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Three dimensional measurements of pelvic tilt in trans-tibial amputations: the effects of pelvic tilt on trunk muscles strength and characteristics of gait

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Abstract

The aim of this study was to determine the degree of pelvic tilt in three dimensions, the trunk muscle strength and effects on gait in trans-tibial amputated patients. This study comprised of 22 unilateral trans-tibial amputated patients who were seen at the authors' Prosthetics and Orthotics Laboratory for the purpose of prosthetic provision. Measurements were made using plurimeter and caliper and gait observations were made by video camera.

In the sagittal and horizontal planes respectively the pelvic tilt was measured to be 12° and 5.73°, and such measurements in relation to the trunk extensor and flexor muscles were shown to be statistically significant ($p<0.05$). On the contrary, the same could not be said for frontal plane measurements. In addition, in 9 cases excessive knee flexion was noted during the stance phase having a direct influence on the pelvic tilt ($p<0.05$).

Introduction

Interactions between the trunk and the lower limb are directly influenced by the adjoining pelvic joints, ligaments and muscles. In addition, posture, living styles and cultural differences also affect posture and pelvis (Steindler, 1970).

Mayer described three types of pelvic obliquity, namely infrapelvic, suprapelvic and pelvic (Crenshaw, 1992). The muscles affecting the infrapelvic obliquity are the abdominals, spinal erectors, abductors and adductors of the hip which are given strength exercises for the abdominal muscles and stretching exercises for the spinal erector muscles and contracture of the hip muscles or are used by orthosis or prosthesis wearers. The lumbosacral muscles, the sacroiliac joints and the bony structures affect the suprapelvic and pelvic obliquity, and they usually necessitate surgery (Crenshaw, 1992; Dontigny, 1985; Tachdjian, 1990; Lavignolle *et al.*, 1983). In the present study measurements were made using infrapelvic pelvises.

Until today, most measurements of pelvic tilt (PT) were taken in the sagittal plane; such results, though consistent, have not definitely illustrated the effects of the strength of the trunk flexors and hip extensors on the PT. To date, photographic measurements, parallelograms, spondylometers, pelvic inclinometers, standard goniometers, gravity goniometers, calipers and trigonometric measurements have all been used (Otman and Alyun, 1991; Gajdosik *et al.*, 1985; Clapper and Wolf 1988; Boone *et al.*, 1978; Low, 1976; Youdas *et al.*, 1991; Alviso *et al.*, 1988; Mayerson and Milano, 1984; Sanders and Stravrakas, 1981; Murray *et al.*, 1970; Walker *et al.*, 1987; Rothstein *et al.*, 1983).

The angle formed by a perpendicular and horizontal line passing through the anterior superior iliac spines (ASIS) and posterior superior iliac spines (PSIS) gives the sagittal plane measurements. If there is a reduction or the angle is 180°, there is said to be posterior pelvic tilt (PPT); if the angle increases, it is

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Fig. 1. Plurimeter and caliper

referred to as anterior pelvic tilt (APT) (Sanders and Stravrakas, 1981; Gajdosik and Bohannon, 1987).

Material and method

Patients ranged from 11 to 73 years of age. Their age, sex, weight, amputated side, length of time of prosthesis use, stump length, the prosthesis type and foot size, the knee joint range of motion, the muscular strength of the trunk, hip and knee, the PT and gait deviations were all noted.

On completion of training in the use of the prosthesis, PT measurements were taken using the Rippstein plurimeter and caliper. This plurimeter contains a very special oil and a large indicator. The caliper's long handle is shown in Figure 1 (Gerhardt *et al.*, 1986; Gerhardt and Rippstein, 1990).

The PT measurements in the horizontal plane were taken in the creeping position with 90° of knee and hip flexion with the caliper placed on a line drawn adjoining both PSIS. Measurements were taken without the prosthesis. The sagittal plane measurements were taken laterally on the amputated side using ASIS and PSIS as landmarks and the frontal measurements were obtained using the bilateral PSIS position measured from the back of the foot (Fig. 2).

Standardised results from previous studies of the PT angle on the frontal, horizontal and sagittal planes were given as 0°, 0-3°, and 9-11° respectively. If the angle exceeds 3° on the horizontal or 11° on the sagittal plane, it is classified as APT. All patients used 18mm SACH (Solid Ankle Cushion Heel) feet in order to offset any deviations in measurements.

Findings

The average age of the 22 patients in this study was 32.3 years (11-73); average mass was 63kg (37-90), 50% were right sided amputees and 50% left. Mean time of prosthetic use was seven years. The stump length was classified into five groups: very short stump (<15%); short stump (15-29%); standard stump (30-44%); long stump (45-59%); and very long stump (>60%). The length of the stump measured from the tibial plateau to the end of the bone was found to be long in 8 patients (36.4%), standard in 6 patients (27.3%) and short in 5 patients (22.7%). Two amputees (9.1%) had very long stumps while the remaining amputee (4.5%) had a very short stump. Some 16 patients (72.7%) used a PTB-SC/SP (Patellar Tendon Bearing Supracondylar/Suprapatellar) type prosthesis, 4 (18.2%) Patellar Tendon Bearing Supracondylar (PTB-SC) and 2 (9.1%) Patellar Tendon Bearing (PTB) type. All of them had SACH feet.

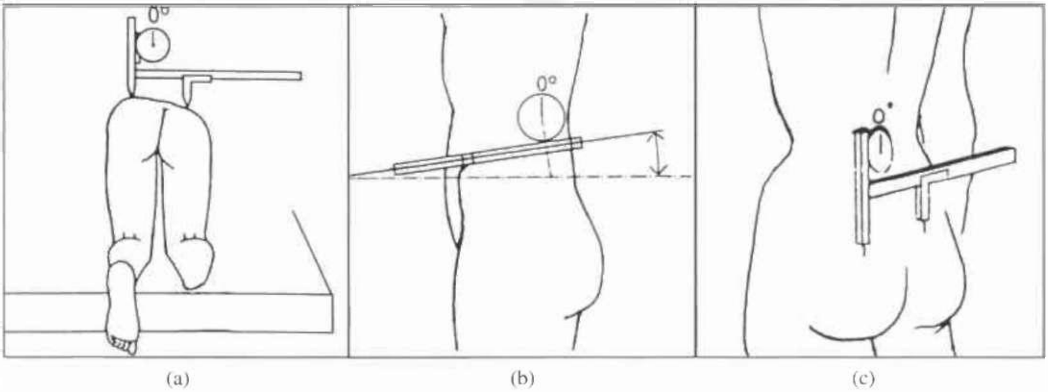


Fig. 2. PT measurements: (a) horizontal plane; (b) sagittal plane; (c) frontal plane.

Table 1.

Case No.	Age	ROM Knee	Muscle Strength	Hip	Knee	Trunk	Pelvic Tilt S H F	Gait Deviations
1.	45	5° ex.lim.	f	4	4	3	13° 7° 0°	+
			e	4	4	2		
2.	40	5° rec.	f	5	4	5	10° 0° 0°	-
			e	5	5	5		
3.	29	15° rec.	f	5	4	4	11° 3° 0°	-
			e	5	5	5		
4.	14	4° ex.lim.	f	5	4	3	12° 5° 0°	-
			e	5	4	4		
5.	37	0°	f	5	5	3	14° 10° 0°	+
			e	5	5	4		
6.	55	5° ex.lim.	f	5	4	3	12° 5° 0°	-
			e	5	4	3		
7.	39	0°	f	5	5	5	10° 0° 0°	-
			e	5	5	5		
8.	29	20° ex.lim.	f	5	5	3	13° 8° 0°	+
			e	5	4	3		
9.	19	5° rec.	f	5	5	4	13° 10° 0°	+
			e	5	5	4		
10.	18	17° ex.lim.	f	4	4	4	11° 5° 0°	-
			e	4	4	4		
11.	11	0°	f	5	4	4	12° 7° 0°	+
			e	5	5	4		
12.	22	20° flex.lim.	f	5	5	3	14° 11° 0°	+
			e	5	4	4		
13.	29	0°	f	4	4	4	13° 10° 0°	+
			e	4	4	4		
14.	19	0°	f	5	5	5	10° 0° 0°	-
			e	5	5	5		
15.	70	0°	f	5	5	3	12° 5° 0°	-
			e	5	5	3		
16.	19	5° ex.lim.	f	4	4	4	11° 5° 0°	-
			e	4	4	4		
17.	53	15° ex.lim.	f	3	4	2	15° 10° 0°	+
			e	4	4	2		
18.	13	15° flex.lim.	f	5	5	4	11° 5° 0°	-
			e	5	5	4		
19.	25	5° ex.lim.	f	5	5	3	14° 12° 0°	+
			e	5	5	4		
20.	26	0°	f	5	5	5	10° 0° 0°	-
			e	5	5	4		
21.	73	0°	f	5	5	3	12° 3° 0°	-
			e	5	5	3		
22.	26	0°	f	5	5	5	11° 5° 0°	-
			e	5	5	4		

S: Sagittal
H: Horizontal
F: Frontal

ex.lim.: extension limitation f.: flexor group
flex.lim.: flexion limitation e.: extensor group
rec.: recurvatum + gait deviation

5: normal 3: fair
4: good 2: poor

Range of motion of joints, muscle strength, PT values and gait deviations are presented in Table 1. In the study, it was noted when the PT angle exceeded the normal 0° in the horizontal plane, the muscle strength was reduced. For example, 6 patients with a PT angle of 0-3° on the horizontal plane, had good to normal muscular strength values for both the flexors and extensors; 9 patients with PT values between 4-7°, had fair to good flexor and extensor strength; 6 patients with PT values of 8-11° and another with 12° had fair to good extensor strength (Table 2a).

Similarly, measurements of the PT angle on the sagittal plane demonstrated the same trend. PT values of 9-11°, had a good to normal average flexor and extensor strength. However, in the presence of APT, muscle strength was reduced. For example, when the PT angle was 12-14°, found in 12 cases, trunk flexors were classified as fair and extensors as good. One patient with a value of 15°, was assessed to have poor flexor and extensor strength (Table 2b).

PT measurements in trans-tibial amputees are very different according to the planes and ages. In the sagittal plane the values were between 10 and 15°, with a mean value of 12+1.48. The horizontal plane values varied between 0 and 12°, with a mean of 5.73±3.77. In the frontal plane PT (elevation or depression) was not observed (Table 1). PPT was not observed in

Table 2a.

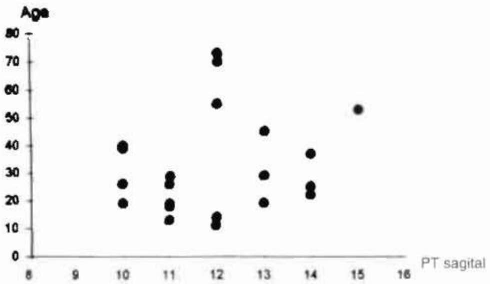
PT horizontal plane	Trunk muscle strength		
	N	f	e
0° – 3°	6	4.5	4.5
4° – 7°	9	3.7	3.6
8° – 11°	6	3.2	3.5
12° – 15°	1	3	4

Table 2b.

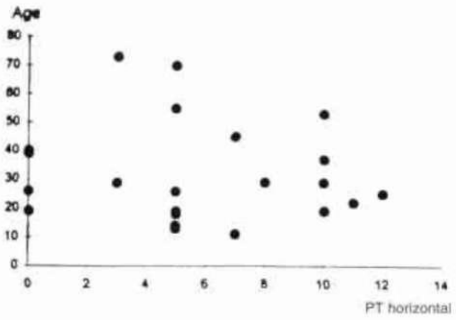
PT sagittal plane	Trunk muscle strength		
	N	f	e
9° – 11°	9	4.6	4.4
12° – 14°	12	3.3	3.5
15° – 17°	1	2	2

f: flexor group
e: extensor group

Graph 1. Relationship between age and PT sagittal plane.



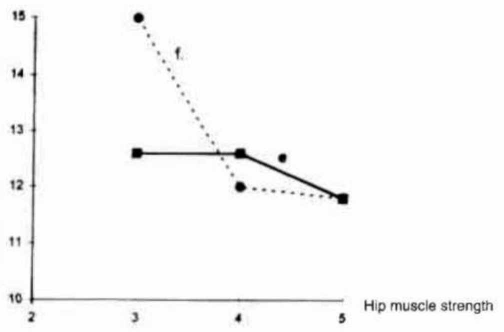
Graph 2. Relationship between age and PT horizontal plane.



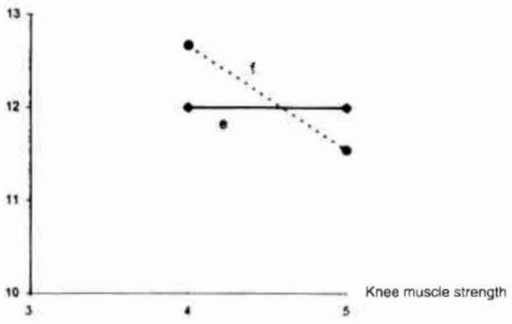
any cases either in sagittal or horizontal planes. However, APT was observed in 16 cases (73%) in the horizontal, and 13 cases (59%) in the sagittal plane (Tables 2a and 2b). The relationship between age and PT angles in the sagittal and horizontal planes are presented in Graphs 1 and 2.

The relationship between the hip, knee, trunk flexors and extensors muscle strength and the PT values obtained in the sagittal plane are presented in Graphs 3, 4 and 5. The same effects in the horizontal plane are presented in Graphs 6, 7 and 8. These relations were compared using the Spearman correlation coefficient to determine whether such a relationship was statistically significant ($p<0.05$) (Table 3). According to Tables 2a and 2b, the relationship was statistically significant, the significance being greater for the flexors. Similarly, PT values were compared to the age, body mass, prosthetic use period and stump length to determine whether there was a statistical significance. According to Table 4, if $p>0.05$ the relationship was not significant.

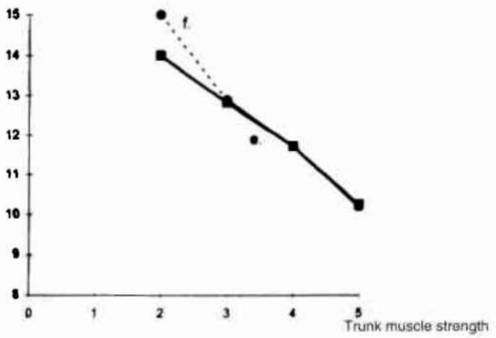
Graph 3. Hip muscle strength effect on PT sagittal.



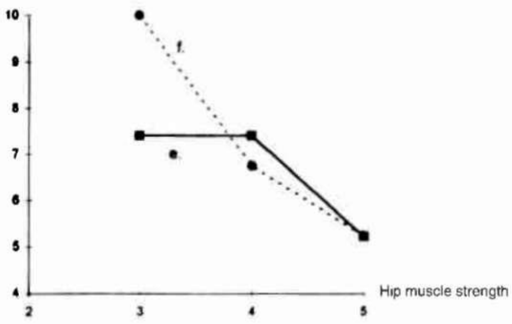
Graph 4. Knee muscle strength effect on PT sagittal.



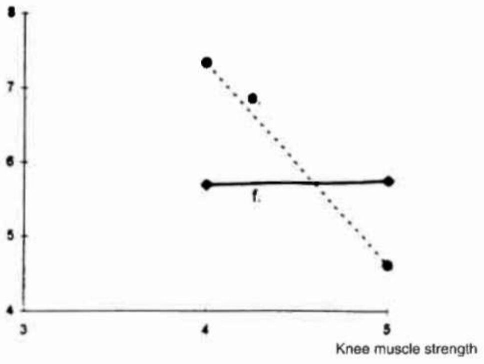
Graph 5. Trunk muscle strength effect on PT sagittal.



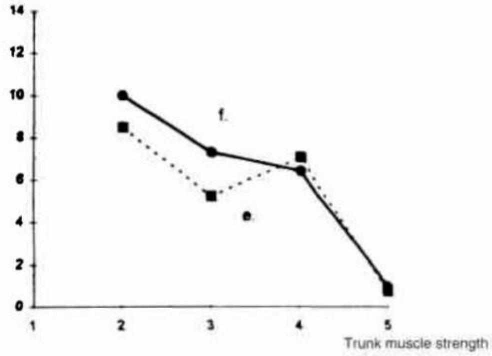
Graph 6. Hip muscle strength effect on PT horizontal.



Graph 7. Knee muscle strength effect on PT horizontal.



Graph 8. Trunk muscle strength effect on PT horizontal.



There were no limitations in hip joint ranges of motion, but in 8 patients (36.4%), there was an average of 9.5° loss in knee extension; in another 2 (9.1%), there was an average loss of 17.5° flexion and there was an average of 8.3° of recurvatum in 3 others (13.6%) (Table 1).

The trunk, knee and hip muscle strength was assessed to range from poor to normal (2-5 grade). In 17 cases 77.3% the hip flexors and extensors were normal and in 10 cases (45.5%) the knee flexors and extensors were normal (Table 1).

Table 3.

		Hip		Knee		Trunk	
		f	e	f	e	f	e
PT horizontal plane	r	-0.260	-0.245	0.015	-0.373	-0.622	-0.429
	N	22	22	22	22	22	22
	p	0.242	0.272	0.948	0.088	0.002*	0.046*
PT sagittal plane	r	-0.232	-0.200	0.007	-0.386	-0.829	-0.600
	N	22	22	22	22	22	22
	p	0.300	0.372	0.974	0.076	0.000*	0.003*

f: flexor group
e: extensor group
r: correletion coefficient
N: case number
p: probability
*: significant

Table 4.

		Age	Mass	Prosthetic use period	Stump length
PT horizontal plane	r	-0.118	-0.156	-0.018	-0.065
	N	22	22	22	22
	p	0.603	0.488	0.940	0.774
PT sagittal plane	r	0.147	-0.015	-0.005	-0.000
	N	22	22	22	22
	p	0.514	0.946	0.984	1.000

In 13 patients gait deviations were not observed; in 9 cases (41%) excessive knee flexion existed. This was reflected in a trunk muscle flexor-extensor strength of fair (3.2-3.4 grade). It was also noted that these patients exhibited high PT values in sagittal and horizontal planes 13.4 and 9.4 respectively, with the presence of APT. This finding was statistically significant p<0.001 (Table 5).

Discussion

Various methods have been used to determine PT measurements of normal people in the sagittal plane for example, Murray *et al.* (1970) using a photographic method, determined the average PT value to be 7°; Day *et al.* (1984) using the same method found the value to be 9.9°. Gajdosik and Bohannon (1987), using trigonometric measurement determined the value to be 8.5°. Burdet *et al.* (1986), Yildirim and Uygur (1987) and Cottingham *et al.* (1988) determined the angle to be between 8.4-11.3° using gravitational goniometric measurements.

In this study using the plurimeter and caliper, PT values in the sagittal plane were found to be between 10 and 15°, with an average of 12°. In the horizontal plane they were between 0 and 12°, with an average of 5.73°. In the frontal plane, pelvic angulations were not observed. The outcome of frontal plane assessments

Table 5. The relationship of gait deviation with the PT on the horizontal and sagittal planes.

	Excessive knee flexion	N	$\bar{X}_{PT}$	SD	p
Gait deviation horizontal plane	+	9	9.44	1.74	0.000*
	-	13	3.15	2.30	0.000*
Gait deviation sagittal plane	+	9	13.44	0.88	0.000*
	-	13	11.00	0.82	0.000*

N: case number
$\bar{X}_{PT}$: mean PT
SD: Standard deviation
p: probability
+: Excessive knee flexion existent
- : Excessive knee flexion non-existent

cannot be discussed due to the absence of previous studies.

Day *et al.* (1984), Kendal *et al.* (1993), Christie *et al.* (1995) as well as many other researchers have suggested that the trunk and hip flexors and extensors play an important role in pelvis control. In this study using the Spearman Correlation Coefficiency, it was concluded that the effects of the strength of the trunk extensors and flexors on the sagittal plane PT values were statistically significant ($p<0.05$). A similar conclusion was made for the horizontal plane. In other words, increasing strength of the trunk flexors and extensors results in reduction of PT in both planes.

However, in most of the cases studied (17 patients), the hip flexors and extensors were normal. Consequently, it was not possible to demonstrate such a relationship as above. Those with extension limitations of the knee (4-20°), showed a direct effect on the APT. For example, out of the 8 patients with extension limitations, 6 of them demonstrated higher sagittal and all demonstrated higher horizontal PT values than the normal (9-11° sagittal; 0-3° horizontal.

The relationship of gait deviations on the PT values was also evaluated and it was concluded that those patients with gait abnormalities resulting from excessive knee flexion were statistically significant ($p<0.001$). This evaluation was carried out after correction of the deformity resulting from prosthetic use during the stance phase.

Youdas *et al.* (1996) have shown that aging, a reduction in physical activity and abdominal muscularity, resulted in an increase in PT; Schenkman *et al.* (1996) noted a reduction in axial rotation.

In this study age, sex, mass, amputation side and prosthesis use time span, were compared with the PT angle using the t test, but were shown to be statistically insignificant ($p>0.05$).

Despite the fact, that the values obtained conformed closely to each other, the differences observed are believed to result as a consequence of racial differences, individual's physical characteristics and the researchers criteria.

Conclusion

Just as the trunk flexors and extensors influence the PT in the sagittal plane, in this study, it was concluded that the same effect also occurs in the horizontal plane. In addition, PT angles are also affected when excessive knee flexion compromises gait in the stance phase. In order to verify and strengthen this finding, further research is ongoing.

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