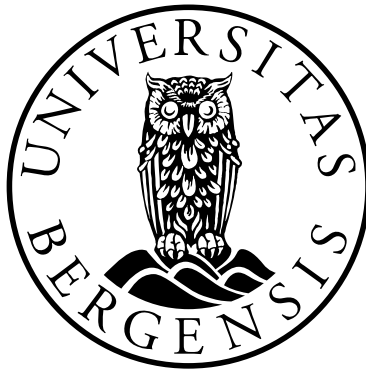


# Trunk control in stroke

Aspects of measurement, relation to brain lesion, and change after  
rehabilitation

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## Scientific environment

The scientific environment of this doctoral thesis was the Physiotherapy Research Group, Department of Global Public Health and Primary Care, University of Bergen, which is led by Professor, dr. philos. Liv Inger Strand, and the Departments of Physiotherapy, Neurology and Physical Medicine and Rehabilitation, Haukeland University Hospital, Bergen, Norway. The thesis is further anchored in the project group for the trial "Early supported discharge after stroke in Bergen" (ESD Stroke Bergen). The ESD Stroke Bergen study is a comprehensive interdisciplinary project at the Department of Physical Medicine and Rehabilitation, Haukeland University Hospital, organised as collaboration between Haukeland University Hospital and the Department of Health and Care in the Municipality of Bergen. This project was initiated and led by Professor, dr. med. Jan Sture Skouen, who also has a part-time position at the Physiotherapy Research Group. The work is also connected to the strategic research programme Research for Allied Health Professions, Bergen Health Authority, led by Assistant Professor II Tone Merete Norekvål, PhD, and organised as part of the Competency Centre for Clinical Research where I have had my office space during this PhD period.

The PhD thesis is also connected to two other strategic research areas:

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- The Regional Western Health Authority: Research Programme Stroke – Bergen Stroke study, led by Senior Consultant Lars Thomassen PhD. The ESD Stroke Bergen is one of the projects in this programme

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**HØGSKOLEN  
I BERGEN**  
BERGEN UNIVERSITY COLLEGE



To Mary

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## Foreword

In my clinical practice as a specialist in neurorehabilitation and Bobath Instructor, I have found reduced trunk control to be a substantial problem for patients' functioning in all phases after stroke, and a major challenge in rehabilitation. Impaired trunk control affects the patient's postural control, efficiency in motor performance and may have an impact on independence in daily life.

In 2004 we searched for assessment tools that reflected trunk control, and found four: Postural Assessment Scale for Stroke - Trunk Control, Trunk Control Test, and two different measures called Trunk Impairment Scale. We found the Trunk Impairment Scale (TIS) by Verheyden and colleagues to best reflect quality of trunk movement assessed at an impairment level. At this time few research articles were published on functional problems related to impaired trunk control in stroke. However, Senior Bobath Instructor Pat Davies had previously published the book "Right in the Middle" (Davies, 1990), focusing on trunk control from a clinical perspective.

In 2006, colleague and friend Tori Smedal started her PhD. I became involved in planning which outcome measures could be appropriate to use in her study, and we decided amongst others to use TIS. I became a tester in her project, and gained extensive experience in using TIS (Verheyden et al., 2004) to assess trunk control in patients with multiple sclerosis. During this time we started the translation process, which later, in 2008 – 2010 became part of my Master's thesis. Trunk control therefore became the main theme both for my Master and PhD theses, and trunk control is the red thread that binds the three studies of the PhD thesis together. The studies have different designs and different aims, thereby viewing trunk control from different perspectives.

Study I is a methodological study whereby the TIS was translated and examined for measurement properties, resulting in a changed scaling and was named the Trunk Impairment Scale – modified Norwegian version (TIS-modNV).



Study II is a translational study investigating a possible relationship between trunk control as evaluated by TIS-modNV and lesion location in the middle cerebral artery territory.

Study III is a group comparison study conducted within the context of a larger randomised controlled trial, Early Supported Discharge after Stroke in Bergen. Several measures were used to capture different aspects of postural control, of which TIS-modNV was one. TIS-modNV was not used as the primary outcome because changes in the activity domain seemed more important from a patient's perspective than changes in impairment.

I am very grateful that I was given this opportunity to spend time to investigate and develop my knowledge in an area that I personally find important for patients' functioning as well as challenging to address as a physiotherapist.

Bergen,

Bente Gjelsvik

## Abstract

Stroke is a leading cause of disability worldwide and affects mostly elderly people. Neurorehabilitation is important for reducing the long-term consequences of stroke, aiming to achieve an optimal functional recovery for home and community reintegration. Physiotherapy is the most common rehabilitation intervention, and the role of the physiotherapist is mainly focussed on improvement in motor function. One of the most important functions of the central nervous system is to coordinate posture and movement to stabilise the body during movements and perturbations. Trunk control is a central aspect of postural control, and has been found to be impaired after stroke. There is limited knowledge on trunk control after stroke, and further studies are warranted. The thesis comprises three studies; one methodological, one translational and one intervention study. The overall aim was to broaden our understanding and knowledge of trunk control in patients with stroke.

The objective of Paper I was to translate the Trunk Impairment Scale (TIS), a measure of trunk control in patients with stroke, into Norwegian and to explore its construct validity, internal consistency, intertester and test-retest reliability. Data from 201 patients with stroke were used to explore construct validity by Item Response Theory and factor analysis. In this process, one of the subscales, static sitting balance, was omitted, and the remaining 14 items were included in six ordinal scales, and named the Trunk Impairment Scale – modified Norwegian version, TIS-modNV. After this modification, the TIS-modNV fitted well to a locally dependent unidimensional Item Response Theory model with one general factor which we call trunk control, and two content specific factors: lower and upper trunk stability. The scale demonstrated excellent construct validity, high internal consistency ( $\alpha$  0.85) and high intertester (ICC 0.77) and test-retest (ICC 0.85) reliability for the total score, supporting its use to evaluate trunk control in patients after stroke as well as other central nervous system disorders. We believe that we achieved a satisfactory translation and cross-cultural adaptation.

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The objective of Paper 2 was to explore the relationship between middle cerebral artery lesion locations (MCA) and trunk control post stroke, and to compare trunk control between patients with lesions in different single and multiple locations, and between left and right hemispheres. A total of 109 patients with acute stroke in the MCA territory were examined using magnetic resonance imaging (MRI) and tested for trunk control using TIS-modNV. To determine the location and extent of the lesion, the MRI scans were scored using the Alberta Stroke Program Early CT Score (ASPECTS), which scores 10 areas in the supply area of the MCA. Single lesion locations were found in 38 of the patients, and data from these formed the basis for further analyses. We found that an ASPECT lesion location in the anterior part of the MCA territory, called M5, demonstrated a hemispheric differentiation for trunk control. Patients with right M5 lesion locations achieved significantly poorer scores on trunk control as compared to left,  $p = 0.030$ . However, there were few patients with M5 lesion locations ( $n = 19$ ), and too few patients to investigate a relationship between other ASPECT locations and trunk control. The results indicate that there is a cortical regulation of trunk control and that the two hemispheres may have different roles in this regard.

Paper III was a group comparison study in the context of a randomised controlled trial. Three different rehabilitation models: two for early supported discharge either in a day-unit or in the patients' own homes, and one traditional uncoordinated treatment were compared for change in physical function after acute stroke. Several outcome measures for balance and walking were used. The Postural Assessment Scale for Stroke was the primary outcome, and TIS-modNV one of the secondary outcome measures. We used data from 167 patients at baseline, 52 in the day-unit group, 60 in the home-rehabilitation group and 55 in the control group. There were no differences between the groups for baseline characteristics or physical function, and no differences between the groups for length of stay in the stroke unit; mean (SD), min-max: 8.6 (3.3) days, 3-17,  $p = 0.948$ . The patients had an overall mild to moderate disability, and high scores on PASS. There was a substantial loss to follow-up with 62.9% of the patients being retested at three months, but no significant differences between the retested groups for baseline characteristics. We found no differences in change

between the groups for PASS,  $p > 0.05$ . We did find differences between the groups for some secondary measures: trunk control, median (95%CI): day-unit, 2 (0.28, 2.31); home-rehabilitation, 4 (1.80, 3.78); control, 1 (0.56, 2.53),  $p = 0.044$ , and self-report on walking,  $p = 0.021$ , and ADL,  $p = 0.016$ , with a tendency to favour the intervention groups over the control group. Mean walking speed improved above minimally important change only in the day-unit group. Bonferroni adjusted pairwise comparisons gave no differences between the groups for trunk control; for self-report on walking, the day-unit group improved more than control,  $p = 0.004$ . For self-report on ADL there was a difference between the home-rehabilitation and the control group,  $p = 0.006$ . We concluded that with regard to secondary outcomes, multidisciplinary, coordinated rehabilitation tended to be more effective than traditional treatment.

In summary, we found that the TIS-modNV has satisfactory measurement properties and can be recommended for use in clinical practice as well as in research. Using the TIS-modNV and ASPECTS, we found indication for a cortical regulation of trunk control, as well as a relationship between lesion location, hemispheric differentiation and trunk control. PASS demonstrated a substantial ceiling effect, and three months after acute stroke no difference was found in change between the groups. On a group level, rehabilitation using coordinated multidisciplinary rehabilitation favoured trunk control, and self-reported walking and ADL.

## List of publications

### Paper 1

Gjelsvik B, Breivik K, Verheyden G, Smedal T, Hofstad H, Strand LI (2012). The Trunk Impairment Scale-modified to ordinal scales in the Norwegian version. *Disabil Rehabil*, 34:1385-95.

### Paper 2

Gjelsvik BEB, Strand LI, Næss H, Hofstad H, Skouen JS, Eide GE, Smedal T. (2014). Trunk Control and Lesion Locations According to Alberta Stroke Program Early CT Score in Acute Stroke: A Cross-Sectional Study. Accepted *Int J Phys Med Rehabil* 12 February 2014. In Press.  
doi:10.4172/2329-9096.S3-001

### Paper 3

Gjelsvik BEB, Hofstad H, Smedal T, Eide GE, Næss H, Skouen JS, Frisk B, Daltveit S, Strand LI. Balance and walking after three different models of stroke rehabilitation: early supported discharge in a day-unit or at home, and traditional treatment (control). Accepted *BMJ Open* 10 April 2014.

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## Abbreviations

ADL	Activities of Daily Living
ANOVA	Analysis of variance
ASPECTS	Alberta Stroke Program Early CT Score
BI	Barthel Index
CFA	Confirmatory Factor Analysis
Coo	Coordination, a subscale of the original Trunk Impairment Scale
CT	Computer tomography
CNS	Central Nervous System
DPMR	Department of Physical Medicine and Rehabilitation
DSB	Dynamic Sitting Balance, a subscale of the original Trunk Impairment Scale
DWI	Diffusion-weighted imaging
EFA	Exploratory Factor Analysis
ESD	Early supported discharge
FAC	Functional Ambulation Categories
5mTW	5 metre timed walk
IADL	Instrumental ADL, e.g. the ability to do house work, use public transport
ICC	Intraclass Correlation Coefficient
ICF	International Classification of Functioning, Disability and Health
IRT	Item Response Theory
MCA	Middle cerebral artery
MIC	Minimally important change
MRI	Magnetic resonance imaging
mRS	Modified Rankin Scale
NIHSS	National Institutes of Health Stroke Scale
NRS	Numerical Rating Scale
NSD	Norwegian Social Science Data Services
PASS	Postural Assessment Scale for Stroke
RCT	Randomised Controlled Trial

REC	Regional Committee for Medical and Health Research Ethics in Western Norway
RMSEA	Root mean square of approximation
$S_w$	Within-subject standard deviation
SDC	Smallest detectable change
SMA	Supplementary motor areas
SSB	Static Sitting Balance, a subscale of the original Trunk Impairment Scale
TIA	Transient ischaemic attack
TIS	Trunk Impairment Scale
TIS-NV	Trunk Impairment Scale – Norwegian version
TIS-modNV	Trunk Impairment Scale – modified Norwegian version
TUG	Timed Up-and-Go
WHO	World Health Organization

## Definitions and interpretation of terms

In this section I have given definitions of central terms used in the thesis.

### *Core stability*

“Core stability is defined as the ability to control the position and motion of the trunk over the pelvis” (Kibler et al., 2006). The core musculature includes the muscles of the trunk and pelvis that are responsible for the maintenance of stability of the spine and pelvis (Kibler et al., 2006).

### *Early supported discharge*

The organisation of early discharge from hospital to home with the provision of support in a community setting, usually followed by rehabilitation while living at home and often supervised by a specialised multidisciplinary team (Fearon et al., 2012), maintaining an equivalent intensity of rehabilitation (Early Supported Discharge Trialists, 2005).

### *Motor control*

Motor control is defined as “...the ability to regulate or direct the mechanisms essential to movement”, and involves aspects of the organisation and coordination of musculo-skeletal activity and the integration of sensory information in human movement by the central nervous system, as well as how movement is influenced by perception, tasks and the environment (Shumway-Cook & Woollacott, 2007c).

### *Neurorehabilitation*

The terms neurorehabilitation and neurological rehabilitation are synonymous.

Neurorehabilitation is an active and dynamic process through which neurologically disabled persons are helped to acquire knowledge and skills in order to maximise their physical, psychological, and social functioning, requiring a multidisciplinary approach (Barnes, 2003). Neurorehabilitation involves three key areas:

- Reduction of disability through appropriate medical treatment
- Optimising activity by learning new skills and strategies

- Environmental adaptations to enable a person with disability to experience minimal handicap

### *Postural control and balance*

Postural control can be defined as the ability to maintain an upright position within the limits of stability or base of support (Tyson et al., 2006; Tyson et al., 2009). Postural control involves controlling the body's position in space for the dual purposes of stability and orientation (Shumway-Cook & Woollacott, 2007d). However, there is no universal definition of posture, balance, postural control, balance reactions or postural reactions (Tyson et al., 2006; Shumway-Cook & Woollacott, 2007b). Shumway-Cook and Woollacott use these terms interchangeably in their book *Motor Control* (Shumway-Cook & Woollacott, 2007b). In this thesis, postural control and balance will be used synonymously.

### *Stroke*

Stroke is defined as: "Rapidly developing clinical signs of focal (at times global) disturbance of cerebral function, lasting more than 24 hours or leading to death with no apparent cause other than of vascular origin" (Hatano, 1976).

### *Stroke unit*

A stroke unit is a specialised hospital based ward with multidisciplinary staffing that provides a complex package of care to stroke patients (Stroke Unit Trialists' Collaboration, 2007).

### *Trunk control*

The segments of the trunk and the pelvis are interconnected and interdependent in human functional movement as most of the deep and superficial muscles of the back and abdomen attach the trunk to the pelvis and spine (Ebenbichler et al., 2001). Trunk control is therefore understood as the selective control of the trunk over the pelvis as well as the pelvis in relation to the base of support, encompassing the dual ability of stability and mobility at the same time, and being an essential component of postural control. In the following, the term *trunk control* will be used to cover both trunk control and core control.

# 1. Introduction

Stroke is a leading cause of disability worldwide and affects mostly elderly people. The greatest impact of stroke on both patients and families are the long-term disability, including impairments, limitations of activities and participation restrictions in life situations (Langhorne et al., 2009; Truelsen et al., 2006; Brewer et al., 2013). Neurorehabilitation is important for reducing the long-term consequences of stroke, aiming to achieve an optimal functional recovery for home and community reintegration (Brewer et al., 2013). Reduced motor control is common and thereby a focus of attention for physiotherapists, as well as the main reason for conducting the three studies in the present thesis.

## 1.1 Stroke

The World Health Organization (WHO) defines stroke as “rapidly developed clinical signs of focal (or global) disturbance of cerebral function, lasting more than 24 hours or leading to death, with no apparent cause other than of vascular origin” (Hatano, 1976). This definition includes most cases of cerebral infarction and subarachnoid and intracranial haemorrhage, but excludes transient ischaemic attacks (TIA) (Aho et al., 1980).

Eighty percent of strokes are ischaemic in origin (Caplan, 2013), and are caused by vascular insufficiency (Warburton et al., 2011). Haemorrhage is the cause of 15%; 5% of strokes are not specified (Langhorne et al., 2011). TIA is a brief episode of neurological dysfunction resulting from a focal temporary cerebral ischaemia not associated with cerebral infarction (Furie & Ay, 2013). Originally, TIA was defined as lasting less than 24 hours, presumably due to a transient decrease in blood supply causing temporary brain ischaemia and neurological symptoms and/or signs. However, recent research shows that there is a risk of permanent tissue injury, even if the TIA lasts less than one hour (Caplan, 2013).

## Epidemiology

Worldwide, 15 million people suffer a stroke each year. Of these, 5 million die each year and another 5 million live with permanent disability (World Health Organization, 2013). In the developed countries, stroke is the third most common cause of death (Warburton et al., 2011), although stroke mortality rates have dropped by approximately 40% in the last decades (Brewer et al., 2013). The incidence of stroke is declining in many developed countries due to improvements in primary and secondary prevention; however, the total number of strokes is still increasing due to an ageing population (World Health Organization, 2013). The number of new strokes from 2000 to 2025 is expected to increase from 1.1 million/year to 1.5 million/year in the European Union (EU) and European Free Trade Association (EFTA) countries together (Truelsen et al., 2006).

In Norway, approximately 15.000 people suffer a stroke each year (Helsedirektoratet, 2010). Incidence rates reported at the 14<sup>th</sup> Conference on Neurovascular Diseases in Bergen in 2010 demonstrated a wide variation of incidence between hospitals and towns in different health regions (Thomassen, 2011), and the estimated incidence rate in Bergen was reported as being low: 105 per 100.000 inhabitants per year, based on data from the NORSTROKE research registry 2007-2009 (Naess et al., 2011).

Petrea and colleagues (Petrea et al., 2009) reported that in the USA, 60.000 more women than men suffer stroke each year. The lifetime risk estimate of stroke shows that one in five women and one in six men, who are stroke free at the age of 55 years, would develop a stroke later in life (Petrea et al., 2009). With regard to gender, the situation seems to be different in Norway and Denmark. Data from the Stroke Registry in Bergen demonstrated fewer female patients (47%) with first time ischaemic infarcts (Naess et al., 2011) and a Danish stroke register for first time stroke, also showed fewer women (48%) than men (Andersen et al., 2010).

Age is the single most important risk factor for stroke (Nudo, 2011). Hypertension, diabetes mellitus, atrial fibrillation and high cholesterol are the highest ranking controllable risk factors for stroke, whereas alcohol consumption, smoking and obesity

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are reported to be the most important life style risk factors for stroke (Andersen et al., 2010).

## **Diagnosis**

Diagnostic procedures encompass the clinical history, clinical findings and supplementary investigations with neuroimaging playing a central role.

### *Clinical observations*

Stroke may cause dysfunction in sensorimotor, cognitive and perceptual functions, as well as speech and language functions. Motor impairments affect approximately 80% of patients to varying degrees (Brewer et al., 2013), and appear as a limitation or loss of motor control (Pinter & Branin, 2012). Almost 50% of stroke survivors suffer hemiparesis (Brewer et al., 2013), and most (83%) have postural control problems (Tyson et al., 2006). These disorders are identified during routine neurological consultation and physiotherapy assessment.

### *Neuroimaging*

Both computer tomography (CT) and magnetic resonance imaging (MRI) are frequently used for the diagnosis of acute stroke. CT is often performed first to exclude a haemorrhagic cause, a prerequisite for giving the patient thrombolytic treatment. However, diffusion-weighted (DWI) MRI appears to have a better sensitivity and accuracy than CT to detect ischaemic tissue within minutes of onset (Brazzelli et al., 2009; Davalos et al., 2004; Naess et al., 2009). Changes in the cellular homeostasis of the brain are early indicators of ischaemia (Bammer, 2003). As a consequence, the motion of microscopic proton diffusion is restricted (van Everdingen et al., 1998). The decrease in water diffusion is seen as hyperintensity on DWI. There are a low number of false-negatives (5%) in DWI MRI (van Everdingen et al., 1998), and 95% of DWI scans were found to detect acute ischaemic lesions, in contrast to 29% of CT scans (Naess et al., 2009). There has been a continuous improvement in the technique over the last decade, and DWI is now in routine clinical use in cerebral

ischaemia. We selected DWI MRI for diagnostic purposes to determine lesion location and the extent of middle cerebral artery lesions in Study II of this thesis.

### *Middle cerebral artery*

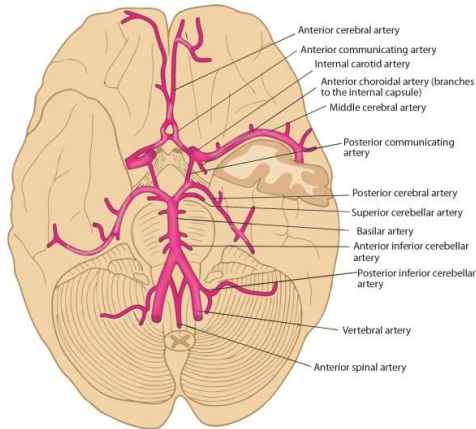
The middle cerebral artery (MCA) is most commonly affected by ischaemic stroke (Balaban et al., 2011). In Study II, the relationship between different locations in the MCA territory and trunk control is investigated. The MCA will therefore be described in more detail in the following.

The blood supply to the brain comes from the internal carotid and the vertebral arteries (Brodal, 2013). MCA is the largest branch of the internal carotid artery (Figure 1a), and is the main supplier to the hemisphere's convexity including the frontal, parietal, temporal and occipital lobes as well as the insula (Kandel et al., 2000). These areas include large parts of the motor and sensory cortices (Brodal, 2013), including the area of representation for the trunk which lies between the arm and leg areas (Figure 1b). Smaller penetrating branches supply the deep white matter and subcortical structures like the posterior limb of the internal capsule, putamen, parts of globus pallidus and body of the caudate (Brodal, 2013; Kandel et al., 2000).

The main symptoms of MCA stroke are contralateral weakness, sensory loss and visual impairment, as well as language disturbance and impaired spatial perception, depending on which hemisphere is involved. Motor and sensory loss is greatest in the hand which is mainly represented unilaterally. The more proximal parts of the limbs and the trunk tend to be represented bilaterally (Kandel et al., 2000). However, clinical experience indicates that the trunk is impaired after stroke, causing a major challenge in rehabilitation.



a.



b.

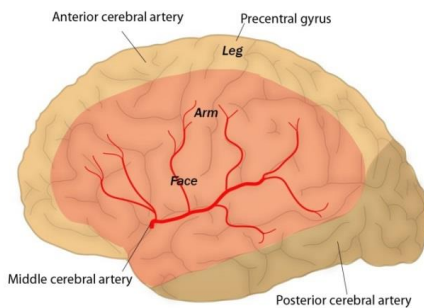


Figure 1. The middle cerebral artery territory (MCA) (Brodal, 2010). a. Arterial supply to the brain; b. The convexity of hemispheres showing representation areas for arm and face supplied by the MCA. The trunk representation area lies between arm and leg areas. The leg area is supplied by the anterior cerebral artery. Reprinted with kind permission from Per Brodal.

### ***Lesion size***

Studies examining the effect of lesion location and lesion size on functional outcome over time have given inconsistent results (Pan et al., 2006), possibly due to differences in assessment methods and assessment tools. Volume has been measured in different ways: volume (mL) (Chen et al., 2000; Saunders et al., 1995), number of lesions (extent) (Perennou et al., 2000; de Margerie-Mellon et al., 2013), diameter of lesion

(Pan et al., 2006) and by tracing the perimeter of the lesion (Page et al., 2013). A relationship between lesion size and outcome has been reported, with larger strokes giving poorer outcomes (Saunders et al., 1995; van Everdingen et al., 1998; Pan et al., 2006), using the Scandinavian Stroke Scale (Saunders et al., 1995), National Institutes of Health Stroke Scale (NIHSS), modified Rankin Scale (mRS) (van Everdingen et al., 1998), and Barthel Index (BI) (Pan et al., 2006; van Everdingen et al., 1998) as clinical outcome. Page et al. (Page et al., 2013) reported that lesion size determined by CT or MRI in mild, chronic stroke was not associated with the Fugl-Meyer upper limb assessment and explained only 1.7-3.1% of the variance in arm motor function (Arm Motor Ability test), and implied that there is no relationship between lesion volume and impairment of upper limb function. Chen et al. (Chen et al., 2000) found that brain lesion profiles; i.e. a combination of lesion size and location, were related to Brunnström's stages of motor recovery and functional outcome as assessed by Functional Independence Measure. Perennou et al. (Perennou et al., 2000) found that location and not lesion size played a primary role for postural stability in sitting.

Stroke localization would seem to be crucial to clinical outcome. However, this needs further empirical investigation.

## **World Health Organization International Classification of Functioning, Disability and Health**

The International Classification of Functioning, Disability and Health (ICF) provides a standard and common language for the description of health and health-related states (WHO, 2002). The ICF gives a reference frame for classifying the multifaceted factors that affect the individual's perception of disability (Sullivan & Cen, 2011). It categorises three main domains in which changes may occur: body structures and functions, activity and participation which represent separate but linked constructs of disablement. Sullivan & Cen (2011) used ICF as a framework to develop a disablement model, and found that participation is influenced directly by activity and indirectly by impairment, and that impairments contribute to difficulties in activity

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(Sullivan & Cen, 2011). Performance relates to what the person actually does in his/her own environment and capacity for what a person with a health condition can do in a standard environment e.g. under test conditions (WHO, 2002).

A list of environmental factors is available to provide a contextual frame for classifying barriers and facilitators for the different domains. Functioning is an umbrella term of all body functions, activities and participation, while disability refers to impairments, activity limitations and participation restrictions. According to ICF, the patients are to be assessed and treated from different functional perspectives: body, individual and societal, and ICF represents, accordingly, a biopsychosocial model (WHO, 2002). Because the ICF is internationally adopted, I chose to use it as a basis for categorising the functional domains of assessment tools in this thesis.

## 1.2 Postural and trunk control

Postural control has been extensively investigated in healthy subjects as well as in individuals with musculoskeletal disorders (Sousa et al., 2012; Winzeler-Mercay & Mudie, 2002). Postural control is organised in relation to the individual, the task and the context in which the task is being performed (Shumway-Cook & Woollacott, 2007d), and one of the most important functions of the central nervous system (CNS) is to coordinate posture and movement to stabilise the body during self-initiated movements and externally triggered disturbances (Horak, 2006). The various body segments are linked together in a functional kinematic chain connecting the eyes to the feet (Massion, 1992) in which the trunk serves at the centre (Borghuis et al., 2008). Trunk control is thus an essential component of postural control (Borghuis et al., 2008; Dickstein et al., 2004; Karatas et al., 2004; Kibler et al., 2006) and is a complex, ever changing and dynamic neuromuscular function. There is still limited knowledge about trunk control and how to influence impaired trunk control after stroke, and further studies are warranted.

The trunk constitutes over half of the body mass and greatly influences the rest of the body (Kang & Dingwell, 2009). The core of the body consists of the musculoskeletal areas of the trunk, pelvis, hips and the proximal lower limbs (Kibler et al., 2006). The abdominal muscles, especially m. transversus abdominis, together with the diaphragm above, the pelvic floor below and the back muscles contribute to postural stability (Ebenbichler et al., 2001). The muscles of the trunk and pelvis are responsible for dynamic stability of the trunk in functional activities (Kibler et al., 2006; Borghuis et al., 2008). The segments of the trunk and the pelvis are interconnected and interdependent in human functional movement because most of the deep and superficial muscles of the back and abdomen attach the trunk to the pelvis and spine. Trunk control is important and complex, therefore careful clinical assessment is required for accurate diagnosis of dysfunction in this area.

Limiting the definition of core stability to “the ability to control the position and motion of the trunk over the pelvis” (Kibler et al., 2006) seems to leave out the base of support as an important prerequisite for trunk stability and movement. Trunk control is therefore understood as the selective control of the trunk over the pelvis as well as the pelvis/hips in relation to the base of support, encompassing the simultaneous control of stability and mobility. In the following, the term *trunk control* will be used to cover both trunk control and core stability.

The human trunk is bilaterally innervated (Carr et al., 1994), and a postural role for muscles on both sides of the trunk during limb movement has been indicated (Dickstein et al., 2004). Anticipatory postural adjustments (APA) precede and accompany limb movement and provide proximal stability for distal mobility (Borghuis et al., 2008; Dickstein et al., 2004; Ebenbichler et al., 2001; Kibler et al., 2006; Massion, 1992) in order to minimise postural destabilisation and orient the trunk to allow the limbs to carry out the desired movement (Borghuis et al., 2008).

Lower trunk postural muscles (axial, erector spinae and rectus abdominis) are involved more in maintaining trunk postural control, while upper trunk muscles are involved more in counteracting the destabilisation brought on by a moving limb (Dickstein et

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al., 2004). The recruitment and timing of appropriate muscles are extremely important for trunk control, more so than endurance and muscle strength alone (Borghuis et al., 2008). Modest levels of trunk muscle co-activation are required to give sufficient stability for the optimal and complex balance between stability and mobility for task performance (Borghuis et al., 2008). The recovery of trunk control thus seems to be a prerequisite for more complex functional abilities; however, this need to be explored in further studies.

### **Impaired trunk control post stroke**

In my clinical experience, many patients with stroke tend to demonstrate insufficient trunk control, affecting their functional ability in many activities, e.g. turning in bed, sitting up/lying down, rising from sitting to standing, standing and walking. Impaired anticipatory activity of the superficial lateral trunk muscles (latissimus dorsi, rectus abdominis and external oblique) on the paretic side has been found to influence the ability to perform daily activities (Dickstein et al., 2004). Patients have demonstrated altered trunk position sense after stroke (Ryerson et al., 2008) and mislocalisation of tactile stimuli to the trunk in the presence of neglect (Rousseaux et al., 2013). Several studies have demonstrated decreased trunk muscle strength (Dickstein et al., 2004; Karatas et al., 2004; Pereira et al., 2011; Tanaka et al., 1998; Winzeler-Mercay & Mudie, 2002), and muscle strength has been found to be positively correlated with balance as measured with Berg's Balance Scale (Karatas et al., 2004). Increased activation of the erector spinae muscle on the paretic side has also been described (Dickstein et al., 2004; Winzeler-Mercay & Mudie, 2002).

Altered recruitment patterns for head and trunk rotation in sitting has been reported whereby patients with stroke move the head and trunk simultaneously instead of in a cranial-caudal pattern (Verheyden et al., 2011). Deficit in segmental rotation between the thorax and pelvis was found to be associated with poorer postural control and walking ability (Hacmon et al., 2012).

Upright sitting has been examined by posturography in the early (Genthon et al., 2007; van Nes et al., 2008) and the chronic stage after stroke (Perlmutter et al., 2010). A larger sway area and larger displacements were found for patients compared to controls (Genthon et al., 2007; Perlmutter et al., 2010). A greater dependence on vision to maintain stability on an unstable base of support was found in patients compared to controls (van Nes et al., 2008). These studies indicate that patients suffer impaired trunk control at all times after stroke. Because trunk control is essential for sitting balance, impairments of the trunk might also affect functional activities involving the use of the arms and hands, e.g. in dressing and reaching, possibly due to altered alignment, stability and movement of the shoulder girdles affecting distal precision. Robertson et al. (Robertson et al., 2012) found reduced protraction of both shoulder girdles in left hemispheric stroke of patients with a dominant right hand. In right hemispheric stroke this was only found for the left shoulder girdle, suggesting a different role of the two hemispheres. They also found reduced dexterity of the non-paretic hand after stroke, which was also experienced by the Norwegian medical doctor and neuroanatomist Alf Brodal (Brodal, 1973).

In addition to impairments, compensatory strategies seem to affect the postural role of the trunk in functional activities. With impaired skills in movements such as reaching, the trunk may exhibit compensatory strategies with increased flexion and/or rotation, as described by several authors (Archambault et al., 1999; Cirstea et al., 2000; Robertson & Roby-Brami, 2011; Reisman & Scholz, 2006; Roby-Brami et al., 2003; Michaelsen et al., 2006; Thielman, 2013; van Kordelaar et al., 2012; Levin et al., 2002; Massie et al., 2009; Woodbury et al., 2009). Empirically, some patients seem to compensate for deficits in selectivity of leg movement during walking by using their trunk to lift and rotate the pelvis in order to swing the most affected leg forward during walking (hip hiking, circumduction). The use of compensatory trunk activity to move a limb implies a secondary source of trunk instability, potentially increasing the patient's functional disability.

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The studies above show that dysfunction in trunk control is a substantial problem after stroke. Therefore, more knowledge about factors influencing trunk control and potential changes in stability and movement of the trunk after stroke is needed.

### **Lesion location, postural and trunk control**

Postural control is complex and based on the interaction of dynamic sensorimotor processes resulting from somatosensory information being processed and integrated within the nervous system (Horak, 2006; Shumway-Cook & Woollacott, 2007d). Visual, vestibular and somatosensory inputs are important for postural control (Shumway-Cook & Woollacott, 2007d). According to Jacobs & Horak (2007), cortical involvement in postural control is controversial. Few studies have been performed to investigate a potential impact of lesion location on postural control. Most of these studies have explored lesion location in patients displaying a specific disorder of body orientation called contraversive pushing behaviour (“pusher syndrome”) which negatively influences postural control (Baier et al., 2012; Johannsen et al., 2006; Karnath et al., 2005). Empirically, many patients with pusher syndrome are unable to sit unsupported due to severe pushing away from the least affected side predominantly using the ipsilesional extremities, causing the patient to fall towards the most affected side. Many of these patients display severely impaired trunk control, either as a primary deficit with paresis, or secondary as a result of non-use due to the severe imbalance of activity between the two body halves. Several lesion locations have been found related to this syndrome: posterolateral thalamus (Karnath et al., 2005; Johannsen et al., 2006), insular cortex, inferior parietal lobe, postcentral gyrus (Johannsen et al., 2006), different areas within the insula, operculum, superior temporal gyrus and internal capsule (Baier et al., 2012).

There is evidence implying that the supplementary motor cortex (SMA) may be involved in the regulation of postural control (Fujimoto et al., 2014; Mihara et al., 2008; Mihara et al., 2012). Mihara et al. (Mihara et al., 2008; Mihara et al., 2012) suggested that a broad cortical network is involved in postural control in both healthy

individuals as well as in patients post-stroke, including prefrontal, premotor, SMA and parietal cortical areas. Palmer et al. (Palmer et al., 1996) argued for a cortical involvement in postural control after finding that electromyographic activity in the contralateral postural trunk muscles was reduced during active movements of the least affected arm following single lesions of the motor cortex.

Also, a hemispheric difference in the regulation of postural and trunk control has been suggested. A right hemispheric dominance for visual contribution to head stabilisation in space was found in one of the earliest studies on hemispheric asymmetry on postural control (Perennou et al., 1997). Later, Manor and colleagues (Manor et al., 2010) concluded that patients with right MCA infarcts are likely to be dependent on vision and non-infarcted brain regions to control postural sway. There are indications that patients with right hemispheric lesions display poorer postural control than with left (Rode et al., 1997; Rode et al., 1998; Baier et al., 2012; Barra et al., 2010). Recently, Abe et al. (Abe et al., 2012) also found a higher prevalence of pusher syndrome in patients with right hemispheric lesions as compared to left.

Only two studies have been found that explored hemispheric asymmetry specifically related to trunk control in stroke (Perennou et al., 2000; Spinazzola et al., 2003). Perennou et al. (Perennou et al., 2000) found that patients with lesions of the right temporoparietal junction had increased lateral instability; i.e. decreased ability to stabilise the trunk in the frontal plane. Trunk postural instability seemed more dominant in patients with right hemispheric lesions while trunk apraxia was more often associated with left hemispheric strokes (Spinazzola et al., 2003). This may indicate that a system located in the right hemisphere plays a major role in the processing of trunk control (Spinazzola et al., 2003). The evidence suggests that cortical regulation of postural and trunk control exists and that the right hemisphere may play a specific role in this control, but this needs further investigation.



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## Prognosis

Approximately half of all stroke survivors will experience some long-term disability (Warburton et al., 2011). Approximately 65% of all strokes occur in people over 65 years (Pinter & Brainin, 2012), and age is a potent factor of poor outcome in humans (Sterr & Conforto, 2012). Irrespective of risk factors and comorbidities, older patients with ischaemic stroke have been reported to have worse functional outcomes than younger patients (Brewer et al., 2013; Pinter & Brainin, 2012).

After stroke, the simplest indicator of prognosis is the degree of motor impairment (Bernhardt et al., 2009; Takeuchi & Izumi, 2013). The mechanisms underlying motor recovery, type of strokes and the individuals suffering strokes are heterogeneous (Maulden et al., 2005; Langhorne et al., 2011), and therefore accurate prognosis based on motor recovery alone would be insufficient.

Many patients live with disabilities after having suffered a stroke. Logan et al. (Logan et al., 2004) found that 49% of patients did not venture outside their house as much as they would wish 10 months after stroke onset. Walker (Walker, 2007) found that 36% of the patients were still unable to dress themselves independently two years after stroke, while in another study ADL independence was achieved by 58% of stroke patients at six months post-stroke (Kwakkel et al., 1996). Kwakkel and Kollen (Kwakkel et al., 2013) reported in a review that 60 to 80% of patients with stroke regained walking independence with or without the use of an aid at six months after stroke, while only five to 20% achieved full functional use of the arm in the same time frame.

Trunk control soon after stroke has been found to be predictive of long-term functional improvement in several studies (Wade & Hewer, 1987; Hsieh et al., 2002; Wang et al., 2005). Trunk control early after stroke has been shown to predict length of initial hospital stay (Duarte et al., 2002) and walking ability at 18 weeks (Collin & Wade, 1990). Trunk control is a prerequisite for ability to sit unsupported (Perennou et al., 2000). The trunk control items of the Postural Assessment Scale for Stroke (PASS) explained 45% of the variance in a comprehensive ADL measure six months after

acute stroke (Hsieh et al., 2002). Trunk control at admission explained 71% of the motor part of the Functional Independence Measure at discharge (Franchignoni et al., 1997), and was a strong predictor of functional outcome (Barthel Index) explaining 50% of the variance (Verheyden et al., 2007a). Verheyden et al. (2006c) examined the relationship between trunk control, balance, walking and overall function in patients with sub-acute and chronic stroke and found that trunk control explained 51% of the variance in balance (Tinetti Balance Assessment) and 44% of the variance in walking (timed Up-and-Go). Trunk control early after stroke has thus been found to be predictive of long-term functional improvement.

Several authors recommend interventions aimed at improving trunk control in stroke (Cabanas-Valdes et al., 2013; Hacmon et al., 2012; Jandt et al., 2011; Karatas et al., 2004; Reisman & Scholz; 2006; Ryerson et al., 2008; Tanaka et al., 1998; Winzeler-Mercay & Mudie, 2002;). Knowledge about how improvement in trunk control relates to recovery of balance after stroke is however, still limited (Geurts et al., 2005), and further research is needed.

## **Assessment tools of postural and trunk control**

There are a great number of tests available for assessment of postural control (Tyson et al., 2006). Measures of the ability to perform activities cannot differentiate between impairments and the use of compensatory movement strategies (Kwakkel et al., 2004a), therefore we need both impairment measures and measures that capture activity limitation. Assessment tools should be readily available to the clinician, have a limited need for equipment, be easy to understand and learn, quick to administer and not exhausting for the patients.

Examples of some postural control measures are shown in Table 1 as well as the ICF domain to which the test is assumed to belong. Tyson & Connell (2009) performed a systematic review of postural control measures used in neurological conditions, and described 10 measures found to be psychometrically sound and of use in clinical practice. Some of these are shown (and marked with <sup>c</sup>) in Table 1.

Table 1. Overview of some postural and trunk control measures used in patients with stroke with suggested ICF domains

Measure	Items evaluated	ICF domain
<i>Self-report</i>		
- Falls Efficacy Scale (Tinetti et al., 1990; Kempen et al., 2007)	Falls, loss of postural control, impact on daily life	Activity Participation
- Numerical Rating Scales <sup>a,b</sup> (Farrar et al., 2001; Farrar et al., 2008)	Originally used to measure pain, but has been used to assess degree of perceived problem also in other areas.	Impairment Activity
<i>Activity- based</i>		
- Timed tests (Tyson & Connell, 2009) e.g. Timed Up-and Go <sup>b</sup> (Ng & Hui-Chan, 2005; Podsiadlo et al., 1991)	Sitting, standing or walking Sitting to standing, walking and turning	Activity
- Trunk Control Test (Duarte et al., 2002)	Lying, sitting	Activity
- Function in sitting Test (Gorman et al., 2010)	Sitting, active movements, moving in relation to base of support, reactive responses to nudging	Activity
- Trunk Impairment Scale (Fujiwara et al., 2004)	Sitting	Activity
- Sitting postural control of the Motor Assessment Scale (Carr et al., 1985)	Sitting	Activity
- Postural Assessment Scale for Stroke <sup>b</sup> (Benaim et al., 1999)	Maintaining and changing postures: supine, sitting, standing	Activity
- Reach tests <sup>c</sup> (Shumway-Cook & Woollacott, 2007a; Tyson & Connell, 2009), e.g. Functional Reach (Duncan et al., 1990)	Sitting or standing, reaching beyond arm's length	Activity
- Berg Balance Scale <sup>c</sup> (Berg et al., 1995)	Maintaining and changing postures: sitting, standing, stepping	Activity
- Brunel Balance Assessment <sup>c</sup> (Tyson & DeSouza, 2004)	Maintaining and changing postures: sitting, standing, stepping	Activity
- Balance section of the Fugl-Meyer Motor Assessment (Mao et al., 2002; Tyson & Connell, 2009)	Sitting, standing	Activity
- Short Physical Performance Battery (Guralnik et al., 1994)	Balance, strength, mobility	Activity/ BFS
<i>Body functions and structures</i>		
- Trunk Impairment Scale <sup>c</sup> (Verheyden et al., 2004)	Stability and movement of the trunk in sitting	BFS
- Motor strategies (Shumway-Cook & Woollacott, 2007a)	Alignment and movement strategies	BFS
- Sensory strategies (Shumway-Cook & Woollacott, 2007a)	Manipulation of vision and base of support	BFS

In the context of this thesis (study III), <sup>a</sup>NRS was used to measure perceived problems with balance; <sup>b</sup>Described in more detail in chapter 3, Methods and Materials; <sup>c</sup>Recommended by Tyson & Connell (2009).

*Abbreviation:* BFS: Body functions and structures.

However, there is no gold standard for assessing postural control in patients with neurological conditions (Tyson & Connell, 2009), and no one that measures all aspects of postural control (Shumway-Cook & Woollacott, 2007a). The assessment tools used in this thesis aimed to capture different aspects of postural and trunk control within the ICF domains of body functions and structures, and activity.

### 1.3 Stroke rehabilitation

The overall aim of stroke rehabilitation is to achieve the best possible physical and psychological function for the individual patient (Kwakkel et al., 2004a). Stroke rehabilitation should start as early as possible after stroke (Bernhardt et al., 2009), and follow a process of assessment of patient's needs, realistic goal setting, appropriate intervention and reassessment to evaluate the progress against the agreed goals (Langhorne et al., 2011). Motor impairments are the most common dysfunction after stroke (Truelsen et al., 2006; Brewer et al., 2013; Kwakkel et al., 2004a). Motor recovery is therefore a main target in rehabilitation, especially postural control and mobility (Tyson et al., 2006), and a primary focus of attention for physiotherapists in general and also for this thesis. Sensation, perception and cognition are important aspects in the treatment of motor control; however, these aspects will not be further discussed.

#### **Stroke Unit**

A stroke unit can be described as a specialised hospital based ward with multidisciplinary staffing that provides a complex package of care (Stroke Unit Trialists' Collaboration, 2007). The focus of early stroke management has changed from early rehabilitation towards acute diagnosis and treatment. All patients have emergency CT, and other diagnostic examinations are performed to find the cause of stroke (Thomassen et al., 2012). Recanalization treatment is given if relevant, and blood pressure, heart rate, temperature and serum glucose are monitored closely

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(Thomassen et al., 2012). The acute management should be combined with early mobilisation and rehabilitation, and secondary prevention (Ringelstein et al., 2013).

Patients who receive stroke unit care are more likely to survive their stroke, to be independent and live at home after one (Stroke Unit Trialists' Collaboration, 2007) and five years (Langhorne et al., 2007) than patients receiving less organised conventional care.

### **Early supported discharge**

Early supported discharge (ESD) was used as the intervention in Study III, and is therefore described in more detail in the following. ESD is defined as the organisation of early discharge from hospital to home with the provision of support in a community setting, usually followed by rehabilitation while living at home and often supervised by a specialised multidisciplinary team (Fearon & Langhorne, 2012), maintaining an equivalent intensity of rehabilitation (Early Supported Discharge Trialists, 2005). ESD interventions may take different forms, and a typical ESD team is either hospital or community based (Fearon & Langhorne, 2012). A consensus on key elements in the delivery of ESD services is that multidisciplinary, specialist stroke ESD teams preferably based in the hospital setting, should plan and co-ordinate both discharge from hospital and provide rehabilitation in the community. The greatest benefits have been found with a co-ordinated ESD team, and the team should comprise a physiotherapist, an occupational therapist and a nurse (Fisher et al., 2011).

Patients receiving ESD were more likely to be independent and living at home, had better instrumental ADL (IADL) abilities and patient satisfaction at the end of a scheduled follow up at median 6 months, compared to patients receiving conventional hospital based care (Fearon & Langhorne, 2012). Patients with mild to moderate disability seem to be most suitable for ESD (Langhorne & Holmqvist, 2007), the typical patients being 66 to 80 years of age with a mean BI of 14/20 (equivalent to 70/100) (Fearon & Langhorne, 2012), and able to transfer with one able carer or independently if living alone (Fisher et al., 2011).

It has been hypothesised that the benefits of ESD may be due to several factors: avoiding complications of hospitalisation, improving patient and carer motivation, more realistic goal setting, providing rehabilitation in a more realistic environment, more self-directed training, and a higher level of input from therapists (Langhorne & Holmqvist, 2007), although the exact components of ESD services responsible for improving outcome remains unclear (Fearon & Langhorne, 2012). The optimal length of ESD intervention has not been defined (Haussen & Yavagal, 2011; Mas & Inzitari, 2012). The needs of stroke patients vary greatly. Interventions should be tailored to different patient groups (Mas & Inzitari, 2012) and to the individual patient's needs.

Previous studies have compared ESD with control, and few studies have used physical tests to examine outcome after ESD (Widen-Holmqvist et al., 1998; Askim et al., 2006; Askim et al., 2010). None of these studies obtained results in favour of ESD on outcomes of physical function such as balance and walking speed. However, the samples in these studies were small, and the impact of ESD needs to be further explored. Also, rehabilitation models may differ, and the effectiveness of different models should be investigated.

## **Multidisciplinary rehabilitation**

Neurorehabilitation plays a central role in reducing the long-term disability after stroke and achieving optimal functional recovery for community reintegration (Brewer et al., 2013). Improvement in functioning is multifaceted and requires teamwork between health professionals, the patient and family (Levin et al., 2009). Multidisciplinary rehabilitation involves physicians, nurses, physiotherapists, occupational therapists, speech and swallowing therapists and social workers (Stroke Unit Trialists' Collaboration, 2007) as well as neuropsychologists if available (Ringelstein et al., 2013), and is a key factor in implementing effective patient centred therapy (Brewer et al., 2013).

Physiotherapy is the most common rehabilitation intervention (Grefkes & Ward, 2013). The role of the physiotherapist in rehabilitation is mainly directed to

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improvement in motor function at both impairment and activity levels. Therapies assisting the patient to adapt to impairments are well recognised, while, according to Ward & Cohen (2004), therapies aimed at restoring function by minimising impairment are poorly developed. One exception is the Bobath Concept in which therapists integrate working on body structure and function, and activity levels to enhance recovery of function (Graham et al., 2009). There is evidence to support that task-oriented and context-oriented practice that is driven mainly by adaptive strategies compensating for impaired body functions can assist a natural pattern of functional improvement (Brewer et al., 2013). Although the hypothesised mechanisms behind different physiotherapy approaches differ, no physiotherapy intervention has been found superior to others in improving motor function post stroke (The European Stroke Association (ESO) Executive Committee et al., 2008; Pollock et al., 2014).

The timing of rehabilitative interventions seems to be important for improving functional outcomes post-stroke (Kleim & Jones, 2008; Maulden et al., 2005; Ward & Cohen, 2004). Delayed treatment may establish compensatory behaviour, which may interfere with rehabilitation (Kleim & Jones, 2008). More therapy time and more intensity of therapy seems to be beneficial for functional outcome (Kwakkel et al., 2004a; Langhorne et al., 2011), and training should be meaningful and repetitive (Langhorne et al., 2009; Takeuchi & Izumi, 2013). However, standard stroke rehabilitation is probably underdosed (Nudo, 2011).

## 1.4 Search strategy

Structured searches have been performed on four occasions: 25 May 2011, 7 January 2013, 29 November 2013, and 4 April 2014, in Medline and Embase, PEDro and SweMed+, covering the following four concepts:

Stroke, Trunk control, Postural Balance and Lesion Location. For each concept suitable subject headings and free text words were used, adapted to the vocabulary of the databases. The searches were limited to humans, adults and English language.

Search histories can be obtained from the author.

Additional searches have been performed at regular intervals mainly in PubMed for articles on trunk control and stroke, as well as scanning the reference lists in articles.

Regular searches have been performed in Cochrane and PubMed on Early Supported Discharge.



## **2. Aims of the study**

The overall aim of this PhD thesis is to broaden our understanding and knowledge of trunk control in patients with stroke. In order to investigate trunk control, a measure of trunk control, the Trunk Impairment Scale, was translated into Norwegian, assessed for measurement properties and further developed, resulting in a modified version. The Trunk Impairment Scale - modified Norwegian version (TIS-modNV) was used to investigate how lesion location would impact on trunk control and to assess possible differences in change over time for patients receiving different models of rehabilitation.

### **Aims of studies I – III**

#### *Study I, Methodological study*

The aim was to translate the Trunk Impairment Scale (TIS), a measure of trunk control in patients with stroke, into Norwegian (TIS-NV) and to explore its construct validity, internal consistency, intertester and test-retest reliability.

#### *Study II, Translational study*

The aim was to explore the relationship between middle cerebral artery lesion locations and trunk control post stroke, and to compare trunk control between patients with lesions in different single and multiple locations, and between left and right hemispheres.

#### *Study III, Intervention study*

The aim was to compare the effect on balance and walking of three different models of stroke rehabilitation: early supported discharge with rehabilitation either in a day-unit or at home, and traditional uncoordinated treatment (control).

### 3. Materials and methods

#### 3.1 Design and statistical analyses

This PhD thesis is based on three studies of patients mostly with stroke. An overview of methodological information is given in Table 2.

Table 2. Overview of designs, patients and statistical tests used in the three studies

Study	Design	Patients			Statistics
		N	Male; n (%)	Age; mean (SD)	
Study I: Methodological	Cross-sectional Longitudinal	251	145 (57.8)	68.1 (16.1)	Descriptive IRT EFA CFA Chi-square Bentler's Comparative Fit Index RMSEA Cronbach's alpha ICC SDC Kappa
Study II: Translational	Cross-sectional	109	53 (48.6)	70.6 (14.4)	Descriptive Independent t-test Mann Whitney U test
Study III: Intervention	Group comparison within a randomised controlled trial	167	95 (56.9)	70.4 (13.2)	Descriptive Independent t-test Chi-square Mann Whitney U test ANOVA Kruskal-Wallis Simple regression <sup>a</sup> Multiple regression <sup>a</sup> Backward stepwise multiple regression <sup>a</sup>

<sup>a</sup>Linear regression analyses. *Abbreviations*: IRT: Item Response Theory; EFA: Exploratory Factor Analysis; CFA: Confirmatory Factor Analysis; RMSEA: Root Mean Square of Approximation; ICC: Intraclass Correlation Analysis; SDC: Smallest Detectable Change; ANOVA: Analysis of Variance

## 3.2 Ethical considerations

Patients in the acute stage after stroke may be vulnerable because of the dramatic event of stroke, and also through experiencing different impairments and problems with activities and daily life. The patients were given written and verbal information and the opportunity to ask questions when invited to take part in the study. The patients were informed that taking part was entirely voluntary, and that they could withdraw from the studies at any time without giving reasons for wishing to do so. If any patient was unable to give informed consent for reasons such as their general condition, consent was given by the next of kin, and the patients had to confirm this in writing as soon as they were able. This procedure was approved by the Regional Committee for Medical and Health Research Ethics in Western Norway. For the reliability-part of Study 1, all patients had to give informed consent in person.

We carefully chose the assessment tools to be used based on the aims of the studies but with the added concern that these should not be too strenuous for the patients to perform. The testers were all experienced and able to judge the patients' level of capacity. They would stop testing if the patient became too tired or potentially unsafe during some of the PASS items (e.g. standing on one leg) or the walking tests. The Norwegian version of the TIS (TIS-NV) was assessed while the patients were sitting on a wide plinth and with the tester close and facing the patient. The well-being of the patient was our main concern. At any sign of discomfort or tendency to fall, the tester would be able to safe-guard the patient. Recommendations from the Helsinki declaration were followed. The studies were approved by the Regional Committee for Medical and Health Research Ethics in Western Norway and Norwegian Social Science Data Services (Table 3).

Table 3. Registration numbers and dates of approval from the Regional Committee for Medical and Health Research Ethics in Western Norway and Norwegian Social Science Data Services.

	<b>Project number REC</b>	<b>Date of approval</b>	<b>Project number NSD</b>	<b>Date of approval</b>
Study I			21829	14.05.2009
Reliability	2009/3199	30.03.2009		
Additional patient inclusion	2009/2458-5	25.08.2010		
Validity	2009/2458 (068.09)	14.12.2009	21829	14.05.2009
Study II	2010/2462-2 (070.08)	19.09.2010	18993	01.09.2008
Study III	070.08	30.10.2008	18993	01.09.2008

Project approval for Study III is covered by the ESD Stroke Bergen both for REC (070.80) and NSD (18993). To use data from ESD Stroke Bergen in Study I (Validity), and Study II, additional approval was sought and given. *Abbreviations:* REC: Regional Committee for Medical and Health Research Ethics in Western Norway; NSD: Norwegian Social Science Data Services.

### 3.3 Patients

Apart from 50 patients in Study I (the reliability part), the patients for all three studies were recruited from Haukeland University Hospital in connection with a larger randomised controlled trial; Early Supported Discharge after Stroke in Bergen (ESD Stroke Bergen), registered in ClinicalTrials.gov (NCT00771771). The protocol has been published (Hofstad et al., 2013).

#### **Inclusion and exclusion criteria**

The inclusion period for the ESD Stroke Bergen was 8 December 2008 to 20 December 2011 (except for holiday periods). Eligible patients had to live at home in the municipality of Bergen prior to stroke, be included within seven days of stroke onset and six to 120 hours after admission to the stroke unit, have a NIHSS score of two to 26 or a two-point increase in mRS scores if 0 - 1 prior to current stroke, and be awake. There was no age limit.

Exclusion criteria: serious psychiatric disorders, current alcohol or substance abuse, other serious conditions of importance to the cerebral disorder and subsequent rehabilitation process such as terminal cancer, and insufficient knowledge of the Norwegian language.

Additional inclusion and exclusion criteria were necessary for Studies I - III.

#### *Study I*

The above inclusion and exclusion criteria were used for investigating validity and internal consistency of TIS-NV. For investigating reliability, patients were recruited from the Department of Physical Medicine and Rehabilitation (DPMR). The patients had suffered brain lesions from stroke, trauma or tumour, and had to be in a sub-acute or chronic stage post brain injury, understand verbal instructions, be able and willing to give informed consent, and have no other physical or mental disorders that could affect performance of the TIS-NV.

#### *Study II*

Additional inclusion criterion: ischaemic stroke in the MCA territory verified by MRI. Additional exclusion criteria: inability to sit upright unsupported for 10 seconds, previous stroke and additional lesions in the brain stem or cerebellum.

#### *Study III*

Additional inclusion criteria: tested with PASS (main outcome) at baseline and discharge directly home from the stroke unit.

### **3.4 Outcome measures and assessment tools used in the three studies**

For all three studies apart from the reliability-part of Study I, the patients' physical function and related self-report was assessed by four physiotherapists who had a mean clinical experience within neurorehabilitation of 10 years, range of two to 27. One

therapist followed the study throughout; the other three were involved for long periods.

Table 4. Assessment tools used in the three studies, and suggested domains of functioning according to the ICF model

Assessment tool	STUDY					Scale domain
	I	II	III	ICF		
Trunk Impairment Scale (Verheyden et al., 2004)	X			BFS		Ordinal
Trunk Impairment Scale – Norwegian version	X	X	X	BFS		Ordinal
Trunk Impairment Scale – modified Norwegian version (Gjelsvik et al., 2012)	X	X	X	BFS		Ordinal
Alberta Stroke Program Early CT Score (Pexman et al., 2001)		X		BFS		Ordinal
Postural Assessment Scale for Stroke <sup>a</sup> (Benaim et al., 1999)				X	Activity	Ordinal
Functional Ambulation Category (Mehrholz et al., 2007)				X	Activity	Ordinal
5 metre timed walk (Salbach et al., 2001)				X	Activity	Ratio
Timed Up-and-Go (Podsiadlo & Richardson, 1991)				X	Activity	Ratio
Numerical Rating Scales (Farrar et al., 2001)				X	Activity	Interval
National Institutes of Health Stroke Scale (Adams et al., 1999; Thomassen et al., 2005)				X	BFS	Ordinal
Barthel Index (Mahoney & Barthel, 1965)				X	Activity	Ordinal
Modified Rankin Scale (Govan et al., 2009)				X	Activity	Ordinal

*Abbreviations:* ICF: International Classification of Functioning, Disability and Health; BFS: body functions and structures. <sup>a</sup>Primary outcome measure Study III.

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To assure standardisation of the test procedures and practice testing to optimise reliability, there were several meetings to discuss the different assessment tools before study start as well as during the three year inclusion period. This was especially important when there were changes related to the test personnel. All patients were tested in a standardised environment; using the same room and plinth in the physiotherapy department.

An overview of assessment tools used in the three studies together with suggested ICF domains is presented in Table 4. The Trunk Impairment Scale, the Alberta Stroke Program Early CT Score and Postural Assessment Scale for Stroke are presented in more detail in the following.

***Trunk Impairment Scale (TIS)*** is a test for assessing motor impairments of the trunk in sitting (Verheyden et al., 2004) through observational movement analysis. The original TIS (Appendix I) contains 17 items scored on ordinal scales, for evaluating aspects of postural control in static and dynamic sitting and coordination, with a maximum obtainable score of 23 (highest score best), which should reflect optimal trunk control. The static sitting balance subscale (SSB) consists of three items with different scoring alternatives: item 1, static upright sitting (scoring alternatives 0, 2); item 2, sitting with a smaller base of support achieved by having the legs crossed by the tester (scoring alternatives 0, 2); and item 3, crossing the legs actively (scoring alternatives 0, 1, 2, 3). The dynamic sitting balance subscale (DSB) consists of 10 dichotomous items with scoring alternatives 0 and 1: side flexion to the most affected side touching the plinth with the elbow three times (DSB items 1-3); side flexion to the least affected side touching the plinth with the elbow three times (DSB items 4-6); lifting the most affected pelvic half off the plinth twice (DSB items 7-8); and lifting the least affected pelvic half off the plinth twice (DSB items 9-10) (Figure 2). The coordination subscale (Coo) contains four items with different scoring alternatives: rotation of the upper trunk without time constraint (scoring alternatives 0, 1, 2); the same again within six seconds (scoring alternatives 0, 1); rotation of the lower trunk without time constraint (scoring alternatives 0, 1, 2); and the same again within six seconds (scoring alternatives 0, 1). Each group of items; DSB items 1-3, 4-6, 7-8, 9-10

and Coo items 1-2, 3-4, are hierarchically organised. Possible compensatory strategies used to achieve the different items are evaluated, and the patients are marked down if they compensate (Table 5). As such, the TIS is a measure of quality of trunk stability and movement.

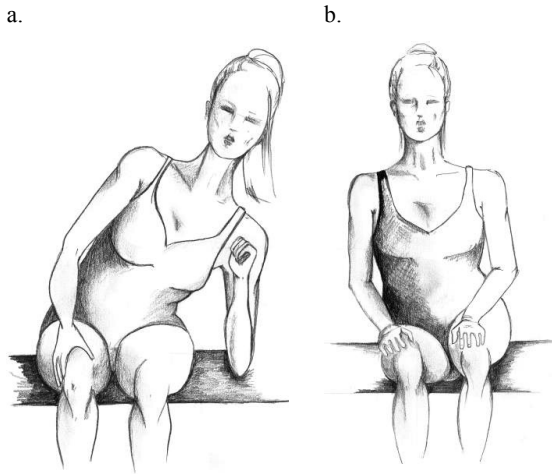


Figure 2. Illustration of a. DSB items 1 – 6: sideflexing to most and least affected side; and b. DSB items 7 – 10: lifting the most and least affected pelvic half off the plinth.  
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Table 5. The hierarchical construction of TIS; example from the subscale Dynamic sitting balance, items 1-3; Sideflexion to most affected side touching the plinth with the elbow

DSB items	Scoring alternatives	Requirements
1	0	Not able
	1	Moves actively
2	0	Trunk movement not appropriate
	1	Trunk movement appropriate
3	0	Trunk movement appropriate but compensates
	1	Trunk movement appropriate, no compensation

If the patient scores zero on Dynamic sitting balance (DSB) item 1, then DSB 2 and DSB 3 are scored as zero. Top sum score for the three items is 3



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The original scale was found to have acceptable reliability and validity, and a change of four points or more for an individual indicates a change above measurement error (smallest detectable change, SDC). A top score, however, does not seem to be a prerequisite for performing ADL activities (Verheyden et al., 2005). TIS has not shown a ceiling effect in patients with subacute or chronic stroke (Verheyden et al., 2006c), and has demonstrated ability to discriminate between healthy individuals and stroke patients (Verheyden et al., 2005).

Content validity was established by face validity. Correlation between TIS total score and BI gave *Spearman's rho* = 0.86, and between TIS and Trunk Control Test, *Spearman's rho* = 0.83, demonstrating satisfactory construct and concurrent validity (Verheyden et al., 2004). TIS scores at admission demonstrated a significant predictive ability with function at six months post stroke as measured using BI (Verheyden et al., 2007a). TIS is quick to score and requires a minimum of equipment; a bed or plinth, and a stop watch. The original scale formed the basis for Study I.

***The Alberta Stroke Program Early CT Score (ASPECTS)*** is a 10-point scoring system used to identify the localisation and estimate extent of the lesion after early ischaemic changes in the middle cerebral artery (MCA) territory (Tei et al., 2011) (Figure 3), which is the most common subtype of ischaemic stroke (Balaban et al., 2011). ASPECTS was initially developed for CT, but as MRI technology rapidly became the most frequently used imaging tool, ASPECTS is applied on diffusion-weighted (DWI) MRI (DWI ASPECTS) (Terasawa et al., 2010). The 10 areas scored are insular cortex, M1 – M6 (cortical areas), the caudate and lentiform nuclei and internal capsule (subcortical areas). A total score is obtained by subtracting one point for each infarcted area, thus a patient with a single infarct in the MCA territory receives a score of nine, and a patient with eight infarcted areas receives a score of two.

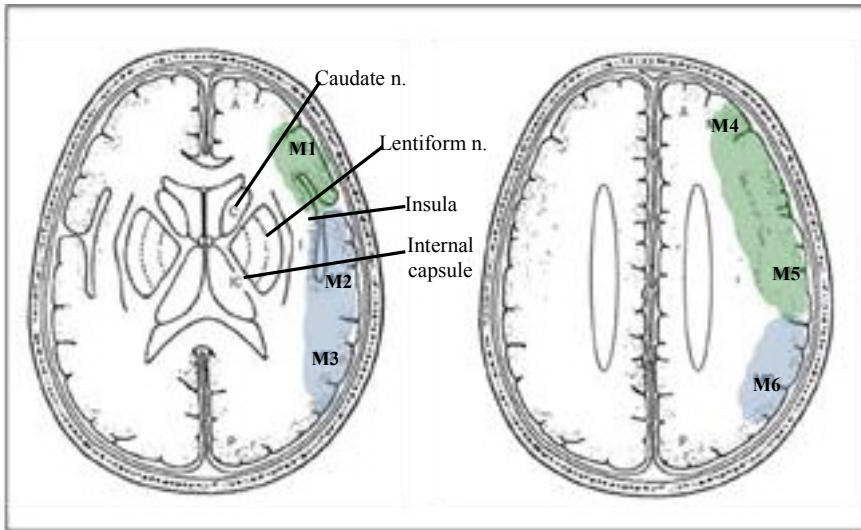


Figure 3. The ASPECTS template showing the geometrical division of the MCA cortex M1 – M6 as well as the areas of the lentiform and caudate nuclei, the internal capsule and the insular cortex. Insular cortex together with M1 – M6 comprise the cortical structures assessed, and the caudate and lentiform nuclei together with the internal capsule, the subcortical structures. The anterior MCA territory corresponds to M1, M4 and M5 (green area), and the posterior regions to M2, M3 and M6 (blue area). The illustration is adapted and reprinted with kind permission of Mayank Goyal, editor of the website Understanding Alberta Stroke Program Early CT Score (ASPECTS) <http://www.aspectsinstroke.com/> 18/2-2013.

Areas M1 – M3 refer to the anterior, lateral and posterior MCA cortex respectively, and areas M4 – M6 are anterior, lateral and posterior MCA cortex immediately superior to the former (Pexman et al., 2001; Tei et al., 2011). The anterior MCA territory corresponds to M1, M4 and M5, and the posterior regions to M2, M3 and M6 (Goyal, 2013). M1 – M6 represent geometrical divisions of the cortex and are not based on anatomical structures.

***Postural Assessment Scale for Stroke (PASS)*** was developed to assess the degree of postural control in stroke. PASS contains items with differing levels of difficulty for maintaining or changing a position: static sitting, standing, standing on one leg, turning in supine, sitting up and lying down, sitting to standing, sitting down, and picking an object from the floor in standing (Benaim et al., 1999; Liaw et al., 2008). PASS is an ordinal scale and contains 12 items with four scoring alternatives (0 – 3),

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adding up to a total score of 36 (highest score best). The test is applicable to a broad range of patients, even those with very poor postural control, and therefore considered appropriate to use in patients with acute stroke. PASS was found to be sufficiently reliable and valid as a measure of postural control (Benaim et al., 1999). It is recommended for use in the acute and sub-acute phase post stroke, but has demonstrated a ceiling effect after three to six months (Benaim et al., 1999; Chien et al., 2007; Mao et al., 2002). SDC in an individual is four points (Liaw et al., 2008). PASS has demonstrated high internal consistency and better psychometric properties than Berg's Balance Scale (BBS) in stroke patients (Chien et al., 2007). PASS scores obtained in the first three months after stroke have been found to be predictive for ADL function after one year (Chien et al., 2007). High associations have been shown between PASS and Berg Balance Scale, *Spearman's rho* = 0.90, early after stroke (O'Dell et al., 2013), and between PASS at admission and Functional Independence Measure at discharge from inpatient rehabilitation, *Spearman's rho* = 0.687 (Di Monaco et al., 2010). Also, PASS scores at admission to rehabilitation were significantly lower in patients who were discharged to an institution compared with patients who were discharged directly home,  $p = 0.002$  (Di Monaco et al., 2010). The subscore PASS-Trunk Control (items 1, 6, 7, 8, 9) has been found to be a strong predictor of comprehensive ADL function (Hsieh et al., 2002). PASS is quick to score and requires only a bed or plinth, and a stop watch.

## 3.5 Paper I

### 3.5.1 Translation

In order to use the TIS as a measure of trunk control in Studies II and III, we translated the scale into Norwegian (TIS-NV). The developer of the original TIS, Geert Verheyden, was contacted in 2006 for approval, which was given. In line with recommendations from WHO (Sommerfeld et al., 2002) we used international guidelines for translating the scale, aiming to approach equivalence between the

original and the translated instrument, as well as cross-cultural adaptation. The following steps were used (Beaton et al., 2000):

1. Translation
2. Synthesis of the translations
3. Back-translation to the original language
4. Expert panel
5. Pretesting in a clinical situation

The process of translation is described in Paper I. Guidelines on how to instruct the patients are not given in the original TIS. We experienced, however, a need to standardise the test by developing phrases for instructing the different items and thereby assure a similar understanding. Geert Verheyden was consulted on a regular basis to clarify any queries regarding interpretation of the different items, and visited our research group in 2009 for further discussions.

### **3.5.2 Measurement properties**

#### *Construct validity*

To assess construct validity, Item Response Theory (IRT), exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) were used. Unidimensionality is a fundamental requirement for construct validity (Tennant et al., 2004) and defined through the property of local independence; i.e. when there are no significant correlations among the items once controlled for the latent trait (here: trunk control) (Morizot et al., 2007). To test for unidimensionality and local independence, EFA and CFA were used.

#### *Internal consistency*

After exploring the dimensionality of the scale, internal consistency was examined. Internal consistency is a measure of to what extent items of a scale measure the same underlying trait; i.e. the homogeneity of the scale, most often evaluated by Cronbach's alpha (Polit & Beck, 2008). To test for homogeneity, correlations between each item and the scale sum score (item-total correlations) were investigated. The contribution of

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each item to the scale as a whole was evaluated by deleting one item at the time (Chronbach's Alpha if item deleted) (Streiner & Norman, 2008b).

### *Reliability*

The data for the reliability study was collected during two time periods: May – September 2009 and May – September 2010, using TIS-NV. The first period represents patients who were recruited for my Master's study, and consisted of 29 patients. The number of patients was considered to be below the recommended minimum for reliability studies (Terwee et al., 2007), and another 21 patients were recruited during the second time period.

Two therapists (SD and BG) assessed the patients simultaneously for intertester reliability, and BG assessed the patients again two hours later for test-retest reliability. In order to standardise the test procedure, all patients were examined in the same room using the same plinth in the physiotherapy department. No patients received physiotherapy between the two test periods. Intertester and test-retest reliability of the individual items of the scale was examined by kappa statistics. Kappa examines the relationship between agreement and agreement by chance (Streiner & Norman, 2008a). Intertester and test-retest reliability were calculated using intraclass correlation coefficients (ICC) (Streiner & Norman, 2008a) for the total score. Within-subject standard deviation ( $S_w$ ) was used to examine absolute reliability, in which the difference between the “true” and the measured score is expected to be less than  $1.96 S_w$  for 95% of the observations for intertester reliability. Measurement error in a test-retest situation is expressed as SDC of two repeated measurements of the same individual, and expected to be less than  $\sqrt{2} \times 1.96 S_w$  (Bland & Altman, 1996). This informs the therapist whether the change observed in a patient is above measurement error.

## 3.6 Paper 2

A cross-sectional design was used to explore the relationship between trunk control and lesion location in acute stroke.

At admission to the stroke unit, patients routinely undergo emergency CT to exclude a haemorrhagic cause of the stroke and in order to consider recanalization treatment (Thomassen et al., 2012). In our stroke unit, DWI MRI is additionally performed in approximately 80% of the patients. Based on DWI MRI, ASPECTS was scored by a senior consultant neurologist (HN) at the stroke unit, and used to determine the location(s) of the ischaemic lesion(s).

We used descriptive statistics to examine the background variables of age, gender, cohabitation, diabetes, previous nursing care, thrombolytic treatment, hemispheric lesion side, ASPECTS sum (extent of lesion), and the distribution of scores from the modified Norwegian version of TIS (TIS-modNV, as a result from Study I) in patients with multiple and single ASPECT locations. Parametric statistics (independent t-tests) were used to compare age, and non-parametric statistics (Mann-Whitney's U test) to compare other background variables between multiple and single ASPECT locations. Non-parametric statistics were used to compare TIS-modNV scores between single right and left hemispheric lesions in cortical, subcortical and individual ASPECT locations. *Post hoc* analysis explored and compared the frequency of TIS-modNV scores in the single lesion location M5 between right and left hemispheric lesions using both descriptive statistics and Mann-Whitney's U test.

To explore the assessment tools used in this study, I will provide results from supplementary analyses on the association between TIS-modNV and ASPECTS in the Results section of the thesis. In addition, comparison of age (independent t-test) and TIS-scores (Mann-Whitney's U test) between genders will be reported.

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## 3.7 Paper 3

In Study III we aimed to compare the three months outcome related to physical function specifically for postural control, trunk control and walking, in three rehabilitation models: two for early supported discharge including either day-unit rehabilitation or home-rehabilitation (intervention groups); and one for traditional treatment. We chose PASS as the main outcome measure even though our main interest was change in trunk control, because from a patient perspective, achieving improvement in basic activities of daily living was considered more meaningful than improvement of trunk control.

A computer-generated list of random numbers in blocks of six was used for the allocation of patients. The randomisation list was kept by a study coordinator and was not known to any persons in the stroke unit, thereby assuring that the person recruiting participants did not have access to the list. A nurse recruited the patients, and the study coordinator consecutively assigned the patients to their groups in the same order as they were included into the study.

The primary outcome measure was PASS, and secondary outcome measures were chosen to reflect different aspects of balance and walking: TIS-modNV, 5 metre timed walk (5mTW), timed Up-and-Go (TUG), and self-report on problems with balance, walking, safety in physical activity, ADL, pain and tiredness using Numerical Rating Scales (NRS). Patients' walking ability was categorised by the use of Functional Ambulation Categories (FAC). For background information on the patients' level of impairment we used a 13 item Norwegian version of the National Institute of Health Stroke Scale (NIHSS) (Thomassen et al., 2005). The patients were assessed at several time points during the first 24 hours post stroke: at admission and every four hours thereafter. We used the NIHSS scores from the admission assessment. Dependence in ADL was measured using BI, and global dependency by modified Rankin Scale (mRS), both measures were assessed at day seven or at discharge from the stroke unit (if earlier).

### *Intervention*

All patients admitted to the stroke unit with a stroke diagnosis received specialised stroke unit care. For the purpose of ESD Stroke Bergen trial, two multidisciplinary teams were established: a hospital out-reach team and a community healthcare team that followed the patients for a limited period of time after hospital discharge. The hospital out-reach team was established at the DPMR. The team members met the patients and carers already in the stroke unit to discuss and evaluate what was necessary to enable each patient's early return home; e.g. acquiring necessary equipment for home use. They organised the transition from hospital to the patients' homes by coordinating the two different levels of health care: specialist stroke unit care and primary health care services. The hospital out-reach and community healthcare teams met with the family and patient at one home visit prior to discharge if possible, to plan the transition from hospital to home. The main role of the community health-care team was treatment at home or treatment in a community day-unit for up to five days per week for up to five weeks depending on each patient's needs.

### Intervention groups

- Day-unit rehabilitation. The patients travelled from home to a day-unit in the community to receive treatment by the community health-care team. The treatment was both impairment and task oriented (Aasebø et al., 2012), including kitchen activities such as preparing lunch, laying the table and clearing away, and outdoor walking. Eating lunch together gave the opportunity to socialise and meet with others in the same situation.
- Home-rehabilitation. The treatment was mostly directed towards task oriented training such as personal ADL, household tasks and preparing food, as well as stair climbing and moving about in the patient's home environment.

### Control group

The patients in the control group received traditional treatment which could consist of services from the primary healthcare providers; home nursing, physiotherapy and/or occupational therapy depending on patients' needs; or they can seek treatment in a private physiotherapy clinic. Treatment and/ or assistance from primary health care



providers would be given in the patients' own homes, while the patients would need to travel to receive private physiotherapy. The different professionals would usually see the patient alone, and interventions would for the most part not be coordinated or team oriented.

We used descriptive statistics to examine the background variables, and the baseline and change scores of all outcome measures. Parametric statistics (independent t-tests) and non-parametric statistics (Mann-Whitney's U test) were used where appropriate, to compare baseline variables between patients who were retested with PASS and those who were not. Parametric (ANOVA) and non-parametric statistics (Kruskal-Wallis, chi-square) were used where appropriate, to compare baseline and change scores between the three groups; day-unit, home-rehabilitation and control. If a difference in change was found for any outcome, pairwise analyses adjusted for multiple comparisons were performed. Simple, multiple and backward stepwise multiple linear analyses with PASS scores at three months as the dependent variable were performed, adjusting for group allocation, age, and other background variables, as well as baseline scores of PASS.

To explore the assessment tools in the study, I will provide results from supplementary analyses on baseline scores of the physical tests and association between TIS-modNV and the other tests in the Results section of this thesis. Descriptive analyses of number of patients who improved above SDC on PASS, TIS-modNV, 5mTW and TUG for the different groups will also be reported.

## **4. Summary of results**

### **4.1 Paper 1**

This study encompasses translation and investigation of measurement properties of the TIS. The back-translated version of TIS-NV was validated by the original developer. The subscale SSB was removed from the test. Six testlets were hierarchically constructed by combining items from the subscales DSB and CoO, and named the Trunk Impairment Scale – modified Norwegian version (TIS-modNV). After these modifications the TIS-modNV fitted well to a locally dependent unidimensional item response theory model. The test demonstrated good construct validity, excellent internal consistency, as well as high intertester and test-retest reliability for the total score.

#### **4.1.1 Translation**

The translation and cross-cultural adaptation process was quite straight forward, but time consuming. Several words in the text could be interpreted in different ways in Norwegian. Examples of discussion points:

- We preferred to use “more affected” and “least affected” instead of “hemiplegic” and “non-hemiplegic” throughout
- The coordination subscale items 1 and 3: to change the word “fixated” to “maintained”
- We found the original description of coordination subscale items 2 and 4 unclear: rotation should be performed within 6 seconds. To score 0: rotation is asymmetrical; to score 1: rotation is symmetrical. We suggested the following for scoring alternative 0: "Rotation is asymmetrical or the patient uses more than 6 seconds"

These changes were accepted by the developer. We found that crossing the arms over the chest facilitated the patients' reference for selective rotation of the lower trunk in CoO subscale items 3 and 4, and proposed to change the position of the arms from “The arms rest on the legs”, but this was not accepted by the test developer.

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The term “appropriate” (DSB items 2, 5, 7 and 9) was discussed. We agreed that this is a subjective evaluation from each tester, and therefore therapists working in the same department need to see patients together to assure sufficient reliability within the clinical group and for research purposes. Clear instructions for each item were developed, and some adjustments were incorporated in Verheyden et al.’s (Verheyden et al., 2010) own revised version of TIS, the TIS 2.0. The translated instrument, TIS-Norwegian version (TIS-NV), was pre-tested and final adjustments were done to clarify the wording of the different items.

#### **4.1.2 Measurement properties**

Data from 201 patients were used for the analysis of construct validity and internal consistency. The TIS-NV did not initially fit a unidimensional CFA model. In the SSB subscale most patients (95.5%) achieved the highest score on item 1, and 66.7% achieved the maximum subscale score of seven points, and as there was a high correlation between the two remaining items, this subscale was removed. We found a high degree of local dependence between DSB items 1-3, 4-6, 7-8, and 9-10, and Coo items 1-2 and 3-4. We therefore decided to merge similar items into ordinal scales making the scoring levels mutually exclusive. This resulted in six testlets instead of the original 14 items (Table 6). The test was named the Trunk Impairment Scale - modified Norwegian version (TIS-modNV). Local dependence was still found between testlets 1 and 2, and testlets 3 and 4 after rerunning CFA analyses. We therefore chose to use an IRT model which allowed local dependence to be taken into account, and achieved a good fit to a unidimensional Item Response Theory model. The results indicate that the scale has one strong general factor which we called trunk control, and two content specific factors reflecting problems with lower and upper trunk control, respectively. Testlets 1, 2 and 5 were found easier to perform than testlets 3, 4 and 6.

Table 6. Overview of transformations and scores from TIS-NV to TIS-modNV

Items	Original TIS-NV		TIS-modNV	
	Old value		Testlets	New value
DSB 1	0		1	0
	1			1
DSB 2	0			
	1			2
DSB 3	0			
	1			3
DSB 4	0		2	0
	1			1
DSB 5	0			
	1			2
DSB 6	0			
	1			3
DSB 7	0		3	0
	1			1
DSB 8	0			
	1			2
DSB 9	0		4	0
	1			1
DSB 10	0			
	1			2
Coo 1	0		5	0
	1			1
	2			2
Coo 2	0			
	1			3
Coo 3	0		6	0
	1			1
	2			2
Coo 4	0			
	1			3
TIS-NV sum	16		TIS-modNV sum	16

*Abbreviations.* TIS-NV: Trunk Impairment Scale-Norwegian version; TIS-modNV: Trunk Impairment Scale-modified Norwegian version; DSB: dynamic sitting balance subscale; Co: coordination subscale

The TIS-modNV demonstrated high internal consistency; Cronbach's alpha (95% CI) 0.85 (0.82, 0.88) for the total sum score, and all the testlets contributed to increase the alpha level (Cronbach's alpha if item deleted).

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Data from 50 patients were used in the reliability study. The intertester reliability of each testlet gave kappa = 0.80 for testlet 1 (excellent, (Streiner & Norman, 2008a)), between 0.44 – 0.58 (moderate) for testlets 2, 4, 5, and 0.40 (fair) for testlet 3. Kappa could not be calculated for testlet 6 as the testers had not all used the same scoring alternatives. Per cent intertester agreement for testlet 6 was 80%. For test-retest reliability, kappa was substantial (0.66 – 0.77) for testlets 1, 3, 4, 5, fair (0.34) for testlet 2 and moderate (0.53) for testlet 6. The TIS-modNV total sum score demonstrated high intertester reliability with ICC 1.1 (95% CI): 0.77 (0.63, 0.86), as well as high test-retest reliability with ICC 1.1 (0.95 CI): 0.85 (0.75, 0.91). The SDC was 2.90, meaning that a change should be above this value in an individual to be above measurement error.

## 4.2 Paper 2

In this study we investigated the relation between trunk control and location of middle cerebral artery (MCA) lesions. A total of 109 patients with first time middle cerebral artery lesions were included; 71 with multiple and 38 with single ASPECT locations. Trunk control was poorer in multiple (median 8.0) than in single (median 11.0) lesion locations,  $p = 0.011$ . The most common single lesion location was M5 (50%) which is situated in the anterior parts of the MCA territory and hypothesised to represent sensory and motor areas of the cortex. Patients with lesions in the right M5 location achieved poorer scores on trunk control as compared to left,  $p = 0.030$ .

DWI MRI was taken, mean (SD), min-max: 1.7 days (1.3), 0 – 9 after stroke onset, and the patients were tested for trunk control, mean (SD), min-max: 4.5 days (1.9), 1-9 after stroke onset (missing information on 4 patients). There was no difference between patients with multiple and single lesion locations for any background variables.

Patients with multiple lesion locations achieved significantly poorer scores on TIS-modNV compared to single. We found M5 to be the most frequent lesion location in

both multiple and single locations. We found a hemispheric asymmetry with lesions of the right M5 achieving median 4 points lower scores on TIS-modNV compared to the left,  $p = 0.030$ .

*Post hoc*, the frequency and comparison of individual testlet scores between the right and left M5 locations demonstrated significant differences between hemispheres for testlets 1, 4 and 6.

### Supplementary analyses

We found a moderate correlation between TIS-modNV sum scores and number of ASPECT lesion locations, Spearman's rho 0.324,  $p = 0.001$  (Figure 4). The patients had a mean (SD), min-max ASPECTS score of 8 (2), 2-9; i.e. they suffered on average lesions in two different ASPECT locations. However, the variability was great.

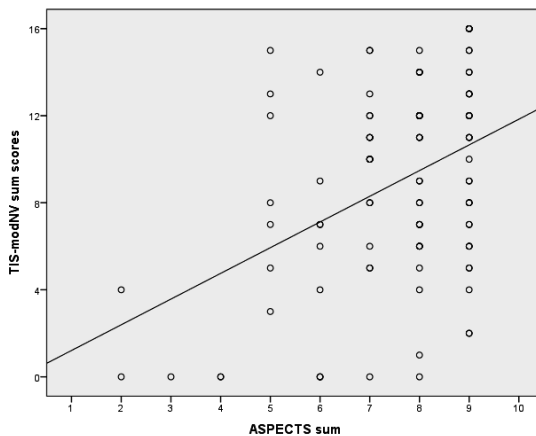


Figure 4. Graphical representation of the association between TIS-modNV scores and ASPECTS sum at baseline. An ASPECTS sum of 10 indicates no lesions detected by DWI MRI in the MCA territory, while a score of 9 indicates a single lesion location. There is a number of overlying data points in the scatter plot.

*Abbreviations.* TIS-modNV: Trunk Impairment Scale-Norwegian version; ASPECTS: Alberta Stroke Program Early CT Score

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We found a significant difference in age between male, mean (SD) 67.0 (13.9) years and female patients 74.0 (14.3) years,  $p = 0.011$ . There was no difference between genders for TIS-modNV baseline scores, indicating that men and women had a similar degree of trunk impairment after stroke, even though the female patients were older.

### 4.3 Paper 3

In this study we compared physical outcome in three rehabilitation models: two for early supported discharge (ESD) and one for traditional treatment. From a total of 306 randomised patients, 167 were tested with PASS at baseline and discharged directly home.

There were no group differences for background characteristics, (Table 7). The patients had an overall mild to moderate disability at baseline, as demonstrated with PASS: median (min-max) 31 (20-36); NIHSS: 2 (0-26); BI: 100 (50-100); and mRS: 2 (0-4). Initial NIHSS scores demonstrated that 86.8% of patients were mildly impaired scoring 0-6; 11.4% moderately impaired scoring 7-15; and only three patients (1.8%) were severely impaired, scoring  $\geq 15$  on NIHSS. There was no difference between the groups at baseline for PASS or any secondary physical capacity measures (Paper 3, Table 3).

There was no difference in length of stay in the stroke unit; the patients in the control group were discharged as early as the intervention groups. All but three patients received the planned intervention. During the three months between inclusion and retest 62 patients were lost to follow-up, mainly because they did not keep their appointment for retest at DPMR (48.4%), withdrew from the study (24.2%); or were not available due to holidays, secondary rehabilitation stay or other reasons (19.4%). One patient in the home-rehabilitation group died. This left 105/167 (62.9%) patients for retest, 63 males, mean age 69 years: day-unit 27/52 (51.9%); home-rehabilitation 43/60 (71.7%); and control 35/55 (58.2%) (Paper 3, Figure 1 Flowchart).

Table 7. Background characteristics of patients who were tested with PASS at baseline (N = 167).

Variables	Day-unit n = 52		Home-rehabilitation n = 60		Control n = 55		p- value	Statistic			
Age; mean (SD), min, max	68.7	13.7	29-90	71.4	12.1	42-92	70.8	13.9	32-98	0.526	ANOVA
Male gender; n (%)	31	59.6		35	58.3		29	52.7		0.755	K-W
Living with partner; n (%)	30	57.7		42	70.0		31	56.4		0.280	K-W
Ischaemic stroke; n (%)	44	84.6		57	95.0		51	92.7		0.137	K-W
Localisation of lesion; n (%)										0.930	K-W
Right hemisphere	21	40.4		21	35.0		18	32.7			
Left hemisphere	18	34.6		25	41.7		28	50.9			
Bilateral	4	7.7		2	3.3		1	1.8			
Brainstem	5	9.6		8	13.3		6	10.9			
Cerebellum	4	7.7		4	6.7		2	3.6			
Most affected body half; n (%)										0.547	K-W
Right	26	50.0		36	60.0		32	58.2			
Left	25	48.1		23	38.3		22	40.0			
Bilateral	1	1.9		1	1.7		1	1.8			
Thrombolysis; n (%)	8	15.4		6	10.0		6	10.9		0.694	K-W
Diabetes; n (%) <sup>a</sup>	7	13.5		8	13.3		12	21.8		0.406	K-W
Previous stroke; n (%) <sup>b</sup>	12	23.1		13	21.7		13	23.6		1.000	K-W
Previous nursing care; n (%)	5	9.6		3	5.0		4	7.3		0.652	K-W
Days stroke unit; mean (SD), min, max	8.5	3.5	2-17	8.4	3.9	3-18	9.0	6.3	3-43	0.591	ANOVA

Abbreviation: K-W: Kruskal-Wallis test, non-parametric. Significant values (p<0.05) marked in bold. <sup>a</sup>Missing information on 1 patient in the home-rehabilitation group <sup>b</sup>Missing information on 1 patient in each of the intervention groups



There was a significantly higher intensity (hours) of treatment but not of duration (weeks) given by the community health care team in the day-unit than in the home-rehabilitation group. The day-unit group received on average one hour more treatment per week.

Comparisons between those who were retested at three months and those who were not, demonstrated significant differences for background characteristics; age, co-habitation, previous stroke and nursing care (Paper 3, Table 1). Those who were retested were younger; more often lived with a partner; fewer suffered previous strokes and had nursing care prior to stroke. The patients who dropped out scored worse on PASS, BI and walking tests, than those who were retested (Paper 3, Table 2).

After three months there was no group difference in change on PASS ( $p > 0.05$ ) (Paper 3, Table 4). Some secondary measures tended to show better outcome for the intervention groups; trunk control, median (95%CI): day-unit, 2 (0.28, 2.31); home-rehabilitation, 4 (1.80, 3.78); control, 1 (0.56, 2.53),  $p = 0.044$ , and self-report on walking,  $p = 0.021$ , and ADL,  $p = 0.016$  (Paper 3, Table 4). Bonferroni-adjusted pairwise comparisons demonstrated no difference between groups for trunk control, but significantly greater improvement for self-report on walking in the day-unit compared to control, and for self-report on ADL in the home-rehabilitation group compared to control (Table 8), with the control group achieving the least change.

Table 8. Pairwise comparisons between the day-unit, home-rehabilitation and control groups for trunk control and self-report on problems with walking and ADL

Pairwise comparisons		TIS-modNV	NRS 1	NRS 3
		<i>p-value</i>	<i>p-value</i>	<i>p-value</i>
Day-unit	Home-rehabilitation	0.031	0.215	0.774
Day-unit <sup>a</sup>	Control	0.886	<b>0.004</b>	0.036
Home-rehabilitation <sup>a</sup>	Control	0.040	0.126	<b>0.006</b>

<sup>a</sup>The results favour day-unit and home-rehabilitation. *Abbreviations:* TIS-modNV: Trunk Impairment Scale – modified Norwegian version; NRS1: self-report on problems with walking; NRS3: self-report on problems with ADL. Bonferroni-adjusted for multiple comparisons setting a significance level of  $p = 0.0167$ . Significant differences in bold.

Table 9. Multiple regression of PASS at 3 months, N = 105

Predictors	Unadjusted simple regression models			Adjusted multiple linear regression model			Final multiple linear regression model <sup>a</sup>		
	b	95%CI	P-value	b	95%CI	P-value	b	95%CI	P-value
Age	-0.163	-0.200, -0.125	<0.001	0.420	-0.117, -0.034	0.001	-0.070	-0.109, -0.031	0.001
Gender	0.492	-0.770, 1.754	0.441	0.006	-0.557, 1.168	0.483			
Female	0	reference		0	reference				
Marital status	-1.604	-2.970, -0.237	0.022	0.050	-0.496, 1.491	0.324			
Living with partner	0	reference		0	reference				
PASS baseline	0.591	0.484, 0.698	<0.001	0.626	0.394, 0.260, 0.527	<0.001	0.394	0.266, 0.523	<0.001
Diagnosis	-0.343	-3.014, 2.327	0.799	0.001	-0.816, -2.690, 1.058	0.389			
Infarction	0	reference		0	reference				
Thrombolysis	-0.921	-3.370, 0.348	0.110	0.025	-0.193, -1.405, 1.019	0.753			
Yes	0	reference		0	reference				
Diabetes	1.597	0.017, 3.177	0.048	0.038	0.812, -0.336, 1.959	0.163			
Yes	0	reference		0	reference				
Prev. cerebral lesion	2.234	0.642, 3.826	0.006	0.071	0.987, -0.101, 2.074	0.075	2.621	0.541, 4.700	0.020
Yes	0	reference		0	reference				
Prev. nursing care	6.421	3.435, 9.407	<0.001	0.150	2.710, 0.408, 5.012	0.022	1.220	0.198, 2.243	0.014
Yes	0	reference		0	reference				
Rehabilitation group			0.720	0.007		0.241			
Day-unit	-0.194	-1.823, 1.436		-0.816	-1.873, 0.152				
Home-rehabilitation	-0.599	-2.048, 0.849		-0.282	-1.203, 0.639				
Control	0	reference		0	reference				
R <sup>2</sup>							0.668		0.647
R <sup>2</sup> <sub>adj</sub>							0.628		0.633

Experimental group I: day-unit rehabilitation; Experimental group II: home-rehabilitation. <sup>a</sup>From backward stepwise selection at significance level 0.05.

Abbreviations: PASS: Postural Assessment Scale for Stroke; Prev.: Previous; R<sup>2</sup><sub>adj</sub>: adjusted R<sup>2</sup>.

Walking speed improved by mean 0.26 m/s in the day-unit patients (Paper 3, Table 4), which is an above clinically important change (MIC) (0.175 m/s) (Fulk et al., 2011). In the day-unit group 13 patients (48.2%) improved above MIC, in home-rehabilitation 14 (32.6%), and in control 11 (31.4%).

Multiple regression analysis with PASS scores at three months as the dependent variable demonstrated a significant effect of age, previous cerebral lesion and previous nursing care, but no effect of group allocation (Table 9).

### Supplementary analyses

The potential for change in outcome measures depends on the baseline scores. The distribution of baseline scores for the physical tests is shown in Figure 5, a-d.

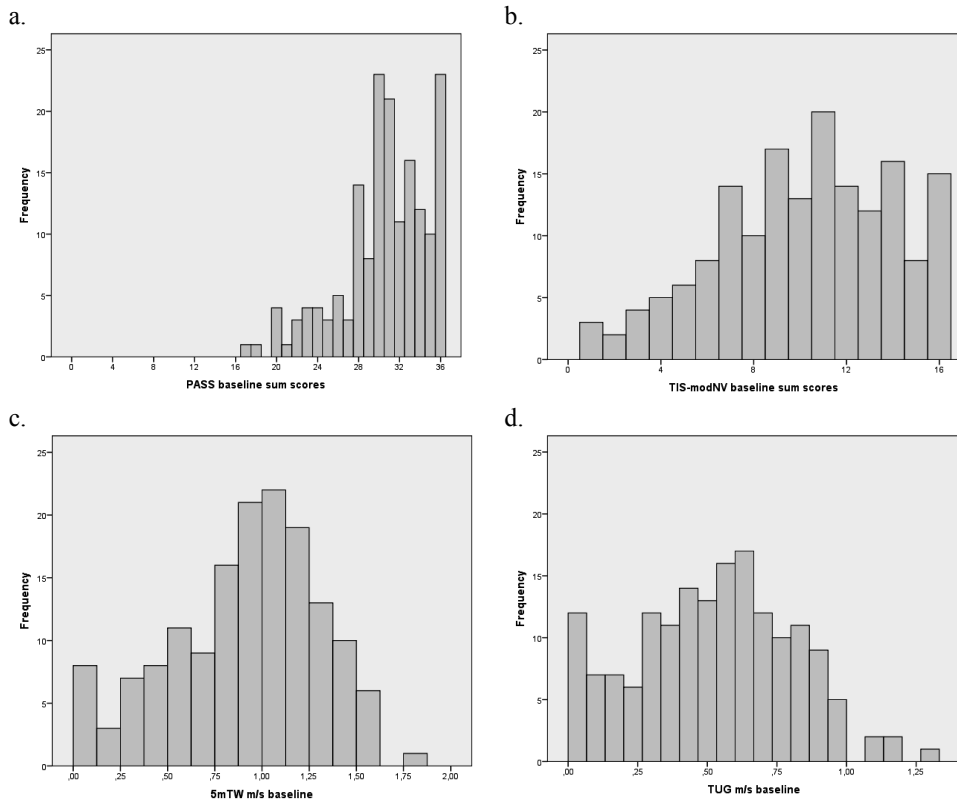


Figure 5. Graphical representation of baseline distribution of a. PASS, b. TIS-modNV, c. 5mTW and d. TUG. *Abbreviations:* PASS: Postural Assessment Scale for Stroke; TIS-modNV: Trunk Impairment Scale – modified Norwegian version; 5mTW: 5 m timed walk; TUG: Timed Up-and-Go.

For the main outcome PASS, a ceiling effect is demonstrated, showing that a substantial number of patients (36.5%) did not have a potential for improvement as they scored above 32 points (top score 36 minus measurement error). Altogether, 106 (63.5%) of 167 patients demonstrated reduced postural control ( $\leq 32$  points on PASS) at baseline, of these 10.8% achieved 13 to 24 points (moderate postural control), and 52.7% achieved 25 to 32 points (good postural control). For TIS-modNV, 23.4% scored above 13 points (top score 16 minus measurement error).

Correlations between TIS-modNV and PASS (*Spearman's rho* = 0.50,  $p < 0.001$ ), TIS-modNV and 5mTW (*Spearman's rho* = 0.51,  $p < 0.001$ ) and TIS-modNV and TUG (*Spearman's rho* = 0.57,  $p < 0.001$ ) were rather similar and moderate, showing that trunk control is associated with both postural balance and walking.

The number of patients achieving above SDC for PASS ( $\geq 4$  points), TIS-modNV ( $\geq 3$  points), 5mTW (0.3 m/s (Fulk & Echternach, 2008)), and for TUG (2.83 seconds in chronic stroke (Hiengkaew et al., 2012)) is shown in Table 10.

Table 10. Number of patients achieving change above measurement error (SDC) for PASS, TIS-modNV, 5mTW and TUG in day-unit, home-rehabilitation and control groups.

Variables	Day-unit n = 27		Home-rehabilitation n = 43		Control n = 35	
	n	%	n	%	n	%
PASS	2	7.4	5	11.6	3	8.6
TIS-modNV	9	33.3	26	60.5	13	37.1
5mTW	7	25.9	8	18.6	4	11.4
TUG	6	22.2	16	37.2	7	20.0

*Abbreviations:* PASS: Postural Assessment Scale for Stroke; TIS-modNV: Trunk Impairment Scale – modified Norwegian version; 5mTW: 5 m timed walk; TUG: timed Up-and-Go

## 5. Discussion

### 5.1 General discussion

The overall aim of the studies was to expand our knowledge of trunk control. This was realised through the use of an impairment measure of trunk control, TIS, which was translated, modified and renamed the Trunk Impairment Scale – modified Norwegian version, TIS-modNV. This assessment tool makes it possible to explore selective control of the trunk in increasingly more challenging movements in sitting.

Measurement properties of this tool were investigated in the methodological study (I). In the translational study (II) it was used to explore a potential relationship between lesion location and trunk control; in the intervention study (III) it was used as a secondary outcome measure in a group comparison study.

Translation was done according to internationally recommended guidelines (Sommerfeld et al., 2002), and we believe that we achieved a satisfactory translation and cross-cultural adaptation. In line with previous research on construct validity of the original TIS (Verheyden & Kersten, 2010), construct validity was also explored in the Norwegian translated measure, which resulted in a modified version of the scale. Verheyden & Kersten (2010) hypothesised that each of the three subscales in the original TIS was unique, and performed a Rasch analysis for structural validation. They found that the static sitting balance subscale (SSB) did not fit the Rasch model as most patients achieved the top score on item 1. Further analysis could not be performed due to the limited number of items (two) left in the subscale. The authors therefore chose to remove the SSB subscale from the scale, which was renamed TIS 2.0, but stated that their basis for leaving out the SSB needed further investigation. The authors had used pooled patient data for the Rasch analysis, from different time points post stroke and from different settings (Verheyden et al., 2004; Verheyden et al., 2008; Verheyden et al., 2007a). We therefore decided to explore the construct validity of the translated TIS scale, and also to examine whether the SSB subscale was appropriate to use in a large sample of patients with acute stroke.

Our results led us to support the decision of Verheyden & Kersten (2010) of removing the SSB in the Norwegian version also, as we found that most patients (95.5%) achieved the highest score on item 1, and that the correlation between the two remaining items was very high. After modifying the remaining two subscales dynamic sitting balance (DSB) and coordination (Coo) by merging similar items into ordinal scales (testlets), the number of items was reduced from 14 to six, and the scale was named the TIS-modNV. We thereby avoided the potential for an artificially high internal consistency, which can be increased simply by adding items (Streiner & Norman, 2008b) or repeating one of the items (Steinberg & Thissen, 1996), while this would not increase construct validity (Steinberg & Thissen, 1996). The TIS-modNV demonstrated sound measurement properties with regard to construct validity, internal consistency, intertester and test-retest reliability, supporting its use both clinically and for research purposes. We found that it displayed a unidimensional construct with one general factor, which we called trunk control, and two content specific factors: lower and upper trunk control (Study I), thereby differentiating between different aspects of trunk control.

Our results also supported a summation of the total scale scores. Verheyden & Kersten (2010) argued that a total sum score would not be informative, and that the different subscales might have different constructs which would not justify a summation to a total score. However, we found that all testlets had a strong relationship to the general factor trunk control, and therefore could be summed together. The total sum seems to be useful to evaluate change in trunk control in individual patients, as well as to reflect functioning in the activity dimension in relation to postural control and walking ability. Particularly for clinical use, the individual testlets give additional information about the individual patient's impairments, highlighting aspects of trunk control that might need more specific attention in treatment.

The TIS-modNV was then used to evaluate the relationship between trunk control and lesion location (Study II). As expected, we found that patients suffering lesions in multiple locations had significantly poorer trunk control than patients with single lesion locations,  $p = 0.011$ . Patients with single M5 lesion locations scored overall

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relatively high on trunk control; median 12 points (16 max) (Paper 2, Table 2). We also found that lesions of the right M5 area had a stronger negative influence on trunk control as compared to the left (Paper 2, Table 3). This indicates a different role for the M5 area in the right and left hemispheres, which is assumed to represent sensory-motor areas of the cortex (personal communication with neuroanatomist Per Brodal). There were too few single lesions in the other locations to indicate a hemispheric differentiation for trunk control, which needs to be explored in future studies.

We chose PASS as the primary outcome in Study III, as it is developed specifically for stroke, and even patients with very poor postural control can be scored. From a patient perspective we considered that improvements in the ability to e.g. turn in bed, sit up, stand up and balance in standing would seem more meaningful than changes related to impairments in trunk control. We did not find any differences in change between the groups for the primary outcome measure PASS. The median change in PASS was small for all groups, which reflects the fact that our patients suffered mostly mild to moderate disability, and the potential for improvement would therefore be smaller.

We did find a difference between the three groups on change in TIS-modNV, suggesting that home-rehabilitation had the most positive effect on trunk control compared to both day-unit and control, with a median improvement of four points (Paper 3, Table 4). Bonferroni-adjusted pairwise comparisons requiring  $p < 0.0167$ , demonstrated no significant difference in change between the groups (Table 8). Supplementary analysis showed, however, that 60.5% of the patients in home-rehabilitation achieved an improvement above measurement error (SDC) for TIS-modNV (three points), while in the day-unit and control groups this was achieved by 33.3% and 37.1% of patients, respectively (Table 10). We had expected a greater improvement in trunk control in the day-unit group, as these patients received treatment aiming also at impairment level. The context of treatment may, however, be important for motivating and achieving functional change. One can speculate whether the patients' rather high level of function early after stroke combined with performing varied daily activities in their home environment facilitated a greater change in trunk control for the home-rehabilitation group.

By using the TIS-modNV we found a relationship between lesion location, hemispheric differentiation and trunk control (Study II), and that home-rehabilitation seems to favour recovery of trunk control in the subacute phase after stroke in patients with mild to moderate disability at baseline (Study III).

## 5.2 Methodological considerations

The sample for the reliability study in Study I consisted of patients with different causes of CNS dysfunction and different times after lesion onset. The original TIS was developed for patients with stroke (Verheyden et al., 2004), but measurement properties were explored also in other populations. Acceptable reliability and validity for both subscales and the total sum were found when used in traumatic brain injury (Verheyden et al., 2006a) and multiple sclerosis (Verheyden et al., 2006b), and for construct validity in Parkinson's disease (Verheyden et al., 2007b) and multiple sclerosis (Verheyden et al., 2006b). Impaired trunk control was found in all these samples, which shows that trunk impairment is common not only in stroke, but in a wide variety of neurological conditions. Reliability is linked to the patient population in which the scale is to be used (Streiner & Norman, 2008a), and based on the above studies we therefore considered that using a mixed sample of patients with different CNS disorders for our reliability study would be acceptable. The patient sample is also representative of patients who clinicians meet and treat in neurorehabilitation.

A large variability in scores ensures that the whole scale is examined. Graphical representations of the sum scores in the reliability analyses (Paper I, Figures 1 and 2) demonstrate that no patient scored above 14 points (max 16), and only two patients scored zero. As reliability reflects to what extent a measurement instrument can differentiate among subjects (Streiner & Norman, 2008a), a study of reliability should preferably include patients with scores at all levels of the scale. It is a potential weakness that the total range of sum scores was not used, although we found reliability for the total score to be high, both for intertester (ICC 0.77) and test-retest (ICC 0.85) reliability. It is a strength of this study that 50 patients were included for the reliability



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analysis, which is the minimum number recommended by Terwee et al. (Terwee et al., 2007). Many reliability studies of physical tests provide less robust data as fewer patients ( $n = 20 - 30$ ) commonly are examined. Nevertheless, the scale should preferably have been examined including also patients with very good and very poor trunk control.

In Study II, narrowing the patient sample to patients with MCA lesions only was a challenge. As it turned out, many patients with multiple and single ASPECT lesion locations had suffered previous strokes, and/or additional lesions in the brain stem and cerebellum. In patients with multiple lesion locations we were not able to examine a particular contribution of a specific location to impairments of trunk control; we therefore mainly focused on the impact on trunk control of single lesion locations. This reduced the number of patients available for analysis, and resulted in many ASPECT locations not being explored for a possible relationship to trunk control.

One can speculate whether ASPECTS is the best instrument to use in a study exploring the relationship between lesion location and trunk control. It is not possible to tie a precise neuroanatomical correlate to the M1 - M6 areas; therefore there is a danger of losing important information related to a possible cortical regulation of trunk control. However, using the original scans from CT or MRI would give very detailed information about infarct locations and possibly more areas to analyse in relation to trunk control, thereby reducing the number of patients with lesions in each location. By using ASPECTS, lesions are defined and grouped within the limitation of 10 MCA locations, and therefore more feasible to use to analyse such a relationship. ASPECTS is quick and easy to score and therefore a clinically useful instrument in the diagnosis of MCA lesion location and extent.

Study III was conducted in the context of the ESD Stroke Bergen trial, and we aimed to include a broad spectrum of patients, excluding only those patients with very mild to no impairments as well as those with the most severe strokes scoring above 26 on the NIHSS. BI and mRS were recorded at day seven or at discharge from the stroke unit (if earlier). We therefore do not know the patients' initial scores, and they would

probably have experienced some spontaneous recovery during the first week after stroke (Nudo, 2011). The initial NIHSS scores together with BI and mRS scores demonstrated, however, that the patients in the study were mostly mildly to moderately impaired, with only three patients in the severe category.

A problem with rehabilitation models exploring early supported discharge is that the patients need to be able to transfer with a partner or independently if they live alone (Fisher et al., 2011), thereby excluding patients with more severe disability. To allow a comparison of change between different rehabilitation models in Study III, only patients who were discharged directly home were included, and 118 patients were thereby excluded from the study due to a different initial discharge destination (community nursing homes, rehabilitation centres or other hospital departments). Additionally 21 patients were not tested with PASS at baseline. This led to altogether nearly half the patients (45.4%) being excluded, which was surprising. Our study was therefore not defined as a RCT, but a group comparison study within a RCT. We needed a sample size of 60 patients to obtain a power of at least 90%, so even with a substantial number of excluded patients, the power is strong, which is a strength of this study.

We experienced a substantial drop-out between inclusion and three month follow-up. The patients who were lost to follow-up in Study III were older, more of them lived alone and they were more disabled. Although not significant, there was a difference in the drop-out rate between the groups; highest drop-out occurred in the day-unit group, and lowest in the home-rehabilitation group, and we could therefore not be sure that the patient groups were comparable. Differences in background characteristics might invalidate the results. We therefore compared the background variables of the patients in this study, and found no difference between the groups. We cannot explain the differentiation in drop-out, apart from hypothesising that patients in home-rehabilitation might have wished to meet other patients in the same situation and therefore had a greater motivation than patients in the two other groups to attend their follow-up appointment. Elderly participants are more likely to suffer health and functional problems making follow-up more challenging, and they may have difficulty

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coming to a central site for testing (Hardy et al., 2009). In an attempt to minimise this problem, the study coordinator phoned all patients shortly before their appointment at the DPMR. If patients did not attend, she phoned again to make an alternate appointment.

The graphical representations in Figure 5 in the supplementary analyses demonstrate a skewed distribution of scores both for PASS and TIS-modNV. We found a substantial ceiling effect for PASS, showing that 36.5% of the patients did not have a potential for change as they scored above 32 points (top score minus measurement error of 4 points) at baseline. A significant ceiling effect is present when more than 20% of the sample cluster at the top end of a scale as reported by Amusat (Amusat, 2009). A ceiling effect of PASS has been reported only after three to six months (Persson et al., 2011; Mao et al., 2002), and we therefore expected a greater change on the scale within the time period of three months after acute stroke. We found though, that the median change in PASS was small for all groups, which reflects the fact that our patients scored high at baseline, and therefore had a smaller potential for improvement. Our results indicate that PASS may not be an appropriate outcome measure for patients with this level of disability at baseline.

TIS has previously been reported not to have a ceiling effect (Verheyden et al., 2004) even in healthy subjects (Verheyden et al., 2005). None of the patients scored in the top end of the scale in the reliability-part of Study I, supporting the results from Verheyden et al. (2004, 2005). However, in Study III, we found that 9% achieved the top score, and altogether 23.4% scored within measurement error of the three highest scores. The patients in Study I and Study III presented with different functional levels, and a small ceiling effect was demonstrated in patients with mild to moderate disability after acute stroke in Study III. TIS-modNV may have a floor effect as the prerequisite for scoring is the ability to sit upright for 10 seconds. This requirement is the same as for TIS 2.0 (Verheyden & Kersten, 2010).

A wide range of outcome measures was used in Study III, and multiplicity could be a weakness. However, using Bonferroni adjustments for 11 variables would be

considered too strict as these variables will be more or less correlated, and a formal correct adjustment is difficult.

### 5.3 Paper 1, Methodological study

In this section, TIS and the developments resulting in TIS-modNV will be discussed in more detail.

After removal of the SSB subscale, there were two subscales left in the original TIS: dynamic sitting balance (DSB) and coordination (Coo). In the DSB subscale the patients are asked to perform the same movements within each group of items: 1-3, 4-6, 7-8 and 9-10. These item groups were judged as being hierarchically ordered with increasing difficulty; each item group graded from “not able to perform an appropriate movement” to “moving with compensation” to “moving without compensation” (top score). In the Coo subscale, the difference between items 1 and 2, and 3 and 4, is the added requirement of maximum time (six seconds) used to complete the movement. We found a high degree of local dependence within these item groups, which was not surprising since the same movement is repeated. The construction of testlets is an accepted solution to the problem of local dependence (Steinberg & Thissen, 1996). Verheyden & Kersten (2010) reported local dependence only between DSB items 4 and 5, and solved this problem by combining DSB item 2 with DSB item 9 into a testlet, which are two items that evaluate different aspects of trunk control: lower and upper trunk stability, respectively. In Coo, they found local dependence between items 2, 3 and 4 which they combined into a testlet for analytical purposes only. Again, these items evaluate lower (item 2) and upper (items 3 and 4) trunk coordination. Through this procedure, the structure of the original two subscales DSB and Coo was confirmed by Rasch analysis, which justified the summation of subscale scores, but not of the total scale (Verheyden & Kersten, 2010). In contrast to Verheyden & Kersten (2010), we chose to further develop the scale by combining each group of similar items into ordinal scales (testlets), which resulted in six testlets from the original 14 in the TIS

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2.0, and found that the TIS-modNV displayed a unidimensional construct and therefore could be summed.

In both previous versions of TIS (TIS and TIS 2.0) it is possible to score 1 on Coo item 1: “rotation is asymmetrical” and at the same time score 1 on Coo item 2: “within 6 seconds: rotation is symmetrical”, giving a sum score of two for these two items. We considered that receiving scores for both being asymmetrical and symmetrical within the same group of items was illogical. By merging similar items into ordinal testlets, this option was removed; in testlet 5 of TIS-modNV a task that is performed asymmetrically (Table 6) receives a top score of one. The same applies to Coo items 3 and 4/testlet 6. The top sum score for the original TIS and TIS-NV is 23, and with the removal of SSB, 16 for both TIS-modNV and TIS 2.0, which is given when a patient displays adequate lower and upper trunk stability and is able to move upper and lower body selectively and symmetrically in relation to each other; i.e. displays optimal trunk control.

The results from Study I indicate that the TIS-modNV testlets 1, 2 (lower trunk stability) and 5 (lower trunk coordination) were easier to perform than testlets 3, 4 (upper trunk stability) and 6 (upper trunk coordination). van Nes et al. (van Nes et al., 2008) found that lateral weight transfer is most impaired in stroke, which support our finding as lifting a pelvic half (testlets 3 and 4) requires the ability to weight transfer to the opposite side. This finding is strengthened by the results of Study II, where more patients achieved top scores in testlets 1, 2 and 5, than 3, 4 and 6 (Paper 2, Table 4), indicating that moving the lower trunk in relation to a stable, upper trunk (testlets 3, 4, 6), is more difficult to perform than moving the upper trunk in relation to a stable lower trunk (testlets 1, 2, 5). No patients were given a score of two on testlet 6, which may indicate a redundant scoring alternative; those patients who were able to rotate the lower trunk symmetrically keeping the upper trunk stable, were all able to perform the task within the set time limit of six seconds. However, the number of patients analysed were few (n=19), and the results need to be confirmed in a larger study.

Repeated testing should ideally be done in a situation where no clinical variation in the patient is expected (Moe-Nilssen et al., 2008). Our patients were inpatients in the DPMR for primary or secondary rehabilitation and expected to improve during their stay. We therefore chose a time frame of two hours for examination of test-retest reliability, the same time interval as used by Verheyden et al. (Verheyden et al., 2004), as we expected minimal or no change during such a short time. Two hours between test and retest could still represent a possible bias as the tester (BG) could have remembered at retest the scores from the first testing. Effort was made to avoid this by testing three or more patients consecutively before lunch, then retesting the patients after lunch, and not summing the scores after the first test. However, we cannot guarantee that scores were not remembered. This bias could have been eliminated by using video to record the patients' performance and scoring the videos some days later. However, in a test-retest reliability study, the difference in performance from one test to the next is part of the variability observed, and should be taken into consideration when judging change in scores in connection with rehabilitation. For this reason video-recordings were not used in the study.

## 5.4 Paper 2, Translational study

In order to enable an analysis of lesion location in the MCA area in relation to trunk control, patients with previous infarct, brainstem or cerebellar lesions were excluded from this study, as this might confound our potential results. Lesions to cerebellum and brain stem are known to cause problems with postural control.

We found a hemispheric differentiation for single M5 locations indicating more trunk impairment after lesions to the right hemisphere as compared to left, which is supported by two previous studies (Perennou et al., 2000; Spinazzola et al., 2003). Other studies have also found that the right hemisphere seems to be involved in the regulation of postural control, both in patients displaying pusher syndrome (Abe et al., 2012; Baier et al., 2012), and in patients with stroke in general (Manor et al., 2010; Rode et al., 1997; Rode et al., 1998). Our results from M5 indicate that the cortex is

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involved in the regulation of trunk control, which is further supported by other studies (Fujimoto et al., 2014; Mihara et al., 2008; Mihara et al., 2012; Penfield & Welch, 1951). However, with only 19 patients, the results are inconclusive.

We also found a significant difference between left and right hemispheric lesions for TIS-modNV testlets 1, 4 and 5 (Paper 2, Table 4), indicating that these testlets may differentiate best between patients with right and left M5 lesions, specifically side flexing to the most affected side (testlet 1).

The graphical representation of the association between TIS-modNV and ASPECTS sum scores depicted in Figure 4 in the supplementary analyses shows that the sample as a whole used all the possible sum scores (0 - 16) on the scale of trunk control. Only patients suffering a single lesion location received the top sum score, at the same time, patients with lesions in as much as five ASPECT locations could still be scored to 15. Perennou et al. (Perennou et al., 2000) suggested that location and not the size of the lesion played a primary role for postural stability, and Page et al. (Page et al., 2013) found that lesion location and the structural integrity of spared tissue may impact on outcome. Our results support these studies, indicating that lesion size as measured by the number of lesion locations (extent) is not the only factor that determines trunk impairment.

## 5.5 Paper 3, Intervention study

In this comparison study, patients with severe dysfunction of postural control were not represented, as the lowest scores obtained on the primary outcome PASS were 13. According to Clark et al. (Clark et al., 2012) low postural control is defined as zero to 12 points on PASS, moderate as 13 to 24, and high as 25 to 36 points. Most of our patients would thereby be described as having high postural control, as 89% scored above 24 points at baseline. This is further illustrated by the supplementary analyses, Figure 5a, showing the distribution of PASS scores at baseline. Most patients scored at

the top end of the scale, giving little room for improvement. This may explain why we did not find a difference between the groups for PASS.

In addition to trunk control, some of the other secondary outcomes also showed a difference between the three groups: self-report on problems with walking and ADL suggesting a better result for the intervention groups compared to control (Paper 3, Table 4). Further pairwise analysis for self-report on walking demonstrated that patients in the day-unit group improved significantly more than control, but not compared to home-rehabilitation (Table 8). The day-unit patients also improved above MIC for walking speed, i.e. 0.175m/s (Fulk et al., 2011). These results point in the same direction, implying that patients in the day-unit group improved their walking more than patients in the two other groups. Our results are supported by Brogardh et al. (2012) who found a large and significant correlation between self-reported walking ability and walking speed in mildly to moderately affected patients with chronic stroke. The day-unit patients lived at home and travelled to the day-unit on average three days per week to receive their treatment. They experienced moving about in more varied environments and more space, which could have impacted their walking ability and enhanced their training effect.

As for self-report on ADL, pairwise comparisons showed that the home-rehabilitation patients improved significantly more than the controls, but not compared to the patients in the day-unit (Table 8). A systematic review found home-rehabilitation superior to centre-based rehabilitation for functional improvement as measured with BI early after stroke (Hillier & Inglis-Jassiem, 2010). At home, the environment might be better for learning daily skills, as patients practise activities where they need to use them. The home environment might also involve both the patient and the carer to a greater degree (Cobley et al., 2013), and give them more motivation and personal responsibility for the functional training. This may explain why self-report on ADL improved most in the home-rehabilitation group.

Supplementary analyses in Study III demonstrate that TIS-modNV is strongly correlated with tests for postural control and walking, indicating that trunk control may



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be a factor of importance also on a functional level. In a longitudinal study by Sandin & Smith (1990) the authors found sitting balance to be strongly correlated with BI scores. Correlations between trunk muscle strength and Bergs Balance Scale was reported to be moderate to strong, as well as moderate between trunk muscle strength and walking (Karatas et al., 2004). Lateral weight transfer in sitting with closed eyes explained 42% of the variance in scores of Bergs Balance Scale (van Nes et al., 2008). Jijimol et al. (Jijimol et al., 2013) found a strong correlation between trunk control as measured with TIS, and functional balance (Tinetti Balance Assessment),  $\rho = 0.911$ . Likhi et al. (Likhi et al., 2013) found a moderate correlation between trunk control and functional ability ( $r = 0.598$ ) as measured with the Functional Independence Measure. In a randomised controlled trial, Dean et al. (Dean et al., 2007) found that training to reach beyond arms' length in sitting improved both sitting performance and quality, which carried over to sit-to-stand ability and standing balance. The improvement was maintained after six months. Age, BI at admission, trunk control, walking ability and lower limb strength were found to be major variables influencing rehabilitation efficiency, as measured by change in BI divided by length of hospital stay (Pinedo et al., 2014). The studies above indicate that there is a relationship between trunk control and functional ability which is in line with our results.

On a group level, improvements were seen for all balance and walking measures (Paper 2, Table 4). The process of motor learning is hypothesised to have similar properties in the healthy and the injured brain (Kleim & Jones, 2008; Ward & Cohen, 2004), although bearing in mind that neuroplasticity may be impaired and thereby affect the potential for learning (Kleim & Jones, 2008). Improvements in motor function after stroke seem to be driven by both spontaneous reorganisation and behavioural experience (Nudo, 2007 and 2011). Spontaneous recovery may cause substantial functional improvement and occurs mostly in the first month (Nudo, 2011) and up to 10 weeks (Kwakkel et al., 2006) after injury. Spontaneous recovery is associated with restitution of neural tissues within the penumbral zone surrounding the injury core and to the reversal of diaschisis; i.e. reduced metabolism and blood flow in intact brain regions well outside the ischaemic core leading to temporary reduced activity in these areas (days to weeks) (Nudo, 2011). Over time, the damaged brain

seems to utilise structures and networks that can generate some form of motor signals, including functionally relevant recruitment of the contralesional premotor cortex as well as some secondary motor areas which may help patients achieve functional improvement (Ward & Cohen, 2004). These functional and structural changes in spared brain tissue seem to depend on post-injury behavioural experience (Nudo, 2011). PASS is a measure within the activity domain of the ICF, and to achieve a greater degree of functional independence patients may develop compensatory strategies which are not taken into account when evaluating tests like PASS (Levin et al., 2009). Improvement in movement quality seems to involve a reduction in motor impairment by reacquisition of motor elements underlying task accomplishment (i.e. muscle activation patterns and kinematics) (Levin et al., 2009). Neural plasticity research supports that a reduction of impairment could lead to improvement in movement quality and function (Kleim & Jones, 2008; Levin et al., 2009), the challenge being to transfer improved movement quality to improvement of skill and general functional ability (Kwakkel et al., 2004a). TIS-modNV is an impairment measure, and improvement would seem to indicate some recovery of trunk control, which may be related to functional improvement in balance and walking.

The length of stroke unit stay for all patients included in the ESD Stroke Bergen study (N = 306) was mean (SD) 11.4 (7.02) days, irrespective of initial discharge destination. The mean length of stay in the stroke unit for patients included in Study III was 8.6 days with no significant difference between the groups. A Cochrane Review (Early Supported Discharge Trialists, 2005) reported a shorter hospital stay of eight days for ESD trials, with a mean stay of 25 days for the intervention groups and 33 days for the control groups. Most studies on ESD were carried out 10 to 15 years ago, and the management of acute stroke has improved since then (Thomassen et al., 2012). In a study protocol from Sweden describing a prospective study to be completed in 2014, the average hospital stay after acute stroke was reported to be 15 days (Sunnerhagen et al., 2013), with a wide variety between hospitals. Whether this relates to the acute management in stroke units only or includes inpatient hospital rehabilitation is unclear. According to the inclusion criteria for the planned Swedish study, they would seem to recruit patients with mostly mild to moderate strokes;

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NIHSS 0-16, BI 50-100, similar to our sample (Paper 3, Table 2). It will be interesting to compare results.

We found a difference between the intervention groups for intensity of treatment given. Adequate intensity of rehabilitation as defined by total treatment time given by therapists, has not been defined, and will vary significantly depending on patients' disabilities and needs. A total of 16 hours of augmented therapy time over a three month period was found to give small gains in ADL (Kwakkel et al., 2004b; Kwakkel, 2006). Otterman et al. (Otterman et al., 2012) reported from a country-wide stroke unit survey in the Netherlands that physiotherapists provided a mean 22 minutes of treatment every day of the working week, and stated that this was not optimal. Pearn & O'Connor (2013) reported from the National Institute for Health and Care Excellence (NICE) guidelines in Great Britain, which recommends that patients receive 45 minutes of each relevant therapy every weekday, and that each therapy needs to give enough intensity to produce a functional change. All in all, in our study the day-unit patients received on average five hours of rehabilitation per week, and home-rehabilitation four hours per week. The intensity of treatment varied greatly. None of the reported studies above are directly comparable to ours, and we cannot indicate whether our patients received an appropriate intensity of treatment for their level of disability. The intensity of treatment appropriate to enhance functional improvement for patients in different phases after stroke and with different types and levels of disability needs further investigation.

We organised the same care for both intervention groups, the only difference being the place of rehabilitation. The question of where the best place for patients with stroke to receive their rehabilitation while living at home was reviewed by Hillier & Inglis-Jassiem (2010): within their own homes (intervention groups) or in an outpatient or day-unit (comparison groups). None of the reviewed studies are directly comparable to ours, as both groups (intervention and comparison) received a variety of different interventions ranging from follow-up by a general practitioner to multidisciplinary rehabilitation. In this respect, the ESD Stroke Bergen trial would seem unique. Hillier & Inglis-Jassiem (2010) found a positive effect for functioning assessed by BI in

favour of home-based rehabilitation at six weeks and three to six months; they concluded however, that there still is insufficient evidence to make specific recommendations for the rehabilitation model to be used. We did not find a difference between the groups for the primary outcome, although some of the secondary measures would seem to favour coordinated multidisciplinary rehabilitation over control. Benefits in self-report and change above MIC in walking and self-report on ADL were gained by different rehabilitation models; day-unit and home-rehabilitation, respectively. The patients are heterogeneous; therefore different patients may gain improved outcomes from different paths.

## 6. Conclusion

This PhD has broadened our understanding of trunk control in patients with stroke. The assessment tool of trunk control, TIS-modNV, was found to have good construct validity, excellent internal consistency, and high intertester and test-retest reliability for the total score, allowing Norwegian physiotherapists to evaluate quality aspects of trunk control with a reliable and valid scale in their own language.

Patients with lesions in multiple ASPECT locations were found to have poorer trunk control than patients with single lesion locations early after stroke. Trunk control was poorer after single right M5 lesions as compared to left, suggesting a different impact on trunk control from M5 lesions of the two hemispheres. We recommend therapists to pay specific attention towards trunk control in rehabilitation of patients with MCA lesions, and in particular with a right M5 location.

Patients who received different rehabilitation models: home- or day-unit rehabilitation, or traditional treatment (controls) and were discharged directly home from the hospital stroke unit, did not display a different change in postural balance three months after stroke. A high ceiling effect of PASS scores was, however, demonstrated with 36% of the patients scoring at the higher end of the scale at the first assessment. According to the secondary outcome measures of trunk control, walking and ADL, home- and day-unit rehabilitation tended to be somewhat more effective than traditional treatment. The results support that coordinated multidisciplinary rehabilitation tends to give greater benefits for physical functioning than does traditional treatment.

## 7. Further research

Many questions have arisen from this PhD thesis, and I will only highlight a few. Various contexts for rehabilitation may have different impacts on patient outcome. There is still limited knowledge of which rehabilitation model is most effective for the individual patient. However, there is a need to investigate the actual intervention given within various rehabilitation models. From my background as a Bobath Instructor, I would like to investigate using the Bobath concept as a treatment intervention specifically focused at impairments in trunk control to improve postural control and mobility

- to compare two different contexts: home and day-unit/hospital rehabilitation
- compared with task-oriented training either in a day-unit/hospital or a home-setting

Cut off values of TIS-modNV to discriminate between patients with different levels of trunk control, and with and without a normal performance in ADL remains to be calculated, as well as determining the minimally important change in TIS-modNV for individual patients. This would make it easier for the clinician to determine the potential of the patient, which interventions to use and the prognosis, and would facilitate the discussion and conclusions from results in intervention studies.

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## 8. Source of data

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