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Modified Dual Axis Pneumatic Knee Brace to Control Genu Recurvatum - A Case Study

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Abstract:

Genu recurvatum, characterized by hyperextension of the knee, can result from various causes, including muscle weakness or abnormal bone structure. This case study presents a modified dual-axis pneumatic knee brace designed to effectively control genu recurvatum by maintaining knee extension and preventing hyperextension. The brace consists of a thigh shell, calf shell, and a posterior knee cap, working in tandem to control knee motion. A three-point pressure system in the sagittal plane is employed, with two posteriorly directed forces—one from the superior thigh shell and the other from the inferior calf shell—and a single anteriorly directed force from a pneumatic popliteal pad. This system ensures that the sum of the posterior forces counteracts the anterior force, stabilizing the knee in maximum extension. The pneumatic pressure system, adjustable via a lateral pump and knob, allows precise control over knee flexion by inflating or deflating the air bladder. Unlike traditional knee braces, this design avoids protrusion at the uprights when seated and allows for unrestricted knee flexion while controlling hyperextension through a stopper mechanism. The modified knee brace offers effective management of genu recurvatum by reducing hyperextension angles and alleviating associated pain, providing a functional and comfortable solution for patients with this condition.

Keywords:- Genu recurvatum, knee hyperextension, dual-axis pneumatic knee brace, three-point pressure system, pneumatic pressure system, popliteal pad, adjustable pneumatic pressure.

Introduction:

Knee hyperextension is also known as genu recurvatum, which is characterized by a ground reaction force vector, which passes in front of the knee resulting in full knee extension (0◦) or more [1]. Knee hyperextension is a progressive, disabling deformity that impairs walking speed, decreases gait efficiency, and increases use of energy during walking, and can result in or might be associated with knee pain [2-3]. Moreover, knee hyperextension can reduce gait symmetry and thus affect cosmetic appearance. The knee hyperextension can be caused by either a single symptom or a combination of symptoms such as weakness, spasticity or retraction of the paretic limb muscles, limited ankle mobility, proprioceptive disorders, and diminished velocity properties of the distal limb muscles [4]. on the etiology of Genu recurvatum, treatments include physical therapy, functional methods of electrical stimulation or electro goniometric feedback, [5,6] botulin toxin A injection in cases in which Genu recurvatum is due to spasticity, orthoses, such as ankle foot orthoses (AFOs), knee ankle foot orthoses (KAFOs), knee orthoses (Swedish knee cages) (9) or hinged soft knee orthoses, orthopedic surgery, or selective tibial neurology. [7] So it's always a challenge to provide a best orthosis for stroke patient with Genu Recurvatum.

This case study introduces a novel design for a modified dual-axis pneumatic knee brace aimed at addressing these challenges. The brace incorporates a combination of a thigh shell, calf shell, and a posterior knee cap to provide dynamic control over knee extension and prevent hyperextension due to various causes. Central to the design is a three-point pressure system, which operates in the sagittal plane, utilizing two posteriorly directed forces (from the thigh and calf shells) and one anteriorly directed force (from a pneumatic popliteal pad) to balance the knee in an optimal position. This unique system ensures that the forces acting on the knee are balanced, stabilizing the joint while preventing excessive hyperextension.

An adjustable pneumatic pressure system, controlled via a lateral pump and knob, offers fine-tuned regulation of knee flexion and extension. The pressure pad inflates and deflates to provide uniform pressure distribution, allowing the knee to flex without resistance while controlling hyperextension effectively. Unlike conventional designs, this brace does not cause discomfort or protrusion when sitting, offering increased comfort and functionality. Furthermore, the detachable pneumatic pressure pad adds convenience for users when the brace is not in use.

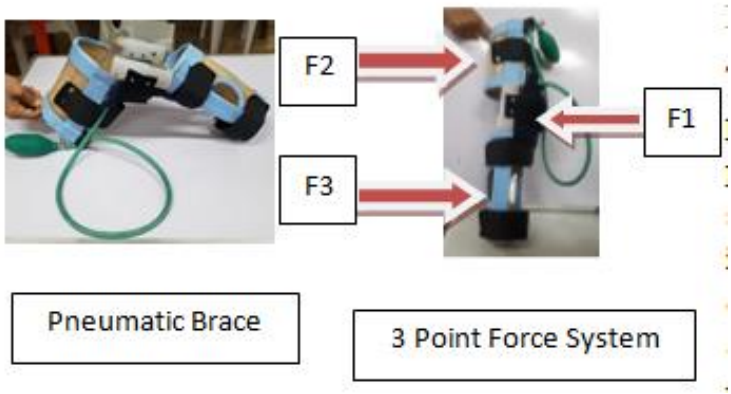
Material and Method:

A 53-year-old male with post-stroke genu recurvatum on the right side presented at the Department of Prosthetics and Orthotics to participate in this study. The patient's age, gender, and other relevant anthropometric data were collected. A thorough explanation of the study was provided, and the patient gave informed consent. After a comprehensive assessment, the patient was prescribed the Modified Dual Axis Pneumatic Knee Brace. The patient was instructed to wear the brace as much as possible during walking, aiming for approximately 8 hours per day. The knee brace was to be removed every 1 to 2 hours for lower extremity strengthening exercises. The effectiveness of the knee brace was evaluated by assessing two key parameters: knee hyperextension angle and pain levels. After a 3-month period of using the knee brace, data analysis was conducted to evaluate the outcomes.

Fabrication procedure of the Brace –

The modified dual-axis knee joints are constructed using 3 mm lightweight polypropylene. They are connected proximally to the thigh shell and distally to the cuff shell. The system includes two aluminum bars, which are secured to the medial and lateral aspects of the shells using two sets of nuts and bolts. These knee joints allow free motion while restricting hyperextension with the help of a stopper. The materials used in the design include:

- Straps (Hook & Loop)
- Rubber tubing
- Rectangular rubber pouch
- Pressure bulb
- Metal valve
- Fabric



Advantages -

- Effective control of genu recurvatum.
- No resistance to knee flexion.
- Knee flexion occurs with uniform pressure distribution by pneumatic pressure pad.
- Pneumatic pressure can inflate and deflate by a pump of lateral aspect of thigh.
- Pneumatic pressure can be adjusted with the help of knob.
- Amount of flexion is being maintained by pneumatic pressure by increase and decrease with the help of knob.
- Pneumatic pressure pad is a detachable unit, can be easily detached from brace when it is not required.

Limitation -

- Needs regular monitoring and follow ups.
- Donning and doffing difficult for first time user, but it is comfortable after repeated use.

Working Principle & Bio Mechanics – The device operates on a three-point pressure system in the sagittal plane. Two posteriorly directed forces are applied: one superiorly by the thigh shell and the other inferiorly by the calf shell. These forces are counteracted by an anteriorly directed force exerted by the popliteal cap over the popliteal fossa.

The system achieves balance by ensuring that the summation of the two posteriorly directed forces is equal and opposite to the single anteriorly directed force provided by the popliteal cap (air bladder combined with the hyperextension strap).

Result:

Knee hyperextension was measured using a goniometer. Before applying the orthosis, the knee hyperextension was recorded at 25 degrees, which reduced to 0 degrees after applying the orthosis.

Pain levels were assessed using the Numeric Rating Scale (NRS-11). The pre-intervention pain score was 9, which significantly decreased to 3 following the use of the knee brace.

Disussion:

The Modified Dual Axis Pneumatic Knee Brace demonstrated significant effectiveness in

managing genu recurvatum and alleviating associated pain in the presented case. By addressing the biomechanical imbalance caused by knee hyperextension, the brace not only corrected the knee alignment but also improved the patient's overall functional outcomes.

The three-point pressure system played a crucial role in stabilizing the knee joint. The posteriorly directed forces from the thigh and calf shells effectively countered the anterior force exerted by the pneumatic popliteal pad, thereby maintaining a balanced and optimal knee position during walking. This mechanism ensured controlled knee extension while preventing hyperextension, a common challenge in stroke-related genu recurvatum cases. A key advantage of this design is the adjustable pneumatic pressure system, which allowed fine-tuning of the force distribution according to the patient's needs. The ability to regulate the pressure through a lateral pump and knob provided customization and ensured comfort during prolonged use. Furthermore, the lightweight materials, such as polypropylene and aluminum, contributed to ease of mobility, while the detachable pneumatic pad enhanced user convenience when the brace was not in use.

The results from this case study support the efficacy of the brace. Knee hyperextension reduced from 25 degrees to 0 degrees, as measured with a goniometer, demonstrating complete correction of the deformity while wearing the brace. Additionally, the Numeric Rating Scale (NRS-11) indicated a significant reduction in pain levels, with scores decreasing from 9 to 3 after the intervention. These findings suggest that the brace not only provides mechanical support but also reduces pain by alleviating the stress on the knee joint caused by hyperextension. Compared to traditional orthotic interventions such as Swedish knee cages or static orthoses, this modified design offers dynamic control without restricting mobility. Unlike rigid braces that may cause discomfort during sitting or prolonged use, the pneumatic system of this brace adapts to the user's movements, enhancing comfort and functionality.

While the results are promising, this study is limited to a single case. Future research involving a larger sample size and longer follow-up periods is recommended to validate the findings and assess long-term outcomes. Additionally, the effectiveness of the brace in various etiologies of genu recurvatum, such as spasticity or weakness, should be explored.

Conclusion:

The Modified Dual Axis Pneumatic Knee Brace has proven to be an effective solution for managing genu recurvatum, as demonstrated in this case study. By employing a three-point pressure system and integrating an adjustable pneumatic mechanism, the brace successfully corrected knee hyperextension and alleviated associated pain. This study highlights the potential of the Modified Dual Axis Pneumatic Knee Brace to improve gait efficiency, reduce energy expenditure during walking, and enhance the overall quality of life for patients with stroke-induced genu recurvatum. However, the findings are based on a single case, and further studies with larger sample sizes and diverse patient groups are necessary to validate the broader applicability of this design. In conclusion, this innovative knee brace offers a promising approach to the treatment of genu recurvatum, addressing both functional and cosmetic concerns while ensuring patient comfort and mobility.

Declaration by Authors Ethical Approval: Approved

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Conflict of Interest: The authors declare no conflict of interest.

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