Effectiveness of orthotic interventions on reducing genu recurvatum in adults post-stroke

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Clinical Question: Which orthotic interventions are most successful at reducing genu recurvatum during hemiparetic gait in post-stroke adults?

Background: Roughly half of all people with hemiplegia resulting from stroke have some degree of knee hyperextension, or genu recurvatum.[1] Regaining function and achieving positive mobility outcomes is time-dependent and relies heavily on early intervention by members of the interdisciplinary rehabilitation team.[2] Weakness or spasticity of knee extensors can cause the ground reaction force to be directed in front of the knee joint, resulting in an abnormal knee extension moment during loading.[1] A plantarflexion contracture at the ankle can also have this effect, causing the foot to remain plantarflexed during midstance, which can worsen genu recurvatum due to the repeated stretching of the ligaments of the knee.[1,3] This strategy may provide mechanical stability during gait; however, continued reliance on these supportive ligaments can cause excessive strain and damage the posterior compartment of the knee. Orthotic interventions, such as a knee-ankle-foot orthosis (KAFO), an ankle-foot orthosis (AFO), or a functional electrical stimulator (FES), can supplement mechanical stability, increase energy efficiency during gait, improve balance, and reduce the risk of deformity and muscle wasting.[4] Tuning the three-point force systems implemented by orthoses must be done with care, as it is essential to prevent not only genu recurvatum but also knee buckling.[3] Due to the differences in how individual patients present with hemiplegia, each will require different treatment interventions.

Search Strategy:
Databases Searched: PubMed, oandp.org (O&PiQ)
Search Terms: *PubMed* - "Orthosis"[Mesh] AND "genu recurvatum" OR recurvatum OR "knee hyperextension" AND stroke*; OPiQ* - knee hyperextension stroke
Inclusion Criteria: English, peer-reviewed, 2012-present, stroke, genu recurvatum, knee hyperextension
Exclusion Criteria: cerebral palsy, SCI, hemophilia, polio, myelomeningocele, abstract only

Synthesis of Results: Four studies were analyzed that compared different orthotic interventions on similar patient populations with similar presentations. All four studies used motion-capture cameras and software to analyze gait data.[5-7] Sample sizes were generally small and ranged from 6 to 20 participants. Three studies included patients 6 months or more post-stroke who presented with genu recurvatum, [5-7] while one included patients 1 month or more post stroke.[4] Cooper et al.[4] examined a group of participants 1 month or more post stroke whose presentations were diverse enough to be considered "…representative of stroke patients seen in a rehabilitation unit." Sixty-five percent of those participants demonstrated genu recurvatum. Only one study excluded participants that had ankle plantarflexion contractures.[6] Orthotic interventions included custom carbon KAFOs[5], short anterior-style AFOs[6], double-upright AFOs[7], and below-knee FESs.[6] Knee-hyperextension angles were reduced in patients that wore KAFOs[5] and increased knee-flexion angles were significant in those who wore AFOs when compared to barefoot walking.[6] FESs did increase knee-flexion angle at loading, but did not prevent genu recurvatum through midstance.[6] Cooper et al. concluded that a weak gastrocnemius was significantly associated with genu recurvatum in midstance due to its origin above the knee joint.[4] Kobayashi et al. showed that increasing plantarflexion resistance (i.e. dorsiflexion assist) in an AFO can increase knee-flexion angle at midstance.[7]

Clinical Message: KAFOs and AFOs accomplish similar goals of reducing genu recurvatum and improving overall gait depending on how they are tuned.[5,6] Increasing plantarflexion resistance in an orthosis design can help encourage knee-flexion moments without causing the knee to buckle. FESs should not be used alone below the knee to correct genu recurvatum. Maintaining muscle strength and ROM with physical therapy may aid in reducing compensation techniques like recurvatum. Each patient's presentation must guide their treatment. Thus, future studies with more commonly used orthotic interventions like conventional KAFOs and thermoplastic solid and articulated AFOs would be beneficial in objectively understanding how patients respond to each type of device.

References:

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Evidence Table

	Boudarham, et al., 2013	Kobayashi, et al., 2016	Dong-Yun Bae, et al., 2019	Cooper, et al., 2012
Population	11 adults (7 male and 4 female) ages 21-75 • Over 18 years old • 72-672 months post-stroke • Hemiplegia following stroke that occurred ≥ 6 months before study participation • Exhibit spasticity or weakness of quadriceps • Genu recurvatum during stance phase (-1.6° to -35.6°) • Able to walk 10m without walking aids • Rx for carbon KAFO in the last 6 months worn daily for at least 1 month before study participation	6 adults (6 male) age 38-64 • 12-132 months post stroke • Hemiplegia resulting from stroke with unilateral-limb involvement • Exhibit hyperextension of knee during midstance (defined as knee extension beyond 0° in stance phase) • Able to walk safely on instrumented treadmill using AFO w/o a walking aid • At least 6 months post stroke with hemiplegia No exclusion criteria specified	12 adults (8 male and 4 female) average age 54.41 ± 19.29 • 13.16 ± 9.73 months post-stroke • MMSE-K (Mini Mental State Examination – Korea version) score ≥ 24 pts • Able to walk independently for ≥ 10m • MAS (Modified Ashworth Scale) scores of 0-2 • "Neurological injury creating requirement for an AFO" • Excessive plantarflexion during stance phase to cause genu recurvatum • Diagnosis of hemiplegia caused by stroke ≥ 6 months prior to study participation <u>Exclusion Criteria</u>: • ≥ 5° plantarflexion contracture • Neurological or orthopedic disease causing other motor disabilities	20 adults (13 male and 7 female) ages 44-88 • 1-47 months post-stroke • Hemiparesis resulting from unilateral single stroke • No joint replacements or rheumatoid arthritis • Able to walk independently without use of walking aid • Plantarflexor contracture absent
Study Design	Cross-sectional	Cross-sectional	Cross-sectional	Cross-sectional observational study
Intervention	Use of custom carbon KAFO	Use of adjustable double upright AFO	Use of a FES device and a plastic UD Flex AFO set in 5° dorsiflexion	Lower extremity muscle group strength testing
Comparison	Those without a KAFO	4 different plantarflexion (PF) resistances	Barefoot with FES device and barefoot with AFO	No comparison or control group

	Boudarham, et al., 2013	Kobayashi, et al., 2016	Dong-Yun Bae, et al., 2019	Cooper, et al., 2012
Methodology	Gait data were recorded @ 100 Hz using 8 optoelectronic cameras and analyzed with OrthoTrack 6.5 software (Motion Analysis Corporation, Santa Rosa, CA) 30 reflective markers were placed on anatomical landmarks using the Helen-Hayes marker set When analyzing KAFO gait, markers were placed at: • Mechanical knee joint of KAFO • Mechanical ankle joint of KAFO 6 trials of 8 gait cycles recorded per participant on 10m gait corridor. Ground reaction forces measured with two force plates (AMTI, Watertown, MA, USA, sampling freq @ 1000 Hz) and synchronized with captured kinematic data	Gait data were recorded using Vicon 10-camera motion analysis system (Vicon Motion Systems, Oxford, UK) on an instrumented split belt treadmill (Bertec Corporation, Columbus, OH, USA) sampled @ 200 Hz for 5 successful steps of AFO leg. Data were analyzed by Visual3D software (CMotion, Germantown, MD, USA) Markers were placed on AFO, limbs, head, and trunk based on modified Cleveland Clinic Market Set to define 8 body segments: • 2 feet • 2 shanks • 2 thighs • 1 pelvis • 1 HAT (head, arm, trunk) Participants given acclimation period for AFO use. Rest provided as needed. Safety harness used to prevent falls AFO plantarflexion resistances altered by exchanging steel springs of different resistances, S1-S4	Gait data was recorded @ 100 Hz by 6 cameras and marker data was analyzed with CORTEX ver 3.6.1 motion capture software (Motion Analysis Corp., Seoul, Korea). Fifteen markers were placed: • L5-sacrum interface (1) • ASIS (1) • L and R medial and lateral femoral condyles (4) • L and R medial and lateral malleoli (4) • L and R 2nd and 3rd metatarsals (4) • Posterior calcaneus (1) FES delivered via XFT-2001D machine (Shenzhen XFT Electronics Co., Shenzhen, China). Cuff with 5x5cm adhesive electrodes placed behind fibula head and 5cm below fibula head on tibialis anterior Participants walked on 6m board at self-selected speed barefoot, with AFO, and with FES Each modality tested 3x, 9 gait cycles total per participant. 10 min break between gait condition evals. 3 min break between each gait cycle	Muscle strength measured with handheld dynamometer (Commander PowerTrak II, JTech Medical) Three reflective markers were placed on subjects' paretic leg at these locations: • lateral malleolus • lateral femoral epicondyle • greater trochanter Participants walked on 10m walkway at self-selected speed while video camera recorded paretic limb through gait at knee level Movement analysis software (Siliconcoach Ltd, Dunedin, New Zealand) measured knee extension angle during stance phase

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Outcomes	Spatio-temporal 1. Velocity over 10m 2. Stride length 3. Cadence 4. Width 5. Step length of non-paretic and paretic limb Gait symmetry 1. Swing phase duration asymmetry ratio 2. Stance phase duration asymmetry ratio Kinematic Parameters 1. Stance phase duration in % and in seconds 2. Swing phase duration in % and in seconds 3. Hip, knee, and ankle angles in stance and in swing Kinetic Parameters 1. Internal joint moments at hip, knee, and ankle at: a. Initial double contact b. Single limb support c. Final double contact	1. TUG (Timed Up and Go) 2. MAS (Modified Ashworth Scale) of affected ankle 3. MMT (Manual Muscle Testing) of ankle & knee 4. Peak plantarflexion angle 5. Internal peak dorsiflexion moment 6. Peak knee-extension angle 7. Internal peak knee-flexion moment in 2nd rocker of stance (early stance to midstance)	1. Knee-flexion angle 2. Ankle-dorsiflexion angle of paretic leg 3. Spatiotemporal parameters a. Gait speed b. Step length c. Stride length	1. Muscle group strength at different phases of gait 2. Knee-extension angle at different phases of gait

	Boudarham, et al., 2013	Kobayashi, et al., 2016	Dong-Yun Bae, et al., 2019	Cooper, et al., 2012
Key Findings	KAFOs reduced gait abnormalities: increased gait velocity and stride length by reducing knee hyperextension	Increased plantarflexion resistances decreased genu recurvatum. Reducing peak knee-flexion moment was associated with a decrease in peak knee-extension angle in all participants	Walking with AFO was associated with significant difference in peak ankle-dorsiflexion angle compared to barefoot walking ($p < 0.05$) FES significantly increased knee-flexion angle from initial contact to loading response ($p < 0.05$) No significant differences were found in gait speed or step or stride length between modalities	Ankle-plantarflexor muscle group weakness was significantly associated with genu recurvatum during midstance ($p = 0.044$) Ankle-dorsiflexion weakness was associated with genu recurvatum but was not statistically significant ($p = 0.051$) No other lower-extremity muscle groups were found to be significantly associated with genu recurvatum
Study Limitations	Small sample size n = 11. Some patients (n=3) had triceps surae contracture of unspecified degree. Varying etiology of patient presentations: • Spasticity of quads (n = 6) • Weakness of quads (n = 2) • Spasticity of triceps surae (n = 3) Each patient has a custom carbon KAFO made by one manufacturer. Findings may not translate to populations that use different designs	Very limited small sample size n = 6. Did not measure effects of plantarflexion stop, but alluded to studies that did Not specified how marker model was modified, i.e., how many markers total there were and their locations	Small sample size n = 12. Relationship between knee/ankle joints and hip not explored. AFO used was very flexible with low trimlines and short lever arms Marker quantity per body segment unclear. Bilateral markers for everything but L5-sacrum would total 17 markers not 15. All modalities tested barefoot, making generalizations to walking with shoes or shoes of different heel heights in daily life difficult	Small sample size n = 20. Spasticity not accounted for. Video analysis software missed 4 subjects' genu recurvatum in midstance