscles (Figure 3).

The purpose of this study was to investigate the effect of different types of braces on the load at the lateral epicondyle.

MATERIAL AND METHODS

To determine the effect of the different braces on the load at the lateral epicondyle, accelerometers (HBM B 12/500) were fixed at the grip of the tennis racket, the skin above the ulna head, and the lateral epicondyle. The sensors were fastened to the skin with tape dressings and an additional elastic bandage that was wrapped around the forearm (Figure 4). In comparing intracortical and skin acceleration measurements at the tibia, it has been reported that the use of an elastic bandage pressing a skin-mounted accelerometer against the bone substantially improves the estimation of bone acceleration.[15,19] The position of the accelerometer was defined exactly by anatomic structures (head of ulna, lateral epicondyle). Additional skin markers ensured that any displacement of the sensors during the testing procedure would be noticed. To minimize potential problems of sensor displacement during the test, all braces were tested in direct succession after the accelerometers were attached to the defined positions. However, in our pretest series we did not find any substantial differences (<5%) in the measured data, as long as the variations were less than 5 mm.

The accelerometers recorded frequencies from 0 to 250 Hz. The nominal acceleration was ±1000 m/s², and the natural frequency was 5 kHz. The weight of the sensors was 17 g. The accelerometers were connected to a Hottinger Baldwin microcomputer for A/D conversion (HBM DMC 9012A). The data were recorded and processed with the software Beam (Vet. 2.2cD) on a Macintosh IIvi computer system. Accelerometers provide information on change in speed in a certain period of time, that is, acceleration (α). Directly after impact, a high acceleration can be recorded. The acceleration initiated by the impact is followed by an acceleration in the opposite direction, caused by the elasticity of the tissue, which finally leads to an oscillating

Figure 1 Brace with clasp at lateral epicondyle.

vibration. The change of direction per second is expressed as frequency. The acceleration signal decays over time (Figure 5).

$$\vec{\alpha} \ = \ \lim_{\Delta t \to 0} \frac{\Delta \vec{\nu}}{\Delta \vec{t}} \tag{1}$$

The difference between the positive and negative maximum values of acceleration (peak-to-peak acceleration) and the integral of the acceleration function were calculated (Figure 6). The integral of the acceleration function is influenced by these maximum values and by the speed at which function deteriorates.

Because of the sensitivity of the sensors and overlying effects of muscular activity, the amplitude could be measured until it fell to approximately 1/100 of its initial value. The course of the acceleration signal can be regarded as a dampened oscillation. The period from the impact of the ball until the amplitude falls to 1/100 of its initial value is the oscillation time. A Fourier spectral analysis was performed to identify the greatest Fourier frequency component (dominant frequency) as resonance frequency.

Acceleration was recorded simultaneously at all 3 accelerometers in the same plane. From these data, shown in Figure 5, the difference in acceleration among racket, distal ulna, and lateral epicondyle was calculated.

Backhand strokes were analyzed. Hennig et al[16] reported backhand strokes to cause a higher load on the extensor muscles than forehand strokes. The balls (new Dunlop Tournament tennis balls—DTB Official) were provided to the player with a ball machine at a speed of 15 m/s to guarantee reproducible impact velocity conditions. The rackets were Adams (Pro Competition) and Wilson (Pro Staff Classic), with the suggested string material at the recommended string tension.

**Figure 2** Brace with silicone pad at lateral epicondyle.

Figure 3 Brace with pad at forearm.

Because the mechanical behavior of the lateral epicondyle without and under the influence of different braces was of prime interest, a maximum of standardization of all other parameters was essential. Knowing that the location of impact between ball and racket and grip tightness and hand position has a definite influence on load and vibration,[5,11,12] the player categorized each stroke in terms of ideal, average, or poor. The ideal area of racket ball contact is often referred to as "the sweet spot," indicating an area where low impact and high rebound velocities are experienced.[6,16] Reproducibility of racket oscillation was guaranteed by controlling acceleration at the grip of the tennis racket. With impacts that were classified as ideal by the player, the variation of acceleration was less than 10% within 1 person.

Trials were performed with 10 test people (5 male and 5 female skilled tennis players) as long as 5 strokes were clearly identified as ideal by the player. The players were then equipped with a brace, and the testing procedure was repeated. There was a randomized choice of braces to ensure that the same brace was not always first or last. The brace was fixed to the arm according to the manufacturers' recommendations to ensure proper fitting of each product. Two clasp-based braces (EpiPoint, Bauerfeind, and Epimed, Thämert), 2 braces with pads at the lateral epicondyle (Tricour, Beiersdorf, and Epitrain, Bauerfeind), and 2 braces with pads placed at the forearm, distal to the lateral epicondyle (Coopercare Lastrap by Coopercare and Ofacare by Ofa), were tested in each player (Figures 1-3).

Data of 5 impacts of each set-up, classified as ideal by the player, were taken for further analysis. In each individual the data recorded at the racket, the wrist, and the elbow were compared (set up without and with each of the 6 braces) with analysis of variance. The quotient of the mean
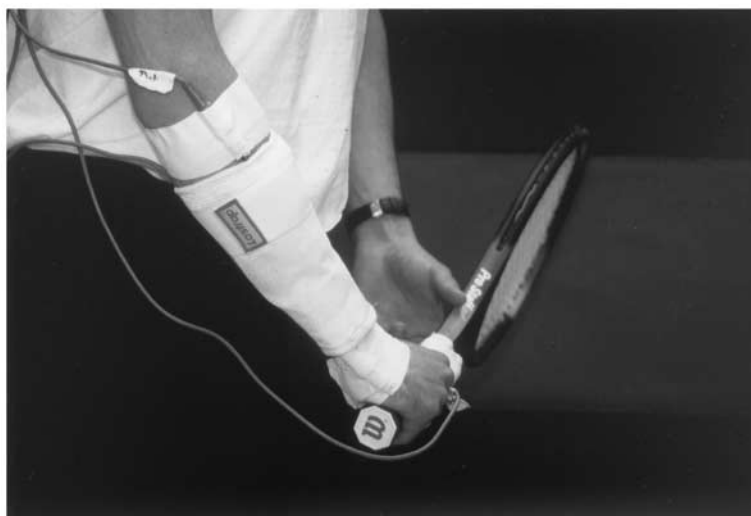
Figure 4 Forearm equipped with accelerometers.
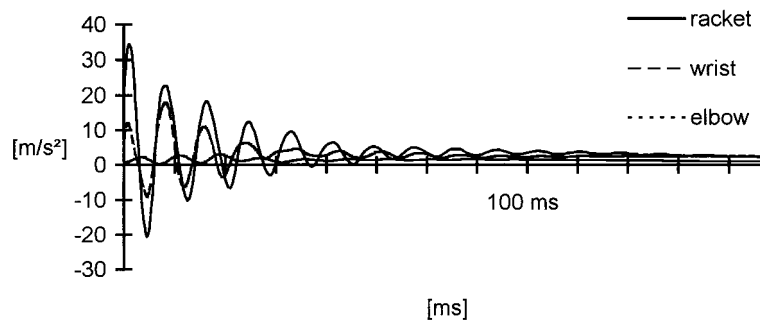
Figure 5 Acceleration signal at racket, wrist, and lateral epicondyle.

value in acceleration magnitude at the elbow and the wrist was calculated in each player without brace and for the 6 braces. These quotients were analyzed for differences by the Kruskal-Wallis test.

RESULTS

Within each individual a significant difference among racket, wrist, and elbow was found ($P < .001$) for the acceleration amplitudes and for acceleration integrals. The peak-to-peak acceleration at the elbow was approximately 20% to 25% of the acceleration at the wrist (Table I). The acceleration integrals at the elbow were also approximately one fifth of the wrist values. At the racket and the wrist, there was no significant difference in peak-to-peak acceleration and integrated acceleration for any 1 individual with or without a brace.

Large differences were found in the acceleration signal among individuals. A variation of 43% for the acceleration integral indicated a substantial difference in acceleration magnitude. To make the results more comparable, the quotient of peak-to-peak acceleration and acceleration integrals between wrist and elbow were calculated (Table 1). The set-ups with and without the different braces were tested for significant differences with the Kruskal-Wallis test (Table II). Clasp-based brace systems (EpiPoint, Epimed) showed a slight reduction of acceleration (−6%) and inte-

grated acceleration (−8%). There were no differences with and without brace in the Fourier spectral analysis. No significant differences between the 2 clasp-based products were detected. In braces with pads placed at the lateral epicondyle (Tricour, Epitrain), a reduced peak-to-peak acceleration of 20% was found. The integrated acceleration was reduced by 22%, with a slight reduction of the dominant frequency in the Fourier analysis. Again, no significant differences between the 2 products of 2 different companies were found. Braces with pads placed at the forearm distal to the lateral epicondyle (Coopercare, Ofacare) had the highest reduction of peak-to-peak acceleration (−46%) and integrated acceleration (−42%). The peak of the resonance frequency was reduced in the Fourier spectral analysis. There were no significant differences between the 2 products.

DISCUSSION

In 1992 Hennig et al[16] investigated the influence of different tennis rackets on forearm vibration. Their findings were similar, as they reported an intraindividual reduction of peak-to-peak acceleration and acceleration integrals between wrist and elbow of approximately 75% to 80% but high variability of peak-to-peak acceleration and integrated acceleration among different individuals. The substantial re-
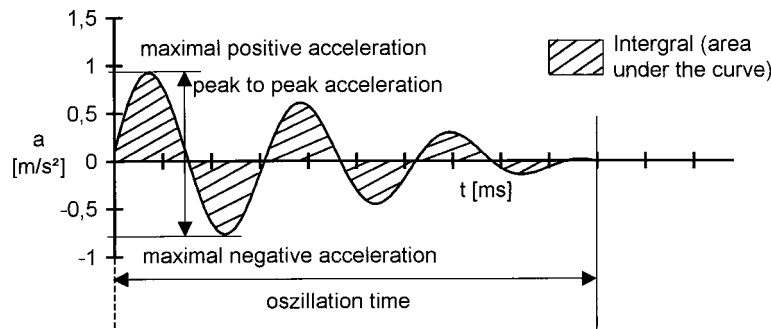
Figure 6 Integral of acceleration function.

Table I Mean quotient of peak-to-peak acceleration and integrated acceleration between wrist and elbow

		Peak to peak acceleration (g)		Integrated acceleration (U)	
		Quotient elbow/wrist	S_x	Quotient elbow/wrist	S_x
Clasp	Without brace	0.27	0.052	0.22	0.032
	EpiPoint	0.24	0.043	0.21	0.030
	Epimed	0.23	0.041	0.21	0.041
Pad at epicondyle	Tricour	0.20	0.033	0.18	0.037
	Epitrain	0.21	0.029	0.17	0.026
Pad at forearm	Coopercare	0.14	0.045	0.13	0.039
	Ofacare	0.15	0.037	0.13	0.041

duction of vibration between the distal part of a limb and the proximal part corresponds to similar findings in walking.[23]

It can be argued that fixing accelerometers to the skin with tape dressings and an additional elastic bandage wrapped around the forearm interferes with its mechanical characteristics. However, earlier investigations by Hennig and LaFortune[15] and Knudson and White[19] have shown this kind of fixation for accelerometers to be suitable for analyzing vibration and acceleration. Moreover, an unchanged fixation was used in the set-up with and without a brace, so if there was interference, it should have been constant throughout the entire experiment.

Grip tightness and the location of the hand on the grip are known to influence racket vibration.[7,14] These parameters were controlled by the accelerometer placed at the grip of the tennis racket. Reproducible results of this parameter lead us to believe that they are constant for any 1 person over time. For a racket with its handle clamped, it has been demonstrated that the further ball impact occurs away from the location of the "sweet spot," the more the oscillation amplitude of the racket will increase.[6] The highest reproducibility of acceleration amplitude and integrated acceleration for a player was found for impacts that were classified as ideal. Because the goal was primarily to provide a standardized stress to the racket-arm complex, the mean of 5 ideal impacts was

taken for further calculation. The reproducibility for ideal impacts was high for any 1 person, having a variation of acceleration of less than 10%. However, the peak-to-peak acceleration was approximately 3 times higher for off-center impacts. A similar difference in load between "sweet spot" impacts and off-center impacts was also found by Hennig et al.[16]

Besides the peak-to-peak acceleration, which represents the maximum load, the integrated acceleration gives additional information. Analyzing the amplitudes of acceleration signals, it was observed that some of the braces with excellent damping properties produce similar high first acceleration amplitudes compared with those with poor damping properties. The integral of the acceleration signal represents both amplitude and duration of the acceleration signal.

Although the racket-arm system performs a dampened oscillation,[3,4] the braces tested did not influence the acceleration of the wrist or racket. The measured acceleration at the wrist seems to be determined exclusively by the mechanical parameters of the racket, the playing skills, and the grip strength.[16] This view is shared by Brody,[7] who concluded that most of the oscillation energy has to be taken by the hand to dampen the vibration of the racket in a short time.

The clasp-based brace systems (Figure 1) had a slight reduction in peak-to-peak acceleration and integrated acceleration. In one product there was a nonsignificant change in the resonance frequency of

Table II Statistical analysis of differences in quotient elbow/wrist (Kruskal-Wallis test)

			Integrated acceleration						
				Clasp		Pad at epicondyle		Pad at forearm	
			Without	EpiPoint	Epimed	Tricour	Epitrain	Coopercare	Ofacare
Peak to peak		Without	—	NS	NS	$P<.01$	$P<.01$	$P<.01$	$P<.01$
	Clasp	EpiPoint	NS	—	NS	$P<.01$	$P<.01$	$P<.01$	$P<.01$
		Epimed	NS	NS	—	$P<.05$	$P<.05$	$P<.05$	$P<.05$
	Pad at epicondyle	Tricour	$P<.05$	$P<.05$	$P<.05$	—	NS	$P<.05$	$P<.05$
		Epitrain	$P<.05$	$P<.05$	$P<.05$	NS	—	$P<.05$	$P<.05$
	Pad at forearm	Coopercare	$P<.05$	$P<.05$	$P<.05$	$P<.05$	$P<.05$	—	NS
		Ofacare	$P<.05$	$P<.05$	$P<.05$	$P<.05$	$P<.05$	NS	—

NS, Not significant.

+5 Hz ($P < .2$) in the Fourier spectral analysis compared with the situation without a brace. There were no significant differences between the 2 clasp-based products. The effect of a clasp type brace on acceleration amplitude and oscillation duration can be categorized as marginal. However, the results of this study are limited by the number of test subjects. Perhaps with a larger number of test subjects, it would be possible to identify significant differences for clasp type braces.

In braces with pads placed at the lateral epicondyle (Figure 2), the peak-to-peak acceleration and the integrated acceleration were reduced ($P < .05$). A reduced peak of the dominant frequency was found in the Fourier spectral analysis. Again, no difference between the products was found.

Braces with pads placed at the forearm distal to the lateral epicondyle (Figure 3) had the highest reduction of peak-to-peak acceleration. The oscillating time was approximately 30% to 40% shorter within individuals, but with a high variability among different players. The racket-forearm complex can be regarded as a dampened harmonic oscillator.[3,13] This type of brace seems to interfere highly with the oscillation properties, resulting in a lowered peak of the resonance frequency in the Fourier spectral analysis, similar in both products. However, the principle of acceleration reduction at the lateral epicondyle is not shared by all manufacturers and, therefore, is not accomplished in their products.

Conclusions

Conservative treatment of patients with lateral epicondylitis requires limitation of repetitive stress to the common extensor origin.[2] It seems reasonable to consider the effectiveness of a brace in reducing load at the lateral epicondyle as one of its quality criteria. The data show that the influence of a brace on load at the lateral epicondyle depends on the characteristics of the product. Pad-based braces result in a much higher reduction of load at the lateral epicondyle than braces with the principle of a clasp. Placing a pad at the forearm, distal to the lateral epicondyle, seems to be superior to placing pads directly at the lateral epicondyle.

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