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Development of a Knee Orthosis to Prevent Falling due to Buckling among Elderlies

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ABSTRACT

The number of elderlies increases over the years and has triggered concerns on healthcare system, the community and the family. Elderly could experience knee buckle and fall due knee osteoarthritis (OA), a common syndrome of weakness due to aging degeneration. It may cause pain and injuries and hence fears to stay mobile. As a result, this would give a negative effect to mental and physical health. It is common that elderlies attempt to wear an assistive knee device in hope of providing security in walking. The aim of this project is to survey the faith of elderlies in knee braces, to investigate the stiffness of sampled market knee braces/orthoses again sudden knee buckling and to propose a novelty design of a mechatronic knee orthosis. From the survey, the elderlies are general having faith in wearing a knee brace / orthosis to provide walking security. Secondly, from the experimental load test, the findings revealed that these sampled knee brace or orthoses do not feature on delayed bending when knee buckling occurred. Finally, the proposed design has revealed improved knee stiffness and prolong delayed knee bending.

1. Introduction

According to Population Division, Department of Economic and Social Affairs, United Nation [1], the world's population continues to grow but at lower growth rate. The population of age 60 and above appears to increase as compared to the middle and the younger generation, towards an aging society [2]. Healthcare and welfare of the aging society [3-5] would be a great challenge to the community and the family. Among the health challenges, functional mobility [6-8] including walking is essential for a satisfactory quality of life. It is common to observe weak knee and knee pain [9,10] among the elderly. Pain due to knee osteoarthritis (OA) is degenerative and there are no therapies

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to alter the natural history of OA [11]. The phenomena would discourage walking and eventually lead to lower rate [12,13] of physical activity and sedentary behaviour. Weak knee and knee pain could affect normal walking and lead to gait disorders [14], causing knee buckling and increase the risks of falling and catastrophic injuries. World Health Organization [15] has reported that falls are the second leading cause of death resulting from unintentional injury. Falls-related injuries are common among elderlies [16].

Many knee braces and orthosis such as valgus knee brace, knee brace with side stabilizers and patella gel, OA unloader knee brace, etc., are available in the market at low to fair cost. It is reported by Moyer *et al.,* [17] that the devices could decrease medial knee compressive force and quadriceps/hamstring and quadriceps/gastrocnemius co-contraction ratios and increase medial joint space during gait. Previous research has looked at the engineering effort in developing enhanced featured knee braces using the 3D printing for customization [18], locking mechanism [19], magneto-rheological damper [20,21] and exoskeleton extension assist suspension [22].

Commonly, elderly can purchase a knee device with and without medical advice. It is worth investigating if the devices could enhance knee stiffness and prolong knee buckling time. The research intends to investigate the faith of the elderly in knee supportive devices and to study the stiffness performance of selected knee braces/orthosis and to propose a novelty design of a knee orthosis.

2. Methodology

The research is planned into three parts, i.e., a survey among the elderlies, stiffness study of existing knee braces/orthosis and our proposed pneumatic knee orthosis. A survey is intended to investigate the elderly regarding their needs for knee orthosis and their faith in these assistive devices to provide security during walking. Furthermore, a knee under body load is modelled and formulated (Figure 1(a)). The formulation provides a target value of knee torque as the knee angle increases. We have selected a few knees braces/orthosis in the market to be tested in the knee test rig as shown in Figure 1(b). The knee test rig is a customized test rig to simulate a knee bending under load. Each knee brace/orthosis would be put on the artificial leg at knee and the dead weight would be quickly released to allow the leg bend under gravitation load, which simulates the scenario of knee buckling. This investigation would reveal if the function of the knee braces/orthosis would be additive knee stiffness under a range of body weight (up 100Kg). Lastly, a customized pneumatic knee orthosis is proposed and developed. It could function as a controlled stiffness.

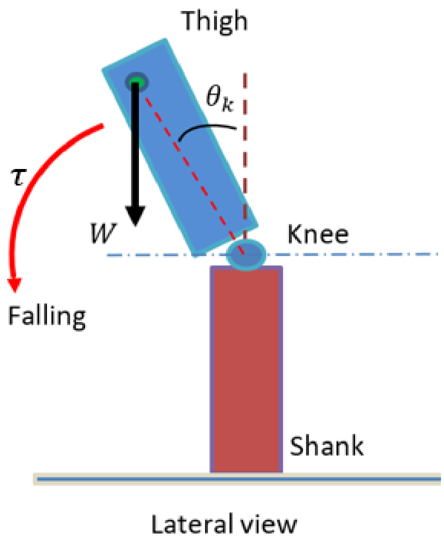
2.1 Load Analysis and Knee Test Rig

A scenario is illustrated in Figure 1(a) where a body weight of 100Kg (W = 981N) and thigh length, l = 0.5m is experiencing heel strike. The load analysis explains the changes of torque at knee. Knee torque increases when the load line, W, miss-aligned with the knee centre as the angle increases. For example, at 30°, the torque is half (sin 30° = 0.5) of the maximum torque ($\tau = 981 \times 0.5 \sin 90^{\circ} = 490.5N$). The torque is formulated in Eq. (1). The load analysis provides a load reference versus knee bending angle. During normal walking, a knee would bend up to 20° (sin 20° = 0.34) during load bearing. The information could be used to estimate the knee torque exerted by the body weight.

$$\tau = W \times \ell \sin \theta_k \tag{1}$$

where,

τ = $Torque\ at\ knee\ (Nm)$
W = $body\ weight\ (N)$
ℓ = $length\ of\ the\ thigh\ (m)$
θ_k = $relative\ angle\ between\ the\ thigh\ and\ body\ weight$ (in unit of degree)



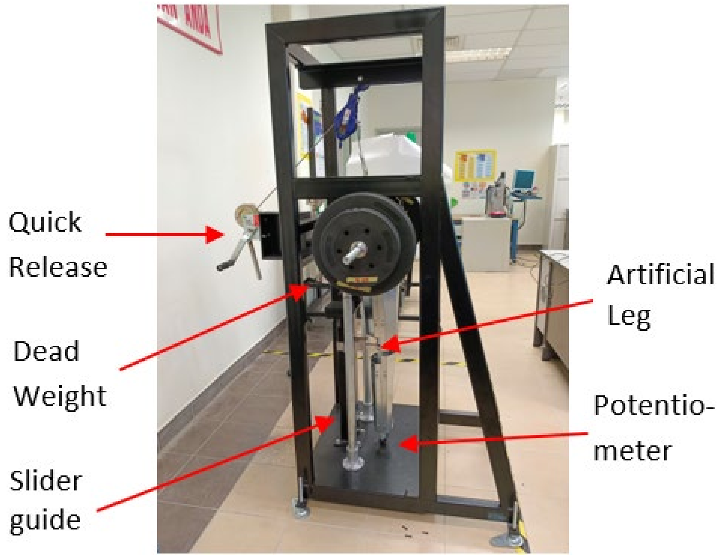
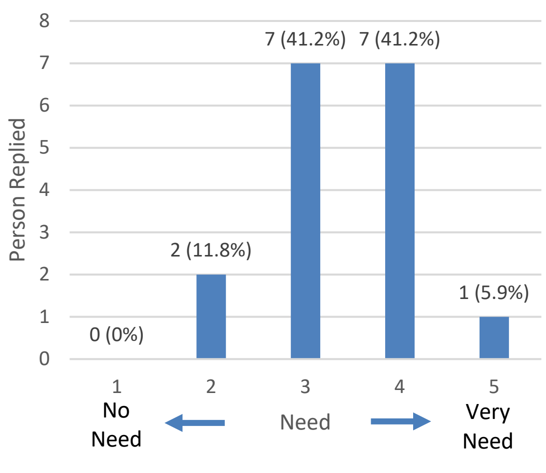


Fig. 1. (a) Load analysis (b) knee test rig

3. Results

3.1 Result of Survey

The survey was conducted using google form and were completed by 17 respondents, age ranging from 40 to 60 years old, 10 males and 7 females. From the response, two key results are concluded. In Figure 2(a), more than 80% of the respondent need a knee brace or orthosis while as shown in Figure 2(b), most of them believed in knee brace/orthosis in providing walking security.



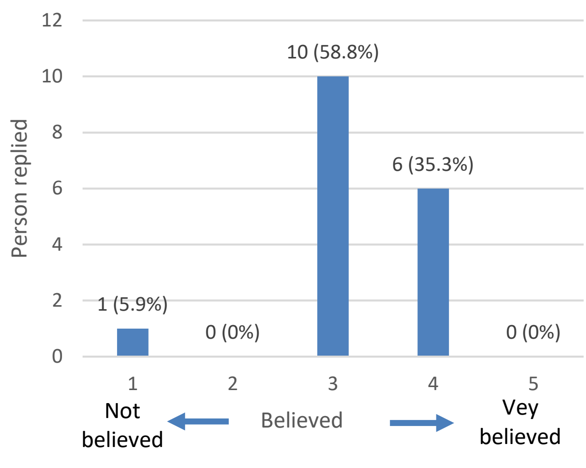


Fig. 2. Key results: (a) need of a knee brace/orthosis (b) belief in knee brace/ orthosis

3.2 Result of Stiffness Study of Existing Knee Braces/Orthosis

Four types of knee braces/orthosis as shown Figure 3(a) to Figure 3(d), were tested using the knee test rig for the load up to 100Kg using the test rig as shown in Figure 1(b). These specimens were bought from the market. Each specimen was put on the artificial leg in upright position before being quick released to fall into 90° bending. The initial load (due to the metal framework) is 19Kg without any dead weight. Each specimen was trialled three times for each load, stepped at 10Kg until maximum at 90Kg (which means 29Kg to 109Kg). A potentiometer was installed on the ankle and read the knee angle via analogue reading from a microcontroller (Arduino UNO).

(a) (b) (c) (d)

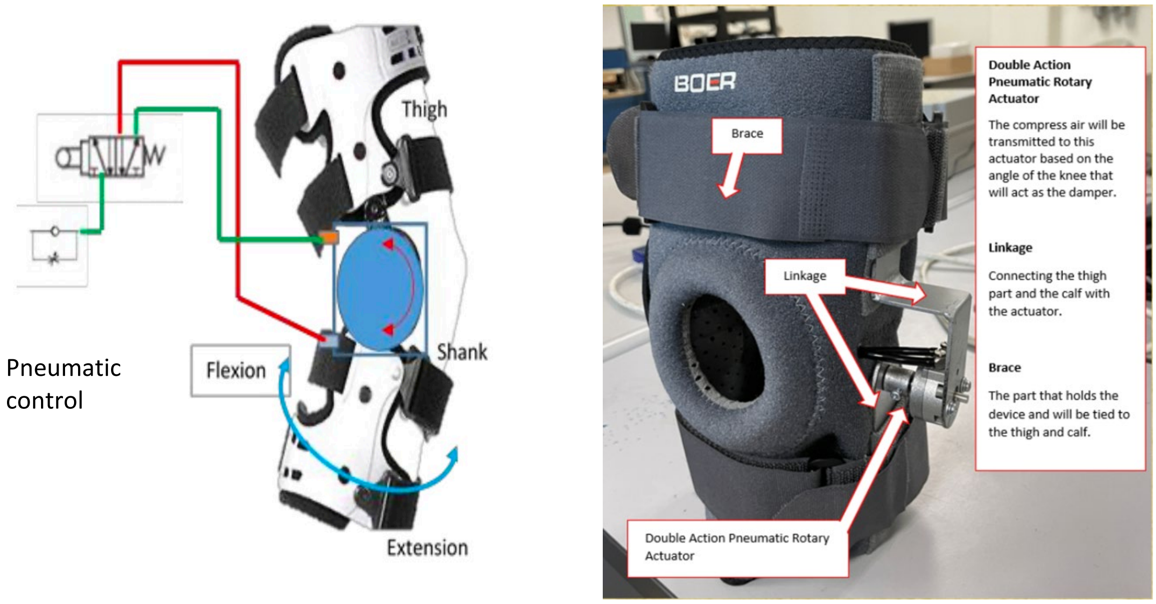
Fig. 3. Four specimens in the study (a) knee brace with side stabilizer (no spring) (b) knee orthosis with angle lock (lock being released during test) (c) power knee support with rear springs (c) knee brace with springy metal at its two sides

The result at 20° knee bending is illustrated in Figure 4 for all specimens versus the falling time in milliseconds. From previous study, knee bending at 20° is about the change of gait phases from Stance to Swing. From the figure, knee bending time ranges from 250ms to 75ms. A downtrend of time is observed except for Specimen 1 which may be caused by the elastic property of the fabric. The elapsed time ranges between 100ms to 150ms by removing initial trial. If the body weight is divided into two zones, i.e., above 60Kg (most adults) and below 60Kg, elapsed time for bending shortens slightly in the heavier side. On the lighter side, Specimen 3 exhibited longer elapsed time as weight was increased. However, on the heavier side, none of specimens showed significant prolonged elapsed time, not until +80Kg and +90Kg where Specimen1 exceled the others. The results suggest that these knee braces/orthoses do improve knee stiffness on lower weight but not significantly on heavier weight. It is noticeable that the range of falling times indicates a glimpse of reaction time for elderly. The results suggest that these knee braces/orthoses might not be helpful to provide additional knee stiffness and delay time for the elderly to react during buckling.

Fig. 4. Comparison results in 20° bending

3.3 Proposed Pneumatic Knee Orthosis

The proposed design is a controllable pneumatic system. The construction of the mechanical design deploys a pneumatic rotary actuator (https://www.smcworld.com/en-jp/, SMC, CRB2, size 10, 180°) that is designed as a controlled damper during stand phase and thus providing additional stiffness to the knee; and being freed during swing phase (not to disrupt the leg). The design concept is illustrated in Figure 5(a) and the prototype is developed as shown in Figure 5(b)). It is intended to control the knee stiffness using pressurized air and a controlled direction valve with an adjustable air orifice. At Initial Contact (IC), the knee is stiffed with pressurized air but still allow knee bending (air is compressible). As the body weight shift forward and shift into Mid Stance (MS), the knee is under controlled stiffness. At Terminal Stance (TS) toward Swing Phase, the knee stiffness is released using the directional valve. At Swing Phase (SP), the knee is freed of additive knee stiffness.



(a) (b)

Fig. 5. Proposed pneumatic knee orthosis (a) the principle (b) the prototype

A proposed knee orthosis with pressurised air was installed as shown in Figure 6. The subject reflected that the knee became much stiff as the air pressure increased to a significant level. Too low or insufficient air pressure could not be felt by the subject as his knee bended. Its performance to increase knee stiffness was experimented using the knee test rig for the load test. Air pressure, 7 Bar, was trialled (could be felt by the subject).

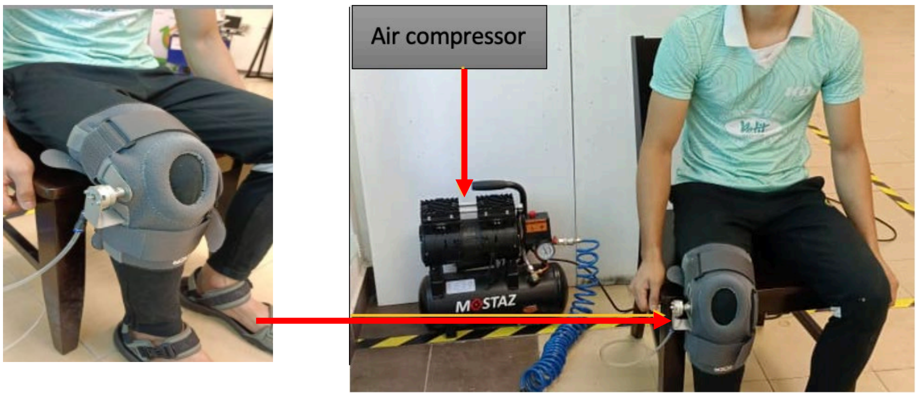


Fig. 6. Proposed pneumatic knee orthosis

The proposed pneumatic knee orthosis was put under stiffness test using the knee test rig. The result 20° knee stiffness test is illustrated in Figure 7. With pressurised air, significant increases in knee stiffness (increase in falling time) were observed. By comparison with the stiffness performance of previous knee braces/orthosis (Figure 4), the proposed knee orthosis with pressurised air excels on the performance and prolong the falling time.

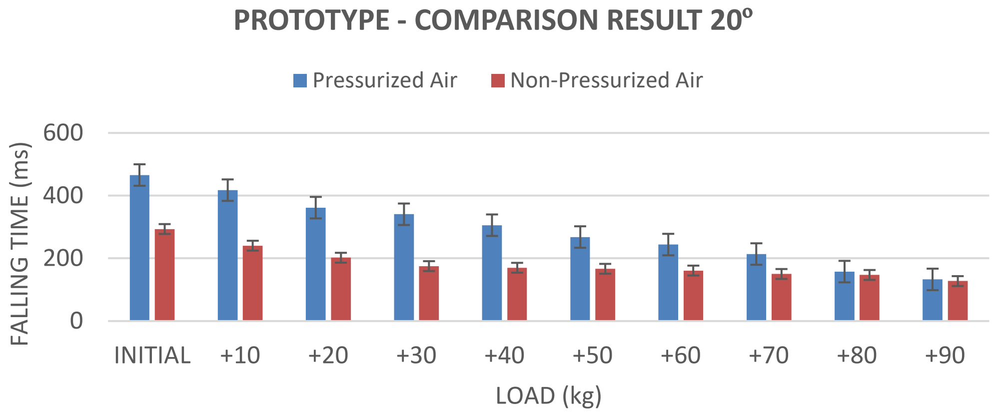


Fig. 7. Stiffness response of proposed orthosis between “Pressurized Air” and “Non-Pressurized Air”

4. Conclusions

Injuries due to buckling and falling among the elderlies cause the pain and financial burden. A knee orthosis is used to improve knee stiffness and hopes to regain mobility. A survey was conducted and found out that the elderlies need a knee brace/orthosis and believe in their function to provide walking security. However, study on the four sampled knee brace/orthosis have revealed that these passive devices did not provide significant improvement in knee stiffness especially during stand phase. The findings revealed that these sampled knee brace or orthoses do not feature on delayed bending when knee buckling occurred. To improve knee stiffness in a knee brace/orthosis, a controllable pneumatic knee orthosis is proposed and load tested. The findings revealed that the improvement in knee stiffness is feasible and knee bending time during sudden load could be delayed. This research is important to provide a feasible direction for the development of an assistive knee brace/orthosis to prevent falling due to buckling among the elderlies. Further research would focus on the controlling strategy and algorithm that matches to gait phases and thus providing a human-like knee stiffness control.

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