厚生労働科学研究費補助金
障害保健福祉総合研究事業

脊髄損傷者用歩行補助装具の開発

平成１４～１６年度　総合研究報告書

主任研究者　太田 裕治

平成１７（２００５）年　４月

目　　次

厚生労働科学研究費補助金（障害保健福祉総合研究事業）
（総合）研究報告書
脊髄損傷者用歩行補助装具の開発　Ｈ１４－障害－０１７

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現在，脊髄損傷者は移動手段として主に車椅子を利用しているが，車椅子のみに頼り歩行放棄すれば，長期的に呼吸循環機能，筋量，骨密度，免疫，消化機能等は低下し，また心理的側面も問題となる．本研究では２足歩行ロボット技術を応用することで，股・膝関節回転にパワーアシスト機構を組込んだ動力化歩行装具を開発し，脊髄損傷者（対麻痺者）に日常利用可能な簡便な歩行補助装具を供することを目的とした．開発と平行して，ロボット型歩行装具による外部強制歩行は周囲筋・関節からの脊髄求心性神経情報によって残存脊髄神経中の歩行パターンジェネレータ（CPG）も変化させ得ると仮定し，ニューロリハビリテーションの観点から歩行機能の再建も検討した．その結果，トレッドミル上の歩行実験等を通じ，腓腹筋および大腿直筋の活動振幅が有意に増加し，外部強制歩行運動が筋活動を変化させることが分かり，CPG 再活性化への展望を開いた．今後，基礎的研究としての CPG 解析と日常利用可能なデバイス開発を両輪とした研究開発を実施することが極めて重要である．

分担研究者　中澤公孝（国立身体障害者リハビリテーションセンター研究所・運動機能系障害研究部・神経筋機能障害研究室長）

１．研究目的

現在，脊髄損傷者は移動手段として主に車椅子を利用しているが，車椅子のみに頼り歩行放棄すれば，長期的に呼吸循環機能，筋量，骨密度，免疫，消化機能等は低下し，また心理的側面も問題となる．本研究では２足歩行ロボット技術を応用することで，股・膝関節回転にパワーアシスト機構を組込んだ動力化歩行装具を開発し，脊髄損傷者（対麻痺者）に日常利用可能な簡便な歩行補助装具を供することを目的とした．同時に，ロボット型歩行装具による外部強制歩行は周囲筋・関節からの脊髄求心性神経情報によって残存脊髄神経中の歩行パターンジェネレータ（CPG）も変化させ得ると仮定し，ニューロリハビリテーションの観点から歩行機能の再建を検討した．

２．研究方法

２－１．歩行研究のための各種デバイス開発

（１）動力化歩行装具（図１）：交互歩行のためのレシプロ機構を有する Advanced Reciprocal Gait Orthosis（ARGO）装具に対し，膝・股関節を小型アクチュエータにより動力化し歩行実験に供した．膝関節機構（図２）としては，膝裏に５節リンク機構を組み込み，低イナーシャ型 DC モータによるリニア

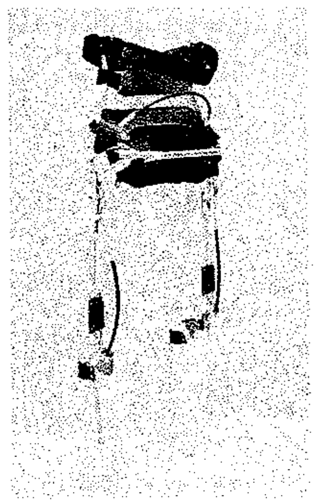

図１　Advanced Reciprocal Gait Orthosis　(ARGO)装具

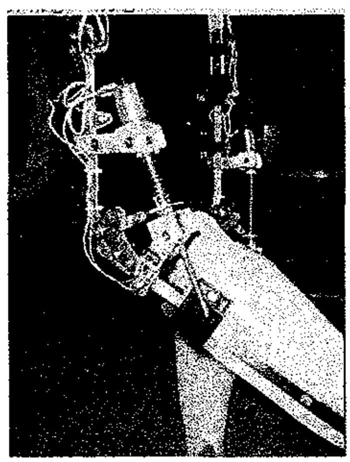

図２　ARGO に組み込んだ膝関節機構

アクチュエータにて動力化した．膝関節屈曲角度は最大で70度とした．また関節ロック機構を利用することで歩行中の膝折転倒に十分配慮した．股関節機構（図3）としては，ARGOのレシプロ機構をリニアアクチュエータにて動力化した．なお外部強制歩行運動がCPGに及ぼす影響を詳細に調べるため，動力歩行条件（速度，アシストトルク等）を自在に変化させ得るよう，DCモータから高制御性ACサーボモータへと改良した2号機も開発した．

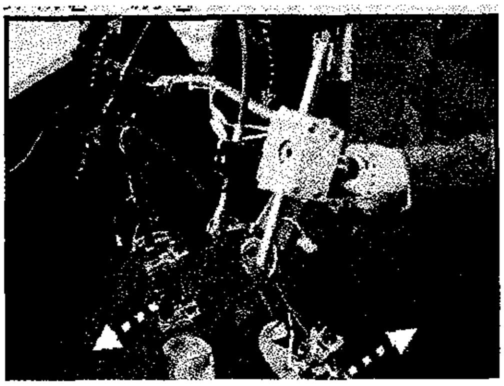

図3　ARGOに込みこんだ股関節機構

（2）足関節外乱デバイス（図4）：CPGの可塑的変化を調べるため，歩行訓練中に任意のタイミングで足関節に強制反射刺激の入力が可能なAFO (Ankle Foot Orthosis) を開発した．これにより脊髄反射系特性を歩行訓練中に調べることが可能となる．原理はバネに1J程度の機械エネルギを蓄え，それを電磁石によってインパルス的に放出することで，足関節を強制的に底・背屈させるものである．

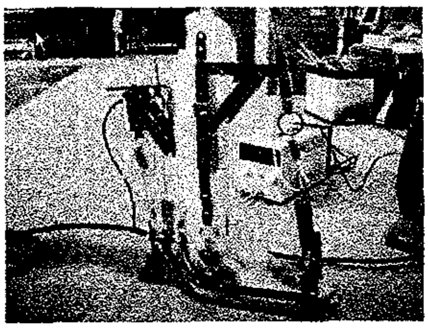

図4　足関節外乱デバイス

（3）痙性軽減のためのデバイス：足関節における痙性低減を目的とする装置を開発した．通常の車椅子のフットレスト部を4〜6回／分，±30度程度の速度で回転させることで，日常的に足関節のストレッチングを行うもので,減速機付DCモータのon-off制御により実現した．

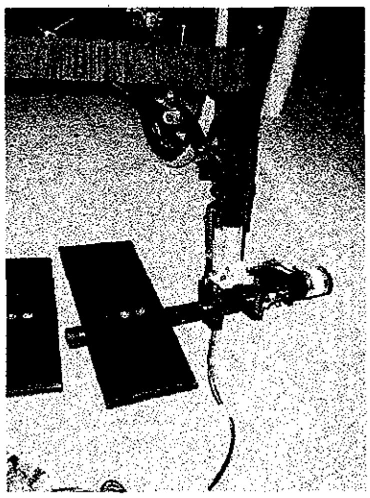

図5　フットレスト回転機構

２－２．被験者

本研究の主旨を理解し，研究参加への同意を得たＴ５～１２の胸髄完全損傷者８名を対象とした．また倫理面への配慮として，歩行計測実験は国立身体障害者リハビリテーションセンター研究所にて実施し，同研究所及び同病院の研究倫理規定に則り被験者の人権を尊重して行った．特に障害者が被験者となるときは，事前に研究趣旨を十分説明し了解の上実施した．また，研究で得たデータを被験者に伝え，健康管理に役立てる方法を考慮した．

２－３．計測項目

通常型・動力化ARGOによる実験室内の自己快適速度での歩行を実施し，

●Kinetics ・ Kinematics: 身体各部位に貼付したマーカの３次元座標データをOxford matrix製VICON 370 Systemにより取得，さらに床面に埋め込まれたKistler 社製３分力床反力計上を歩行することにより床反力を記録した．

●歩行関連筋の EMG 計測 (SOL, MGAS, TA, RF, BF),
歩行エネルギ評価

などを行った．歩行計測に際しては，約 6m 区間の自由歩行ならびにトレッドミル上歩行を実施した．

３．主な研究結果及び考察

[エネルギ計測] 8名に対し呼吸ガスモニタ（換気流量, VO2, VCO2），血中乳酸濃度，心拍計測による装具歩行中の生理量計測を行った結果，全例とも有酸素運動の範囲内であり，動力化の有効性確認のためには被験者群を傷害部位で分けるなどの工夫が必要と考えられた．また，胸髄高位損傷者では，歩行中の定常状態酸素摂取量と歩行速度から算出したエネルギーコストが動力補助により改善し，杖の床反力が減少する傾向を示した．

[歩容計測－膝関節] T12 被験者に対し装具歩行解析を行った結果（図６），歩行速度は訓練とともに劇的に向上すること，遊脚期に膝関節の屈曲-伸展動作（膝関節可動域：31.8±1.9 deg，伸展角速度：152.4 ± 1.5 deg/sec，屈曲角速度：204.4± 6.2 deg/sec）が実現されこと，杖に加える力も歩行目的に合致するよう柔軟に学習すること等がわかり，適切な装具による訓練を実施することで，日常歩行を実現できることが分かった．

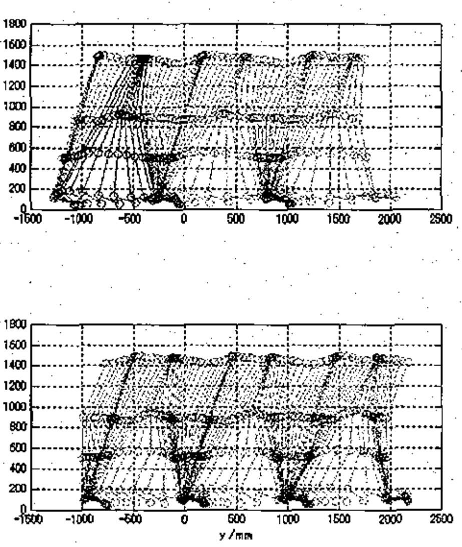

図６　アシスト機構による歩行
上：膝回転なし　下：膝関節を回転させた場合

[歩容計測－股関節] 股関節アシスト機構を用い，４名に対し VICON を用いた歩行運動の損傷部位依存性に関して検討した．その結果，損傷高位となるにつれ上半身の動きを多用しつつ歩行すること（＝energy cost の上昇）が分かり，また動力化の有効性も高位損傷者を中心に確認できた．

[上肢負荷の計測] 脊髄損傷者の装具歩行時における愁訴として前腕筋疲労があることから，床反力計により上肢負荷を計測した．その結果，力は２峰性となることが分かり，特に第２峰（杖接床期後期）に関しては損傷高位の場合には有効な推進力として作用しないことがわかり，別途，動力化による推進機構が必要と考えられた．

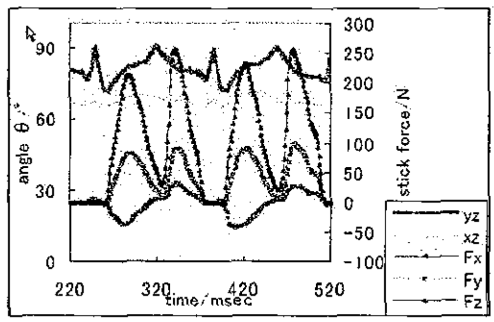

図７　上肢負荷の計測例

[膝関節回転と CPG] T12 被験者の歩行実験を通じ，歩行周期に同調した筋活動（歩行様筋活動）を見出した．とくに遊脚期における大腿直筋，立脚期における内側腓腹筋に，膝屈曲-伸展動作に伴う活動振幅の有意な増加が認められた．この変化は膝関節動作による求心性神経情報の変化が脊髄運動ニューロンの興奮性に変化を及ぼした可能性を示す事象であり，膝関節動作の実現により麻痺領域の神経活動を促し得ることを示す重要な所見と考える．装具歩行により麻痺領域に対し機械的負荷を課す，あるいは運動ニューロンの活動喚起により麻痺筋に反射性筋活動を発現させることが可能となれば，脊髄損傷後の身体機能を維持する重要な方策と成り得ると考えられる．

［トレッドミル上歩行−CPG 解析］トレッドミル上でより長時間安定して歩行することで，CPG 特性に関する詳細検討を行った．その際，被験者の歩行速度に合わせて各関節の動作位相・時間を制御できるよう改良した動力化装具（２号機）を用いた．５名を対象に麻痺下肢筋群の活動を計測した結果，遊脚期における膝関節屈曲−伸展動作の実現に伴って腓腹筋および大腿直筋の活動振幅は有意に増加することを見出した．

［歩行パターンジェネレータの解析のための外乱デバイス］健常者を対象に試作外乱デバイスの特性を確認し，数 100deg/sec 程度の足関節屈曲回転速度が得られ，それに対する筋電反射信号も安定して得られた．今後，被験者実験を通じ歩行パターンジェネレータの特性解明に利用可能と考えられた．

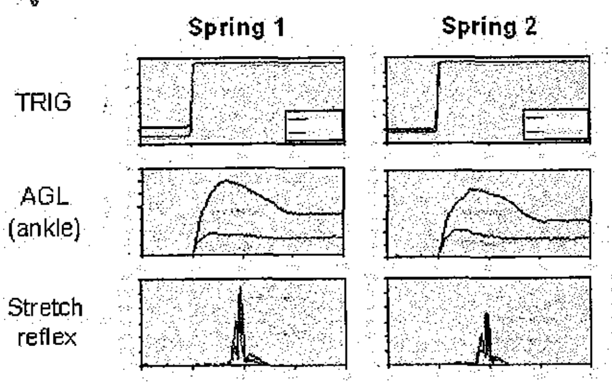

図８　外乱デバイスによって得られた H 反射

4．評価（研究成果）

1）達成度について

●歩行装具に関して：市販の歩行装具を２点の小型アクチュエータにより動力化し得た．簡便な機構かつ安全性も高いため，実用化が可能であり，目標は達成しえたと考える．また，CPG 検討用に同様の機構で制御性に優れる２号機も開発した．本技術の普及に際しては装具歩行がより一般的となることが前提であり，そのためには，車椅子との整合性をより高めることで歩行装具自体の問題点−車椅子からのトランスファー，装具の脱着，座位−立位の移動，歩行エネルギなどを解決する必要がある．すなわち，車椅子と歩行器を一体化した新たなモビリティデバイスの設計が求められる．

●CPG 再活性化に関して：被験者実験を通じ，膝関節・股関節回転とも，有効な CPG への入力要素となりうることが分かった．デバイス開発に時間が掛かったこと，また傷害部位の様々な被験者群であったため，３年間の研究期間では明確な結論に至っておらず，今後，開発した各種デバイスを用いて CPG 特性・制御性に関して検討を行う必要がある．

2）研究成果の学術的意義について

●従来，膝関節回転可能な歩行装具は存在せず，開発機はリハビリテーション工学的に高い意義を有する．今後，多数の被験者実験を通じ，歩行機能，歩容解析，エネルギーコスト，cosmesis などの観点で有効性の確認が期待できる．

●従来，CPG の再活性化には，股関節の伸展信号および抗重力筋への荷重負荷が必要と考えられていたが，本研究はそれらに加え，膝関節の屈曲進展も同様の作用を有することを見出し，学術的意義は極めて高い．研究開発を通じ CPG 解析のためのデバイス開発を終えていることから，今後，被験者数を増やすことで，CPG 特性に関する神経科学面での新知見が得られると考える．

3）研究成果の行政的意義について

●適切な動力化装具・歩行支援システムによる自立歩行の可能性を広く周知することで，多くの脊損者に対して歩行への関心を喚起することが可能となる．脊損者の日常的自立歩行が実現すれば，心身諸機能の維持，二次障害の予防，Quality of Life の向上に貢献できよう．

●本研究の成果を今後急増が予想される自立歩行困難な高齢者・高齢障害者の立位歩行トレーニングへ応用可能である．それにより寝たきり高齢者・障害者数の減少も期待できる．さらに立位歩行トレーニングが体力・健康の増進に極めて効果的であること

を考えれば，医療費・介護費用の削減に大きく貢献するであろう．

4）その他特記すべき事項について

研究ニーズ，展望として２つの開発に向けた方向性が考えられる．

●歩行リハビリテーションとしてのロボティックデバイス：本研究では，完全脊髄損傷者を対象としたデバイス開発を行ったが，歩行機能回復訓練に対しては，不完全脊髄損傷，片麻痺，脳卒中，高齢者など極めて大きなニーズが存在する．これまではPTによる用手的経験的訓練が行われてきたが，人手，訓練労力，客観評価などの観点で問題が残る．これに対しDietz (University Hospital Balgrist, Swiss) らのグループが開発を行っているようなロボット型歩行訓練機 (Lokomat) の開発が求められよう．さらにはロボット訓練機とEMG計測やBiofeedbackを組み合わせることで，サイエンスベースのリハビリテーションへの展望も開けると考えられる．本研究で開発したデバイスはそれらの基盤技術となり得ると考えられる．

●本研究を通じ歩行訓練を通じたCPG再構築の可能性が見えてきたが，完全脊髄損傷の場合は道程は遠い．その一方で生理心理面での立位歩行の様々な有効性の認識は高まっている．移動のためのデバイスとしては，今後は，現在の「車椅子 and 歩行器」という組合せではなく，両者が一体となった新しいモビリティデバイスを開発することで，彼・彼女らの真のニーズに応え得ると考える．

5．結論

●直流モータおよびリンク機構を組み合わせた簡便な膝・股関節のパワーアシスト機構を開発し，市販装具であるARGOに搭載し，小型コンパクトな動力化歩行装具を実現した．

●パワーアシスト機構により脊損者の歩行労力は減少し歩行能力も向上した．また，訓練とともに歩行能力は著しく改善され，立位歩行は脊髄損傷者の健康管理・維持増進に極めて有効であることを示した．

●歩行のkinetics，kinematicsを解析した結果，損傷部位により歩容が大きく異なること，また上肢負担が大きいことなどを定量的に解析した．

●自由歩行・トレッドミル上歩行実験等を通じ，腓腹筋および大腿直筋の活動振幅が有意に増加し，外部強制歩行運動が筋活動を変化させることが分かり，CPG再活性化への展望を開いた．今後，基礎的研究としてのCPG解析と日常利用可能なデバイス開発を両輪とした研究開発を実施することが極めて重要である．

6．研究発表

（8ページ以下を参照）

7．知的所有権の出願・取得状況

特許「歩行補助装具」．出願番号特願2000-404456，公開番号2002-191654，出願年月日2000.12.22．

特許「歩行補助装具」．出願番号特願2002-088945，出願年月日2002.3.27．

発表者氏名	論文タイトル名	発表誌名	ページ	出版年
Ohta Y, Yoshida M, Shinoya Y, Matsumoto A, Kawashima N, Nakazawa K, Yano H	A gait orthosis for paraplegics with a motor-driven knee joint.	4th World congress of Biomechanics.	CD-ROM	2002
吉田ももこ，河島則天，中澤公孝，矢野英雄，太田裕治	脊髄損傷者の歩行装具と理論値の比較検討	第18回ライフサポート学会大会講演予稿集	130	2002
河島則天，太田裕治，谷崎雅志，中沢公孝，赤居正美，矢野英雄	装具歩行の kinematics の違いが脊髄損傷者の麻痺筋活動に及ぼす影響	第18回 日本義肢装具学会（福岡）	268-269	2002
Ohta Y, Yoshida M, Kawashima N, Nakazawa K	A gait orthosis for paraplegics with a motor-driven hip joint.	International Society for Postural and Gait research 2003	142-143	2003
Kawashima N, Sekiguchi H, Miyoshi T, Nakazawa K, Akai M	Inhibition of the human soleus H-reflex during standing without descending commands.	Neuroscience Letters, 345	41-44	2003
Kawashima N, Sone Y, Nakazawa K, Akai M, Yano H	Energy expenditure during walking with weight bearing control orthosis (WBC) in thoracic level of paraplegic patients.	Spinal Cord, 41	506-510	2003
河島則天、太田裕治、谷崎雅志、中澤公孝、赤居正美	脊髄損傷者の装具歩行における膝関節屈曲－伸展動作付与の試み	日本義肢装具学会誌，19(3)	222-227	2003
Yuji Ohta, Noritaka Kawashima, Kimitaka Nakazawa	Development of a powered gait orthosis for spinal cord injury patients	2nd International Conference on Biomechanics of the Lower Limb in Health, Disease and Rehabilitation	30-31	2003
山口裕子，矢野裕美，吉田ももこ，河島則天，中澤公孝，太田裕治	脊髄損傷者の装具歩行時における上肢負荷	第19回ライフサポート学会大会講演予稿集	61	2003
矢野裕美，山口裕子，吉田ももこ，河島則天，中澤公孝，太田裕治	脊髄損傷者の歩行運動の損傷部位依存性	第19回ライフサポート学会大会講演予稿集	60	2003
田口大介、河島則天、太田裕治、中澤公孝、赤居正美	脊髄損傷者の損傷高位に応じた歩行装具の開発－股関節動力補助機構の試作	第19回義肢装具学会(仙台)	216-217	2003
河島則天、谷崎雅志、田口大介、太田裕治、中澤公孝、赤居正美	脊髄損傷者の損傷高位と装具歩行パフォーマンスの関連	第19回義肢装具学会(仙台)	214-215	2003

松元明弘, 田中聡, 秋元俊成, 太田裕治	受動的歩行の概念を導入した歩行補助機械の設計に関する考察	精密工学会春季大会	511	2003
Kawashima N, Nakazawa K, Ishii N, Akai M. and Yano H.	Potential impact of orthotic gait on natural killer cell activities in thoracic level of spinal cord injured patients.	Spinal Cord vol. 42	420-424	2004
Nakazawa K, Kakihana W, Kawashima N and Akai M.	Induction of locomotor-like EMG activity in paraplegic persons by orthotic gait training.	Experimental Brain Research vol. 157	117-123	2004
山口裕子, 矢野裕美, 河島則天, 中澤公孝, 太田裕治	膝関節屈曲ー伸展動作を実現する脊髄損傷者用歩行補助装具の開発	第2回生活支援工学系学会連合大会講演予稿集	73-74	2004
矢野裕美, 山口裕子, 河島則天, 中澤公孝, 太田裕治	膝関節屈曲ー伸展動作を実現する脊髄損傷者用歩行補助装具の開発	第2回生活支援工学系学会連合大会講演予稿集	75-76	2004
太田裕治, 河島則天, 中澤公孝	健康・福祉工学におけるME 技術の応用と今後の展開. 脊髄損傷者のための歩行支援技術	第43回日本エム・イー学会大会論文集	158	2004
村木亜沙美, 中友美, 松元明弘, 太田裕治	トルクユニットによる松葉杖のパワーアシスト	精密工学会春季大会	1213-1214	2004
Kawashima N., Nozaki D., Abe OM., Nakazawa K., and Akai M.	Alternative leg movements contribute to amplify locomotor-like muscle activity in spinal cord injured patients.	Journal of Neurophysiology vol. 93	777-785	2005
Kawashima N, Nakazawa K, and Akai M	Muscle oxygenation of the paralyzed lower limb in spinal cord injured persons.	Medicine Science & Sports Exercise vol. 36	印刷中	2005
田口大介, 河島則天, 太田裕治, 中澤公孝, 赤居正美	脊髄損傷者の装具歩行における股関節動作の動力補助	日本義肢装具学会誌 21(1)	36-43	2005

A GAIT ORTHOSIS FOR PARAPLEGICS WITH A MOTOR-DRIVEN KNEE JOINT

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INTRODUCTION

Various kinds of orthopedic devices have been developed to assist walks and stances in paraplegic patients up to now. Furthermore, the devices have been combined with functional electric stimulation techniques to reduce the effort needed and to walk farther. In this study we developed a new gait orthosis featuring the rotating knee joint mechanism powered by a linear actuator, and tested it with a spinal cord injury patient.

MATERIALS AND METHODS

Figure 1 shows the schematic diagram and the photograph of the device we developed. A linear motion actuator was mounted at the back of the knee joint of an Advanced Reciprocating Gait Orthosis (ARGO). The actuator consists of a low-inertia DC motor (3557, Faulhaber, Switzerland) and a ball screw (Kuroda Precision Industries Ltd., Japan). The stroke length of the linear actuation and the maximum knee rotational angle were set at 15 cm and 70 degree, respectively. As shown, the mechanism mounted is compact and its weight is 0.8 kg. We used Ni-H rechargeable batteries featuring both lightweight and large capacity (HR-3US, 1600 mAh, Sanyo Co., Japan). From the viewpoint of safety, we adopted an infrared switch to control knee action in case that a user might be caught by a cable and fall down. The switch is placed on an arm crutch handle and pushed by a user itself along with every step. Furthermore, the knee joint of ARGO stays locked throughout extension phase. It is unlocked by the actuator through flexion phase and is locked again at heel strike. We measured the gait of a patient (male, 23 yrs, T12) with this device on, by using the vicon system (Oxford Metrics Co., UK) at the sampling rate of 60Hz.

RESULTS AND DISCUSSION

Figure 2 shows the self-paced gait of the patient with and without the device. As shown, the walking pattern with the device was found to be close to healthy subject's one. The walking speed with the device was about 0.4 m/s, which could be faster by trainings. The knee joint rotated about 40 degree at maximum flexion. The patient expressed that the effort required for walking was drastically reduced due to the device. The fully-charged battery could last for about one hour walk without exchange. The relationship between the foot-floor clearance of the device and the mechanism must be studied through further experiments.

SUMMARY

We developed a new gait orthotic device for paraplegics. The feature is the motor-driven knee joint mechanism which makes patient's gait close to healthy one. Through preliminary experiments with a patient, we found that the walking speed was about 0.4 m/sec, and we make sure that the effort for walking was reduced by rotating the knee joint during swing phase.

REFERENCES

Marsolais, E. B. et al (2000). *J. Spinal Cord Med.*, **23**, 100-108.

Greene, P. J. and Granat, M. H. (2000). *Clin. Biomech.*, **15**, 536-540.

ACKNOWLEDGEMENTS

This study was supported by Tateishi Science and Technology Foundation.

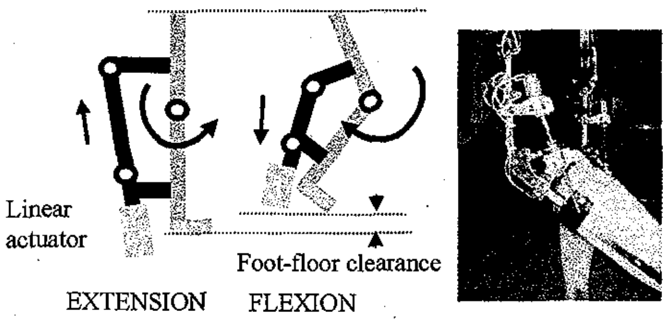

Figure 1 Mechanism of the motor-driven knee joint and its photograph at flexion.

Gait with/without the device

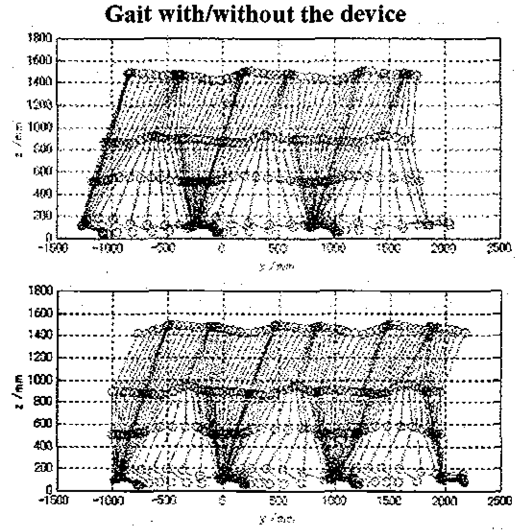

Figure 2 Measurement of the gait (right leg) with (*lower*) and without (*upper*) the device.

153

脊髄損傷者の装具歩行と理論値の比較検討

Measurements of the gait of paraplegics with an powered orthosis and a comparison with the simulation data

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1. はじめに

現在，脊髄損傷者の日常移動は車椅子によるものであるが，座位状態の継続は心肺機能，循環動態，骨強度，筋量，心理状態等に及ぼす影響が大きく，本来は立位歩行が望ましいと考えられる．このため脊髄損傷者（対麻痺）の立位歩行を可能とする様々な歩行補助装具が開発されてきが，それらの装具の殆どは動力化されておらず，下肢振出しが不可能な脊髄損傷者では体幹残存筋で下肢を前方に振り出さねばならず歩行に多大な労力を必要とする．これが装具歩行が継続されない理由の一つと考えられる．我々はレシプロ機構を有するAdvanced Reciprocating Gait Orthosis（以下ARGO）に着目し，その機構部（股関節）をリニアアクチュエータで動力化することで歩行労力の軽減を可能とした装具を既に開発しており，本研究ではその評価を行った．

2. 目的

本研究では動力化 ARGO を用いて脊髄損傷者の3次元歩行を計測・解析し，動力化による歩容向上を評価する．

3. 方法および結果

3-1. 実験方法

VICON370 システムを用いることで脊髄損傷患者 2 名（23ys T12 及び 29ys T6）の約 6 m 区間の有杖 ARGO 歩行を計測した．本システムは周囲に配置した 7 台の CCD カメラでマーカを撮影し 3 次元座標化すると同時に床反力計データを採取するものであり，被験者および装具上に計 18 個のマーカを設置した．座標データのサンプリング周波数は 60 Hz とした．以下，動力化装具を power-assisted ARGO（以下 p-a ARGO），通常の ARGO を normal ARGO（以下 n ARGO）とする．

3-2. 結果

(1) 歩行速度

動力化によりいずれの患者からも歩行労力が軽減されたとのコメントが得られた．これは歩行速度にも現れており，それをTable 1に示す．表より動力化により歩行速度が患者 1，2 でそれぞれ 23%，28%向上したことが分かる．

Table 1 Gait speed/(m/s)

	Subject 1	Subject 2
n ARGO	0.43	0.16
p-a ARGO	0.53	0.21

(2) 骨盤中心の振幅

VICON システム（座標軸 Fig.1 参照）により計測された骨盤中心の軌跡を Fig. 2（n ARGO 歩行），Fig. 3（p-a ARGO 歩行）に示す（患者 1）．x-y 平面での計測結果から分かるように左右に振りながら前進することが分かる．これは下肢全体を左右に傾斜させることで foot floor clearance を作り出しているためと考えられる．その振幅量を Table 2 に示すが，動力化により 22%減少したことが分かる．

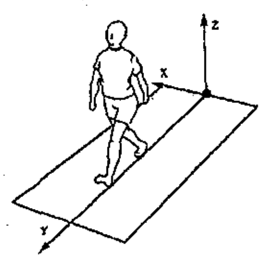

Fig. 1 Definition of axes

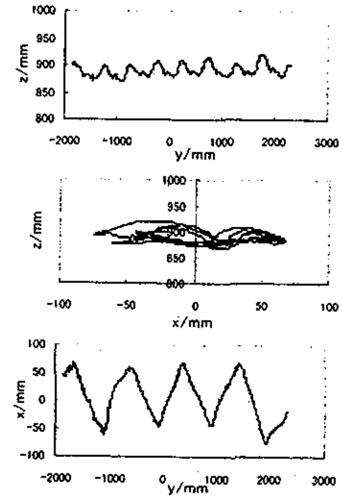

Fig. 2 Trajectory of the center of pelvis (subject 1, normal ARGO)

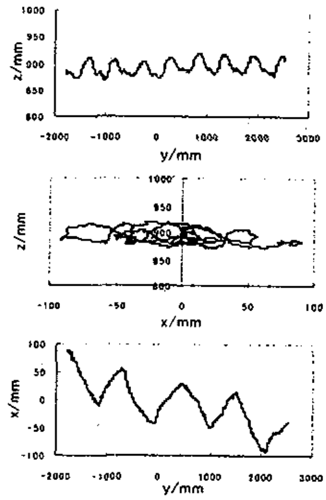

Fig. 3 Trajectory of the center of pelvis (subject 1, p-a ARGO)

Table 2 Amplitude of the center of pelvis (subject 1)

		normal ARGO	p-a ARGO
Amplitude/cm	上下	2.9(0.5)	3.5(0.4)
	左右	11.0(1.6)	8.6(2.3)

4. まとめ

レシプロ機構部の動力化により患者の歩行速度は向上し，骨盤の左右への揺れは減少した．今後，呼気ガス計測を通じて歩行労力の軽減効果を定量化する必要がある．またTashman[2]らは8自由度のモデルを用いて同様の検討を行っており，現在詳細な比較検討を進めている．

参考文献

1. 矢野英雄，「脊髄損傷者のために開発した人工肢ー荷重制御式歩行補助装具ー」，*Research Journal of Walking*, **1**, 15-30, 1997.
2. Tashman S, Zajac FE, Perkash I. "Modeling and simulation of paraplegic ambulation in a reciprocating gait orthosis", *J Biomech Eng(ASME)*, **117**(3), 300-308, 1995.

装具歩行の kinematics の違いが脊髄損傷者の麻痺筋活動に及ぼす影響

脊髄損傷者　装具歩行　歩行様筋活動

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Ⅰ 緒 言

我々はこれまで、脊髄完全損傷者の装具歩行中に麻痺下肢筋に歩行周期に同調した筋活動（以下、歩行様筋活動）が生じることを報告してきた 1,2)。脊髄完全損傷者では麻痺領域への随意性神経信号が遮断されていることを勘案すると、上記歩行様筋活動の発現機序は、歩行動作に伴う末梢性感覚入力によって脊髄運動ニューロン活動が喚起されたことによるものに他ならない。

今回我々は、歩行遊脚期に膝関節の屈曲-伸展を可能にした改良型 ARGO（Advanced Reciprocating Gait Orthosis）を試作し、この装具用いた歩行時の下肢麻痺筋活動を測定した。脊髄損傷者の歩行様活動が歩行に伴う末梢性感覚入力に依拠するのであれば、膝の屈曲-伸展に伴って、筋活動に変化が生じることが予想される。本研究の目的は、歩行 kinematics の変化により脊髄損傷者の麻痺領域に認められる歩行様筋活動がいかなる変化を示すかを検討することであった。

Ⅱ 方 法

胸髄 12 番完全損傷者 1 名（受傷後 22 カ月経過、24 歳）を対象とした。被験者は交互歩行装具（ARGO）を用いた 18 ヶ月にわたる歩行トレーニングを経ており、実験時には歩行時の kinematics、kinetics はほぼ安定し、歩行周期に同調した歩行様筋活動も高い再現性を示した。この被験者に従来型 ARGO、歩行遊脚期に膝関節の屈曲-伸展を可能にした改良型 ARGO（図 1）による歩行を行わせた。

図 1　改良型 ARGO の膝屈曲伸展機構（アクチュエータの駆動により遊脚期に膝関節屈曲-伸展動作を実現、立脚期には従来型同様、伸展固定位を保持）

アクチュエータの制御は杖のグリップ部に設置されたボタンによって被験者自身が行った。

両装具による歩行中の麻痺筋 EMG 活動を以下の筋より計測した。ヒラメ筋（SOL）、内側腓腹筋（GAS）前頸骨筋（TA）、大腿直筋（RF）、大腿二頭筋（BF）。データは生体アンプにて増幅後、A/D 変換器を通して周波数 600Hz にて記録した。同時に VICON system による 3 次元動作解析、歩行中の床反力計測を実施した。

Ⅲ 結 果

改良型 ARGO による歩行中の膝関節可動域は約 25 度、伸展角速度は約 150deg/sec であった。膝関節の動作を除いては、両装具による歩行中の kinetics, kinematics には大きな差異は認められなかった。図 2 に示したように、いずれの装具を用いた場合でも歩行周期に同調した筋活動が発現した。膝関節の屈曲伸展により直接筋長の変化がもたらされる大腿筋群、腓腹筋はいずれも通常型 ARGO 歩行時とは異なる活動振幅、位相を示した。

Ⅳ 議 論

脊髄損傷者の装具歩行は健常者の歩行動作とは若干異なる動作形態を持つが、装具歩行動作によって生じる脊髄への末梢性感覚入力

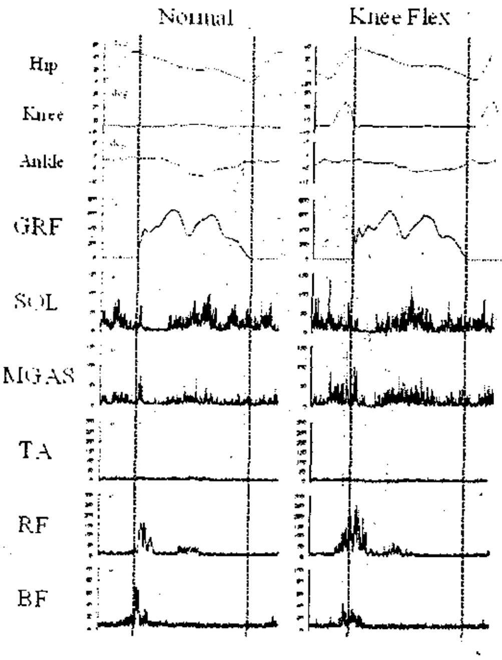

図２　通常型（左）、改良型 ARGO（右）による装具歩行中の kinematics、kinetics、麻痺下肢の歩行様筋活動（５試行分の加算平均波形）

は健常歩行のそれとかなりの部分で類似するものと考えられる。一方で歩行中に発現する筋活動は、健常者では随意性筋活動と反射性筋活動が混在しているのに対し、脊髄完全損傷者では麻痺下肢への随意性神経信号が遮断されているためその発現機序から脊髄上位の関与が棄却される。脊髄損傷者における装具歩行中の歩行様筋活動を検討することは即ち、歩行動作に伴う諸々の末梢性感覚入力に対して、上位中枢からの影響がない状況下で脊髄神経機能がどのような応答を示すかを検討することを可能にする。

本研究では、通常の膝関節部分にアクチュエータを搭載し、通常型ARGOでは実現されない膝の屈曲-伸展動作を可能にすることによって、この装具を用いた歩行中に歩行様筋活動が変化を示すか否かに着目した。

図２に示したように、改良型 ARGO 歩行中には遊脚期に膝関節の屈曲-伸展動作を実現し、かつ他の関節の動作は通常型 ARGO 歩行中と大きな変化は示さなかった。通常型、改良型ともに歩行中の下肢筋活動は、歩行周期に依存して筋ごとに異なる位相で活動したが、膝関節の動作によって筋長の変化がもたらされる大腿直筋、大腿二頭筋、腓腹筋において両装具間で異なる活動位相、振幅を示した。この結果は、上位中枢と脊髄の神経性結合が完全に遮断された脊髄損傷者であっても、装具歩行の kinematics 変化に伴う求心性入力の変化に応じて麻痺筋に異なる位相、振幅で活動電位を発現することを示唆している。

両装具による歩行中の筋活動の発現機序について言及するにはさらに症例数を重ねて検討する必要があるが、この差異を生じさせた要因が膝関節の屈曲-伸展動作の有無であることは明らかであり、この動作に伴う関節および筋・腱の固有受容器からの求心性神経入力が発現機序の一端を担うことは間違いないものと考えられる。

Ⅴ　結　論

本研究で認められた両装具における麻痺下肢の歩行様筋活動の差異は、装具歩行動作の変化に伴う求心性入力の変化に応じて、脊髄神経回路が可変的に応答する事実を示す結果であった。これらの事象は、上位中枢との神経性結合が完全に遮断された脊髄の機能に依拠するものであり、脊髄に内在する歩行中枢の基礎的性質を示す重要な根拠となるものと考えられる。

Ⅵ　参考文献

[1] Kojima N., Nakazawa K., Yamamoto S., Yano H. Phase-dependent electromyo- graphic activity of the lower-limb muscles of a patient with clinically complete spinal cord injury during orthotic gait. Exp Brain Res. 120:139-142 (1998)

[2] Kojima N., Nakazawa K., Yano H. Effects of limb loading on the lower-limb electromyographic activity during orthotic locomotion in a paraplegic patient. Neurosci Lett. 274:211-213 (1999)

Sødring Motor Evaluation Scale (SMES), the Barthel ADL-Index, and the Nottingham Health Profile (NHP) were used. Following parameters were also registered: length of stay in the hospital, use of assistive devices for mobility, and the patients accommodation after discharge from the hospital.
Results: Patients treated according to MRP stayed fewer days in hospital than those treated according to Bobath (mean 21 days versus 34 days, p=0.008).Both groups improved in MAS and SMES, but the improvement in motor function was significantly better in the MRP-group. The two groups improved in Barthel ADL-Index without significant differences between the groups. However, women treated by MRP improved more in ADL than women treated by Bobath.There were no differences between the groups in the life quality test (NHP), use of assistive devices or accommodation after discharge from the hospital.
Discussion and Conclusions: The present study indicates that physiotherapy treatment according to MRP is preferable to the Bobath program in the acute rehabilitation of stroke patients.
References:Langhorne P, Wagenaar R, Partridge C. Physiotherapy after stroke: more is better? Physiother Res Int 1996;1: 75- 88. 2 Ernst E. A review of stroke rehabilitation and physiotherapy. Stroke 1990;21:1081 - 85. 3 Wagenaar RC, Meijer OG. Effects of stroke rehabilitation. A critical review of the litterature. Rehabil Sci 1991;4:61 -73
.4 - 27: contact author for complete reference list.

P74 - MOVEMENT TIME DURING TRANSFER FROM SITTING TO STANDING AND BACK IN ELDERLY PEOPLE: COMPARISON BETWEEN DEMENTS AND CONTROL SUBJECTS

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Introduction: The frequency of the posture and movement disorders increase with age and often cause great dependency. In this study we wondered if Alzheimer disease entails some disturbance of movement organization and execution apart from aging.

Methods: the movements of specifics sites of the body were measured using a 100HZ opto-electronic movement analyzer (ELITE). Data were obtained from 7 females showing Alzheimer disease (76-88 years) and 11 control subjects (70-80 years). The first purpose was to compare the two groups from execution time of Sitting to Standing transition (STS) and Back to Sitting (BTS). The second purpose was to find out if the STS duration was different from BTS in the group of dements.

Results: in the STS time a significant difference ($p<0.05$) was found between the dements and the controls. The dements moved more quickly (1.454 ± 0.382 sec vs 2.005 ± 0.465 sec). Although the average duration of BTS was shorter in dements (1.965 ± 0.355 sec vs 2.260 ± 0.597 sec), no significant difference was found between the two groups. In dements, the STS duration was significantly quicker ($p<0.05$) than BTS duration (1.454 ± 0.382 sec vs 1.965 ± 0.355 sec).

Discussion and Conclusions: the first result may look surprising as Alzheimer disease has been reported to cause a deterioration of motor control especially in complex tasks. However, this result can be accounted for by the fact that dements pay less attention. Finally, the last result is in accordance with data from the literature both in non demented old people and young people. The BTS is a complex task which needs fine postural control. This control doesn't seem altered in the subjects showing moderate cognitive disorder.

P75 - A GAIT ORTHOSIS FOR PARAPLEGICS WITH A MOTOR-DRIVEN HIP JOINT

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Introduction: Various kinds of orthopaedic devices have been developed to assist walking and keeping stance of paraplegic patients up to now. Furthermore, several research studies have been conducted to apply functional electric stimulation techniques in order to reduce efforts necessary and to walk farther. As another trial of powering it, we have proposed assistive orthopaedic devices by using electric actuators. And we developed a device with a motor-driven knee joint and found that it could significantly improve walking ability of spinal cord injury (SCI) patients (1). In this study we installed a linear actuator on the hip joint of the orthosis to assist swinging of lower limb, and tested it with SCI patients.

Methods: A linear actuator was developed by combining a DC motor (3557,Faulhaber, Switzerland) and a rack-and-pinion gear (EP150, Asahi Seiko Co. Ltd., Japan) , and we mounted it at the hip joint of an Advanced Reciprocating Gait Orthosis (ARGO). The actuator controls the reciprocating mechanism which is originally provided on the orthosis and enables both legs to swing forward. Whole mechanism mounted on the orthosis is really compact and its weight is only 1.4 kg. We used Ni-H rechargeable batteries featuring both lightweight and large capacity (HR-3US, 1600 mAh, Sanyo Co., Japan). From the viewpoint of safety, we adopted an infrared switch to control hip joint rotation in case that a user might be caught by a cable and fall down. The switch is placed on an arm crutch handle and pushed by a user itself along with every step. We measured the gaits of two patients (male 23ys T12, and male 29ys T6) with this device on, by using the VICON system (Oxford Metrics Co., UK) at the sampling rate of 60Hz.

Results: We measured self-paced gait speed from VICON data and found that the power assisting mechanism increased it for both patients (T12:23% and T6:28%). Stride length also increased (T12:7% and T6:22%). The normal ARGO needs body sway on the coronal plane (between left and right) to produce enough foot-floor clearance for the leg swing. Since this power assisting mechanism is supposed to decrease the patient's body sway, we analysed the trajectory of pelvis center projected on the coronal plane and measured the amplitude. As a result, the amplitude was found to decrease (T12:22%). The patients expressed that the effort required for walking was drastically reduced due to the mechanism. It is the point that has to be evaluated quantitatively by oxygen consumption method for future study.

Discussion and Conclusions: We developed a hip joint driven orthosis for SCI patients and found that it could improve the patients' gait and reduce the walking effort significantly. Combining this reciprocating mechanism and our previous motor-driven knee joints would show the way to a new robotic walking device. We could expect increase of potential patients applicable for walk orthosis. That also means increase of possibility that functional centers in the injured spinal cord might be re-activated through daily locomotor trainings (2).

References:
1. Ohta Y, et. al. Fourth World Congress of Biomechanics, 2002,in CD-ROM.
2. Colombo G, Wirz M, Dietz V. Spinal Cord 2001;39(5):252-5.

P76 - KINEMATIC MODEL OF THE SPINE : STUDY OF PARAPLEGIC SUBJECTS

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Introduction: Many different tests of mobility are based on analysis of the final position of the performed movement [1-2]. However, such methods are not able to quantify the spinal column's behaviour during the movement. A solution may be the modelisation of the back as a multi-body kinematic chain, allowing to understand and quantify how the movement is organised. In order to better understand the repercussion of the injury level, we propose a segmentation of the back model adapted to the injured level of the spinal cord. This model is used to analyse the maximal flexion of the back on two subjects, whose injured levels are different.
Methods: For this study, we have selected two paraplegic subjects : one is a young woman, suffering from a low paraplegia (L3-L1), who keeps a good back mobility. The last patient is injured in the high spinal cord part (T11-T12 level). The subjects were asking to realise several trunk flexion-extension cycles of maximum amplitude. Their hands rested on the hips and they were asked to fix a target aligned with their eyes when they stand straight on the stool. A Motion Analysis system (Santa Rosa, California) was used to collect the experimental data. Thirteen markers were glued over anatomical landmarks allowing to define each body segment. Six cameras were located around the subject so that each passive marker can be seen by at least two cameras during the whole movement cycle. The 3D trajectories of these markers were then tracked by the system, with a sampling frequency of 60 Hz. The kinematic model of the back consisted in ten rigid segments connected by nine joints. As the back movement during propulsion is roughly contained within the sagital plane, only flexion-extension degrees of freedom are measured for each joint model. The kinematic chain base corresponds to the pelvis, defined by right and left anterior and posterior iliac spines. Then, the lumbar spine is split into 3 segments : from the middle of the posterior iliac spines to the 4th lumbar vertebra (L4), from L4 to L2 and from L2 to the 12th thoracal vertebra T12. The thoracic spine is split into 5 segments : T12-T10, T10-T8, T8-T6, T6-T4 and T4-T2. The last segment corresponds to the cervical spine and the head. The angular variations between two adjacent segments are computed from the trajectories of the corresponding landmarks, all along the flexion-extension cycles, in order to identify the rigid and mobile parts of the back for each subject.
Results: We have been interest by the value of the corner at the beggining and the end of the flexion. The areas of great or small mobility can be defined with the amplitude of the movement between the differents segments. The low level paraplegic patient shows 3 mobile zones. One is located nearby L2 (18.4%), another about T4 (12.3%), and the last one at the cervical level T2 (12.3%). The high level injured patient also presents 3 mobile areas : two in the lumbar part L4 (9.3%), L2 (10%), and one in the cervical part T2 (10%), but the movement amplitudes of these joints are smaller. The amplitude of the whole back (segment defined from the middle of the posterior iliac spines to the top of the head) is 48.3% for the low level injured patient and 30.3% for the high level spinal cord injury.
Discussion and Conclusion: The kinematic behavior of paraplegic patients confirms that the mobility of the back is directly dependent on the level of the spinal cord injury. Actually, the mobility of the patient injured at T11-T12 levels is focused in the lumbar part whereas the thoracic part is moving like a rigid block. For this patient, a segmentation in two parts (lumbar and cervical) whereas the other one would be represented by a model in three parts (lumbar, thoracic, cervical). The results confirm the hypothesis that a quik simple kinematic model, which segmentation is adapted to the cord injury level, is a usefull tool to analyse the back mobility.
References: [1] Kendall FP, McCreary EK, Provance PG. Muscles: Testing and Function (4th ed.). Baltimore: Williams & Wilkins; 1993:270
[2] A. Dauphin and A. Thevenon, Sagittal mobility of the trunk: comparison between clinical and rachimetric measurements, Annales de Réadaptation et de Médecine Physique, Volume 43, Issue 6, July 2000, Pages 270-278

P77 - EMG-ANALYSIS OF THE LEG MUSCLES IN HEMIPLEGIC CHILDREN WITH AND WITHOUT HINGED ANKLE-FOOT ORTHOSES

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Introduction: Among the various treatment options in hemiplegic cerebral palsy (CP) children, ankle-foot orthoses (AFOs) are widely used to prevent deformity and to support normal alignment and mechanics. The AFO achieves its function by modifying the forces and moments which the body is subjected to. When the body's internal force system is inadequate, most commonly an abnormal pattern of motion will occur. If, however, an orthosis has been correctly designed, constructed and applied to the patient, it may act or resist this abnormal pattern of motion and hence restore more normal function. The myoelectric signal, recorded as electromyogram (EMG), during gait provides valuable information with respect to timing of muscular activity. Previous studies involving 3D gait analysis [1-3] showed that AFOs are successful in correcting the excessive plantarflexion angle in the swing phase of gait to improve pre-positioning of the foot for initial contact and allow a heel strike in CP patients. EMG data on this improvement of gait function towards normal have been less investigated. The aim of this study was to evaluate changes in muscle activation in children diagnosed with hemipelegic CP during gait with and without wearing AFOs.
Methods: 8 Children (5 boys, 3 girls; mean age 9.8±1.8 years) with mild to moderate hemiplegic CP have been investigated. The children did not have any prior surgeries or fixed contractures and are experienced users of hinged AFOs. The children were tested barefoot and wearing a hinged AFO and shoes. Only children with an initial toe-strike barefoot and a physiological heel-strike with the AFO were included. All children performed a 3D gait analysis with a 6-camera, 50 Hz VICON 370 motion measurement system (Oxford Metrics ltd., UK) and two forceplates (Kistler Instrumente AG, CH). Surface EMG (Zebris/Biovision, Germany) of the vastus medialis, vastus lateralis, rectus femoris, biceps femoris caput longum, semimembranosus/semitendinosus, gastrocnemius lateralis (only barefoot), and tibialis anterior muscle groups was collected of the involved side.
Results, Discussion and Conclusions: Mean ankle plantarflexion at initial foot contact was 16.1° (range: 0.2° to 27.7°) when walking barefoot and 3.4° of dorsiflexion (range: -5.6 to 8.2°) with the AFO. EMG data showed reduced tibialis anterior muscle activity by the AFO in all patients, especially in early to mid swing phase. Muscle activation pattern was corrected towards normal for knee extensors and hamstrings as well. These results indicate that the pathological muscle activation pattern present in CP-patients is not only due to spastic activation but also to a compensation for the abnormal gait pattern.

ELSEVIER

Neuroscience Letters 345 (2003) 41–44

Neuroscience Letters

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Inhibition of the human soleus Hoffman reflex during standing without descending commands

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Received 12 March 2003; received in revised form 12 April 2003; accepted 15 April 2003

Abstract

The purpose of the present study was to ascertain the contribution of peripheral sensory inputs to posture-related Hoffman reflex (H-reflex) modulation in the human soleus muscle. The soleus H-reflexes were elicited in the sitting (SI) and passive standing (ST) conditions in patients with clinically complete spinal cord injuries (SCI) and in neurologically normal subjects. The results clearly showed suppression of the H-reflex amplitude during the ST compared with the SI condition especially in the SCI group. Considering the lack of a descending neural command in the SCI patients, our findings suggest that peripheral sensory inputs primarily contribute to the reduction of the soleus H-reflex during the upright standing posture.

Keywords: Hoffman reflex; Task-dependent modulation; Standing posture; Spinal cord injury

Previous studies have revealed that the amplitude of the soleus Hoffman reflex (H-reflex) was reduced during upright standing compared with other postural conditions, such as sitting [4], lying prone [8], or standing with back support [6]. This modulation is in line with the well established task-dependent nature of the H-reflex [2], which has been assumed to have a central origin, because this type of modulation is impaired in patients with central nervous system disorders [11,12]. On the other hand, it is generally thought that peripheral sensory inputs according to postural changes would also play a role in suppressing the excitability of the spinal motoneuron pool. However, it remains unknown to what extent peripheral sensory inputs contribute to the inhibition of H-reflex excitability during standing posture. In the present study, we attempted to clarify whether the soleus H-reflex in patients with motor complete spinal cord injury (SCI) is reduced when they stand passively with support. We hypothesized that since patients have lost neural transmission from the higher center to the lumber level of the spinal motoneurons which innervate the soleus muscle, if the amplitude modulation of the H-reflex were to appear in accordance with postural changes, we could at the very least conclude that those changes were not induced by descending commands.

Experiments were performed on six SCI patients and six neurologically normal controls (SCI group: 29.5 ± 7.8 years, normal group: 28.8 ± 6.7 years). All of the SCI patients had lesions at the thoracic level (ranging from Th 5 to 12), and were categorized in clinically motor complete, which corresponds to grade 'A' or 'B' according to the classification of the ASIA (American Spinal Injury Association) [9]. Each subject gave informed consent to the experimental procedure, which was approved by the biological ethics committee of the National Rehabilitation Center for the Disabled (NRCD), Japan.

Subjects were placed in a special device (Easy Stand Glider 6000, Altimate Medical, Inc.) that enables subjects to passively maintain a standing posture while it holds their trunks and knees. The experiments were conducted under two postural conditions, sitting (SI) and passive standing (ST). In the ST condition, the body load can be applied in a manner similar to that of normal standing; therefore, it was considered that a large portion of the sensory inputs, i.e. cutaneous input from the sole of the foot and afferent input from joint receptors, was similar to that during normal standing posture. In both conditions, the ankle joint angle was kept at 90 degrees, and the hip and knee joint angles

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doi:10.1016/S0304-3940(03)00485-3

were set at 90 degrees (flexion) in SI and 0 degrees in ST, respectively.

The surface electromyographic (EMG) signal was recorded from the soleus muscle with the use of bipolar electrodes. Because SCI patients generally tend to have larger impedance in their paralyzed leg, special care was taken to reject any artifacts in the EMG recording. The EMG signal was amplified (The Bagnoli-8 EMG System, DELSYS, USA) with band-pass filtering between 20 and 450 Hz and digitized at 5 kHz. The digitized EMG signals were full-wave rectified after subtracting the DC component. The H-reflex was recorded from the soleus muscle every 5 s by applying rectangular pulses of 1 ms duration to the posterior tibial nerve in the popliteal fossa with a constant voltage stimulator (DPS-1300D, Dia Medical System Co.). To record the recruitment curve of the M responses and the H-reflexes, the stimulus intensities were gradually increased from an initial value below the threshold of the H-reflex to the maximal M responses. Five responses were obtained at each stimulus intensity. The stimulus intensity was expressed as the relative value of the motor threshold intensity.

The magnitude of the M response and the H-reflex were measured as the peak-to-peak amplitude of each response. The maximum value of the H-reflex (H_{max}) and motor response (M_{max}) were quantified. To evaluate the excitability of the spinal motoneuron pool, the H_{max}/M_{max} ratio was calculated. Additionally, 50 H-reflex responses were elicited simultaneously as the relative value of the motor threshold intensity.

Values are given as the mean ± SEM. The statistical difference of each parameter was tested by two-way ANOVA (2 × 2; condition × group) with repeated measures. Multiple comparisons (LSD method) were applied to identify differences between the SI and ST conditions, and between the SCI and normal groups. Significance was accepted at $P < 0.05$.

Neither the SCI group nor the normal group showed any background EMG activity (BGA) in the soleus muscle during ST. In previous studies regarding posture-related H-reflex modulation, the effect of background EMG activity in the soleus muscle during standing was eliminated by the use of voluntary contraction trials in neurologically normal subjects in other postural conditions, such as sitting [4] or standing with back support [6]. In contrast, in the present study, the passive standing posture allowed for comparison of the H-reflex amplitude in subjects standing and sitting, and the background EMG activity was also eliminated.

Fig. 1A illustrates a typical example of the recruitment curve of the H-reflex and M response under each postural condition. As clearly shown in this figure, the reduced H-reflex responses in the ST condition were lower than those in the SI condition, in both the SCI group and the normal group. The average values of the M_{max}, H_{max}, and H_{max}/M_{max} ratio are summarized in Fig. 1B. Although it was not statistically significant, the M_{max} value showed differences between the two conditions. In both groups, the H_{max}/M_{max} ratio was lower in the ST condition than in the SI condition (SCI group: SI vs. ST, 0.73 ± 0.05 vs. 0.55 ± 0.08, $P < 0.05$; normal group: 0.57 ± 0.09 vs. 0.47 ± 0.10, $P < 0.05$). The amplitude of the H-reflex under the condition of a constant size of the M response also showed significantly lower values in the ST condition ($P < 0.05$, Fig. 2).

Depression of the H-reflex amplitude itself was in good agreement with findings from previous reports [4,6,8]. As regards the neural mechanism of this modulation, it is thought that the descending command from the higher

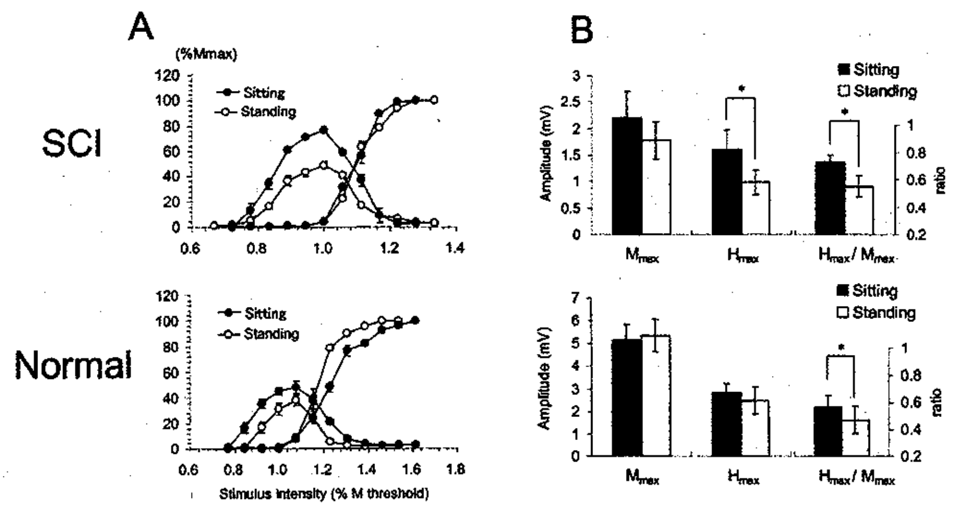

Fig. 1. (A) Typical example of the recruitment curve of the H-reflex and M responses during passive standing (open circles) and sitting conditions in a spinal cord injured patient (above) and in a normal subject (below). Response size and stimulus intensity are expressed as a percentage of the maximal M response and the motor threshold, respectively. The error bars indicate the standard error of the mean value. (B) Summary of the M_{max}, H_{max}, and calculated H_{max}/M_{max} ratio in each postural condition. The error bars indicate the standard error of the mean value. *Significant difference ($P < 0.05$).

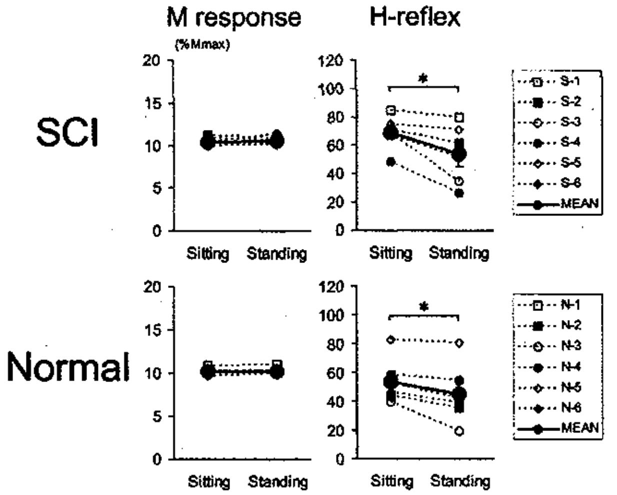

Fig. 2. The magnitude of the M responses (left) and H-reflex (right), expressed as a percentage of the M_{max} value. The M responses were set to a constant value (approximately 10% M_{max}). The dotted and thin lines indicate the individual and mean data, respectively. The error bars indicate the standard error of the mean value. *Significant difference ($P < 0.05$).

center is dominant over the peripheral sensory inputs. However, the present results in the SCI patients clearly demonstrated that the peripheral sensory inputs associated with postural changes would be the primary neural source responsible for modulating the excitability of the spinal motoneuron pool.

Due to the postural transition from sitting to standing, the body load applied in a vertical direction would be expected to undergo a large shift. Dietz et al. (1989) [3] conducted an underwater experiment to demonstrate that the compensatory EMG response (long latency reflex) to stance perturbation increases as body weight increases, but is saturated at a subject's actual body weight, suggesting the importance of load information for determining spinal reflex sensitivities. As regards the contribution of load-related peripheral inputs to the soleus H-reflex, we observed that in a micro-gravity environment produced during parabolic flights, the soleus H-reflex was significantly increased while the subjects were maintaining a standing posture [10]. Furthermore, our group recently observed that H-reflex excitability also was enhanced in a reduced gravity condition under water as well. Interestingly, the H-reflex was reduced when the knee joint or ankle joint was loaded by the attachment of additional weights; moreover, the H-reflex increased with the unloading of those joints (unpublished data), suggesting that the somatosensory information related to load plays a role in the reduction of the SOL H-reflex while standing. In the current study, the presence or absence of body load caused marked differences in the H-reflex responses observed under SI and ST conditions. It is therefore possible that the load related to peripheral inputs plays a role in the underlying mechanism responsible for the present results. Furthermore, Knikou and Conway [7] recently revealed that the H-reflex amplitude was reduced as a result of tonic mechanical loading applied to the sole of the foot. Importantly, this result was observed in clinically complete SCI patients, suggesting that cutaneous afferents exert an inhibitory effect on the H-reflex at the spinal level. Taken together with the above findings, the present results suggest that graviception, i.e. the load at the vertebral column and lower limb joints, and/or cutaneous information from the sole of the foot each play a role in reducing the excitability of the spinal motoneurons to the Ia inputs while standing upright.

In this study, both M_{max} and H_{max} values showed significant decreases in the SCI group as compared with the normal group. These results may be accounted for by changes in the muscular and neural composition after SCI. On the other hand, the H_{max}/M_{max} ratio under the SI condition was significantly greater in the SCI than in the normal group (SCI vs. normal: 0.72 ± 0.04 vs. $0.56 \pm 0.08\%$, $P < 0.05$). Previous investigations have revealed that SCI patients generally show hyperexcitability of the spinal motoneuron pool, as a result of the lack of descending neural regulation from the higher nervous center to the spinal cord [1,5]. The hyperexcitability of the spinal motoneurons has generally been considered to be relevant to the spasticity, which is a typical symptom in patients with SCI. Considering these points, the reduced H-reflex observed during the ST condition in the SCI group suggests that even in SCI patients, the standing posture could generate inhibitory neural inputs to the soleus spinal motoneuron pool. This finding might have some implications as regards the development of rehabilitative strategies to counteract spasticity in SCI patients.

In summary, in this study, we aimed to ascertain the contribution of peripheral inputs to posture-related H-reflex modulation by examining how the soleus H-reflex in SCI patients and healthy subjects differs when posture changes. We hypothesized that if the peripheral sensory inputs due to the postural changes can modulate the excitability of the motoneuron pool, then the magnitude of the H-reflex in SCI patients would be altered. The results clearly revealed differences in the H-reflex responses under ST and SI conditions in SCI patients, suggesting that peripheral sensory inputs may indeed play a role in reducing the excitability of the spinal motoneurons when subjects are standing. These results provide evidence of the existence of a peripheral component involved in posture-related H-reflex modulations.

References

[1] B. Calancie, J.G. Broton, K.J. Klose, M. Traad, J. Difini, D.R. Ayyar, Evidence that alterations in presynaptic inhibition contribute to segmental hypo- and hyperexcitability after spinal cord injury in man, Electroenceph. clin. Neurophysiol. 89 (1993) 177–186.

[2] C. Capaday, R.B. Stein, Amplitude modulation of the soleus H-reflex in the human during walking and standing, J. Neurosci. 6 (1986) 1308–1313.

[3] V. Dietz, G.A. Horstmann, M. Trippel, A. Gollhofer, Human postural reflexes and gravity – an under water simulation, Neurosci. Lett. 106 (1989) 350–355.
[4] R. Hayashi, K. Tako, T. Tokuda, N. Yanagisawa, Comparison of amplitude of human soleus H-reflex during sitting and standing, Neurosci. Res. 13 (1992) 227–233.
[5] L.P. Hiersemenzel, A. Curt, V. Dietz, From spinal shock to spasticity: neuronal adaptations to a spinal cord injury, Neurology 54 (2000) 1574–1582.
[6] R. Katz, S. Meunier, E. Pierrot-Deseilligny, Changes in presynaptic inhibition of Ia fibres in man while standing, Brain 111 (1988) 417–437.
[7] M. Knikou, B.A. Conway, Modulation of soleus H-reflex following ipsilateral mechanical loading of the sole of the foot in normal and complete spinal cord injured humans, Neurosci. Lett. 303 (2001) 107–110.
[8] D.M. Koceja, M.H. Trimble, D.R. Earles, Inhibition of the soleus H-reflex in standing man, Brain Res. 629 (1993) 155–158.
[9] F.M. Maynard, M.B. Bracken, G. Creasey, J.F. Ditunno, W.H. Donovan, T.B. Ducker, International standards for neurological and functional classification of spinal cord injury, Spinal Cord 35 (1997) 266–274.
[10] T. Miyoshi, D. Nozaki, H. Sekiguchi, T. Kimura, T. Sato, T. Komeda, K. Nakazawa, H. Yano, Somatosensory graviception inhibits soleus H-reflex during erect posture in humans as revealed by parabolic flight, Exp. Brain Res. 150 (2003) 109–113.
[11] T. Sinkaer, E. Toft, H.J. Hansen, H-Reflex modulation during gait in multiple sclerosis patients with spasticity, Acta Neurol. Scand. 91 (1995) 239–246.
[12] J.F. Yang, R.B. Stain, K.B. James, Contribution of peripheral afferents to the activation of the soleus muscle during walking in humans, Exp. Brain Res. 87 (1991) 679–687.

Spinal Cord (2003) 41, 506–510

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Original Article

Energy expenditure during walking with weight-bearing control (WBC) orthosis in thoracic level of paraplegic patients

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Study design: Comparative study of the effectiveness of walking exercise with a newly developed gait orthosis, the weight-bearing control (WBC) orthosis, for thoracic level of paraplegic patients.
Objectives: To test its feasibility as a rehabilitation alternative for paraplegic patients, the energy consumption and cost during walking with WBC were calculated and compared with the values of conventional orthoses given in previous reports.
Setting: National Rehabilitation Center for the Disabled, Japan.
Methods: Four paraplegic patients with traumatic spinal cord injuries ranging from T8 to T12 participated. Experiments were conducted after 3 months of the orthotic gait training with WBC. The cardiorespiratory parameters were continuously measured at rest and during walking with a telemetric device. The steady-state value of the oxygen uptake (V_{O_2}), heart rate (HR), the energy consumption (J/kg/s) and energy cost (J/kg/m) were calculated.
Results: The average walking speed was 19.0 ± 2.58 m/min. The steady-state value of the V_{O_2} and HR were 16.08 ± 1.93 ml/kg and 147.3 ± 10.94 b/min, respectively. The energy cost during orthotic walking tended to be better than the values of conventional orthoses, whereas the energy consumption was almost similar.
Conclusion: WBC enables thoracic level of paraplegic patients to walk at relatively higher speed than conventional orthoses under similar energy expenditure. The special devices equipped with WBC are therefore considered to lead to improvement of the energy cost of walking. The physical intensity presumed by cardiorespiratory responses during walking with WBC is suited to promote their aerobic capacity. Therefore, it is concluded that the WBC orthosis could be an effective alternative in rehabilitation for thoracic level of paraplegic patients.
Spinal Cord (2003) **41,** 506–510. doi:10.1038/sj.sc.3101494

Keywords: spinal cord injury; orthotic gait; rehabilitation; energy consumption; energy cost; physical intensity

Introduction

Previous studies have pointed out that the high energy cost has been one of the major problems of the orthotic gait for paraplegic patients.[1–5] Although many devices have been developed to improve this problem to date, it is still difficult to satisfy the requirements of both paraplegic patients and therapists. The futile energy cost should lead to exhaustion in a few minutes of walking. As a consequence, orthotics are frequently abandoned after being used for only a short time in therapeutic phase.[6] Especially for thoracic level of paraplegic patients, a considerable effort of their upper limb and trunk above the paralysis is required during orthotic gait, and this is the main reason of the limitation of the orthotic use.[2,7]

One of the major purposes of the orthotic gait for paraplegic patients is the promotion of their health. Since previous studies have suggested the positive effects of walking exercise on secondary disorders, such as the urodynamics[8] and digestive functions,[9] paraplegic patients should make efforts to facilitate their own physical activities in daily life not only with a wheelchair, but also with walking exercise. To this end, the energy cost

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