Human gait has undergone more analysis biomechanically than any other movement. For the fundamental researcher it has posed many challenging questions re neuromuscular control, efficiency, intersegment dynamics, and 3D modelling. For clinicians the challenge has been to pinpoint the primary degenerative patterns vs. the adaptations and thereby make surgical and rehabilitation decisions. Based on my experience in both the fundamental and clinical areas I would like to share major learning experiences, which I shall generalize and represent with specific examples.

1. Learn from individual patient studies, their altered motor patterns are loud messages re the adaptive capability of the neuromuscular skeletal system. Two examples are now presented. (i) A knee arthroplasty patient walked stiff legged but with a dominant flexor knee moment during all of stance. This patient was adapting to years of knee pain by avoiding quadriceps use and was compensating with increased hip extensor and ankle plantarflexor activity. The knee flexor moment resulted from hamstring and gastrocnemius activity associated with the compensating hip and ankle patterns but because of smaller muscle moment arms of these muscles at the knee the extensor patterns at the hip and knee more than cancelled the knee flexor contribution to the support moment (Winter, 1980). (ii) A 30 year old male A/K amputee fitted with SACH foot and spring damper knee mechanism showed his major adaptations to his prosthesis when we look at the power generation/absorption profiles. The ankle could not generate or absorb energy. During stance the knee was locked and also was not involved with the energy profiles. All the adaptation had to be at the hip with extremely high generation by the hip extensors during the first half of stance to propel the body forward “from behind.” This was followed by hip flexor absorption during middle and late stance and by a sharp generation before and after toe off to unlock the knee joint and to accelerate the total limb forward during swing.

2. Failed hypotheses (surprises) should not turn you off; more likely you are being sent new messages re the fundamental characteristics of the system. In an early study on day-to-day variability of moment profiles of young adults resulted in unexpectedly high intra-subject variability in the hip and knee moments. Variability was so high as to discourage single day assessments on patients. Further analysis of these data led to the identification of a combined balance/support synergy. The hip moment was seen to be variable because of its dominant role in balancing the head, arms and trunk (HAT) during stance. The knee was also equally variable in the opposite direction so as to maintain a consistent sum of hip and knee moment acting on the thigh segment. A subsequent covariance analysis showed an 89% covariance between the hip and knee stance-phase profiles and a 75% covariance between the knee and ankle profiles (Winter, 1984). These measures quantify how the support moment synergy to prevent vertical collapse collaborates with the HAT balance synergy to keep HAT erect during stance.

3. Neurophysiologists need to be aware that anthropometric measures are critical to the understanding of the control of gait and balance. (i) All biarticulate lower limb muscles have a common characteristic based on their proximal and distal moment arms: the distal is always greater (Winter, 1991). Thus any activity of the gastrocnemii and hamstrings during stance will result in a net extensor thrust away from the ground. This combined with the dominant uniarticulate extensor muscles at all three joints will produce a dominant extensor pattern preventing collapse. (ii) The non-linear series elastic element of all plantarflexor (Winters, et al., 1988) provides a uniquely simple and stable spring stiffness control of A/P balance during quiet standing (Winter, et al., 2001). The intersection of the gravitational load line with
these non-linear characteristics yields a motor operating point that is inherently stable: further forward sway increases the ankle moment more rapidly than the gravitational load.

4. Narrow hypotheses may frustrate you; in asking fundamental questions firing a shotgun at the system will get at the full story. A major study of the gait of the fit and healthy elderly vs. young adults was not possible without a total kinematic, kinetic and EMG study. Also, in hindsight we found that only with 10 repeat kinetic trials was it possible to tease out the compensating and degenerative patterns and relate them to the subtle kinematic changes (Winter, et al., 1990).

References


