International Orthopaedics (SICOT) (2016) 40:561–567
DOI 10.1007/s00264-015-3023-0

ORIGINAL PAPER

The effect of an external hip joint stabiliser on gait function after surgery for tumours located around the circumference of the pelvis: analysis of seven cases of internal hemipelvectomy or proximal femur resection

Toru Akiyama[1] · Kazuo Saita[1] · Koichi Ogura[2] · Akira Kawai[2] · Jungo Imanishi[3] · Yasuo Yazawa[3] · Noritaka Kawashima[4] · Toru Ogata[4]

Received: 10 May 2015 / Accepted: 17 October 2015 / Published online: 10 November 2015

Abstract
Purpose Limb-sparing resection of malignant pelvic tumours provides the opportunity for patients to obtain better post-operative mobility. However, because few studies have examined in detail the gait function of patients following pelvic tumour resection, the factors affecting gait performance remain to be clarified. Here, with the laboratory-based computer-assisted gait analysis, we evaluated these patients' gait objectively and the impact of a hip-stabilising supporter on gait improvement was simultaneously examined.
Methods Three-dimensional gait analysis was performed to obtain cross-sectional data for seven post-operative patients (mean age, 42.7 years; range, 20–61 years) who underwent various types of resection, including P1/4 internal hemipelvectomy (IH), P1/2/3 IH, and proximal femur resection with prosthetic reconstruction. To assess the immediate effects of a hip joint stabiliser, we instructed subjects to walk at their self-selected preferred speed and compared gait parameters with and without use of the hip stabiliser.
Results At baseline, the average walking speed was 0.75 m/s (95 % CI 0.53–0.97). As shown by the intra-subject comparison, the hip stabiliser increased walking speed in all but one subject, increasing both temporal and spatial parameters. Ground reaction force of operated limbs increased for some subjects, while step length increased on at least one side in all subjects.
Conclusions Improvement in the gait parameters is indicative of better control provided by the external hip stabiliser over the affected limb. Moreover, our findings show the potential of a biomechanical approach to improve gait function following pelvic tumour resection.

Keywords Tumour resection · Motion analysis · Orthotics · Reconstruction surgery

✉ Toru Ogata
ogata-toru@rehab.go.jp

[1] Department of Orthopaedic Surgery, Saitama Medical Center, Jichi Medical University, Saitama, Japan

[2] Department of Musculoskeletal Oncology, National Cancer Center Hospital, Tokyo, Japan

[3] Department of Orthopaedic Oncology and Surgery, Saitama Medical University International Medical Center, Hidaka, Saitama, Japan

[4] Department of Rehabilitation for the Movement Functions, Research Institute, National Rehabilitation Center for Persons with Disabilities, 4-1 Namiki, Tokorozawa, Saitama 359-8555, Japan

Introduction

Resection of malignant pelvic tumours remains challenging, particularly in limb-salvage surgery [1, 2]. Limb-sparing surgery for malignant pelvic tumours (or internal hemipelvectomy) offers several advantages with respect to amputation, including preservation of the patient ability to walk using his/her own lower limbs and a decrease in cosmetic and psychological adverse effects [1, 3]. In addition to survival, the quality of life and mobility function are central to outcome analysis in patients undergoing pelvic tumour surgery. However, to date, little information has been available on the functional outcomes, such as gait parameters, following pelvic tumour resection [2].

From a biomechanical viewpoint, lateral pelvic stability is provided by a hip abductor [4]. The reconstruction of abductor muscles, which provide hip joint stability, has been reported as a key to achieving a better functional outcome after proximal femur resection [5]. On the other hand, the pelvic site of the bony attachment of the abductor muscles is typically resected without abductor reconstruction in patients undergoing pelvic tumour resection.

External hip stabilisers have been developed using various structures and materials; some of these stabilisers have been developed to provide additional support to the hip abductors. Therefore, we hypothesised that a hip joint stabiliser would provide a better functional outcome to not only patients of proximal femur resection but also to those of pelvic tumour resection. However, no previous reports have investigated the effect of abductor stabilisation on the functional outcomes in patients undergoing pelvic tumour resection.

In the present study, we aimed to assess objectively the immediate effect of a hip-stabilising supporter on gait parameters following the resection of tumours located around the circumference of the pelvis using laboratory-based computer-assisted gait analysis. We also aimed to compare the data of a laboratory-based computer-assisted gait analysis to the Musculoskeletal Tumor Society rating scale (MSTS score), which is used worldwide to functionally evaluate patients with a musculoskeletal malignant tumour in the lower limbs.

Subjects and methods

Subjects

In this study, we analysed seven eligible patients who underwent surgical treatment for bone or soft tissue tumours around the pelvic ring. Inclusion criteria were (1) wide resection with limb salvage for tumours around the pelvis, (2) no local recurrence, (3) no metastasis, and (4) completion of the treatment for a primary tumour at a minimum of six months prior to the gait analysis. All patients were recruited after providing informed consent during a hospital visit. The surgical procedures for these seven patients were P1/4 internal hemipelvectomy (IH) (2 patients), P1/2/3 IH (3 patients), and proximal femur resection with prosthetic reconstruction (2 patients) according to the Enneking's classification [1, 6]. Type I resection (P1) is that involving the ilium; type II resection (P2), that involving the acetabular bone; type III resection (P3), that involving the pubis and ischium; and type IV resection (P4), that involving the unilateral sacrum [6]. Thus, P1/4 internal hemipelvectomy indicates iliac wing resection combined with partial sacrum resection. P1/2/3 internal hemipelvectomy indicates resection of the iliac wing, acetabulum, and pubic bone. The patient background data are shown in Table 1. The experiment was conducted with the approval of the Ethics Committee of National Rehabilitation Center for Persons with Disabilities. Each subject provided informed consent for the experimental procedures in written form, which were performed in accordance with the Declaration of Helsinki. The measurements were carried out between 2013

Table 1 Patient demographics and walking parameters

Case no.	Age/gender (yr)	Follow up (months)	Pathology	Resection	Reconstruction	Postoperative complications	Oncological outcome	Walking speed (m/s)		The MSTS score (%)	Body weight (kg)	Walking aid	MMT	
								Baseline	w/hip stabilisers				Hip abductor	Hip extensor
1	24/F	14	Giant cell tumour of bone	PFR	Proximal femoral prosthesis	None	CDF	1.26	1.29	87	52	None	4	4
2	44/M	17	Osteosarcoma	PFR	Proximal femoral prosthesis	None	CDF	1.11	1.21	60	70	None	4	4
3	52/M	106	Chondrosarcoma	P1/4	FVFG	Deep infection	CDF	0.82	0.81	83	74	Double Lofstrand crutches	2	2
4	57/F	7	Chondrosarcoma	P1/4	NVFG	Surgical site necrosis	CDF	0.42	0.45	33	49	T cane	2	2
5	61/M	35	UPS	P1/2/3	Hip transposition	None	CDF	0.52	0.57	77	66	T cane	2	2
6	20/M	12	Ewing's sarcoma	P1/2/3	Hip transposition	None	CDF	0.62	0.76	53	38	Double axillary crutches	2	2
7	41/F	104	Recurrent soft tissue sarcoma[a]	P1/2/3	Constrained THA	None	AWD	0.49	0.55	36	45	Single Lofstrand crutch	2	2

F female, *M* male, *MSTS* Musculoskeletal Tumor Society, *PFR* proximal femur replacement, *CDF* continuous disease free, *AWD* alive with disease, *UPS* undifferentiated pleomorphic sarcoma, *FVFG* free vascularised fibula graft, *NVFG* non-vascularised fibula graft, *THA* total hip arthroplasty

[a] Intermediate grade myofibroblastic sarcoma

and 2014 at the gait laboratory of the National Rehabilitation Center for Persons with Disabilities.

Motion analysis

Three-dimensional gait analyses were conducted with a motion analysis system (MAC3D, Motion Analysis Co., Santa Rosa, CA) using eight infrared cameras. Twenty-nine reflective markers were placed on the subject according to the Helen Hayes Marker Set. The sampling rate of the system was set at 200 Hz for measuring the three dimensional positions of the markers. Eight force platforms (Forceplate, Kistler, Amherst, NY) were also situated at the midpoint of the walkway for obtaining the vertical components of the ground reaction force.

The subjects were instructed to walk on the seven metre walkway at a self-selected preferred speed four times for each condition (i.e. with or without hip stabiliser) at one-minute intervals. We measured self-selected preferred walking speed, not maximum walking speed, because those subjects who have pathological gait patterns tend to use a different walking strategy between a normal walk and a fast walk. For the baseline measurement, the subjects used their personal walking aid(s) (e.g. crutches, cane, orthotic shoes) if they usually used one. Afterwards, hip-stabilising supporters were placed on the subjects to provide additional stabilisation on the operated hip joint. In brief, six of the subjects wore an elastic belt-type hip joint supporter (elastic band), which applied pressure to the greater trochanter to stabilise the hip joint (Daiya Co., Okayama, Japan; Fig. 1). The remaining one subject (case 6), who already used a soft brace-type hip stabiliser with a hinged bar (Tokuda Ortho-Tec, Kumamoto, Japan), walked without the stabiliser and then walked with his own stabiliser. After five minutes of practicing with the hip stabiliser, the subjects were instructed to walk on the same walkway four times under the same conditions used in the baseline measurements. Both kinematic and kinetic data were standardised according to gait cycle, starting with heel contact on the force plates. The location of the markers set at the heel was used to determine stride length and gait cycle duration. The average of those parameters from four trials was used to calculate gait speed and cadence of the individual. Weight bearing was quantified from the vertical ground reaction force (vGRF) over the stance phase. Typically, we observed two peaks, and recorded the maximum force for each peaks. For evaluating the asymmetry of locomotion, the force plate data were used to determine the stance time of each leg. Then, the asymmetric index of stance time (AI_{stance}) was calculated using the following formula: (intact limb stance time)/(affected limb stance time). We also calculated the asymmetric index of average of the vertical ground reaction force (GRF) during quiet standing (AI_{GRF}) using the following formula: (intact limb GRF)/(affected limb GRF).

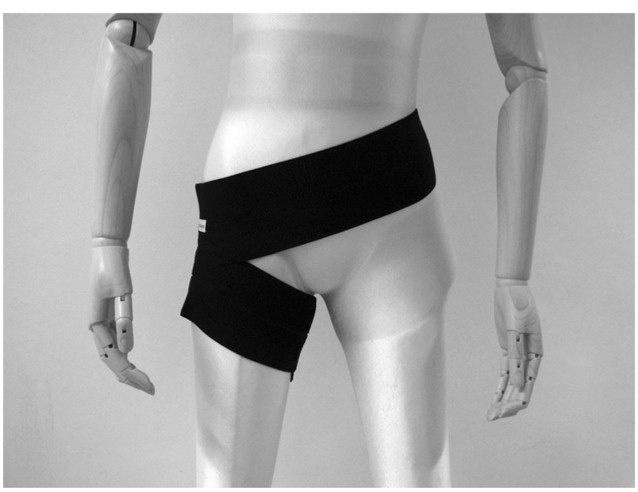

Fig. 1 A photograph of the hip stabiliser used in the present study. The hip stabiliser is an elastic band

The MSTS score

The MSTS score has been used widely to assess the lower limb function in patients with musculoskeletal malignant tumours. It was originally described by Enneking in 1987 and also by Enneking et al. in 1993 [7]. It is based on an analysis of six factors patient-related and completed by a clinician. Each factor is assigned a value of 0 to 5 points (maximum overall score, 30 points), and the total score is usually converted to a percentage, thus transforming the results to a range of 0–100 %.

Statistics

SPSS version 17 software (SPSS, Chicago, IL, USA) was used for all statistical analyses. To investigate the effect of the hip stabilisers, we compared the parameters between the gait at baseline and the one with the stabiliser. Statistical intra-subject comparisons were performed with the paired *t*-test. The relationship between the gait analysis parameters and the MSTS scores was analysed with Spearman's rank-order correlation coefficients. A p value of <0.05 was considered to indicate statistical significance. Values are shown as the mean.

Results

Effects of hip stabilisers on gait speed

Table 1 summarises the background characteristics, individual walking speeds, and the MSTS scores of the subjects. The average walking speed of the seven subjects was 0.75 m/s [95 % confidence interval (CI) 0.53–0.97]. As shown by the intra-subject comparison, the gait speed increased with use of a hip stabiliser for all but one subject (case 3) (stabiliser, 0.81 m/s vs. baseline, 0.75 m/s; p=0.025).

Effects of hip stabilisers on temporal and spatial parameters of gait

Because the aim of this study was to reveal how a hip-stabilising supporter modifies gait parameters, we analysed the change in temporal and spatial factors, which are the main components of gait pattern. In this study, the cadence (number of steps per minute) and stride length [the distance between two placements of the same foot (i.e., two right and left step lengths)] were selected as representative temporal and spatial factors, respectively. While the cadence of all the subjects increased when using the stabilisers, the stride length increased in all but one subject (case 3). The cadence showed significant improvement when the subjects walked with the stabilisers than without them (stabiliser, 93.9 step/min vs. baseline, 89 step/min, p=0.002) (Fig. 2a). Meanwhile, there was a non-significant tendency for the stride length to be longer with the stabilisers (stabiliser, 1.02 m vs. baseline,

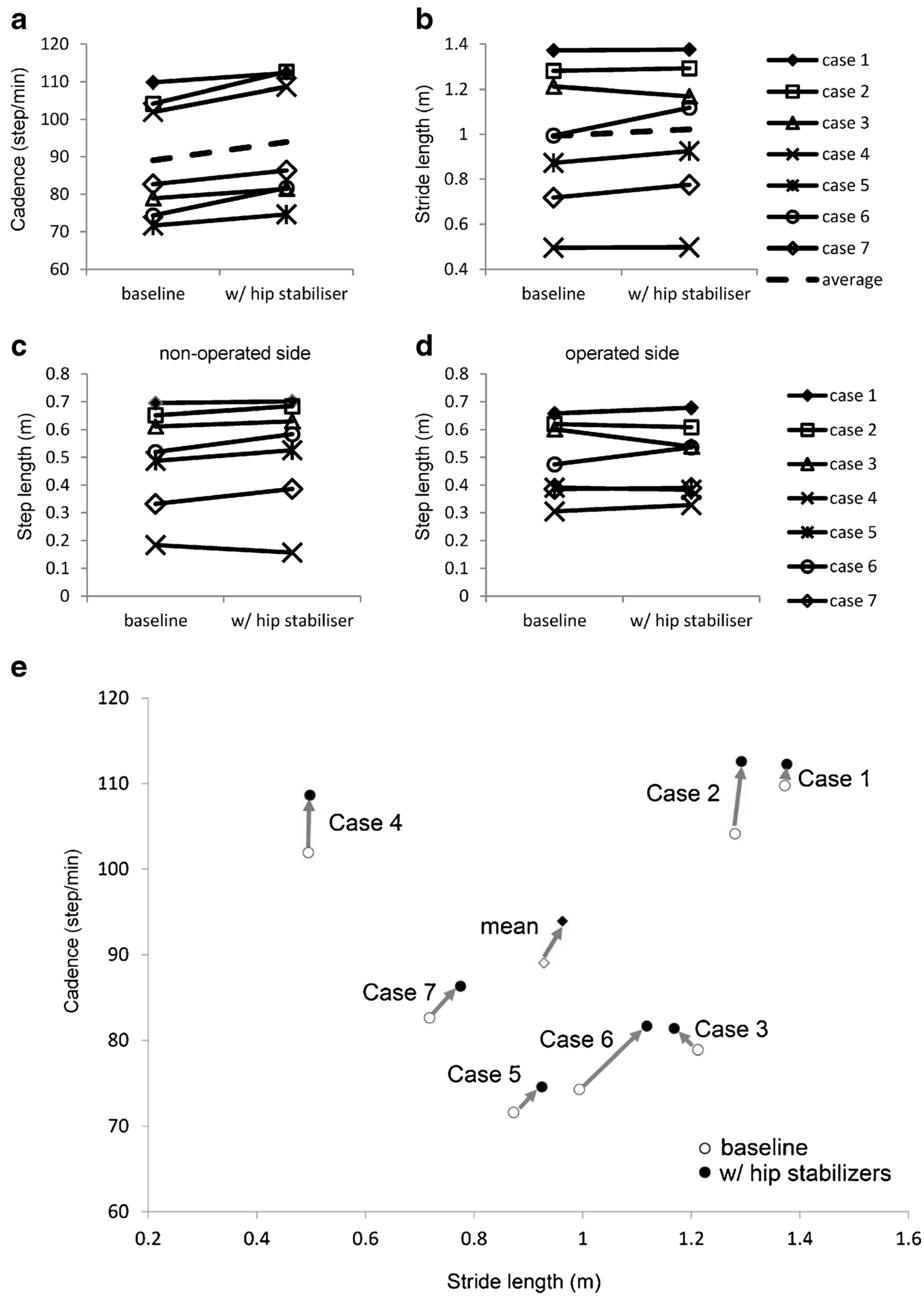

Fig. 2 The change in gait parameters after the use of a hip stabiliser. **a**,**b** Individual data for cadence and stride length at baseline and with the hip stabiliser. **c**,**d** Individual data for step length changes for the non-operated (**c**) and operated (**d**) lower limbs. **e** Scatter plot of individual data at baseline (*open circle*) and with the hip stabiliser (*filled circle*)

0.99 m, p=0.19) (Fig. 2b). In more detail, the use of a hip stabiliser resulted in increased step length on the unaffected side for four subjects, on the operated side for two subjects and on both sides for oneEffects of hip stabilisers on weight-bearing during gait subject (Fig. 2c, d). However, those changes were not statistically significant (the unaffected side, stabiliser 0.52 m vs. baseline 0.50 m, p=0.06; the operated side, stabiliser 0.49 m vs. baseline 0.49 m, p=0.81). Figure 2e shows a scatter plot of the individual data, indicating both cadence and stride length improved concurrently in most of the subjects.

Effects of hip stabilisers on weight-bearing during gait

One possible mechanism for the increase in gait speed associated with use of a hip stabiliser is an increased load-bearing on the operated lower limb, as indicated by the increase in the vGRF compared to baseline values. The typical vGRF profile includes two peaks, one during early stance phase and one during the late stance phase, and we analysed maximum value of both. Hip stabilisers increased the peak vGRF over the early stance phase in four subjects (cases 1, 2, 4, and 7; Fig. 3a) and the peak vGRF over the late phase in three subjects (cases 2, 5, and 7; Fig. 3b). These effects of a hip stabiliser on peak vGRF, however, did not reach significance (early stance vGRF, stabiliser 553 N vs. baseline 538 N, p=0.13; late stance vGRF, stabiliser 507 N vs. baseline 515 N, p=0.46).

Effects of hip stabilisers on asymmetry indices

Because all the subjects showed difficulty in loading on the affected limb, we evaluated the asymmetry during quiet standing. The average AI_{GRF} at baseline was 1.45 (95 % CI 1.13–1.80) (Table 2). As for the asymmetry during locomotion, although none of the subjects experienced pain during locomotion for a short distance, they tended to avoid standing on the affected limbs, which resulted in a shorter stance time for the affected side. The average AI_{stance} at the baseline was 1.14 (95 % CI 1.07–1.23) (Table 2).

Because the use of the hip stabilisers had increased the gait speed together with the temporal and spatial factors, we expected an improvement in the asymmetry of either quiet standing or locomotion. However, no significant changes were observed in either AI_{GRF} or AI_{stance} (AI_{GRF}: stabiliser, 1.46 vs. baseline, 1.45, p=0.93; AI_{stance}: stabiliser, 1.17 vs. baseline, 1.14, p=0.37). Therefore, the use of stabilisers had minimal effects on asymmetry between the healthy and affected limbs.

Correlation of gait parameters to the MSTS scores

Statistical analysis demonstrated a strong positive correlation between the MSTS score and gait speed at baseline and with the hip stabiliser. We found no significant correlation between the MSTS score and GRF asymmetry or the asymmetry in stance time (Table 3).

Discussion

Pelvic tumour resection is a challenging surgical procedure and can have a substantial functional, social, and psychological impact on the patient [3]. Pelvic tumour resection with limb salvage, or internal hemipelvectomy, has emerged over the last 30 years [8], and is performed if a reasonably functioning extremity can be saved without compromising local control of the tumour [8, 9]. Moreover, the extensive resection of pelvic sarcomas often necessitates reconstruction to avoid severe functional disabilities as a result of loss of the acetabulum, an incomplete pelvic ring, and loss of the abductor musculature [10].

Recently, the functional and psychological advantages of internal hemipelvectomy relative to external hemipelvectomy have been reported [11]. The reported functional outcomes of pelvic tumour resection measured by the MSTS score were over 70 % and identical to those of distal femur replacement [12, 13]. Of note, the MSTS scores >90 % have been reported for P1 resection or iliac wing resection [12]. However, these analyses were considered not to reflect the precise gait function. In particular, the MSTS scoring system has recently been questioned for not providing objective and quantitative information about functional recovery [5].

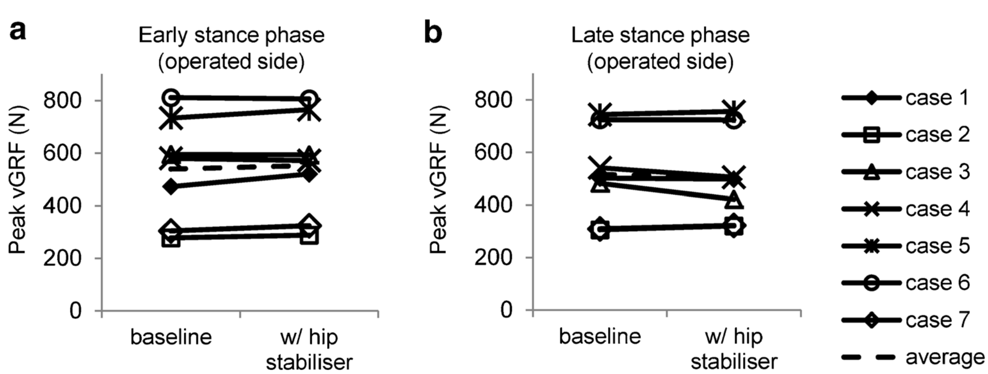

Fig. 3 The change in peak vertical ground reaction force (vGRF) during gait. **a**,**b** Individual data for peak vGRF at baseline and with the hip stabiliser over the early phase (**a**) and late phase (**b**) of stance

Laboratory-based computer-assisted gait analysis represents the best method for objectively assessing the technical outcome of a procedure designed to improve gait [14]. However, the functional outcome following internal hemipelvectomy has seldom been evaluated with gait analysis [5, 15–17]. The causes underlying precise gait analysis being rarely conducted for internal hemipelvectomy may be attributed to not only the rarity of internal hemipelvectomy but also the substantial variation in internal hemipelvectomy and reconstruction methods. In the present study, the gait analysis showed that the use of hip stabilisers improved both temporal and spatial gait parameters. We chose self-selected preferred walking speed rather than maximum speed, because the strategy for fast walking might be different from that for normal walking among post-operative patients. We assumed that the elastic band or hinged supporter would provide stabilising effects on hip joints, thus leading to better limb control on the operated side. The fact that all of the subjects showed longer step length in one of either side (6 cases) or both sides (1 case) with hip stabilisers is indicative of the effectiveness of a hip stabiliser in facilitating stance or swing motion of the operated limbs. Although the gain in gait speed was limited, the better control of the affected limbs may improve patients' gait performance. Longer-term intervention, possibly combined with qualitative methods, would be required to evaluate how the identified benefits affect their mobility in daily life.

Of the seven cases analysed, one subject (case 3) showed a minimal decrease in gait speed with the use of a hip stabiliser (stabiliser 0.81 m/s vs baseline 0.82 m/s). This subject had undergone surgery 106 months prior to the study and had a high MSTS score of 83 % at baseline. Therefore, this subject had achieved a satisfactory level of gait post-operatively, with little additional improvement possible with the use of a hip stabiliser. In fact, the hip stabiliser disrupted the functional gait adaptations this subject had achieved, decreasing the vGRF on the operated limb, with a concomitant decrease in the step length on the same side. Although further practice with the hip stabiliser might improve gait parameters for this subject, evaluation of such chronic effects is an issue for future study.

Table 2 Results of asymmetry factors

Case number	GRF asymmetry		Stance time asymmetry	
	Baseline	w/ hip stabiliser	Baseline	w/ hip stabiliser
1	1.02	1.03	1.04	1.02
2	1.11	1.10	1.07	1.02
3	1.02	1.03	1.08	1.02
4	1.23	1.37	1.14	1.29
5	2.03	2.08	1.28	1.36
6	1.61	1.57	1.07	1.12
7	2.15	2.02	1.33	1.37

GRF ground reaction force during quiet standing

Table 3 Coefficient of correlation between gait analysis parameters and the MSTS score

Parameter	MSTS score
Speed, base line	0.821, p=0.023
Speed with stabiliser	0.821, p =0.023
GRF asymmetry	–0.631, p =0.129
Stance time asymmetry	–0.523, p =0.229

MSTS Musculoskeletal Tumor Society, *GRF* ground reaction force during quiet standing

Previously, the gait function following P1 resection was reported as a satisfactory one achieving a nearly full score by the MSTS scoring system [12]. Our data showed that even gait function after P1 resection could be improved with the additional stabiliser, indicating the mobility function of these patients had room for further improvement. In our study, the MSTS score correlated with the parameter of gait speed in the gait analysis, but not with asymmetry. For the precise analysis of the gait after pelvic tumour resection, not only the MSTS score but also gait analysis system should be considered as a measurement system. Pelvic tumour resection methods are still improving. The ideal method of reconstruction after acetabular resection remains a subject of controversy, and the outcome in terms of the impact of therapy is still unknown [2]. Our data demonstrated that the stabilisation of hip joints is preferable and clinically meaningful in terms of the mobility of patients following various types of surgical resection of tumours located along the circumference of the pelvis.

Our study had several limitations. First of all, the effects we observed were the immediate effects of the hip stabiliser. To evaluate the long-term effects, further studies are needed to measure energy expenditure and gait performance after the subjects become accustomed to using the hip stabiliser. Second, the number of subjects was small, and variation was present in the follow-up after surgery. In addition, the reconstruction procedure following pelvic tumour resection differed between patients. However, we believe the hip stabilisers can improve gait function following pelvic tumour resection since all of the patients suffered from abductor dysfunction.

In conclusion, additional hip stabilisation could provide better gait function for patients who have undergone various types of pelvic tumour resection and proximal femur resection for the treatment of malignant musculoskeletal tumours. As a hip stabiliser, the abductor support elastic band is a simple and effective aid for promptly improving gait function in this type of patient.

Acknowledgement We thank Koji Sato and Sho Watanabe for their effort in data collection and technical assistance.

Compliance with ethical standard

Conflict of interest The authors declare that they have no conflict of interest.

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