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Bouncy knee in a semi-automatic knee lock prosthesis

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Abstract

The Bouncy Knee concept has previously proved of value when fitted to stabilised knee units of active amputees. The stance phase flex-extend action afforded by a Bouncy Knee increased the symmetry of gait and also gave better tolerance to slopes and uneven ground. A bouncy function has now been incorporated into a knee of the semi-automatic knee lock design in a pilot laboratory trial involving six patients. These less active patients did not show consistent changes in symmetry of gait, but demonstrated an improved ability to walk on slopes and increased their walking range. Subjective response was positive, as noted in the previous trials.

Introduction

Many knee mechanisms in above-knee prostheses are rigidly locked by some means while the limb is weight-bearing. This ensures the security of the knee against collapse into flexion. However the rigidity of the locking causes an asymmetry in gait, since the natural knee undergoes a flex-extend-flex action while under load in the walking cycle. In contrast, the rigidly locked prosthetic limb becomes a pole over which the pelvis must vault between heel strike and toe-off.

In 1981, Judge and Fisher described the concept of a 'bouncy' knee, a way to provide a more natural flex-extend-flex action in the knee unit of a prosthesis during the stance phase of gait. The absolute security of the knee is guaranteed by the conventional locking device, but an additional torsional spring incorporated into the knee still permits some degree of flexion. Torques naturally generated by the foot-floor reaction force during stance phase cause a flex-extend action 'bounce' in the torsional spring, which the authors demonstrate to approximate the natural knee action. Tests with an experimental knee unit on a single subject were favourable.

The Bouncy Knee concept was subsequently incorporated into a commercial knee unit for a six patient trial. The unit selected was the Blatchford Stabilised Knee (B.S.K.), a unit with a mechanism which automatically locks the knee when the limb is subjected to an axial load. This device is most frequently fitted to the prostheses of reasonably active patients, who can make use of its facility to allow free swing of the knee during swing phase of gait with automatic locking during stance phase. The B.S.K. trial (Fisher and Judge, 1985) established the predicted potential to improve symmetry of gait, by both subjective assessment and biomechanical measures. Additionally, the volunteer users reported a number of other benefits which they felt to be major. Among these were improved ability to walk on rough ground or slopes, improved balance lifting heavy loads, and improved socket comfort due to shock absorption (presumably in the rubber torsional spring).

The extremely positive response of the pilot volunteers encouraged the United Kingdom Department of Health and Social Security to initiate a 25 patient field trial with the Bouncy Knee/B.S.K. units. This is now completed and the findings were similar to that of the pilot trial, with the main advantages being a more natural gait, more tolerance of rough and sloping ground, and improved comfort. These advantages are all gained from a unit which carries insignificant overhead in terms of limb cost or weight.

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It had been intended from the onset to explore the use of the Bouncy Knee with different types of knee mechanisms, particularly the category of Semi-Automatic Knee Lock (SAKL). The knees of these prostheses automatically lock when fully extended, as for example when the wearer rises from a chair. During standing and gait, the knee remains locked in the fully extended position. The lock is released manually when the wearer wishes to flex the limb again, usually to sit down. This type of knee unit is used mostly with less active patients who need the confidence of a locked knee at all times. It was possible that the advantages of improved symmetry from the Bouncy Knee would not be realised in a limb which is predominantly used with less active patients, whose gait is perhaps too impaired to approach a natural rhythm. The results of the trial with the B.S.K. units indicated, however, that the additional bonus of improved comfort and slope tolerance were important benefits which might also be achieved for the SAKL users. This report describes the pilot trial which was conducted with SAKL prostheses wearers.

Bouncy Knee action on non-level ground

One of the major problems of lower limb amputees in walking in the natural environment is the intolerance of prostheses to ground which is not level and even. Compensation for irregular ground is made by the non-amputee by adjustments in posture denied to the amputee by the mechanics of their prosthesis. In this context, the Bouncy Knee can assist to restore stability when the ground is inclined or changes level in the line of progression of gait.

Consider the plight of an above-knee amputee standing on an incline with a rigidly locked knee and a fixed ankle joint. When the prosthetic foot is flat on the ground with a symmetrical stance, the line of bodyweight is necessarily thrown towards the anterior of the support base by the physical geometry of the fixed limb. Unless a counterbalancing force is provided through arm support via rails or sticks, or the natural limb and body posture are used to compensate, the person is in danger of toppling over forward. In walking down a slope a similar effect is imposed, whereby the line of bodyweight is too far forward over the base of support for stability whenever the prosthetic foot is flat on the ground. The patient must resort to an unnatural gait in order to negotiate even a moderate slope in safety, frequently edging down the slope sideways.

By allowing the knee to flex during load bearing, the Bouncy Knee can assist the amputee to do with his prosthesis what the natural limb would do on the same incline—bend the knees in order to allow the centre of gravity to stay over the base of support. Consequently in mid-stance phase on the prosthetic limb, the pelvis is not forced to move precariously anterior. In practice, a flexible ankle such as on the uniaxial foot will also affect the anterior-posterior stability on an incline.

Similar biomechanical arguments explain the increased tolerance to walking on rough ground. A locally inclining surface under the prosthetic foot has less tendency to topple the person over forwards. Lifting heavy loads is another instance where the non-amputee normally compensates by leaning posteriorly, and the Bouncy Knee flexion can assist the. amputee to sit back on his prosthesis. In the B.S.K. trial, subjects reported that they were able to mount kerbs without breaking step; normally the natural limb is preferred for the first step onto the higher level, whereas either limb was acceptable with the Bouncy Knee unit fitted. This is again a feature of the Bouncy Knee, which allows the prosthetic foot to go flat earlier on the pavement by flexion at the knee.

The SAKL Bouncy Knee

The design has been based on the VIP Mk.2 SAKL limb currently produced by Vessa Ltd. who have cooperated throughout this trial. The VIP knee enables a simple spring design to be housed within its hemi-spherical knee ball. The pivot of the Bouncy Knee unit is placed 50mm anterior to the knee axis bolt with a neat appearance and ease of production (Fig. 1). For simplicity twin helical compression springs were used to provide the bounce function. Three different pairs coupled with nesting springs of the opposite helix were available to provide a range of torsional stiffness. A simple hook attached to the pivoted plate and engaging with the knee bolt of the prosthesis acts as a back check to prevent hyperextension of the bounce unit. Maximum bounce flexion is 15°. This unit is experimental only.

The knee unit was fitted to a prosthesis made to the identical prescription as the normal

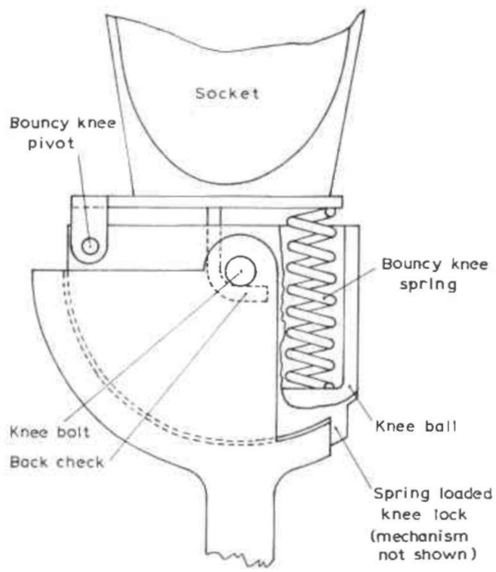

Fig. 1. The experimental Bouncy Knee/SAKL unit, based on the Vessa VIP knee.

service prostheses, all of which had uniaxial feet. The cosmesis was not fitted since the trial was to be conducted entirely intramurally; by this means the weight of the experimental and the service prostheses were kept the same.

The action of the Bouncy Knee depends on the line of the floor reaction force passing behind the bounce axis during stance phase, and thereby causing flexion. For the B.S.K. it was established that this condition could be met when the knee axis and bounce axis are coincident. However the B.S.K. knee alignment is set 'lively' with the axis forward for ease of swing. For the SAKL limb this alignment criterion is not relevant, and the line of the reaction force may possibly fall anterior to the knee bolt. To ensure that the floor reaction force falls behind the bounce axis, it was decided to place this axis well forward in the SAKL knee unit.

Trial procedure

The trial was conducted entirely in the laboratory and the walking training school. Six patients who were accustomed SAKL wearers were selected to represent a whole spectrum of activity level. This was to establish a 'cut-off point if it occurred. All were in reasonable health, had a medium length stump, and were reasonably happy with the fit of their current prosthesis. The subjects completed the trial sequentially from the most active to the least. Subjects 1 and 2 used one walking stick, Subjects 3 and 5 used two walking sticks, Subject 4 used two forearm crutches and Subject 6 used a Zimmer walking frame.

An experimental SAKL/Bouncy Knee limb was made for each subject, incorporating a facility to activate or disable the bounce with all other factors remaining constant. The gait of each subject was assessed subjectively by a physiotherapist, first with the service limb and then with the experimental limb (bounce inoperative). This confirmed that the gait of the subject was similar with both limbs. The gait of each subject was then monitored wearing the experimental limb (bounce inoperative) to give a baseline.

The bounce function was then activated. A force platform (Lord and Smith, 1984; Smith and Lord, 1985) was used to assess static alignment, particularly the centre of foot pressure and the line of the foot-floor force at knee level. The subjects' limbs were realigned to check whether any adjustment was beneficial to the Bouncy Knee action; however the final alignments were not measurably different from the starting service alignments, although this might not always be the case. The gait was reassessed after a period of familiarization comprising a few days walking training (level, slope and stairs). The gait was then monitored in the laboratory. The patient's comfort and confidence were assessed by questionnaire. The trial was then terminated.

The biomechanical assessment techniques used were a simple instrumented fishing reel line to monitor speed of walk along the level or down a slope; a footswitch on each heel to record heel strike; heel markers onto a strip of paper in order to measure stride and step lengths during level walking; and a special-purpose goniometer on the bounce axis to record bouncy knee flexion when operative. Measurements on a forceplate inserted in a walkway were discontinued as less active subjects experienced difficulty. Parameters calculated included length of stride, speed of walk, and maximum flexion of the Bouncy Knee in level walking and when walking down a slope of 1 in 7. The subjective reactions were assessed by questionnaire.

Experimental results

All six subjects completed the trial. The results of the biomechanical analysis are shown in Table 1. Statistical confidence levels are not given, since the numbers on the trial were small and the sample non-uniform in ability. The table demonstrates that, with the exception of subject 5,

stride lengths were increased,

walking on a slope was enabled or facilitated,

the bounce function was active in level and slope walking,

step length asymmetries were improved (S2 & S3), remained the same (S1 & S4), or worsened (S6).

The questionnaire and physiotherapist assessments indicated that,

it was much less effort to walk,

distance of walking before tiring increased 25% to 50% (S2, S3, S4 & S5), and 150% (S6),

although sometimes no changes in walk pattern were detected, the subjects stated that it was more comfortable to walk.

The physiotherapist assessed that subject 1 felt unsure of the bounce when first fitted as it gave him a feeling of insecurity.

It was noted that subjects who walked down the slope with a locked knee did so hesitatingly with a physiotherapist in front and at the side to increase confidence. With the bounce operative this was not necessary and the subjects walked unaided.

A consistent static alignment by the project prosthetist ensured that the line of bodyweight supported by the prosthesis fell posterior to the bounce axis; this was indicated by the centre of pressure under the foot.

Discussion

Improved symmetry of gait was not the major benefit sought from the Bouncy Knee in the SAKL prosthesis; indeed analysis of the ratio of left to right step lengths shows that the asymmetry was reduced in two subjects who were the most asymmetrical at outset (S2, S3); remained unchanged in the two subjects who were fairly symmetrical at outset (S1, S4); and increased in the last two cases (S5, S6). Subject 5 shows a deterioration in all the biomechanical measures which might not be ascribable to the bounce function since this was nearly unutilized throughout (Table 1).

With the exception of subject 5, all other subjects increased their stride length with the speed of level walking remaining about the same or increasing.

Regarding the additional benefits noted in the earlier trials, it was again shown that the ability to walk down a slope is considerably enhanced by a Bouncy Knee. The increased bounce

Table 1. Stride lengths and step lengths are the mean of the central 8 to 10 strides along a level walkway. 'Bounce' is defined as knee flexion during stance phase. A slope of 1 in 7 was used.

Subject No.		Stride Length mean,mm L-L R-R	Step Length mean,mm L-R R-L	Speed mean, Level	m/s Slope	Bounce maximum, degs. Level	Slope	Age; Date Side Amp
1	FIXED KNEE	565:582	288:277	0.38	—	—	—	80 yr
	BOUNCY KNEE	652:653	318:333	0.57	0.32	6.0	9.5	3/84 L/AK
2	FIXED KNEE	659:651	501:149	0.49	—	—	—	73 yr
	BOUNCY KNEE	697:695	457:238	0.52	0.30	3.5	7.0	10/82 R/AK
3	FIXED KNEE	536:540	96:441	0.31	0.15	—	—	71 yr
	BOUNCY KNEE	552:557	143:409	0.33	0.20	5.5	7.0	4/84 L/AK
4	FIXED KNEE	440:439	199:241	0.23	—	—	—	68 yr
	BOUNCY KNEE	520:514	232:289	0.24	0.11	12.5	15.0	6/84 L/AK
5	FIXED KNEE	459:461	304:164	0.25	—	—	—	83 yr
	BOUNCY KNEE	385:383	289: 93	0.23	—	1.8	—	11/83 R/AK
6	FIXED KNEE	385:381	277:109	0.12	0.08	—	—	68 yr
	BOUNCY KNEE	411:423	307:105	0.14	0.08	1.0	7.0	5/84 R/AK

showed the extent to which bounce flexibility was being utilized in this activity. Walking on rough ground was not tested in the laboratory.

Subjective assessments by the physiotherapist and amputees were again favourable, especially with regard to 'making walking easier'. Even subjects 5 & 6, at the most disabled end of the spectrum and with a lack of entirely positive biornechanical outcome, liked the experimental limb with its bounce function.

It has been proposed that knee flexion during the stance phase of gait is energy-efficient (Bresler et al, 1957). Flexion of the knee and consequent shortening of the limb at mid-stance phase assists the centre of gravity of the body to pass forward approximately in a level horizontal plane, and minimizes the cyclical variation of kinetic energy in the vertical direction which would otherwise occur. This hypothesis may partially explain the frequent observation of the subjects that they could walk further-up to 150% in distance—without tiring. Other factors to take into account are that the Bouncy Knee has an energy storage capability, absorbing energy during early stance phase and releasing it during mid-to-late stance phase; and that the altered symmetry of gait reduces energy losses in other modes (not investigated).

Conclusion

This pilot trial of the Bouncy Knee incorporated into a SAKL design has demonstrated the potential benefit of the device to less active amputees. The benefits are particularly evident in an increased tolerance of uneven ground and slopes, and in the increase in distance which the subjects could walk without tiring. The loss of rigidity at the knee did not cause these subjects any great concern, with only one subject showing an initial hesitation—later overcome. The trial has opened the way for further design work to develop a production unit.

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REFERENCES

BRESLER, B., RADCLIFFE, C. W., **BERRY, F. R.** (1957). Energy and power in the legs of above-knee amputees during normal level walking. Berkeley C.A.: University of California, Lower extremity Research Project, (Series II, Issue 31).

FISHER, L. D., **JUDGE, G.** W. (1985). Bouncy knee: a stance phase flex-extend unit. *Prosthet. Orthot. Int.* ***9*,** 129-136.

JUDGE, G. W., **FISHER, L.** (1981). **A** bouncy knee for above-knee amputees. *Eng. Med.* **10,** 27-32.

LORD, M., **SMITH**, D. M. (1984). Foot loading in amputee stance. *Prosthet. Orthot. Int.* **8,** 159-164.

SMITH, D. M., **LORD**, M. (1985). A tool for standing load line assessment. In: Whittle, M., Harris, D. (eds) Biornechanical measurement in orthopaedic practice—Oxford: Clarendon Press, 211-219.