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A vascular basis for repetitive strain injury

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Abstract

Objective. The blanket term 'repetitive strain injury' (RSI) covers a wide variety of work-related clinical syndromes, most of which are localized lesions. However, some patients complain of diffuse forearm pain, a clinically distinct form of RSI, the aetiology of which is unknown.

Methods. Using Doppler ultrasound, we measured the vascular responses to muscular work in the radial artery in 13 patients with bilateral diffuse forearm pain, seven with unilateral diffuse pain and 19 controls with localized arm pain.

Results. We found that in diffuse forearm pain the radial artery is relatively constricted compared to the controls and fails to vasodilate with exercise, which suggests that diffuse forearm pain may be due to physiological claudication of the working forearm muscle.

Conclusion. A possible explanation is inhibition of local endothelial nitric oxide function, and this may be an unusual secondary, but self-perpetuating, pain condition which can follow other more specific, but chronic, arm pain syndromes in susceptible individuals.

KEY WORDS: Diffuse repetitive strain injury, Inhibited local vascular responses, Endothelial nitric oxide.

Although work-related arm pain has been known for centuries, it was from Australia in the early 1970s that the concept of repetitive strain injury (RSI) arose [1], when it was defined as 'a collective term for a range of conditions characterized by discomfort or persistent pain in muscles, tendons or other soft tissues, with or without physical manifestations, caused by or aggravated by work of a repetitive nature' [2], but the catch-all nature of this description, with its emphasis on causation rather than diagnosis, has discouraged clinicians from investigating these disorders further.

Patients with work-related arm pain can be clinically subdivided into those with a local and definable condition, such as epicondylitis or carpal tunnel compression, and those with diffuse and often progressive forearm symptoms where the pain and disability cannot be readily attributed to a specific local lesion. This study was undertaken to investigate whether the latter, which we have called 'diffuse forearm pain syndrome' (dfps), could be related to local vascular abnormalities, since the muscle pain and rapid fatiguing on exercise were suggestive of ischaemia. Keyboard operators with arm pains have been shown to have colder arms than controls in thermographic studies [3].

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Study

Patients

Patients referred to the rheumatology clinic at the University Hospital of Wales with arm symptoms attributable to repetitive work were invited to take part in the study and gave their informed consent. 'Attributable to work' meant that patients were involved in tasks requiring long periods of repetitive arm action, and that their symptoms were made worse by undertaking such activity. Thirty-nine subjects (34 female, five male), with an age range of 18–55 yr, were included, the majority VDU operators. Patients smoking more than five cigarettes per day were excluded, and in practice almost all were non-smokers. All were in good health in all other respects with no identifiable cause for their symptoms other than their working practices.

The duration of symptoms varied from 4 yr to 9 months and all patients with dfps were unable to continue with their original work. No long-term medication, except analgesics or low-dose non-steroidal anti-inflammatory drugs (NSAIDs), were being taken. A common feature was work stress, usually of recent origin. Symptoms could be either unilateral or bilateral, according to the nature of the work, but the arm symptoms were identical in both situations. Although the primary aim of the study was to evaluate dfps in a work-related context, this syndrome has also appeared in other situations, indicating this may be a secondary pain phenomenon which can be triggered by other painful stimuli.

Clinical definitions

Dfps—a clinically definable complaint of diffuse chronic pain in the forearm, unilateral or bilateral, of gradual onset, in the presence of an otherwise clinically normal hand and forearm, rapidly worsening on usage to a point at which the patient is obliged to stop. The symptoms may then subside to a background level, but can affect sleep and affect all other activities requiring use of the arm. Symptoms such as tingling, colour change, numbness, swelling and diffuse tenderness in the forearm are variably present. Since the hand is entirely normal in appearance and mobility, as well as being virtually painfree, dfps differs from reflex sympathetic dystrophy (RSD) where a painful, stiff and often discoloured hand is usual. In six patients, technetium bone scans were performed. Pooling was found in the early vascular phase, but no increased bone uptake in the third phase, as would be expected in RSD. We feel that these two conditions, although both may be secondary regional pain syndromes, are separate entities. Patients were classified into three groups.

Group 1 (19 patients): control group, localized arm pain. Any specific local chronic painful condition of the arm such as epicondylitis (2), tenosynovitis including de Quervain's syndrome (2), joint and ligament strains (2), carpal tunnel compression syndrome (4), degenerative joint disease of thumb (2), focal muscle dystonia (1), local muscle injury (1), fibromyalgia (1), and referred pain from the shoulder or trapezius (2), but not RSD or inflammatory joint disease. In two patients, the diagnosis was not identified.

Group 2 (seven patients): unilateral dfps. Two patients had a history of uncomplicated forearm fracture, one an acute tenosynovitis, as triggering events but all had the symptoms of dfps as described above. The rest were work related.

Group 3 (13 patients): bilateral dfps. One patient who was unable to work because of dfps was included, but without a history of repetitive work. She was taking cabergoline (Dostinox), an ergometrine derivative, for a prolactinoma. In the others, the symptoms of dfps were all work related.

Methods

Blood flow rate and arterial diameter were measured by Colorflow Doppler ultrasound scanning (Toshiba Powervision) with a 7.5 MHz linear array transducer. This technique is in routine local use for the evaluation of vascular disease, including peripheral arteriopathies and Raynaud's phenomenon. The procedures were standardized and carried out blind by the same experienced physicist or specialist research nurse. After resting for 10 min at room temperature, the blood flow in millilitres per minute at the radial artery at the wrist at rest is measured in the right arm, being calculated automatically from the product of the arterial diameter, the angle of the transducer relative to the artery and the mean flow rate. The arterial diameter can be seen on the visual display, enlarged $\sim$10-fold, and the record is produced as a waveform which is recorded photographically and used for the blood flow calculations. The radial artery was chosen for its ease of access and was taken as being indicative of muscular blood flow in the forearm as a whole. The same operator (NP) carried out all the tests.

Using a rubber bulb-operated grip strength meter, the maximum grip is recorded, then the patient asked to squeeze the bulb at a rate of $\sim$40 times/min for 3 min or until the pain obliges them to stop, to about half their indicated initial maximum grip strength each time. Immediately after cessation of the exercise, the blood flow is measured again, and the exercise repeated on the left arm.

In a supplementary study, seven patients with dfps took part in another standard blood flow test in which the arterial diameter of the brachial artery at the elbow is measured in a similar manner to that described above. The technique has been described in detail elsewhere [4], but in summary after the initial reading a blood pressure cuff is put over the forearm, inflated to arterial pressure, deflated after 5 min, and the arterial diameter again measured. This test is in routine local use for evaluating endothelial nitric oxide (eNO) activity in cardiovascular disorders, and these results have been compared with age- and sex-matched normal controls from published data, from the source, i.e. same operator, method and equipment [5], but not otherwise part of this study.

Data are shown as radial artery diameter (Table 1) and blood flow (Fig. 1) at rest and after exercise, in six groups, namely:

1. Group 1a, left arm; Group 1b, right arm.
2. Unilateral dfps: Group 2a, asymptomatic arm; Group 2b, painful arm.
3. Bilateral dfps: Group 3a, left arm; Group 3b, right arm.

It can be seen that the results in Groups 1a, 1b and 2a are very similar to each other, as are 2b with Groups 3a and 3b. For further analysis, the first three have been combined as 'control data' and the latter three as 'dfps data'.

Results

Four consistent differences were found between patients with dfps compared with the controls (Table 1): (1) the mean resting artery diameter was much smaller, indicating a relative vasoconstriction; (2) there was minimal vasodilatation on exercise; (3) exercise-related blood flow increase was much less; (4) there was no correlation between diameter and blood flow in the dfps group ($r^2 = 0.008$, $t = 0.5$, not significant), while there was good correlation in the control group ($r^2 = 0.4$, $t = 6.3$, $P < 0.001$). Blood flow is highly dependent on arterial diameter, resistance to flow being inversely proportional to radius [4], so this loss of relationship is unexpected. Dfps patients who underwent the ischaemia/reperfusion test showed a reduced vasodilatation response to this

TABLE 1. Changes in diameter (mm) and blood flow (ml/min) in the six groups of patients as described. Data are expressed as mean and S.D.

	Group					
	1a Localized pain, left arm	1b Localised pain, right arm	2a Asymptomatic arm	2b Painful arm	3a dfps left arm	3b dfps right arm
Resting diameter (mm)	1.88 ± 0.31	1.91 ± 0.40	1.90 ± 0.44	1.69 ± 0.41	1.63 ± 0.52	1.63 ± 0.53
Post-exercise diameter (mm)	2.24 ± 0.35	2.33 ± 0.40	2.14 ± 0.43	1.64 ± 0.30	1.56 ± 0.41	1.55 ± 0.50
% change	19.30	22.30	13.90	−0.20	−0.17	−3.60
Resting blood flow (ml/mm)	9.21 ± 7.8	10.75 ± 11.11	11.38 ± 11.05	7.61 ± 6.73	6.65 ± 4.71	4.45 ± 3.34
Post-exercise blood flow (ml/min)	29.42 ± 11.67	31.79 ± 16.14	27.15 ± 19.67	7.77 ± 6.33	9.83 ± 6.77	9.55 ± 5.25

t-test values, combined results.

Groups 1a, 1b and 2a (pooled control data) *vs* 2b, 3a and 3b (pooled dfps data): resting mean diameters (mm) 1.89 *vs* 1.62 ($P = 0.012$); post-exercise mean diameters (mm) 2.25 *vs* 1.58 ($P < 0.0001$).

Groups 1a, 1b and 2a (pooled control data) *vs* 2b, 3a 3b (pooled dfps data): resting mean blood flow 10.2 ml/min *vs* 6.02 ($P = 0.03$); post-exercise mean blood flow 29.9 ml/min *vs* 9.25 ($P < 0.0001$).

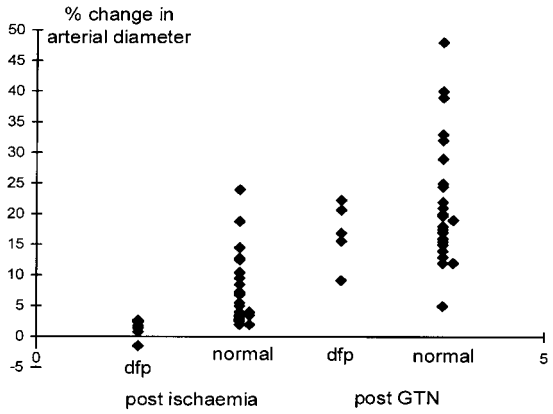

FIG. 1. Changes in arterial diameter in seven patients and controls following ischaemia and glyceryl trinitrate (GTN). Seven patients with dfps compared with normal controls tested for eNO responsiveness by the ischaemia/reperfusion test. Controls were not part of the current study, but from an age/sex-matched control group using the same operator, equipment and conditions.

test as well (Fig. 1), although all responded normally to inhaled glyceryl trinitrate (GTN).

We were concerned that the data might be influenced by patients failing to exert maximum grip strength, but we found that there was no significant difference between the mean grip strength exerted by each of the three groups. Also, the resting diameters and the post-ischaemia/reperfusion data are outside the patient's control, so the results are consistent.

Discussion

Arm pain in those engaged in repetitive tasks is as old as industry itself, but has rediscovered and renamed itself on many occasions. In Japan, it is called occupational cervicobrachial syndrome [6], in Australia and New Zealand RSI, in the USA national cumulative trauma disorder [7] and in the UK work-related upper limb disorder [8], but the terminology remains confusing since it is based on the cause rather than the nature of the complaint. In 1977, Hadler [9] coined the term industrial rheumatology to bring some clinical logic to work-related disorders, but many clinicians and lawyers, given the lack of unambiguous pathological data, deny the existence of RSI at all [10]. In spite of this, the concept of RSI remains in the public consciousness and the best that clinicians can do is to realize its limitations and add as specific a clinical description as possible to individual situations.

Dfps has been described in other papers on work-acquired arm pain [11, 12], but usually lumped together with other arm pains rather than being considered separately [13]. By defining dfps as a clinically specific entity, it has been possible to examine it for reproducible physiological abnormalities, and by evaluating the vascular response to exercise in real time with a simple and non-invasive technique, a new diagnostic approach to this condition is possible, based not on appearance or parameters at rest, but on the arm's dynamic response to specific exercise. We have shown that although the arm is clinically normal at rest, there is a substantial and reproducible physiological abnormality in both the resting artery and in its response to exercise. Patients with dfps develop progressive and disabling pain in the forearm muscles identical to the symptoms of claudication seen under other, better known, circumstances. This observation, taken with the demonstrated failure in appropriate vasodilatation, suggests that dfps may be due to physiological claudication.

This may be a secondary phenomenon which can be triggered by a variety of painful conditions in the forearm. In most cases, dfps is associated with prolonged muscle fatigue and overuse, but some patients had a specific acute pre-existing arm lesion, two a definite but uncomplicated injury, one an acute tenosynovitis. Support for a vascular phenomenon is suggested by the one patient who was taking cabergoline, with the same work-related arm pain as the others in the group.

While physiological claudication is a logical explanation of the work-related crescendo pain, the situation is more complex since patients also complain of a chronic resting pain and, usually at night, of episodes when their hands are hot, oedematous and red. The latter situation may be due to inappropriate reflex vasodilatation,

possibly the explanation of the hot areas seen in the blood pool phase of the technetium bone scan in this condition. This implies, as does the normal GTN response, that the artery is capable of vasodilating, but is being inhibited from doing so under specific pain-related circumstances.

It is possible that eNO dysfunction is the key to all the abnormalities found in patients with dfps. eNO is the essential local vasodilator, synthesized in the vascular endothelium by nitric oxide synthase (NOS 111) in response to increased local blood flow and pulsatility, and is the basic mechanism for maintaining efficient blood flow in local vasculature. In its absence, the resting artery constricts and organ perfusion is patchy and inefficient [14, 15]. If eNO vasodilates the artery in response to increased blood flow, then its loss could also explain the absence of the expected relationship between blood flow and artery diameter in dfps. eNO dysfunction occurs in several atherogenic disorders [16] such as diabetes, smoking and hypercholesterolaemia, as well as cardiac syndrome X [17], none of which applied to our patients. Although eNO dysfunction, possibly due to pain-related inhibition of NOS 111, is thus an attractive and unifying explanation for dfps, this remains unproven and the neurophysiological pathways unknown. Since dfps can exist unilaterally, it appears to be an acquired local defect, not an inherent one.

While it is clear that dfps can be initiated by a variety of painful triggers, ischaemic muscle itself is a further potent cause of chronic pain. This may be the basis of a pain/ischaemia/pain feedback mechanism, responsible for the chronicity of this syndrome.

Management of this condition is difficult due to the complex triggers involved and patients rarely return to their original jobs. Early recognition prior to the condition becoming chronic therefore becomes important, as three patients with well-established dfps retested a year later remained unchanged. Demonstration of this abnormal response, however, gives a further approach for therapeutic intervention, as well as demonstrating that a traditionally subjective complaint can be attributed to a reproducible physiological abnormality.

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