Larson *et al.* (1988) stated that the device was flow independent up to 3 L s^{-1}; however, they did not quantify the consequences of higher flow rates. It is important to note that athletes are capable of developing unloaded inspiratory flow rates in excess of 12 L s^{-1} so, in this regard, the performance of the device at flow rates in excess of 3 L s^{-1} is of functional significance.

Data produced by Copestake (1995) whilst evaluating the Threshold are more specific. He observed that the pressure load increased by 8.12 ± 7.25 cm H_2O across the range of load settings when flow was increased from 0.33–1.0 L s^{-1}. Unfortunately, there are no published data to establish the threshold performance of the device, although both Gosselink *et al.* (1996) and Larson *et al.* (1988) refer to a very low inspiratory flow at the onset of inspiration effort. The aggregate of these data suggest that The Threshold is able to provide a reasonably constant load at least during spontaneous breathing patterns. However, the lack of flow independence at higher flow rates, coupled with the limited range of loading, render the device inappropriate for nonclinical groups.

The desirable characteristics of an IMT device

The devices described are suboptimal inasmuch as none provide a genuine threshold load, nor are they maximally flow-independent. Furthermore, most of the devices pay little attention to ergonomic considerations. An ideal device would possess the following characteristics:

1 genuine threshold loading (initiation of flow observed only once the threshold pressure is achieved; cessation of flow observed where the threshold pressure is no longer maintained);
2 truly flow-independent loading (resistance to inspiration remains constant regardless of variations in flow rate);
3 adequate range of load selection (high loads, up to approximately −150 cm H_2O, need to be available to implement effective resistive training regimes in healthy adults);
4 resolution of load selection (load selection should be continuous rather than discrete to permit accurate selection of training intensities);
5 reproducibility of loading (a given setting should provide a consistent load over a period of continuous and prolonged intermittent use);
6 comfortable and practical to use (user discomfort likely to result in reduced compliance);
7 simple to maintain and sterilise (should be straightforward to dismantle and reassemble).

With the exception of flow independence, all the above characteristics were deemed to be achievable within the current design process. Modifications to the valve technology described by Larson *et al.* (1988) would be necessary; however, most other design refinements would be concerned with ergonomic issues. With regard to flow independence, whilst this is desirable it cannot be achieved with a mechanical system. However, several factors interact to determine the degree of flow dependency, thus it was judged that improvements on existing devices could be realised.

Methods

The relationship between resistance, pressure and flow

Most design strictures were dictated by the physical relationships between pressure and flow, and between force and pressure. A summary of both these relationships follows.

Pressure is a product of the resistance and the flow within any system:

$$V = I \times R \quad R = (V/I)$$

where V = pressure, I = air flow-rate and R = resistance.

Thus,

$$\text{Resistance (cm H}_2\text{O L}^{-1}\text{ s}^{-1}) = \text{Pressure (cm H}_2\text{O) / Air-flow (L s}^{-1})$$

Of particular interest is the relationship between resistance and aperture size, or inlet opening. For