Clinical Summary

The overall aim of this thesis was to elucidate on mechanisms contributing to hyper-resistance of the triceps surae muscle (TS) in children with spastic cerebral palsy (SCP). During gait, TS hyper-resistance in children with SCP and the associated ankle dorsal flexion hyper-resistance frequently results in abnormal plantar flexed orientations of the foot. Clinical interventions aim to improve gait and prevent progression of abnormal plantar flexion angles by reducing TS hyper-resistance. To extend knowledge regarding the underlying mechanisms of TS hyper-resistance, we investigated various determinants of TS hyper-resistance in children and adolescents with SCP and in typically developing (TD) children. In this context, we particularly focussed on the morphology of the gastrocnemius medialis muscle (GM), which is part of the TS. The results of this thesis showed that relations between GM morphology and TS hyper-resistance differ between TD and SCP children. Previously, it has been shown in TD children, that structural components constituting the GM muscle-tendon complex (i.e. muscle fibres, aponeuroses and tendons) grow uniformly (Bénard et al., 2011). This indicates that with childhood growth, structural components constituting the GM muscle-tendon complex are scaled, preserving the internal ratios. In Chapter 2, we provided new insights in GM growth in TD adolescent males. We found that longitudinal growth of the GM is mediated by increases in physiological cross-sectional area ($A_{\text{fasc}}$) and not by increases in fascicle length ($l_{\text{fasc}}$) or tendon length ($l_t$). We hypothesised, that increases in $A_{\text{fasc}}$ may have contributed to a decreased ankle dorsal flexion range of motion in the older TD adolescent males. In a similar way, altered GM growth in children and adolescents with SCP may also be related to a reduced ankle dorsal flexion range of motion.

In addition to an altered GM growth, ankle dorsal flexion range of motion in children with SCP may also be influenced by foot deformations. Previous research showed that foot deformations in children with SCP may cause erroneous assessments of TS extensibility when based on foot sole rotations. Passive ankle dorsal flexion range of motion (ROM) and TS hyper-resistance are often clinically inferred from assessments focussed on foot sole ROM. Foot sole flexion angles are measured as the angle between the foot sole and the shank (Fig. 1). Clinicians often use the examination of “foot” ROM to infer TS muscle extensibility, however, caution is required. In Chapter 4, we showed that during physical examination, foot deformations in both TD and SCP children contribute to foot sole ROM by on average 30%. Based on these findings, we advise clinicians and researcher to take foot deformations into account when evaluating TS hyper-resistance during physical examination in children with SCP, but also in TD children.

To evaluate differences in whole GM morphology in both SCP and TD children, we improved and extended an existing 3-dimensional ultrasound (3DUS) technique to enable fast reconstructions of 3DUS images of entire muscles by using multiple ultrasound sweeps (Chapter 3). The improved technology now allows for in-depth assessments of muscle volume, physiological cross-sectional area, fascicle length, and tendon length of the m. gastrocnemius medialis (GM) and the m. vastus lateralis muscle. In Chapter 5, we showed using the improved 3DUS technique, that GM geometry of TD and SCP children mainly differed in the muscle belly and tendon growth rates. GM muscle volume in children with SCP was smaller compared to that in TD children, particularly in children with a larger body mass (i.e. at an older age). In contrast to TD children, GM muscle volume of children with SCP was only correlated to $A_{\text{fasc}}$, and not to $l_{\text{fasc}}$. (Chapter 5, Fig. 4). This finding suggests that muscle growth in children with SCP is not related to increases in fascicle, but to radial increases instead. In contrast to the slower growth rates in muscle volume in children with SCP, the longitudinal increases of tendinous structures exceeded those in TD children. Interestingly, the longitudinal increase in tendinous structures in children with SCP even exceeded the increase in their lower leg length. In
children with SCP, but not in TD children, extension of the muscle-tendon complex between two standardised externally applied loading condition (GM extensibility) was negatively correlated to both $A_{fasc}$ and $\ell_t$. These findings imply that the muscle-tendon complexes of SCP children with a lower $A_{fasc}$ and a shorter $\ell_t$ are more compliant towards extension compared to SCP children with higher values of $A_{fasc}$ and $\ell_t$. As growth of $A_{fasc}$ and $\ell_t$ both contribute to longitudinal GM muscle-tendon complex growth, it is concluded that growth of these components negatively affects GM extensibility in children with SCP. Based on the observation that muscle growth in children with SCP is characterised by hampered longitudinal growth of muscle fascicles, interventions targeting longitudinal fascicle growth and preventing longitudinal tendon growth are likely favourable to improve muscle-tendon complex extensibility.

In Chapter 6, we presented a case study in which we showed short-term improvements in gait of a child with spastic paresis after Botulinum Neurotoxin-A, serial casting and physiotherapy treatment. Short-term gait improvements were mainly explained by a reduction of spasticity and increased foot flexibility rather than the anticipated longitudinal growth related changes of the GM muscle-tendon complex. The outcome of this case study questions the rationale of administering BoNT-A in triceps surae muscles and subsequent serial casting to induce longitudinal fascicle growth.

To conclude, it has been shown that substantial morphological variations characterises children with SCP. The results of this thesis suggest that a few morphological features should be taken into account to improve clinical interventions and to further research that aims to reduce TS hyper-resistance in children with SCP. Assessments described in this thesis are ready to be used in a clinical setting to support clinical decision making, and to evaluate interventions that aim to reduce TS hyper-resistance in children with spastic cerebral paresis.

Figure 1. Physical examination of foot sole range of motion, typically used to infer on ankle hyper-resistance and m. triceps surae hyper-resistance. This figure is adapted from: ‘Handleiding standaard lichamelijk onderzoek bij kinderen met een centraal motorische parese’; J.G. Becher 2011