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Computer modeling of gait abnormalities in cerebral palsy: application to treatment planning

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The treatment of gait abnormalities in persons with cerebral palsy is challenging. Theoretically, gait abnormalities can be diminished by decreasing the muscle forces that disrupt normal movement (e.g. via muscle–tendon lengthenings or tone-altering medications) and/or increasing the muscle and ground reaction forces that have the potential to improve movement (e.g. via strengthening exercises, orthoses, or derotational osteotomies). However, different patients exhibit varying degrees of neurologic impairment, spasticity, weakness, and bone deformity, suggesting that gait deviations arise from a variety of sources, each of which requires a different treatment. Treatment planning is further complicated because there is currently no scientific basis for determining how patients' neuromusculoskeletal impairments contribute to abnormal movement. This paper describes how biomechanical models can be used, in combination with experimental data, to enhance our understanding of gait abnormalities and to provide a theoretical basis for planning treatments. Two examples are presented, and suggestions for future work are discussed.

Keywords: Modeling; Treatment planning; Weakness; Bone deformity

1. Introduction

The management of gait abnormalities in children with cerebral palsy is challenging. Musculoskeletal surgeries and other treatments, such as tone-altering medications, orthoses and physical therapy are often prescribed in an effort to improve the alignment of patients' limbs, prevent the progression of bone deformities, and increase walking ability. However, different patients with cerebral palsy exhibit varying degrees of neurologic impairment, spasticity, weakness, muscle contracture, and bone deformity, suggesting that gait deviations arise from a variety of sources, each of which requires a different treatment. Treatment planning is further complicated because there is currently no scientific basis for determining how patients' neuromusculoskeletal impairments contribute to abnormal movement (figure 1). This paper describes how biomechanical models can be used, in combination with experimental data, to enhance our understanding of gait abnormalities and to

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References

Arnold, A.S. and Delp, S.L., 2004, The role of musculoskeletal models in patient assessment and treatment. In *The Treatment of Gait Problems in Cerebral Palsy*, J. R. Gage (Ed.) (London: Mac Keith Press).

Arnold, A.S., Asakawa, D.J. and Delp, S.L., 2000, Do the hamstrings and adductors contribute to excessive internal rotation of the hip in persons with cerebral palsy? *Gait and Posture*, **11**, 181–190.

Arnold, A.S., Blemker, S.S. and Delp, S.L., 2001, Evaluation of a deformable musculoskeletal model for estimating muscle–tendon lengths during crouch gait. *Annals of Biomedical Engineering*, **29**, 263–274.

Arnold, A.S. and Delp, S.L., 2001, Rotational moment arms of the medial hamstrings and adductors vary with femoral geometry and limb position: implications for the treatment of internally-rotated gait. *Journal of Biomechanics*, **34**, 437–447.

Arnold, A.S., Komattu, A.V. and Delp, S.L., 1997, Internal rotation gait: a compensatory mechanism to restore abduction capacity decreased by bone deformity? *Developmental Medicine and Child Neurology*, **39**, 40–44.

Bleck, E.E., 1987, *Orthopaedic Management in Cerebral Palsy* (London: Mac Keith Press).

Chong, K.C., Vojnic, C.D., Quanbury, A.O. and Letts, R.M., 1978, The assessment of the internal rotation gait in cerebral palsy: an electromyographic gait analysis. *Clinical Orthopaedics and Related Research*, **132**, 145–150.

Delp, S.L., Hess, W.E., Hungerford, D.S. and Jones, L.C., 1999, Variation of hip rotation moment arms with hip flexion. *Journal of Biomechanics*, **32**, 493–501.

Delp, S.L., Ringwelski, D.A. and Carroll, N.C., 1994, Transfer of the rectus femoris: effects of transfer site on moment arms about the knee and hip. *Journal of Biomechanics*, **27**, 1201–1211.

Free, S.A. and Delp, S.L., 1996, Trochanteric transfer in total hip replacement: effects on the moment arms and force-generating capacities of the hip abductors. *Journal of Orthopaedic Research*, **14**, 245–250.

Gage, J.R., Perry, J., Hicks, R.R., Koop, S. and Werntz, J.R., 1987, Rectus femoris transfer to improve knee function of children with cerebral palsy. *Developmental Medicine and Child Neurology*, **29**, 159–166.

Goldberg, S., Piazza, S.J. and Delp, S.L., 2001, The importance of swing phase initial conditions in stiff-knee gait: a case study. *Gait and Posture*, **13**, 246–247.

Perry, J., 1987, Distal rectus femoris transfer. *Developmental Medicine and Child Neurology*, **29**, 153–158.

Perry, J., 1992, *Gait Analysis: Normal and Pathological Function* (Thorofare: SLACK, Inc.).

Piazza, S.J. and Delp, S.L., 1996, The influence of muscles on knee flexion during the swing phase of gait. *Journal of Biomechanics*, **29**, 723–733.

Schmidt, D.J., Arnold, A.S., Carroll, N.C. and Delp, S.L., 1999, Length changes of the hamstrings and adductors resulting from derotational osteotomies of the femur. *Journal of Orthopaedic Research*, **17**, 279–285.

Sutherland, D.H., Schottstaedt, E.R., Larsen, L.J., Ashley, R.K., Callander, J.N. and James, P.M., 1969, Clinical and electromyographic study of seven spastic children with internal rotation gait. *Journal of Bone and Joint Surgery, American Volume*, **51-A**, 1070–1082.

Tachdjian, M.O., 1990, *Pediatric Orthopedics* (Philadelphia: W. B. Saunders).

Zajac, F.E., 1989, Muscle and tendon: properties, models, scaling, and application to biomechanics and motor control. *CRC Critical Reviews in Biomedical Engineering*, **17**, 359–411.

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