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# Science and medicine of rowing: A review

ROY J. SHEPHARD*

*Faculty of Physical Education & Health and Department of Public Health Sciences, Faculty of Medicine, University of Toronto and Health Studies Programme, Brock University, St. Catherines, Ontario, Canada*

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The biology and medicine of rowing are briefly reviewed. Effort in a 2000-m race is about 70% aerobic. Because the boat (and in some instances a cox) must be propelled, successful competitors are very tall, with a large lean mass and aerobic power. Large hearts may lead to erroneous diagnoses of a cardiomyopathy. Large respiratory minute volumes must be developed by chest muscles that are also involved in rowing. The vital capacity is typically large, and breathing becomes entrained. Expiration cannot be slowed relative to inspiration (as normally occurs at high rates of ventilation) and the limiting flow velocity may be reached, with the potential for airway collapse. Performance is strongly related to the power output at the 'anaerobic threshold', and lactate measures provide a guide to an appropriate intensity of endurance training. Peak blood lactate levels are higher in males (commonly 11–19 $\text{mmol}\cdot\text{l}^{-1}$ and occasionally as high as 25 $\text{mmol}\cdot\text{l}^{-1}$) than in females (9–11 $\text{mmol}\cdot\text{l}^{-1}$), probably because males have a greater muscle mass in relation to blood volume. The skeletal muscles are predominantly slow twitch in type, developing an unusual force and power at low contraction velocities. Many rowers have a suboptimal diet, eating excessive amounts of fat. Lightweight rowers also have problems of weight cycling. Aerobic power and muscle endurance often change by 10% over the season, but such fluctuations can be largely avoided by a well-designed winter training programme. Injuries include back and knee problems, tenosynovitis of the wrist and, since the introduction of large blades, fractures of the costae.

*Keywords*: aerobic power, biomechanics, body build, efficiency, height, injuries, lactate, nutrition, training, vital capacity.

## Introduction

Rowing is not only a major competitive sport, but also a form of physical activity that can contribute substantially to both aerobic and muscular fitness. It also has a low injury rate (Budgett and Fuller, 1989). Reviews of the associated biology and medicine (Secher, 1983, 1990, 1992, 1993; Hagerman, 1984; Körner and Schwanitz, 1985) have come from only a few centres. Available information has been growing rapidly, indicating the need for an updated review. The present review summarizes recent data on body build, biomechanics, physiological characteristics, nutrition, training techniques and risks of injury in competitive rowers.

There are major differences in biological characteristics between rowers, kayakers and canoeists (Sidney and Shephard, 1973; Sklad *et al*., 1994); the selection of rowers emphasizes height, whereas that of the kayakers and canoeists emphasizes muscular development. This review is thus restricted specifically to rowers. Even within this narrower category, there are some differences in the biological demands of sweep and sculling boats, and the need for a massive body build is increased if the craft carries a cox (Secher, 1990).

## Body build

Rowing is a weight-supported sport. Nevertheless, the resistance to forward movement of the boat is approximately proportional to the 2/3rd power of the weight of the vessel and its crew members (Secher, 1990). Except in competitions with a specific weight-limitation (the lightweight categories, a maximum body mass of 72.5 kg for males and 59 kg for females), it is advantageous to recruit rowers with a massive body build, thereby ensuring that a high proportion of the total mass transported is active muscle, rather than the 'dead-weight' of the cox and the vessel itself.

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* Address all correspondence to Roy J. Shephard, PO Box 521, Brackendale, British Columbia V0N 1H0, Canada.

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Various attempts have been made to determine the relationship between body dimensions, muscle power and aerobic power. Theoretical analyses in general have suggested a relationship to the second power of standing height (Asmussen and Christensen, 1967), or the 2/3rd power of body mass (Secher, 1992), but empirical observations over the period of growth have implied that aerobic power increases approximately as a cubic function of stature (Shephard *et al.*, 1980). Whether the relationship is quadratic or cubic, it is an advantage for the rower to be tall. Long arms are particularly helpful in giving extra leverage (Stein *et al.*, 1983). Ideally, the body mass should contain a high proportion of muscle; Russo *et al.* (1992) found a high body density in rowers. Perhaps because it is difficult to combine muscularity with leanness, a number of the teams sampled have also carried a substantial amount of body fat (for example, 16.8% in the men examined by de Pauw and Vrijens, 1971; 11% in men and 14% in women in the series of Hagerman *et al.*, 1979; 13.6–29.3% in the elite female rowers of Pacy *et al.*, 1995; and a mean of 20.4% in the male Masters athletes studied by Kavanagh *et al.*, 1989). Nevertheless, the percentage of body fat seems to have been decreasing in recent years. Carter (1982a,b) found means of 7.8% in men and 15.2% for women participating in the Montreal Olympics, and McKenzie and Rhodes (1982) reported a mean of 9.6% for the Canadian Olympic team.

Secher (1990) assembled descriptive data on a substantial sample of rowers, drawn from 14 laboratories. In the men, the FISA champions were 10.0% taller and 27.2% heavier than the general Canadian population, and in women the corresponding differences were 6.8% and 18.7% (Shephard, 1986). Hirata (1979) also pointed out that gold medal winners were consistently taller and heavier than the average for national champions; in the case of the single sculls, the respective differences were a substantial 0.12 m and 9.6 kg. Khosla (1983) noted that the heights required for competitive success were unlikely to be found among Asian, African and Latin American populations, thus calling into question the fairness of international competitions.

Comparing the different classes of boat, Hirata (1979) found that sweep rowers were consistently taller and heavier than scullers, the difference amounting to some 0.02 m and 3.8 kg for men, and 0.035 m and 3.5 kg for women. In competitions where a cox was carried, there were further small increases in the height and body mass of the successful rowers, 0.03 m and 5.0 kg in the case of male pairs (Hirata, 1979).

In the series of Secher (1990), the advantage the 'experienced' male rowers had over the general population (5.5% for height and 1.0% for body mass) was much smaller than for national and international competitors. Williams (1976) and Hollings *et al.* (1989) also found few differences in the anthropometric characteristics of elite and colt athletes in New Zealand, and there were few differences in the physical characteristics of the general population and a small group of 20-year-old rowers from Northern Italy (Russo *et al.*, 1992).

Additional data, mainly accumulated since Secher's (1990) review, are summarized in Table 1. Carter (1982a,b) suggested that the body dimensions of national level contestants were increasing by about 0.02 m and 5 kg per decade. The conclusions regarding elite competitors have changed little with more recent research, except that the women may now be a little heavier. Successive years have nevertheless brought a progressive improvement in rowing speeds, averaging some 0.2% per year; this reflects in part an improvement in the design of boats and competitive courses, the introduction of big blades (around 1992) and enhanced training and preparation (Secher, 1973). Given the lack of change in body size, it seems that a more rigorous process of selection has contributed little to this advance.

In men, the gap between the size of the national and the 'experienced' competitors remains (Table 1), but perhaps because the national competitors are less rigorously selected among the women, they are almost identical with the 'experienced' group.

Malina (1994) noted that promising rowers were already taller than the general population during childhood, and that they maintained their relative advantage throughout adolescence. The most able young rowers could be distinguished by their height, skeletal robustness and muscular development (Piotrowski *et al.*, 1992). Wright *et al.* (1977) pointed out that, based on the criteria of lean mass, strength, vital capacity and aerobic power, junior rowers were some 10% worse than their adult counterparts. Nevertheless, they argued that further training rather than continued growth or better selection of competitors would be required to make good this deficit. In support of this view, Sklad *et al.* (1993) found that a year of intensive training increased arm and chest circumferences, and relative body mass, in 41 male and 18 female rowers aged 17–18 years.

The body build of a previous generation of rowers, as seen in Masters competitors (Kavanagh *et al.*, 1989; Wiener *et al.*, 1995), is somewhat less favourable than the 'experienced' category of Secher (1990). This is true in particular in the case of the women.

The physical characteristics of lightweight rowers differ radically from those of their heavier peers (Mahler *et al.*, 1984; Burge *et al.*, 1993). Indeed, in male competitors, de Rose *et al.* (1989) found no differences from student controls. Nevertheless, many competitors in this group still have a very high absolute aerobic power.

**Table 1** Mean height, body mass and aerobic power of various categories of rowers (number of observations in parentheses)

| Category/authors | Height (m) | Body mass (kg) | $\dot{V}O_{2max}$ ($l \cdot min^{-1}$) |
|---|---|---|---|
| **Men** | | | |
| *FISA champions* | | | |
| Secher (1990) | 1.93 (18) | 94 (18) | 6.1 (41) |
| *National class* | | | |
| Di Prampero *et al.* (1971) | 1.89 (5) | 85 (5) | 5.0 (5) |
| Williams (1976) | 1.86 (42) | 85 (42) | |
| Hirata (1979) | | | |
| single scull | 1.89 (17) | 88 (17) | |
| double scull | 1.86 (28) | 83 (28) | |
| four scull | 1.86 (48) | 83 (48) | |
| coxless pairs | 1.88 (38) | 86 (38) | |
| coxless fours | 1.88 (59) | 88 (59) | |
| coxed pairs | 1.91 (28) | 91 (28) | |
| coxed fours | 1.89 (52) | 90 (52) | |
| coxed eights | 1.89 (91) | 88 (91) | |
| McKenzie and Rhodes (1982) | 1.93 (8) | 93 (8) | |
| Danuser and Buhlmann (1983) | 1.84 (16) | 80 (16) | |
| Sanderson and Martindale (1986) | | 85 (1) | |
| Biersteker *et al.* (1986) | 1.90 (9) | 87 (9) | |
| McCully *et al.* (1989) | 1.90 (6) | 89 (6) | |
| de Rose *et al.* (1989)* | 1.91 (65) | 90 (65) | |
| Secher (1990) | 1.92 (538) | 88 (545) | 6.0 (535) |
| Fischer *et al.* (1992) | | 90 (24) | |
| Tittel and Wutscherk (1992) | 1.93 | | |
| Hartmann *et al.* (1993) | 1.95 (81) | 93 (84) | |
| Roth *et al.* (1993) | 1.92 (16) | 90 (16) | |
| Peltonen *et al.* (1995) | 1.87 (6) | 80 (6) | |
| Total | 1.91 (1153) | 89 (1178) | |
| *Experienced* | | | |
| Wright *et al.* (1976) | 1.82 (13) | 85 (13) | 4.8 (13) |
| Mester *et al.* (1982) | 1.88 (10) | 78 (10) | |
| Martindale and Robertson (1984) | 1.92 (2) | 88 (2) | |
| Koutedakis and Sharp (1985) | 1.85 (7) | 81 (7) | |
| Fukunaga *et al.* (1986) | 1.74 (5) | 67 (5) | 3.9 (5) |
| Bell *et al.* (1989) | 1.82 (15) | 78 (15) | 4.5 (15) |
| Brien and McKenzie (1989) | 1.87 (6) | 82 (6) | |
| Poortmans *et al.* (1990) | 1.79 (12) | 72 (12) | |
| Roy *et al.* (1990) | 1.88 (23) | 83 (23) | |
| Secher (1990) | 1.85 (14) | 82 (16) | 4.7 (30) |
| Chènier and Lèger (1991) | 1.78 (7) | 74 (7) | 4.8 (7) |
| Russo *et al.* (1992) | 1.76 (19) | 70 (19) | |
| Hanel *et al.* (1993) | 1.86 (8) | 81 (8) | |
| Lakomy and Lakomy (1993) | | 80 (11) | 4.7 (11) |
| Lormes *et al.* (1993) | 1.83 (6) | 73 (6) | |
| Snegovskaya and Viru (1993) | 1.92 (30) | 90 (30) | |
| Steinacker *et al.* (1993a) | 1.92 (5) | 85 (5) | |
| Cohen *et al.* (1995) | 1.83 (17) | 74 (17) | |
| Nielsen *et al.* (1995b) | 1.82 (6) | 75 (6) | |
| Oda and Moritani (1995) | 1.79 (25) | 74 (25) | |
| Stupnicki *et al.* (1995) | | 91 (41) | 5.6 (41) |

**Table 1** (contd)

| Category/authors | Height (m) | Body mass (kg) | $\dot{V}O_{2max}$ ($l \cdot min^{-1}$) |
|---|---|---|---|
| Beneke (1995) | 1.87 (9) | 81 (9) | |
| Beneke and von Duvillard (1996) | 1.89 (11) | 83 (11) | |
| Jensen *et al.* (1996) | 1.85 (28) | 79 (28) | 5.3 (28) |
| Marriott and Lamb (1996) | 1.87 (9) | 82 (9) | |
| Total | 1.84 (287) | 81 (341) | 4.96 (122) |
| *Lightweight* | | | |
| Mahler *et al.* (1984) | 1.83 (12) | 72 (12) | |
| Secher (1990) | 1.86 (130) | 71 (130) | 5.1 (147) |
| de Rose *et al.* (1989) | 1.77 (20) | 70 (20) | |
| Burge *et al.* (1993) | 1.82 (8) | 73 (8) | 4.7 (8) |
| Raymond *et al.* (1994) | 1.76 (9) | 72 (9) | 4.3 (9) |
| Total | 1.84 (179) | 71 (179) | 5.08 (192) |
| *Junior* | | | |
| Wright *et al.* (1977) | 1.89 (5) | 80 (5) | 4.6 (5) |
| Sanderson and Martindale (1986) | | 91 (1) | |
| Steinacker *et al.* (1993b) | 1.92 (19) | 84 (19) | |
| Stupnicki *et al.* (1995) | | 87 (14) | |
| Zdanowicz *et al.* (1993) | 1.75 (6) | 65 (6) | 5.0 (6) |
| Total | 1.88 (30) | 82 (45) | 4.82 (11) |
| *Masters* | | | |
| Kavanagh *et al.* (1989) | 1.80 (38) | 81 (38) | 3.4 (38) |
| **Women** | | | |
| *National class* | | | |
| Hirata (1979) | | | |
| single scull | 1.75 (10) | 69 (10) | |
| double scull | 1.72 (22) | 66 (22) | |
| four scull | 1.75 (36) | 69 (36) | |
| coxless pairs | 1.75 (22) | 69 (22) | |
| coxed fours | 1.76 (33) | 71 (33) | |
| coxed eights | 1.77 (65) | 71 (65) | |
| Biersteker *et al.* (1986) | 1.76 (22) | 68 (22) | |
| Sanderson and Martindale (1986) | | 66 (1) | |
| Secher (1990) | 1.73 (40) | 68 (40) | 4.3 (52) |
| Khosla (1983) | 1.75 (187) | | |
| de Rose *et al.* (1989)* | 1.74 (51) | 67 (51) | |
| Mahler *et al.* (1991a) | 1.71 (21) | 65 (21) | 3.5 (210) |
| Vermulst *et al.* (1991) | 1.78 (6) | 71 (6) | |
| Tittel and Wutscherk (1992) | 1.77 | | |
| Fischer *et al.* (1992) | | 76 (12) | |
| Vervoorn *et al.* (1992) | 1.78 (6) | 71 (6) | |
| Hartmann *et al.* (1993) | 1.84 (20) | 76 (20) | |
| Pacy *et al.* (1995) | 1.78 (15) | 73 (15) | |
| Total | 1.73 (556) | 70 (382) | 4.1 (73) |

**Table 1** (contd)

| Category/authors | Height (m) | Body mass (kg) | $\dot{V}O_{2max}$ ($l \cdot min^{-1}$) |
|---|---|---|---|
| *Experienced* | | | |
| Mester *et al.* (1982) | 1.73 (10) | 65 (10) | |
| Clarkson *et al.* (1984) | 1.75 (10) | 75 (10) | |
| Martindale and Robertson (1984) | 1.71 (2) | 65 (2) | |
| Mahler *et al.* (1985) | 1.72 (7) | 70 (7) | 3.2 (7) |
| Sanderson and Martindale (1986) | | 65 (1) | |
| Mahler *et al.* (1987) | 1.74 (12) | 71 (12) | 3.2 (12) |
| Szal and Schoene (1989) | 1.76 (9) | 70 (9) | |
| Mahler *et al.* (1991b) | 1.73 (17) | 70 (17) | 3.4 (17) |
| Chènier and Lèger (1991) | 1.72 (7) | 64 (7) | 3.5 (7) |
| Bell *et al.* (1993) | 1.71 (20) | 65 (20) | 3.1 (20) |
| McCargar *et al.* (1993) | 1.73 (14) | 62 (14) | |
| Kramer *et al.* (1994) | 1.77 (20) | 73 (20) | 3.3 (20) |
| Hanel *et al.* (1993) | 1.74 (4) | 60 (4) | |
| Lormes *et al.* (1993) | 1.72 (5) | 64 (5) | |
| Stupnicki *et al.* (1995) | | 77 (25) | 3.1 (25) |
| Total | 1.74 (137) | 69 (163) | 3.23 (108) |
| *Lightweight* | | | |
| de Rose *et al.* (1989) | 1.68 (13) | 58 (13) | |
| *Junior* | | | |
| Stupnicki *et al.* (1995) | | 73 (15) | |
| *Masters* | | | |
| Wiener *et al.* (1995) | 1.67 (6) | 66 (6) | 2.2 (6) |

* Apparently identical with the series reported by Carter *et al.* (1982).

As in other forms of weight-categorized sport, there is a temptation for competitors to achieve their designated body mass by techniques more commonly discussed in the context of wrestling (Marquart and Sobal, 1994). Such practices are undesirable from the point of view of health, and attempts at rapid rehydration may fail to restore either aerobic power or muscle strength.

## Biomechanics

The energy cost of rowing is due largely to the drag and wind resistance opposing forward motion of the boat; this cost is proportional to around the third power of speed (Secher, 1990, 1993). There are also smaller frictional and gravitational costs associated with the motion of the body back and forth on the seat of the boat.

Depending on the skill of the rower, between a quarter and a third of the energy applied to an oar is lost in the flow of water around the blade (Affeld *et al.*, 1993). Further energy losses are incurred in balancing the vessel (Wagner *et al.*, 1993). Because drag bears a power relationship to vessel speed, oscillations of speed over the rowing cycle are a further source of inefficiency (Sanderson and Martindale, 1986). Such oscillations can be minimized by adopting a rapid stroke rate, but such an adjustment is limited by the maximum speed of muscle shortening (Celentano *et al.*, 1974).

Measurements made during actual and simulated rowing (Henry *et al.*, 1995) suggest a relatively high mechanical efficiency (typically in the range 16–24%: Hagerman, 1984; Fukunaga *et al.*, 1986; Lisiecki and Rychlewski, 1987; Steinacker, 1993). The figure is some 10% greater in an experienced rower than in a novice (Nelson and Widule, 1983).

Kinematic and electromyographic studies show that task learning leads to a longer stroke, a higher stroking rate, a better summation of joint forces and a more efficient recovery phase (Marr and Stafford, 1983). Competitive success is strongly influenced by the mean propulsive power per kilogram of body mass, stroke-to-stroke consistency and stroke smoothness (Deming *et al.*, 1992; Smith and Spinks, 1995). Novices also sustain electromyographic activity longer than experienced rowers (Daireaux and Pottier, 1983). A comparison of younger juniors, older juniors and seniors showed that, at the anaerobic threshold, the respective power outputs for males were 226, 258 and 316 W, and for females 153, 170 and 212 W (Zdanowicz *et al.*, 1992).

Telemetry has allowed recordings of the acceleration of the boat and the forces exerted on the oars (Ishiko, 1971). There are surprising variations in movement patterns even between top-level competitors. Paradoxically, the oxygen cost of rowing is proportional to the 2.24th power of speed rather than the third power, as might be predicted from drag force calculations (Lakomy and Lakomy, 1993), and changes in the oxygen content of inspired air have a larger effect upon maximal oxygen intake than upon rowing performance (Peltonen *et al.*, 1995). Over the range 37–41 strokes per minute, Olympic rowers achieve a greater boat speed at higher stroke rates; there is a greater application of force during the driving phase of the stroke, and force is exerted over a greater percentage of the entire stroke cycle (Martin and Bernfield, 1980).

Electromyography suggests that muscle groups are active in combination at most points during simulated rowing (Wilson *et al.*, 1988). Thus, in addition to building overall muscle strength, it is important for the rower to develop an effective coordination between upper and lower body reactions (Rodriguez *et al.*, 1990).

Bompa *et al.* (1985, 1990) demonstrated that the elbow flexors are able to develop a greater mechanical force if a semi-prone grip is substituted for the classical prone grip. Mechanical efficiency can be further improved by the use of a larger blade (Sanderson and Martindale, 1986).

## Physiological characteristics

The usual 2000-m rowing course demands high levels of both aerobic power and anaerobic capacity. Gayer (1994) found that peak power, the lactate threshold and lean body mass were the physiological characteristics that provided the best discrimination between successful and unsuccessful competitors. To this list, Kramer *et al.* (1994) added competitive experience and the coach's ranking. Anaerobic effort is particularly important during the initial spurt, and typically contributes 20–30% of the energy demand of a 2000-m race (Secher, 1990). In shorter events, the anaerobic contribution is proportionately greater.

Physiological issues that have attracted recent attention include methods of measuring aerobic power, cardiopulmonary function, blood lactate levels, muscle strength and fibre characteristics.

### *Methods of determining aerobic power*

Many early determinations of aerobic power used a non-specific methodology (for example, uphill treadmill running or cycle ergometry). Some authors have found that the peak oxygen intake and blood lactate values are similar following cycle ergometry and rowing ergometry (e.g. the study of female Masters athletes by Wiener *et al.*, 1995). However, non-specific tests are likely to underestimate the true maximal oxygen intake, especially in elite rowers (Bouckaert *et al.*, 1983). The overall peak power output of experienced competitors is often 10–16% higher in rowing than in cycling, presumably because rowing involves a larger active muscle mass (Nanshen, 1989; Beneke and von Duvillard, 1996).

The ideal method of testing is to measure oxygen consumption on the water, using either a Douglas bag (Jackson and Secher, 1976; Chènier and Lèger, 1991) or a modern telemetric oxygen consumption monitor (Kawakami *et al.*, 1992). Measurements of rowing can also be completed in a rowing tank (DiPrampero *et al.*, 1971; Hagerman and Lee, 1971).

Several designs of rowing ergometer are available. A kinematic comparison of rowing and rowing ergometry (Lamb, 1989) demonstrated some differences in arm and forearm movements, because 'feathering' of the oar is not needed on the ergometer; nevertheless, the dominant movements of the legs and trunk are similar for the two types of activity. There are also differences in internal work and energy exchange between ergometry and actual rowing (Martindale and Robertson, 1984), but rowing ergometers seem to yield closely similar aerobic power values to those obtained on the water (McKenzie and Rhodes, 1982; Hagerman, 1984; Mahler *et al.*, 1984; Chènier and Lèger, 1991; Kramer *et al.*, 1994). The heart rate–lactate relationship is also similar for the two forms of exercise, although the 'anaerobic threshold' is lower on the water, and mechanical efficiency is greater in actual rowing (Steinacker *et al.*, 1993a).

Jensen and Katch (1991) demonstrated that, if subjects lacked rowing experience, the force developed by the active muscles could be sufficient to impede local blood flow and thus restrict the subject's measured aerobic power. They redesigned the test protocol for their hydraulic rowing machine to ensure lower peak muscle forces, and they found that this change led to a substantial increase in the measured maximal oxygen intake.

When measured in absolute units, the aerobic power of rowers is high (6.0–6.6 $\text{l}\cdot\text{min}^{-1}$), but this is mainly an expression of their body size (Secher, 1983). Because the body mass is also large, the relative aerobic power is not particularly high except in lightweight rowers, when values may reach 75 $ml \cdot kg^{-1} \cdot min^{-1}$ (Howald, 1988). Given the skill requirements of rowing, individuals with very similar levels of maximal oxygen intake may differ widely in competitive performance (Steinacker, 1993).

### *Cardiovascular function and cardiac function*

The heart of a rower often shows substantial hypertrophy (Wieling *et al.*, 1981; Keul *et al.*, 1982; Jensen *et al.*, 1984), with increases of internal diameters and wall thicknesses. Pellicia *et al.* (1991) noted that 15 of 16 individuals with dimensions in the supposedly pathological range were either rowers or canoeists; some 7% of rowers had a left ventricular wall thickness exceeding the commonly cited normal limit of 13 mm.

Both Secher (1993) and Clifford *et al.* (1994) suggested that such hypertrophy was a consequence of what are essentially Valsalva manoeuvres, repeated with each rowing stroke. In the study of Clifford *et al.* (1994), the systolic pressure peaked at 192 mmHg, although the mean arterial blood pressure showed little increment (rising from 110 to 122 mmHg during 6 min of all-out rowing). Both arterial and central venous pressures developed large superimposed fluctuations, coincident with each stroke. Secher (1993) also reported peak systolic blood pressures of close to 200 mmHg. Kozera (1993) examined the electrocardiograms of 101 male and 52 female junior rowers. The most common findings were sinus bradycardia and left ventricular hypertrophy; occasionally, there were related disorders of intraventricular conduction.

Particularly in women, the stroke volume is smaller in rowing than in cycle ergometry, the values decreasing substantially as maximal effort is approached (Rosiello *et al.*, 1987). This presumably reflects problems in perfusing muscles that are contracting at a large fraction of their maximal voluntary force, as discussed above.

The observation of a very low pH in the gastric mucosa of rowers following 30 min of rowing ergometry (Nielsen *et al.*, 1995a) points to marked splanchnic hypoperfusion during this form of physical activity.

### *Pulmonary function and pulmonary dynamics*

Rowers sometimes develop a larger negative intrapleural pressure than is needed to achieve their required tidal volume. Biersteker *et al.* (1986) have suggested that rowers stabilize their thorax by taking an inspiration at the catch phase of their stroke. This action seems particularly important in women, and the resulting increase of lung compliance and reduction of elastic recoil predispose to expiratory collapse of the airways.

Very large respiratory minute volumes must be developed during competition, typically greater than 200 $l \cdot min^{-1}$ (McKenzie and Rhodes, 1982) and sometimes as high as 250–270 $l \cdot min^{-1}$. Selection thus favours rowers with large total lung and vital capacities (Donnelly *et al.*, 1991). Since pulmonary distensibility remains normal, the large static lung volumes seem a consequence of an increased number of alveoli rather than pulmonary distension. The importance of initial selection is suggested, since intensive training does not increase total lung capacity or vital capacity once adult stature has been attained (Danuser and Bühlmann, 1983).

Peak expiratory flow rates reach values of 15 $l \cdot s^{-1}$ in elite competitors, but some of these individuals also show a plateau in expiratory flow rates suggestive of airway collapse (Carles *et al.*, 1980; de Swiniarski, 1990; Steinacker *et al.*, 1993a). Attainment of a plateau of expiratory air flow appears to be particularly common in female competitors, possibly because the female body build requires greater fixation of the thorax during rowing (Biersteker *et al.*, 1986).

Smith *et al.* (1994) found that, during submaximal exercise, the ventilation for a given oxygen consumption was similar for rowing, cycling and treadmill running. However, the maximal ventilation observed during rowing was lower than for the other two modes of exercise; the difference was statistically significant for average performers, but not for elite rowers, suggesting that the latter group had at least partly overcome ventilatory limitations by heavy training.

*Entrainment of ventilation.* Entrainment of the ventilatory rhythm is particularly important in rowing, since the respiratory muscles not only serve the needs of ventilation, but also stabilize the thorax and assist in the generation of propulsive forces (Biersteker *et al.*, 1986; Mahler *et al.*, 1991a). Because of this complex role, and associated mechanical changes in the thorax, breathing rates are higher for a given intensity of submaximal effort during rowing than during cycling (Szal and Schoene, 1989).

Maclennan *et al.* (1994) found no reduction in the oxygen cost of breathing and no reduction in the perceived effort of breathing when untrained subjects undertook rowing at an entrained rather than a randomly selected breathing frequency. It remains possible that there are benefits to entrainment in highly trained competitors who develop a much higher peak oxygen intake and thus require a much greater respiratory minute volume. Mahler *et al.* (1991a) found entrainment at maximal effort in 7 of 9 elite female rowers but in only 3 of 10 less experienced rowers. Among the novices, the proportion of individuals showing entrainment increased as training developed (Mahler *et al.*, 1991b). Steinacker *et al.* (1993a) noted entrainment in all five of their male subjects. At moderate intensities of effort, inspiration accompanied one stroke, and expiration the next, but as the ventilatory demand increased and tidal volume approached the flat part of the compliance curve, there was a transition to a pattern of one breath per rowing cycle. Szal and Schoene (1989) also observed a change in entrainment, from 1 : 1 in the early stages of submaximal rowing to near 1 : 1.5 as maximum effort was approached, although in their series synchronization with the rowing stroke was less clearly established.

The rapid rates of exhalation that are required by rowers predispose to dynamic compression of the airway (as discussed above). Unfortunately, the breathing pattern imposed by the rowing cycle does not permit compensation by a shortening of inspiration and a lengthening of expiration.

Subjects who are late in making the transition to a higher entrainment ratio tend to under-ventilate, with a corresponding drop in arterial oxygen saturation and a rise in $pCO_2$ levels (Steinacker and Wodick, 1984; Szal and Schoene, 1989). Secher (1993) found a 20 mmHg decrease in arterial oxygen tension during all-out exercise, although he attributed this to a decrease in pulmonary diffusing capacity rather than an inappropriate choice of breathing frequency.

*Pulmonary diffusing capacity.* As in a number of other endurance sports, a bout of rowing is commonly followed by a 10–20% reduction in pulmonary diffusing capacity (Nielsen *et al.*, 1995b). The disturbance is accompanied by an increase in residual lung volume, and both changes may persist for 2–3 days (Rasmussen *et al.*, 1988); Rasmussen *et al.* (1988) blamed a transient pulmonary oedema. However, Hanel *et al.* (1993) have argued against either pulmonary oedema or a change in integrity of the pulmonary capillary wall, since the phenomenon can be detected after even a mild training session (sustained exercise at 61% of maximal oxygen intake). Pulmonary diffusing capacity reflects both membrane transfer and pulmonary capillary blood volume; Hanel *et al.* (1993) thus suggested that a fall in central blood volume may be responsible.

Since heavy exercise causes sub-clinical muscle trauma, a third theoretical possibility is an excessive inflammatory reaction, with the development of something akin to the acute respiratory distress syndrome. Against this hypothesis, there are no significant increases in plasma levels of endotoxin, interleukin-1-$\alpha$, interleukin-8 or tumour necrosis factor-$\alpha$ (Nielsen *et al.*, 1995b, 1996).

### *Anaerobic metabolism*

Sharp and Koutedakis (1987) used an arm ergometer to assess the anaerobic power and capacity of rowers. The blood lactate level of rowers has proved to be of particular interest, both as a guide to an appropriate training intensity and as a measure of the peak intensity of effort that is achieved under race conditions. Post-exercise lactate levels are influenced by pre-exercise cortisol concentrations, suggesting an influence of the initial hormonal milieu upon the proportion of anaerobic–glycolytic metabolism that is undertaken during exercise (Stupnicki *et al.*, 1995).

*Lactate and training intensity.* The ventilatory and anaerobic thresholds are sometimes used as guides to an appropriate intensity of training (e.g. Obuchowicz *et al.*, 1989; Zdanowicz *et al.*, 1993). The 'anaerobic threshold' (corresponding to a blood lactate concentration of 4 $\text{mmol} \cdot \text{l}^{-1}$) is reached at a power output that is some 10% higher than that which allows a full steady state (Beneke, 1995; Beneke and von Duvillard, 1996). The endurance capacity (the power output measured at a blood lactate concentration of 4 $\text{mmol} \cdot \text{l}^{-1}$) is one of the better predictors of competitive success (Wolf and Roth, 1987).

Measurements of the ventilatory and anaerobic thresholds should be made on specific apparatus such as a rowing ergometer, or preferably during actual rowing. Bunc and Leso (1993) demonstrated that, although the ventilatory threshold was only 75% of maximal oxygen intake when highly trained male rowers exercised on a cycle ergometer, it increased to 85% of maximal oxygen intake when similar measurements were made on a rowing ergometer.

There may also be differences between ergometers. Lormes *et al.* (1993) found higher lactate levels for a given heart rate on the Gjessing than on the Concept II rowing ergometer, possibly because of power losses in the transmission system of the Gjessing device. Urhausen *et al.* (1993) commented further that, at comparable lactate levels, heart rate was on average 10 $\text{beats} \cdot \text{min}^{-1}$ higher on the water than when operating a Gjessing ergometer. They thus advocated determining the relationship between heart rate and lactate under field conditions when setting an appropriate intensity of training.

Steinacker (1993) has cautioned that, if competitors are undertaking very high volumes of training (sometimes as much as 1000 h per year), even the anaerobic threshold can prove an excessive intensity of effort.

*Peak lactate levels.* Peak lactate levels should always be determined on well-rested and well-nourished competitors, since values can be influenced by both recent exercise and glycogen depletion. Rowing performance is influenced by the intramuscular rather than the plasma lactate concentration; this probably explains why plasma lactate levels diminished, but rowing ergometer performance was unchanged, when acidosis was induced by the ingestion of ammonium chloride (Brien and McKenzie, 1989).

The peak blood concentrations appear to be substantially higher in male competitors, both adults and juniors (typically 11–19 $\text{mmol}\cdot\text{l}^{-1}$ and occasionally as high as 25 $\text{mmol}\cdot\text{l}^{-1}$: Hagerman *et al.*, 1978; McKenzie and Rhodes, 1982; Urhausen *et al.*, 1986, 1987; Zdanowicz *et al.*, 1993; Sitkowski *et al.*, 1994), than in females (8.6 $\text{mmol}\cdot\text{l}^{-1}$: Vermulst *et al.*, 1991; 10.5 $\text{mmol}\cdot\text{l}^{-1}$: Wiener *et al.*, 1995). The main explanation is likely to be that men have a larger muscle mass relative to blood volume than women. Differences in active muscle mass are also a probable explanation of why the oxygen deficit is 36% larger during rowing than during treadmill running (Bangsbø *et al.*, 1993). The peak lactate concentrations reached by male competitors are inversely related to the proportion of slow twitch fibres in the active muscle groups (Steinacker, 1993).

Lactate clearance following a 2000-m race is faster if the athlete continues to exercise at 40% of maximal oxygen intake than if there is a reversion to total rest or exercise is continued at 60% of maximal aerobic power (Koutedakis and Sharp, 1985).

### *Muscle strength and fibre characteristics*

The muscles of well-trained rowers are able to develop an unusual force and power at low contraction velocities (Lormes *et al.*, 1990). In male world-class rowers, the power that is applied to the boat (as calculated from forward and lateral movement) averages about 420 W for a 6-min event, but may be as high as 650–990 W for the first five strokes (Steinacker, 1993). Based on the peak force recorded by a strain gauge and the corresponding velocity (Hartmann *et al.*, 1993), peak figures of 3230 W for men and 1860 W for women have been registered during the first 5–10 strokes on a Gjessing ergometer.

The muscle strength of the rower shows considerable specificity. Thus the oarside knee extensors are up to 6% stronger than the corresponding muscles in the contralateral limb (Kramer *et al.*, 1991). The percentage decline in muscle force during a sustained contraction is also less for the trained than for the untrained arm (Oda and Moritani, 1995).

The fibre characteristics of the rower are also highly specific, with a greater proportion of fast twitch fibres in stroke than in bow rowers (Roth *et al.*, 1993). Both fast and slow twitch fibres show substantial hypertrophy in the main muscles that contribute to rowing, but in men at least 70% of fibres have slow twitch properties, the proportion of slow fibres being greater in the more successful competitors (Steinacker, 1993). Female rowers apparently have a somewhat lower proportion of slow twitch fibres than men (Clarkson *et al.*, 1984), although the results for female contestants are older, and it also remains unclear whether this is the result of a lesser degree of selection among women competitors.

The capillary–fibre ratio is high in successful rowers. Such individuals also have high levels of aerobic enzymes. The glycolytic enzymes are not unusually developed, although both skeletal and cardiac muscle show high percentages of the LDH sub-types 1–3 (Hasart *et al.*, 1988).

## Nutrition

As in many sports, the existing diet of competitors points to the need for nutritional advice. Steen *et al.* (1995) found that a sample of 16 female collegiate heavyweight rowers reported an average daily energy intake of only 11 MJ, as compared with the estimated energy usage of 25–29 $\text{MJ}\cdot\text{day}^{-1}$ in male and 21–25 $\text{MJ}\cdot\text{day}^{-1}$ in female competitors (Körner and Schwanitz, 1985). Even allowing for some under-reporting, it is clear that these rowers were not eating enough, possibly in some instances in attempts to attain their weight category. Protein intake was apparently adequate, but the intake of fat was undesirably high relative to carbohydrate, and a significant proportion of the group were taking less than two-thirds of the recommended dietary intake of calcium, zinc and vitamins B6 and B12 (Steen *et al.*, 1995). Giampietro and Colombo (1991) also noted an excessive intake of animal fat among rowers.

If athletes are already taking the recommended daily quantities of minerals and vitamins, there seems little benefit in providing specific vitamin supplements (Telford *et al.*, 1992).

Given the substantial component of anaerobic work, there have been suggestions that rowing performance might be enhanced by boosting muscle creatine stores, but any benefit appears to be quite small. Rossiter *et al.* (1996) provided creatine supplements of 0.25 $\text{g}\cdot\text{kg}^{-1}$ on each of 5 days. An average creatine uptake of 3.5 $\text{mmol}\cdot\text{kg}^{-1}$ lean mass was estimated, and 16 of 19 experimental rowers increased their simulated 1000-m performance by an average of 1%. Whole-body creatine stores tended to show a significant relationship with performance ($r = 0.43$; $P < 0.088$).

Participants in lightweight rowing categories and those who wish to qualify for the position of cox face many of the problems of ‘making weight’ that are encountered in other weight-restricted sports (Clark, 1991). McCargar *et al.* (1993) noted that female lightweight rowers showed a 4–5 kg cycling of body mass as they prepared for competition. This did not appear to modify either basal metabolism or tri-iodothyronine levels. However, Burge *et al.* (1993) documented how a dehydration–rehydration schedule impaired maximal rowing performance relative to the euhydrated condition. Function was impaired by both the decrease in plasma volume and the reduction in muscle glycogen stores.

## Training

Determinants of competitive success include various psychological attributes such as self-motivation (Raglin *et al.*, 1990), an appropriate use of mental imagery (Barr and Hall, 1992), technical skills including balance (Mester *et al.*, 1982), teamwork (Hardy and Kelly-Crace, 1991), coordination with other crew members (Wing and Woodburn, 1995) and pain tolerance (Whitmarsh and Alderman, 1993), in addition to the physiological characteristics of muscular endurance and aerobic power.

A well-designed training programme seeks to optimize the biomechanical, physiological and psychological components. Novices learn the specific skills of movement timing and control of intensity faster if they are given added visual and acoustic feedback (Gauthier, 1985).

The physiological characteristics often seem the most important determinants of success. Thus, Wright *et al.* (1977) found that an objective score based upon standing height, muscle strength, vital capacity, aerobic power and anaerobic endurance closely matched the coach's assessment of rowing performance in a team of junior oarsmen.

### *Seasonal factors*

The use of appropriate protective clothing can extend the training season and increase the safety of the rower when conditioning must be carried out in cold climates (Schaefer, 1981). Nevertheless, climate limits or precludes on-water training for much of the year (Wright *et al.*, 1976) in a number of countries.

Aerobic performance deteriorates substantially if the weekly rowing distance drops below 100 km (Steinacker, 1993). Klusiewicz (1993) documented a 7.6% increase in power at the 'anaerobic threshold' during the March preparatory phase, and a 6% decline relative to the initial baseline in November, when competition had ceased. Likewise, Hagerman and Staron (1983) observed seasonal differences of 12% for maximal oxygen intake and 14% for peak power in male rowers; Mahler *et al.* (1985) found corresponding gains of 14% and 18% in collegiate oarswomen. In contrast, the force–velocity curves for the active muscles remain constant over the training cycle (de Koning *et al.*, 1984).

Rowing ergometers now offer a relatively specific option for winter training. Fortunately, very similar back and leg forces are developed when rowing and when operating a rowing ergometer (Lamb, 1989). However, perhaps because the behaviour on the rowing ergometer is stereotyped, noradrenaline levels are higher than when rowing at a similar heart rate on the water (Urhausen *et al.*, 1993).

One measure of success of the winter programme is the change that is seen once training on water is resumed. Wright *et al.* (1976) found that, when the land-based programme was well-designed, seasonal fluctuations were largely avoided, and neither strength nor aerobic power were augmented by water training.

### *Optimal training plan*

Aerobic exercise contributes 70–80% of the energy required in a 2000-m competition, with the remainder being provided by anaerobic metabolism (Vermulst *et al.*, 1991; Steinacker, 1993). Stepwise multiple regression indicates that inboard leg strength and the blood lactate concentration observed after a peak oxygen intake measurement provide the best prediction of rowing power. Although the main basis of training should be prolonged aerobic activity, it is important also to develop leg strength and anaerobic endurance (Jensen *et al.*, 1996).

To avoid over-training, the intensity of the aerobic effort should be regulated by such indicators as the heart rate–lactate relationship (Urhausen *et al.*, 1993), serum urea, creatine kinase levels and cortisol–testosterone ratios (Steinacker *et al.*, 1993b).

Sprint training and general athletics training can make up much of the remainder of the training programme (Steinacker, 1993). During the season, some tempo training should be included, although there does not appear to be any advantage in allocating more than 5–10% of training time to this mode of exercise (Michalsky *et al.*, 1988). Weight-training should aim at strengthening the main muscles used in rowing (Boland and Hosea, 1994). Neykova and Dontchev (1987) noted that the simple tactic of rowers working in pairs, using their body weight as a resistance, improved rowing performance more than weight-lifting. Bell *et al.* (1989) found no great advantage in adopting a velocity-specific pattern of resistance training.

Gains of strength can be maintained by as little as one session of resistance training per week, allowing the main focus of training to become the development of aerobic power in the taper period leading up to competition (Bell *et al.*, 1993).

### *High-altitude training*

Because rowers rely heavily upon aerobic effort, some rowing teams have engaged in high-altitude training. Unfortunately, the low oxygen pressure limits training, and gains in performance on return to sea level are questionable (Jensen *et al.*, 1993). Another option is to simulate the hypoxia of altitude in the laboratory. Hahn *et al.* (1992) had 8 of their 16 elite rowers breathe an oxygen–nitrogen mixture equivalent to an altitude of 3100 m during 30–60 min of rowing ergometry each day. The resulting improvements in rowing performance were similar to the other eight subjects who breathed room air from medical gas cylinders.

### *Monitoring training*

Although lactate levels are commonly used to monitor the intensity of training, perceptual ratings offer a much simpler alternative. Marriott and Lamb (1996) found a highly consistent relationship between Borg ratio-scale perceptions of exertion on a rowing ergometer and heart rate ($r = 0.95$). Perhaps because athletes tend to minimize perceptions, increments of heart rate at a given rating were substantially greater than the 1 : 10 ratio found in average adults. When the rating of perceived exertion was used as a means of producing an appropriate training heart rate, it was satisfactory, but only at the higher intensities of effort (ratings of 15 and above).

One method of assessing the training response is to examine gains in peak power output or peak aerobic power (Mahler *et al.*, 1984). Nevertheless, Vermulst *et al.* (1991) have suggested that increases in the power output sustained at a blood lactate of 4 $\text{mmol} \cdot \text{l}^{-1}$ provide a better index of the training response.

Snegovskaya and Viru (1993) noted that, as performance improved, rowers showed increased plasma levels of both growth hormone and cortisol following exercise. Fischer *et al.* (1992) argued that, at least in males, the relative balance of anabolism and catabolism during training could be assessed from urinary excretion of 17-ketosteroids and 17-hydroxyketosteroids. Obminski *et al.* (1994) suggested that salivary cortisol levels also provide a valid method of assessing the strain imposed by a given training session. However, the free testosterone–cortisol ratio does not appear to be an adequate indicator of anabolic–catabolic balance in female elite rowers (Vervoorn *et al.*, 1992).

## Risks of injury and infection

### *Injury*

Rowing is a very safe sport (Brosh and Jenner, 1988). Indeed, from the point of view of injury prevention, the primary aim is to modify winter training rather than the sport itself. Budgett and Fuller (1989) found an injury rate of 0.4 per 1000 h while on the water, compared with 4 per 1000 h during dry-land training. Cohen *et al.* (1995) found that rowing enhanced bone mineral density in the lumbar spine, but had little effect on bone mineral content in other regions.

The most common problem is a back injury, and the only injury characteristic of rowers is a tenosynovitis of the extensors of the wrist. Jepsen and Larsen (reported by Secher, 1990) found that only 40 of 880 rowers attending the 1987 World Championship were treated by the medical services, and only four incidents (all of extreme fatigue) were associated with the actual racing events. Boland and Hosea (1994) have suggested that problems arise from a combination of poor technique and fatigue. Thus they are more likely to be encountered in novices than in experienced rowers.

*Back injuries.* Trunk movements in a well-trained rower range from some 30° of flexion at the 'catch' to 28° of extension at the end of the stroke (Hosea *et al.*, 1989). During the stroke, the back serves as a braced cantilever, transmitting a heavy force from the legs to the oar. The compression load on the spine rises to around seven times body mass (Hosea *et al.*, 1987). An electromyographic study by Coquisart *et al.* (1987) disproved the hypothesis that specific breathing patterns contributed to the back injuries of rowers. Hagerman (1984) blamed such injuries on a maximal contraction of the muscles in the lower back when they were hyperextended.

The incidence of back problems varies quite widely from one report to another. Hagerman (1984) reported results of chronic back pain in only 26 of 931 rowers (2.8%), with a further 11 (1.2%) complaining of knee pain. More than a half of the back injuries led to loss of less than a week of training, but in six cases it was necessary to withdraw from rowing for the entire season. In contrast, Howell (1984) found low back pain in 82% of lightweight female rowers, compared with 20–30% in the general population. Boland and Hosea (1994) found chronic back problems in 39 of 180 university-class rowers, including five cases of herniated nucleus pulposus and five cases of spondylosis. Budgett and Fuller (1989) recorded 9 of 69 oarsmen reporting back injuries on the water, and a further 15 during land training.

Back problems have apparently become more prevalent in recent years, possibly owing to a longer seat slide and raised foot position in modern boats (Stallard, 1980). The problem is undoubtedly exacerbated by the heavy land-based training programmes that are now adopted.

Preventive measures include a pre-participation examination for low back problems (Boland and Hosea, 1991), a strengthening of the surrounding lower abdominal and paraspinal muscles, a regular lumbosacral and hamstring stretching programme (Howell, 1984), and avoidance of either hyperflexion (Howell, 1984; Boland and Hosea, 1994) or hyperextension (Stallard, 1980) of the spine. Roy *et al.* (1990) have developed a technique for identifying susceptible individuals, based on the changes in the surface electromyogram induced by a fatiguing, high force contraction. Therapeutic measures follow the usual pattern of the sports medicine clinic: non-steroidal anti-inflammatory drugs, ice, heat, ultrasound and transcutaneous electrical nerve stimulation.

*Knee injuries.* Knee pain has been attributed to chondromalacia (Chen *et al.*, 1976), possibly with some contributions from patellar tendinitis and iliotibial band syndrome (Boland and Hosea, 1994). The underlying mechanical problem is the repeated flexion and extension of the knee joint while under heavy loading, and anatomical variants such as genu valgum, genu varum, femoral anteversion and patellar malalignment may be precipitants.

Budgett and Fuller (1989) observed no knee problems in their sample of 69 rowers, although three of five coxes suffered knee injuries. Hosea *et al.* (1989) found 22 cases of chondromalacia, 15 cases of iliotibial band syndrome, 7 cases of patellar tendinitis and 8 miscellaneous lesions in a sample of 180 crew from Harvard and Rutgers universities.

Individuals with pre-existing knee problems should be advised that such conditions may be worsened by rowing. Treatment includes temporary curtailment of rowing and anti-inflammatory medication, with stretching and resistance exercises for the quadriceps.

*Tenosynovitis of the wrist extensors.* Some 10% of elite rowers develop tenosynovitis of the wrist extensor muscles. Problems are apparently more prevalent in the cold weather of the early spring (Boland and Hosea, 1994). The primary cause is probably repeated hyperextension of the wrist when feathering the oar. The problem commonly subsides spontaneously over 2–3 weeks, and it does not usually lead to any great loss of training time (Budgett and Fuller, 1989). Preventive measures include an improvement of feathering technique and muscle strengthening exercises. Surgical treatment may occasionally be required (Williams, 1977).

*Other problems.* Shoulder ailments develop occasionally. Boland and Hosea (1994) found four cases of impingement and one anterior shoulder dislocation in 180 university-class rowers. Two of 69 individuals had shoulder problems in the series of Budgett and Fuller (1989).

McKenzie (1989) described the case of an oarsman who induced a stress fracture of the ninth rib at the point of insertion of the serratus anterior muscle. This was attributed to a faulty training technique, and the condition responded favourably to conservative treatment. Four similar cases of costal injury in elite female rowers were described by Holden and Jackson (1985), and there were eight incidents of stress fracture, four cases of costochondritis, three cases of strain and one contusion of the ribs in the series of 180 crew surveyed by Hosea *et al.* (1989).

Paralysis of the long thoracic nerve can arise due to an entrapment syndrome associated with heavy action of the medial scalene muscle. DiFilippo *et al.* (1989) described such a case in a male rower. There have also been occasional incidents of carpal tunnel syndrome that appeared to be due to rowing (Collins *et al.*, 1988).

Finally, problems can arise from blistered hands, particularly early in the season. Rowers with tender skin may find leather gloves helpful.

### *Infection*

Both cellular and humoral responses of the immune system are modified by rowing, as with other bouts of vigorous exercise (Nielsen *et al.*, 1996; Shephard, 1997). However, in contrast to most other forms of exercise, the resting lymphocyte count and natural killer cell activity are increased on the day following a bout of rowing. Repetitive bouts of rowing (three bouts of 6 min on each of 2 days) enhance the response to a single bout of rowing (Nielsen *et al.*, 1996). As in other sports, excessive training can cause a depression of the immune system, with an increased susceptibility to upper respiratory tract infections (Shephard, 1997). Nevertheless, in the case of rowers, the risk does not seem to be very high. Over a single season, 69 oarsmen reported a total of 41 illnesses, or 0.6 per person, a figure that seems likely to be less than that for the general population (Budgett and Fuller, 1989).

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