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HRC adjustable pneumatic swing-phase control knee

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Abstract

Since 1972 the Hyogo Rehabilitation Centre has been developing a variable-resistance-type pneumatic control device, the HRC Adjustable Pneumatic Swing-Phase Control Knee. Successful field tests have been carried out on 20 cases with Model IV since 1973 with only a limited number of mechanical troubles.

This paper introduces the HRC adjustable pneumatic swing-phase control knee with follow-up studies.

Objectives

Recently pneumatic swing-phase control devices providing improved control of the knee over wide ranges of walking speeds have been developed. Pneumatic control knees such as those produced by Blatchford or Hosmer have been commercially available (Veterans Administration Program Guide, 1973) which have shown superior swing-phase characteristics (Radcliffe and Lamoreux, 1968; Lewis, 1971). Because of the difference in the way of life between western countries and Japan, it is not only expensive for the amputee to get these pneumatic knees from other countries, but also difficult to get follow-up services. In designing the HRC unit, two major points have been taken into account.

1. The need to speed up the prosthetic gait whenever the amputee requires a faster, safe speed such as when crossing a busy road. To this end adjustability of the speed of prosthetic gait by the amputee himself is desirable.
2. The desire to reduce the terminal impact which is caused by increased speed in gait.

To fulfil those major points for a pneumatic swing-phase control unit, the following three independent functions are necessary (Radcliffe, 1973):

i. Resistance to excessive heel rise between toe off and the instant of maximum knee flexion.
ii. Voluntary adjustment of the acceleration by amputee himself from maximum knee flexion to maximum forward velocity.
iii. Reduction of terminal impact.

Since September 1972, the Centre has built 6 models, the latter 4 with the technical aid of the Nippon Air Brake Company. Model I realized the desired kinematic behaviour of the pneumatic knee, and in Model II the outside bypass was modified by incorporating it within the piston-rod. Adjustable resistance for a sliding mechanism and a cushion mechanism for a terminal impact were added to Model III and in Model IV a check valve was added in the piston to increase the walking speed. Field tests were performed with Model IV and V (Fig. 1).

Description of Model IV unit

The HRC pneumatic control unit Model IV consists of the following; a pneumatic cylinder, a knee block, and a wood shank which contains

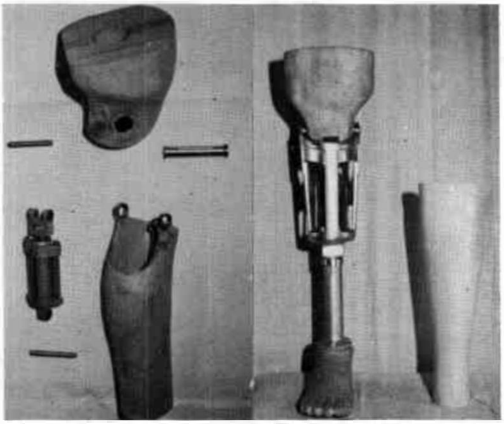

Fig. 1. Left, HRC Model IV. Right, HRC Model V.

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the cylinder. The attachment of the unit to the knee block is by a pin passing through the piston rod head into bushes 3 cm. posterior to the knee bolt. The movement of air is limited by the piston. The rate of leakage between upper and lower cylinder can be varied by a needle valve which is contained within the piston rod. It is adjusted by operating an adjustment screw in the head of the piston rod and located to the rear of the knee joint. This mechanism enables the amputee to adjust the slide resistance of the piston in a natural manner without any supplementary devices.

Inside the cylinder head, there is a small air chamber A (Fig. 2) which can act as an air cushion mechanism as the knee comes into full extension. When the largest part of the piston-rod (ϕD) comes to the cushion seal in the cylinder head, the air of the chamber A is trapped and a cushion effect can be obtained because the rate of air-release through the cushion valve is very small. This cushion valve is also adjustable. With this system, the reduction of terminal impact was much more pronounced than without it (Nakamura and Sawamura, 1973).

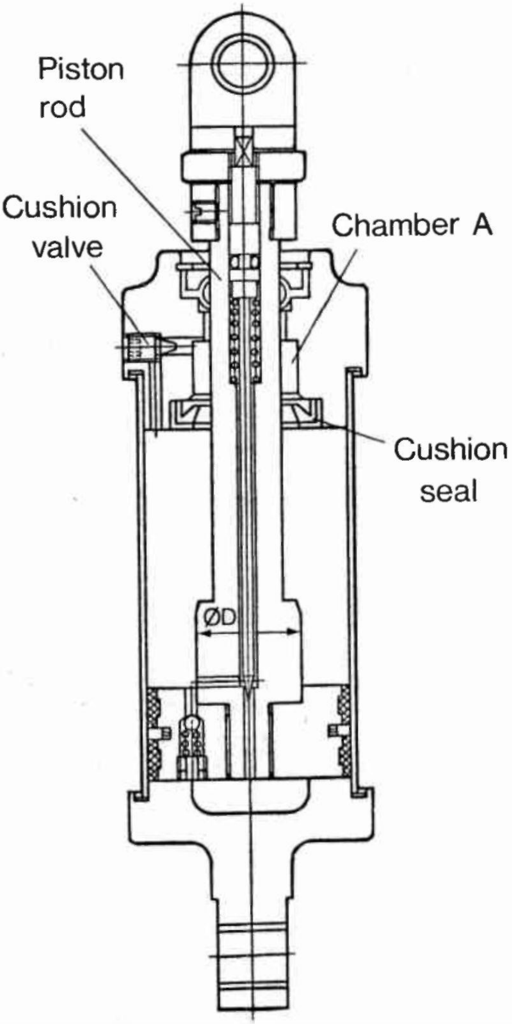

Fig. 2. Sectional drawing of Model IV cylinder.

Operation speed	30 mm/sec in both directions
Frequency	14 times/min
Total no. of cycles	2×10^5

Fig. 3. Frictional durability test conditions.

A frictional durability test of the pneumatic cylinder was performed and Figure 3 shows the test conditions. During this test temperature and size of the parts were not affected (Nakamura and Kayatani, 1974). Figure 4 shows the material of the cylinder.

Part	Material
Cylinder tube	A6063
Piston	A1, compound rubber
Piston rod	A2B4–T6
Cover	A 4C–T6
Cushion seal	Compound rubber
Rod packing	Compound rubber
Needle valve	SUS 27

Fig. 4. Model IV cylinder parts and materials.

Field test and evaluation

After obtaining a successful result in the mechanical durability test, a field test of Model IV was performed for 20 cases. The evaluation programme consisted of three groups as follows.

1. Objective evaluation tests by physical therapist.
2. Subjective evaluation to check the acceptability by the amputee.
3. Biomechanical tests with measuring instruments. Details of the test programme are shown in Figure 5.

A. Objective evaluation
  1. Gait speed
  2. Cadence
  3. Stride
  4. Knee flexion angle
  5. Weight
  6. Noise
  7. Gait appearance
  8. Stability

B. Subjective evaluation
  1. Gait speed
  2. Easiness of acceleration
  3. Waiting time during swing-phase
  4. Terminal impact
  5. Weight of toe
  6. Total weight
  7. Noise
  8. Stability

C. Biomechanical test
  1. Maximum knee flexion angle during swing-phase
  2. Inner pressure of the pneumatic cylinder

Fig. 5. HRC pneumatic knee evaluation programme.

Age	Number
15–19	3
20–29	7
30–39	5
40–49	2
50–59	2
60–69	1
	20
Range: 17–62	
Mean: 32	

Fig. 6. Age of test subjects.

No. of years	Number
0–3	10
4–7	2
8–11	5
12–15	3
Range: 3 mo.—15 yr.	20
Mean: 5.3 yr.	

Fig. 7. Length of time prosthesis worn.

Group	Level	Number
H	Hip-disarticulation	3
K	Through knee	4
S	Short A/K stump	6
M	Medium A/K stump	3
L	Long A/K stump	4
		20

Fig. 8. Amputation level.

The 20 amputees participating in the study have been wearing the test unit since 1973. They were classified into 5 groups, H, K, M, S and L, according to the amputation levels. Details of test subjects as shown in Figures 6, 7 and 8. Average gait training period was 3 months.

The results of objective evaluation test are shown in Figure 9. The abbreviations C and N are used to represent the results of the pneumatically *controlled* knees and *non-controlled* knees respectively. The difference between C and N can be regarded as an effect of the characteristics of the HRC knee because the tests were performed under the same conditions, that is, same fitting and same alignment, except for attaching the pneumatic cylinder to the knee joint. Each figure in Figure 9 represents the average value of each group, the total average value in each test being given in the final column.

From the normal gait speed test it can be seen that the control unit improves 16 seconds on average for the amputee to walk 100 metres; Groups M and L are dominant in improving their gait speed among the 5 groups. The dominance of Groups M and L holds in 100 metre fast gait speed test as well as in the cadence test. The double-stride test indicates that with this control unit amputees could make their double-stride 12 cm longer. However the unit has no particular merit for slopes and stairs.

In the gait analysis of Figure 10, excessive heel rise and terminal impact are greatly improved. It may seem strange but lateral bending of the trunk is reduced by using this unit. According to the table, symmetry of the strides is lost but this means that the stride of the affected side is nearly 1 cm longer than the unaffected side. The average total weight of the

C: Control N: Non-Control

		Hip (H)	A/K (S)	A/K (M)	A/K (L)	T/K (K)	Ave.
Gait	Speed	min. sec.	min. sec.	min. sec.	min. sec.	min. sec.	min. sec.
Normal	N	1 56	1 51	2 06	1 51	1 32	1 53
(100m)	C	1 50	1 39	1 39	1 33	1 31	1 37
	C-N	-6	-12	-27	-18	-1	-16
Fast	N	1 45	1 22	1 44	1 33	1 21	1 33
(100m)	C	1 42	1 14	1 27	1 22	1 18	1 23
	C-N	-3	-8	-17	-11	-3	-10
Cadence							
	N	86	94	93	92	98	93
	C	84	95	101	101	98	96
	C-N	-2	1	8	9	0	3
Double-Stride		cm	cm	cm	cm	cm	cm
	N	120	125	112	121	112	118
	C	135	132	129	125	129	130
	C-N	15	7	17	4	17	12
Slope		sec.	sec.	sec.	sec.	sec.	sec.
Up	C-N	0	0	1	0	0	0
Down	C-N	1	0	2	0	1	1
Stair							
Up	C-N	2	-1	2	4	2	1
Down	C-N	-1	5	1	4	0	2

Fig. 9. Results of the objective test.

above knee prosthesis was about 4 kg and the pneumatic cylinder unit weighed 400 gm.

In the subjective evaluation test programme, many of the amputees under test felt they were able to walk more easily and faster than before (Fig. 11). The pneumatic control unit did not provide any stance-phase control, however many amputees felt that the stability of the knee was improved at the beginning of the stance-phase.

The knee flexion angle during prosthetic gait was measured with a high-speed camera, film motion analyser, and PDP-12 mini-computer. The maximum knee flexion angle during swing-phase in each group reached normal value except H Group (Fig. 12). To measure the inner pressures of the pneumatic

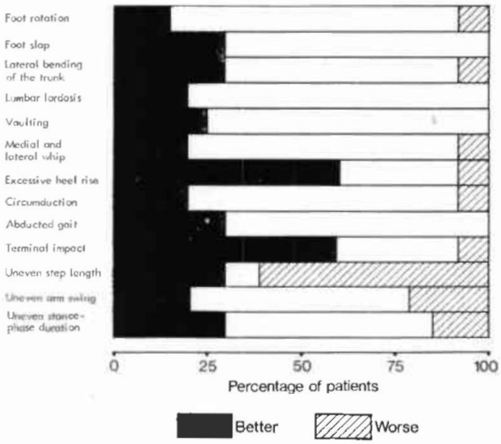

Fig. 10. Gait appearance.

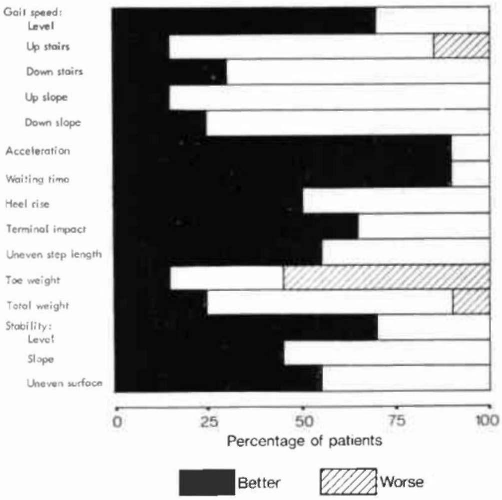

Fig. 11. Subjective test.

		Hip(H)	A/K(S)	A/K(M)	A/K(L)	T/K(K)	Av.
Maximum knee flexion angle (degrees)	N	132	115	98	105	105	109
	C	140	122	109	123	119	122
	C−N	8	7	11	18	14	13

Fig. 12. Maximum knee flexion angle during swing-phase.

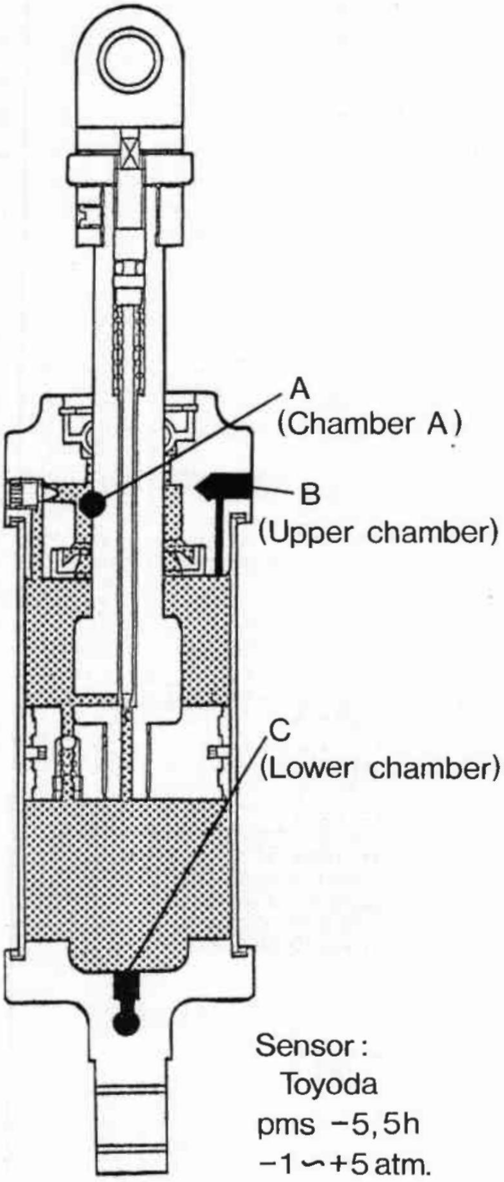

Fig. 13. Position of pressure transducers.

cylinder miniature type pressure transducers were attached to points A, B, and C as can be seen in Figure 13. Typical pressures are shown in Figure 14. Negative pressures in chamber A and the upper cylinder contribute to reduction of excessive heel rise and acceleration of the shank. Positive pressure in the chamber A is used to reduce the terminal impact.

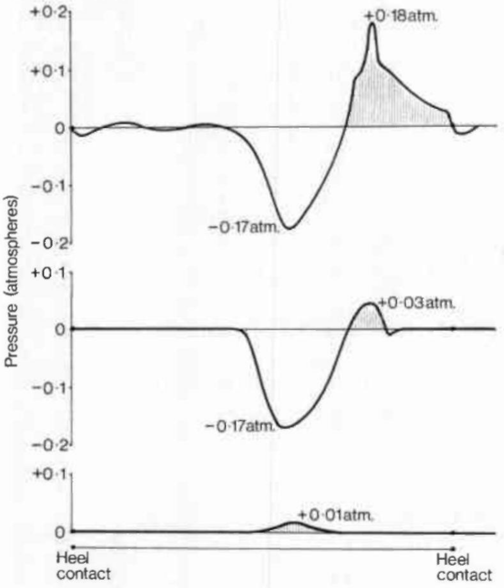

Fig. 14. Pressure within each chamber of the cylinder. Top, A. Centre, B. Bottom, C.

Mechanical problems

During this field test several types of mechanical troubles were experienced in a limited number of cases.

Trouble occurred at the needle valve with Model IV in 3 cases out of 20 . When the wearer revolved the adjustment screw too tightly, the needle valve was inserted too firmly into the hole in the piston and did not work well.

The problem of noisy joints was solved by using Oiles no. 80 bushes.

Breakdown of the cylinder rod-head occurred in 2 cases with Model IV which resulted in the wearer suffering a violent fall. Another case of breakdown was in a through knee prosthesis; as the knee joint hyperextended repeatedly, the cylinder rod-head broke down after 2 years.

Trouble has occurred in one case out of 50 with Model V. The bakelite of the bearing at the knee joint wore out and would not work after 2 years of constant use. To avoid these problems the models were changed 3 times. The last type is the Model VI (Figure 15) and field test of it started in May 1977.

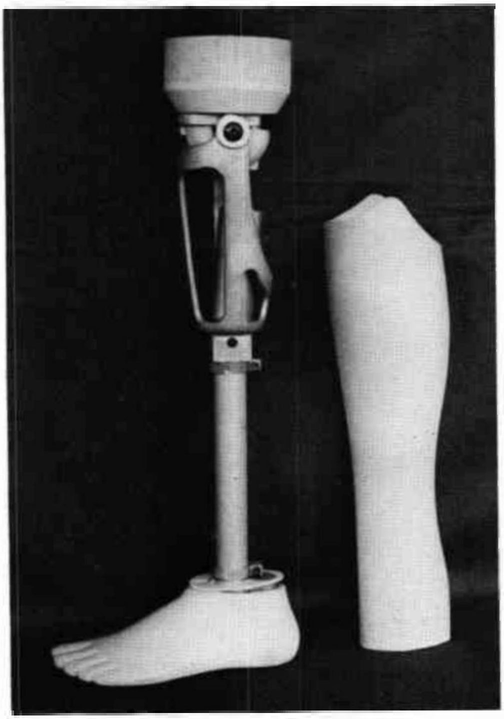

Fig. 15. HRC Model VI.

Summary

The amputee can voluntarily change the acceleration at the beginning of swing-phase by adjusting the rate of air leakage of the pneumatic cylinder without any supplementary devices. This unit furnishes the mechanism for reduction of terminal impact. Voluntary acceleration and reduction of terminal impact provides an amputee with smoother and faster gait on level walking. This improvement is dominant especially in the case of long and medium length above knee stumps.

The 20 cases of Model IV and 50 cases of Model V have been field tested successfully except for a limited number of mechanical troubles. Negative reaction of test subjects are non existent, they all want to wear the unit.

To solve the mechanical troubles experienced during the field tests with Model IV and V, Model VI was developed.

Acknowledgement

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REFERENCES

LEWIS, E. A. (1971). Clinical evaluation of a pneumatic knee system. The University of California Biomechanics Laboratory Swing-Control Unit. *Bull Pros. Res.*, **10–15**, 85–94.

NAKAMURA, S. and SAWAMURA, S. (1973). Development of pneumatic swing-phase control knee. Proc. 16th Joint Conference on Automatic Control in Japan, **16**, 329.

NAKAMURA, S. and NISHIOKA, M. (1973). Evaluation of HRC pneumatic swing-phase control knee. *Jap. J. Phys. Ther. and Occ. Ther.*, **8**, 253.

NAKAMURA, S. and KAYATANI, F. (1974). Development of pneumatic gait-control device. *Jap. J. Hydraulics and Pneumatics*, **12**, 53.

RADCLIFFE, C. W. and LAMOREUX, L. W. (1968). UC-BL pneumatic swing control unit for above-knee prostheses. *Bull Pros. Res.*, **10–10**, 73–89.

RADCLIFFE, C. W. (1973). Biomechanics of swing phase control in prosthetic knee mechanisms. Proc. 1st International Congress on Prosthetics Techniques and Functional Rehabilitation, **4**, 275.

VETERANS ADMINISTRATION PROGRAM GUIDE (1972). Selection and application of knee mechanisms. *Bull. Pros. Res.*, **10–18**, 90–158.