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Basic biomechanical and anatomical principles underpinning grabrail prescription for sit-to-stand transfers

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Introduction

This paper outlines basic research undertaken within the Faculty of Health Sciences since 1992. It examines the basic biomechanical, anatomical and anthropometric principles underlying an understanding of how grabrail prescription impacts on normal sit to stand activities particularly the activity of toileting for ambulant older persons. The significance of these issues is accentuated by confusion amongst therapists in the context of high caseloads, limited time, relatively low funding, and laws and regulations, which are not framed to apply to individuals homes or to include the community service sector.

Background

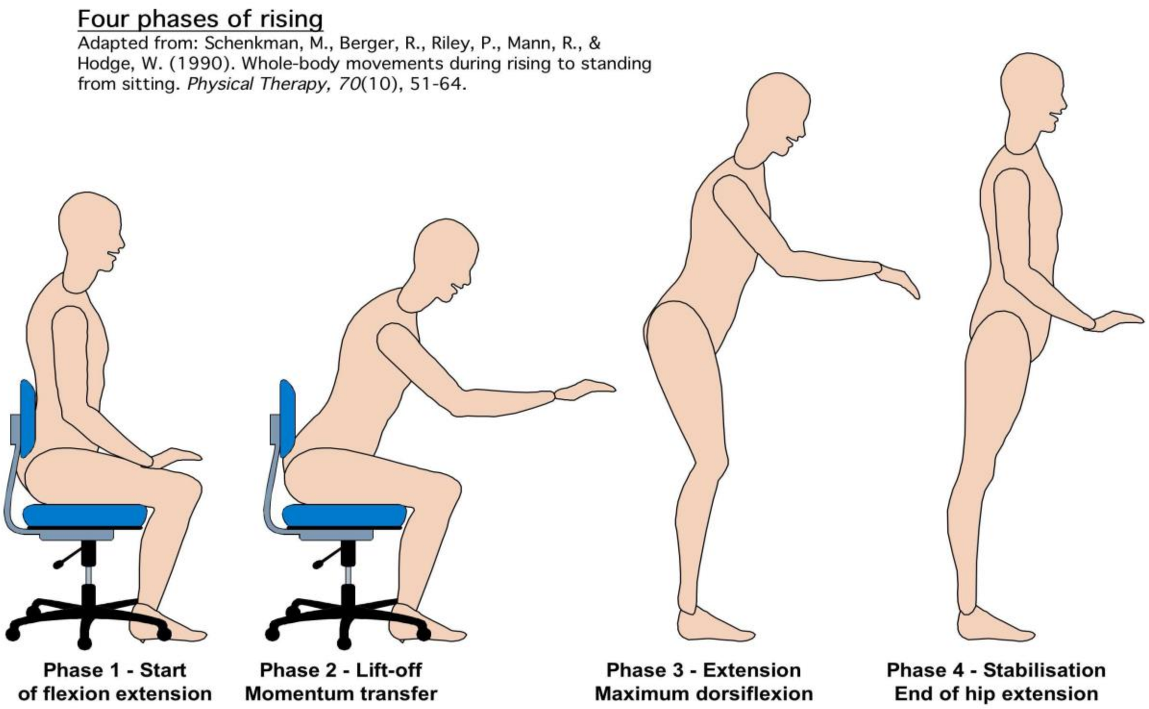
Older persons typically demonstrate little desire to relocate regardless of unsuitable housing because of the importance of dwelling familiarity in maintaining self-esteem and social relations (Golant, 1999). Consequently, the trend towards ‘ageing in place’ has massively increased the demands for community care, highlighting the inappropriateness of much of the existing Australian housing infrastructure for older persons (Bridge, Kendig, Quine, & Parsons, 2002). Two previous random control studies of environmental modification of living environments provide some evidence that adaptation to suit individual ability can maintain wellbeing and reduce morbidity (Cumming et al., 1999; Mann, Ottenbacher, Fraas, Tomita, & Granger, 1999). This is in a context where the proportion of people aged 65 years continues to increase (Australian Bureau of Statistics, 2002a) with recent projections indicating that by the by 2031, the population of people aged 65 years and over will reach 22% of the total population (Australian Bureau of Statistics, 2002b).

Aim

This occasional paper seeks to address some of the relevant knowledge required by therapists in prescribing grabrails to improve safety and functional ability of older ambulant persons in sit to stand from a toilet.

The action of sit-to-stand

The general assumption behind normal sit to stand is intact upper and lower biomechanical and anatomical function. Typically, rising requires changes in the centre of the mass of the human body and an impulse-momentum relationship has to be established. Propulsion is thus generated by creating forward momentum in the horizontal direction (a product of both centre of mass and velocity). The propulsive impulse must then be reversed or falling forward will tend to occur and thus phase four is potentially the most dangerous part of any sit-tostand activity (Schenkman, Berger, Riley, Mann, & Hodge, 1990). This is clearly demonstrated in Figure 1, below.



Four phases of rising

Adapted from: Schenkman, M., Berger, R., Riley, P., Mann, R., & Hodge, W. (1990). Whole-body movements during rising to standing from sitting. *Physical Therapy, 70*(10), 51-64.

Phase 1 - Start of flexion extension

Phase 2 - Lift-off Momentum transfer

Phase 3 - Extension Maximum dorsiflexion

Phase 4 - Stabilisation End of hip extension

Figure 1. Four whole body movements evident in sit-to-stand

Basic principles of grabrail provision for toileting activities

Results from current research, indicate that men and women have different requirements (O'Connor & Bridge, 1995) and that individual anthropometric dimensions such as height and proportion are crucial. For instance, it is generally assumed that the relationship between overall height and individual limb segment length remains in proportion and remains constant. However, whilst this is true for most persons, it is untrue for some, eg. some types of types of achondroplasia and in some developmentally acquired disabilities.

The principle of providing a grabrail that is angled is based on this principle as the 30-45° angle of the rail maintains the height to limb segment ratio allowing a larger therapeutic window for accommodating a number of persons of different heights than can be achieved using either horizontal or vertical grabrail configurations. Whilst no biomechanical studies have yet compared vertical, horizontal and angled configurations, a reasonable hypothesis at this point would be that because the shoulder and elbow angles remain similar in both ‘normal’ angled and vertical grabrail use, that arm and leg forces and torques should remain the same. This implies that an angled grabrail user would exhibit the same or similar muscle strength, flexion and extension of the arm as that noted in biomechanical analysis of vertical rails with the exception of some expected change in wrist torques and forces because of some difference of wrist positioning. However, these changes could reasonably be anticipated to be insignificant for users with no impairment of normal wrist function.

Vertical grabrails are generally preferred over horizontal rails all things being equal. The major difference is one of push versus pull and of ability to aid momentum and stabilisation following full body extension and deceleration. As an angled or a vertical rail when correctly positioned provides significantly greater assistance in both phase 1 (creating forward momentum in the horizontal direction) and phase 4 (stabilisation). Analysis of sit to stand implies that phase 1 is advantaged due to the further forward positioning better enabling the act of propulsion whilst reducing the amount of muscle strength needed. Unfortunately, horizontal rails do not generally provide effective support in phase 4, whereas vertical or angled rails are most likely to prevent falls by enabling full extension with support during the stabilisation phase. Consequently, vertical and angled rails might be considered safer especially for those persons with problems in initiating propulsion or who are generally unsteady on their feet as they better facilitate any person with muscle weakness and appear to be more effective in preventing falls.

Indeed biomechanical research carried out in the Faculty of Health sciences with over 40 subjects demonstrates that most subjects prefer a height of at least 4 cm above their greater trochanter (McDonald, 1997; McDonald, Bridge, & Smith, 1996; Ongley, 1999; Roland, 1996). This finding is supported by other studies that indicate that higher rails generate more arm and foot forces and thus reduce the possibility of toppling backwards. Indeed, anthropometric guidelines suggest that an optimal pulling force is exerted when the elbow is positioned in 150-180° of flexion and the shoulder is in approximately 90° of flexion (Woodson, 1981). In practice, this translates into positioning a vertical or angled grabrail to accommodate the clients sitting shoulder height.

Other key findings are that using a vertical grabrail:

Reduces;

- the total range of movement required at the hip joint (Roland, McDonald & Ongley found this statistically significant)
- hip extension torque’s (Roland found this to be statistically significant)
- the movement required at the knee (no statistical significance)
- the knee extension torque’s (McDonald found this statistically significant for people with OA)
- maximum compressive knee joint forces (McDonald found this statistically significant with OA)
- reduces perceived pain levels (no statistical significance)

Increases;

- maximum sheer knee joint forces (Roland & McDonald found statistically significant) The increase in sheer knee forces indicates a potential contraindication for clients with knee joint instability resulting from previous ligament damage. This may however be offset by the comparatively low values of force overall and the reduction in knee extension torque and compressive knee joint forces.

In conclusion, overall biomechanical results to date support grabrail prescription as a means to reduce biomechanical demands on the lower limbs. Moreover, they indicate that this reduction is most significant with higher grabrail positioning. Ongley (1999) also demonstrated that combining a higher toilet pan height with a vertical grabrail provided the greatest reduction in biomechanical load.

There was also a good correlation between subjects perceptions of pain, comfort and height preferences which indicates that these are likely to be valid factors to consider in the process of prescribing.

Basic functional anatomy of the upper limb

To perform any upper limb movements such as reaching for and grasping a grabrail, the upper limb uses 21 muscles (see Figure 2 , below) which act on the skeletal framework to achieve rotation, supination, pronation and flexion/extension movements of the forearm. The major muscles responsible for flexion are the brachialis and biceps brachii whilst those for extension are the anconeus and triceps brachii. Muscles work synergistically and where weakness or paralysis is evident adaptation, trick movements and compensation are always evident.

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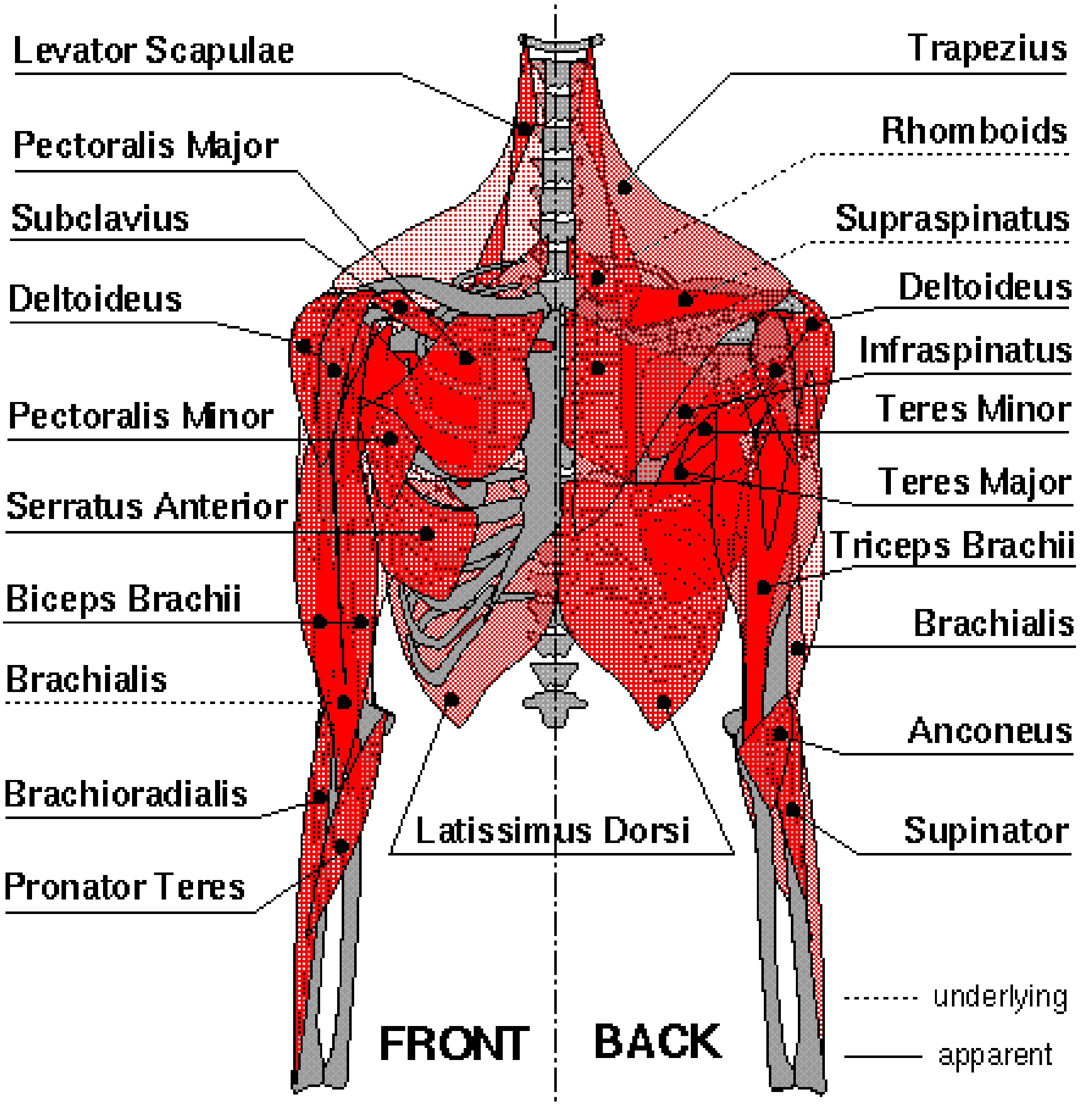

Figure 2. Muscles of the upper limb (Maurel, 1999)

Table 1. Function of muscle groups

Upper limb components	Functional action
skeleton	- Provide degrees of freedom - Provide leverage
coracobrachialis	- Flexion of the humerus - Adduction of the arm
deltoideus	- Flexion of the humerus (anterior head) - Adduction of the humerus (lateral head) - Extension of the humerus (posterior head)
infraspinatus	- Laterally rotate arm
latissimus dorsi	- Medial rotation of the arm - Extension of the humerus - Adduction of the humerus
levator scapulae	- Elevation of scapula - Rotation of scapula, thereby tilting glenoid cavity inferiority - Retraction of scapula - Lateral flexion of the neck
pectoralis major	- Flexion of the humerus (clavicular head) - Adduction and extension of the humerus (sternocostal head)
anconeus	- Extension of the forearm
biceps brachii	- Flexion of the forearm
brachialis	- Flexion of the forearm - Supination of the forearm
brachioradialis	- Flexion of the forearm - Supination of the forearm when in extension
pectoralis minor	- Inferior and anterior drawing of scapula
pronator teres	- Pronation of the forearm
rhomboids	- Retraction of the scapula - Rotation of scapula, thereby depressing glenoid cavity
serratus anterior	- Protraction and rotation of scapula
subclavius	- Medial drawing of the clavicle - Anterior drawing of the shoulder
subscapularis	- Medial rotation of the arm - Adduction of the arm

Upper limb components	Functional action
supinator	- Supination of the forearm
supraspinatus	- Acts with rotator cuff muscles - Assists deltoid to abduct arm
teres major	- Adduction of arm - Medial rotation of arm
teres minor	- Lateral rotation and adduction of the humerus
trapezius	- Superior elevation of scapula - Middle retraction of scapula - Inferior depression of scapula - Mixed; superior rotation of scapula
triceps brachii	- Extension of the forearm - Adduction of the arm

Source: Table material extracted from Maurel, (1999)

Clinical implications

Any impairment such as breaking, tearing, or paralysis of upper limb components will mean that standard or typical vertical, horizontal or angled grabrail applications designed to assist normal sit-to stand activities will require modification. This means that careful individual clinical problem solving both in respect of the person, other residing with them and the constraints imposed by their home will be required.

Some specific known common disability issues affecting sit-to-stand transfers

Hemiplegia

According to (Patten, McGill, Lateva, & Rose, 2000), compensatory spinal segmental adaptations appear to occur in hemiparetic persons and generally serve to improve the likelihood of producing effective motor output in the face of reduced descending motor drive and reduction in the pool of functioning motor units. Such compensation, however, exerts deleterious effects on the sensitivity of force regulation and leads prematurely to fatigue. Poor control of movement and undue fatigue are frequent complaints of hemiparetic persons.

Amputees

According to (Wong & Brown, 1999) the hamstrings and quadriceps are the most active lower limb muscle groups in sit to stand with the lowest correlation between dominant leg and non-dominant leg normal and amputee groups evident. The most significant being between the non-dominant leg of able bodied persons 60% versus the non-dominant leg of amputees 2% during sitting down. In general, quadriceps are more active in sitting down and hamstrings slightly more active in standing up.

Arthritis of the knee

A number of researchers (Alexander, Schultz, & Warwick, 1995; McDonald, 1997; McDonald et al., 1996; Pai, & Rogers, 1991; Pai, Chang, Chang, Sinacore, & Lewis, 1994; Pai, Naughton, Chang, & Rogers, 1994; Seltzer et al., 1995; Wretenberg, Aborelius, Weidenhielm, & Lindberg, 1993) have noted different limb biomechanics (higher hip torque, lower knee extension torque, reduced dynamic knee action, greater knee extension and ankle plantarflexion) and generally slower speed. People with bilateral osteoarthritis typically alter movement patterns to decrease biomechanical demand and pain on affected joints.

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