Original Article

Biomechanical study of modular hemipelvic endoprosthesis for Type I-IV defect of pelvic tumor

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Background: The modular hemipelvic prosthesis has been used in patient of Type I-IV pelvic tumor with good outcomes, but how to keep the stability between the prosthesis and the residual sacrum is a problem. An additional screw-rod system seems to solve it, but its biomechanical characters are still not well understood, which need experimental evaluation.

Methods: Six pelvic specimens were prepared in three conditions (normal intact pelvis, "normal"; the pelvis of left Type I-IV defect and implanted with prosthesis without/with additional screw-rod system, "rod-" and "rod+"). Compressing biomechanical experiments (50-500N) were performed in these three conditions, respectively.

Results: The loadings during the experiments are in accordance with the linear elastic control mode. Under the increasing loading, the implanted pelvises displaced asymmetrically, unlike normal intact pelvis. The vertical displacement of "rod+" changed significantly, whereas "rod-" did not. For both implanted pelvis, right side displaced less than left side (P values <0.05).

Conclusions: The implanted pelvis showed asymmetric displacement under loading, where healthy side displaced more. The implanted pelvis plus screw-rod system showed less displacement at implanted side but more at contralateral side in comparison with those without screw-rod system.

Keywords: Pelvis of Type I-IV defect; modular hemipelvic endoprosthesis; biomechanical experiment

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Introduction

Pelvic tumor treated by en bloc resection with limb-salvage procedures becomes preferred choice. Different prostheses were designed and used for the reconstruction, among which, the modular hemipelvic prosthesis had the best functional outcomes (1). This prosthesis pursues the goal as that it should be modular, stable and durable, small in size to allow for better soft tissue reconstruction, and also preserve hip function (2). Via computer-aided design and computer-aided manufacture, a customized hemipelvic prosthesis allows easier and more accurate implantation, providing patients the most effective limb length and earlier restoration of function (3).

Different parts assemblies were used depending on the type of the pelvic tumor [cf. the Enneking system, (4)]. The type of I-IV defects involves sacroiliac joint, where the prosthesis has to be fixed firmly to the residual sacrum by screws with or without bone grafts. Due to the strong shear force in this location, the fixation faces a challenging biomechanical problem, e.g., the potential of prosthetic loosening or breakage. Moreover, the clinical experiences showed the functional scores are significantly lower for patients with sacroiliac joint involvement (2).

In order to figure out the above problems, an additional pedicle screw-rod fixation system seems to be helpful for preventing implant failure (5,6). However, its biomechanical characters are still not well understood. Also, its influences

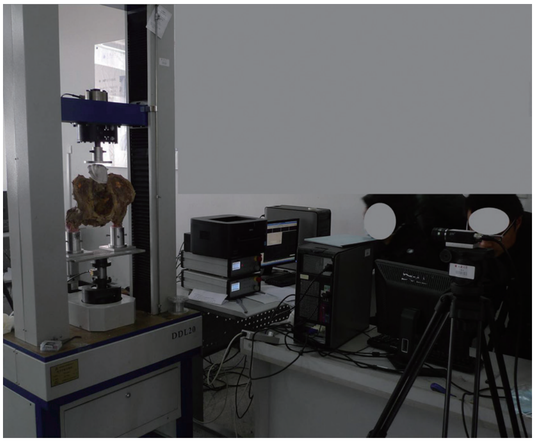

Figure 1 The setting of mechanical test.

on the whole pelvis lack of detail study. The purpose of the current study was to evaluate the advantages and disadvantages of the combination of prosthesis and screw-rod fixation in comparison with the prosthesis without screw-rod fixation and the normal pelvis, using biomechanical experiments.

Methods

Six pelvic specimens (three males and three females, between 54 and 76 years old) were harvested from fresh-frozen human cadavers, while the inner organs were resected and all ligaments were preserved. These pelvises include lumbar 5 and upper parts of bilateral femurs. Twenty-four hours before the mechanical testing, the pelvises were taken out and thawed.

Firstly, the intact pelvises ("normal") were performed static axial stress test according to the linear elastic control mode via DDL20 hydraulic material testing machine (Changchun Research Institute for mechanical science Co. LTD, Changchun, China). The setting is as *Figure 1*.

The vertical compressive force was applied on the upper face of L5 vertebrae. 200N of preload was applied twice before the normal tests, in order to reduce the influences of joint and bone's creeping. The normal tests started at the initial load of 50N, then the compressive load increased continuously with the increment of 2 mm/min to the maximum 500N. A CCD camera (JAI CV-A1, Denmark) collected the serried images of the pelvic continuous movements anteriorly.

Secondly, the Type I-IV defects (left side) were made by one surgeon (HH), and implanted with modular hemipelvic endoprosthesis without the additional pedicle screw-rod instrumentation ("rod–", Shanghai Shengshi Medical Instrument Science and Technology Co., LTD, Shanghai, China). The same test procedures were repeated as for normal pelvises.

Thirdly, the additional pedicle screw-rod instrumentation were fixed, in which the screws were placed in the lumbar 5 ("rod+"). Then the same test procedures were repeated.

All specimens in above three steps were categorized to "condition" for latter analysis, which were "normal" (condition 1), "rod–" (condition 2) and "rod+" (condition 3).

Five points were selected to represent the whole pelvis or pelvis with prosthesis (*Figure 2*) as follow: Point 1, right Anterior Superior Iliac Spine (rASIS); Point 2, right lower edge of sacroiliac joint (rSIJ); Point 3, left lower edge of sacroiliac joint (lSIJ) or inner corner of upper part prosthesis (similar position to lSIJ, also abbreviated the same); Point 4, left Anterior Superior Iliac Spine (lASIS) or outer corner of lower part of prosthesis (similar position to lASIS, also abbreviated the same); Point 5, upper edge of Pubic Symphysis (PS). On basis of the continuous photo images, each point was picked up for 10 times. Their continuous movements in line with the increasing loading were calculated by custom-made digital imaging processing system based on digital image correlation (7). Data at the loads 50N, 100N, 150N, 200N, 250N, 300N, 350N, 400N, 450N and 500N were chosen for further analysis.

Statistical analysis was subsequently performed with SPSS 16, using $P<0.05$ as threshold for significance. To estimate the effects of conditions and points in the continuous loading, Generalized Estimated Equation (GEE) was used, taking "condition" and "point" as main variables (factor), "load" as covariable.

Results

The loadings during the mechanical test are in accordance with the linear elastic control mode (*Figures 3* and *4*). Due to the minimal changes in anterior-posterior displacement, we only analyzed the transversal displacement (positive values stand for to the right direction) and vertical displacement (positive values stand for to the downward direction).

For normal intact pelvises, the main displacement occurred in the vertical direction, while transversal displacement changed a little. Left and right points are symmetric. But for the two implanted pelvises ("rod–" and "rod+"), they had similar trend with the increasing

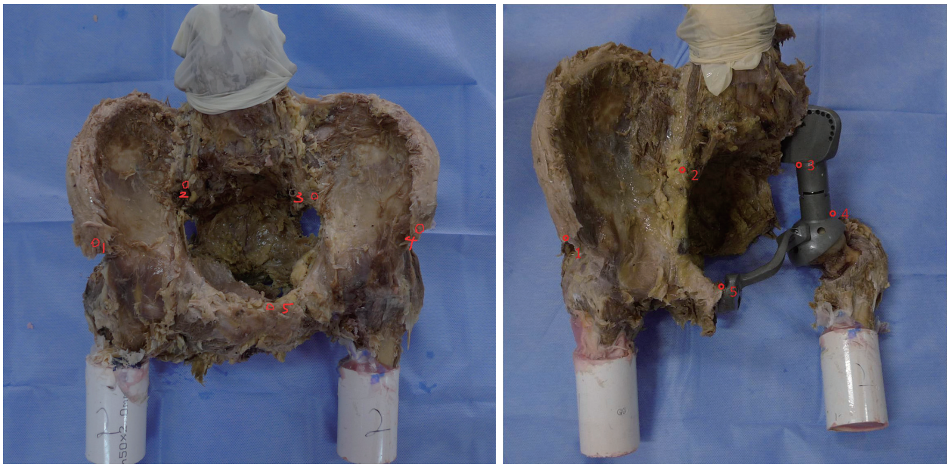

Figure 2 Selected points to represent the whole pelvis or pelvis with prosthesis.

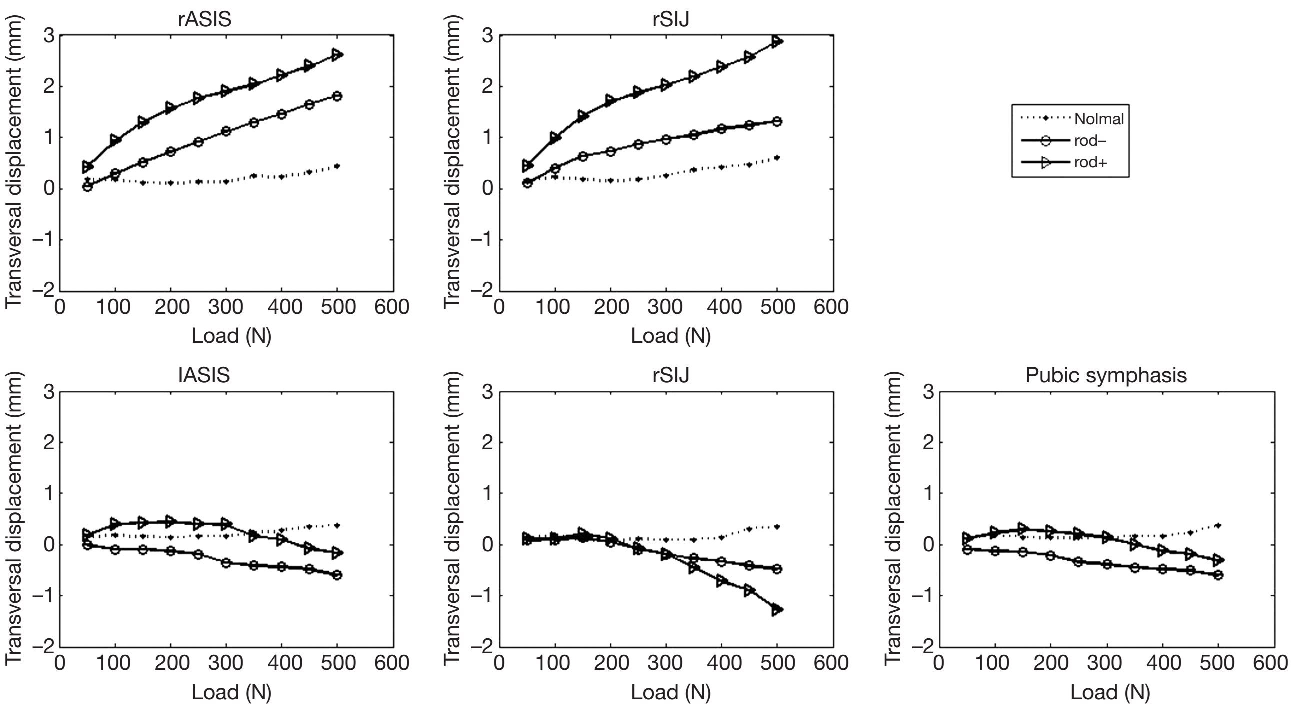

Figure 3 Transversal displacement of five points against applied loads for three conditions.

loading. The transversal displacement of left points (side of prosthesis) went opposite direction to the right points; whereas the vertical displacement of left points increased fewer than that of right points.

Statistical results (*Table 1*) revealed that, in general effect, transversal displacement of “rod–” and “rod+” had significant changes than “normal”, so as vertical displacement of “rod+” (P values <0.05). However, the vertical displacement of “rod-“ had no significant difference with “normal” (P=0.641). For the “rod–” and “rod+”, the right side (prosthesis side) had significant less changes than contralateral side (B values <0, P values <0.05) in both directions, but the points in the same side stayed no significant difference (P=0.718 and 0.147). Additionally,

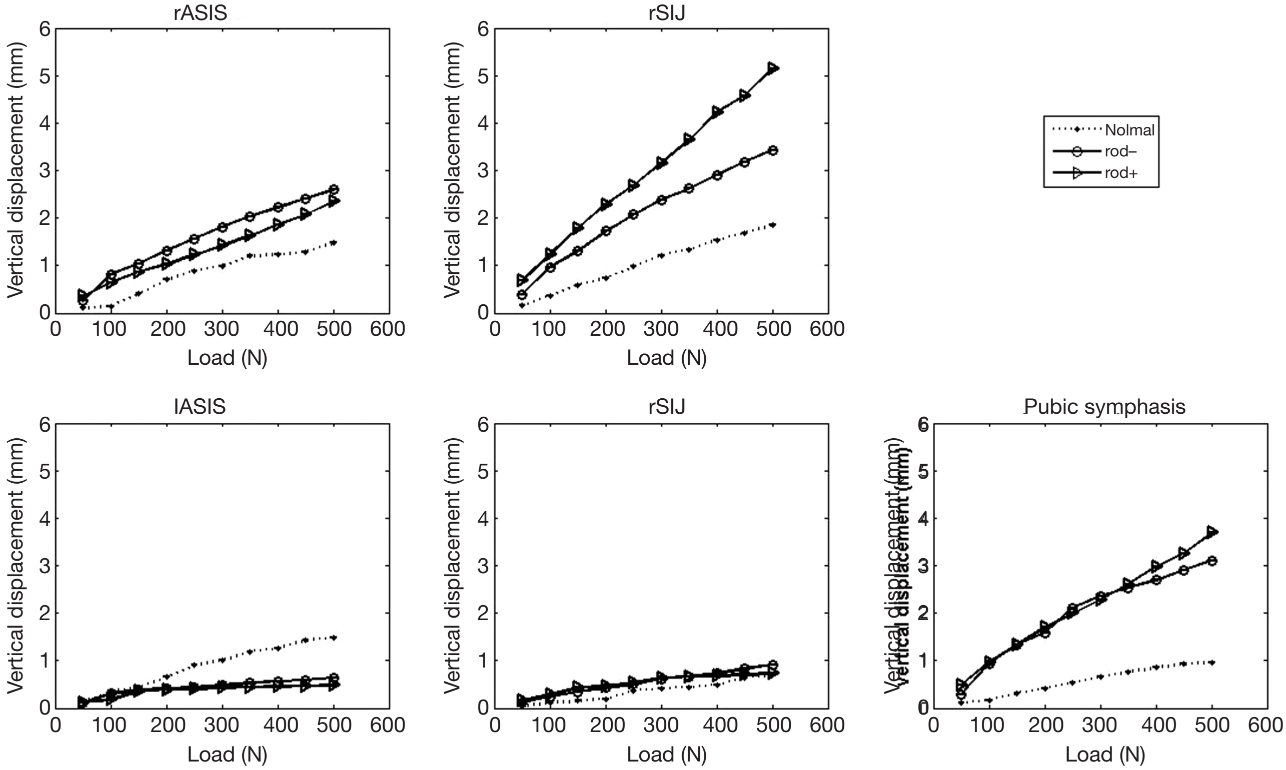

Figure 4 Vertical displacement of five points against applied loads for three conditions.

Table 1 Regression coefficients (B), standard error (SE) and P values from GEEs of transversal and vertical displacements (mm) among the three conditions (normal, rod– and rod+) and the five points during a continuous loading (“load” as covariate) in the general model

	Transverse displacement			Vertical displacement		
	B	SE	P values	B	SE	P values
Intercept	0.666	0.194	0.001	0.417	0.122	0.001
rod+	0.329	0.032	0.000	1.020	0.217	0.000
rod–	0.342	0.071	0.000	0.106	0.228	0.641
Normal*						
Marked Points						
PS	–1.417	0.065	0.000	–0.026	0.279	0.926
lASIS	–1.358	0.054	0.000	–1.262	0.150	0.000
lSIJ	–1.506	0.052	0.000	–1.374	0.075	0.000
rSIJ	–0.116	0.321	0.718	0.410	0.283	0.147
rASIS*						
Load	0.057	0.012	0.000	0.167	0.022	0.000
(scale)*	0.481			0.782		

*, the reference item for each variable.

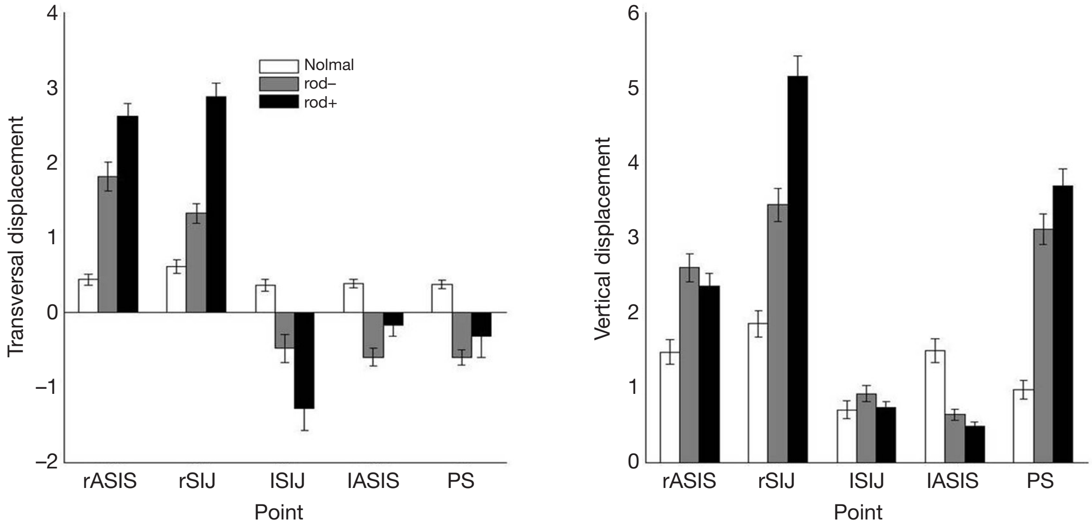

Figure 5 Average displacement (mm) of five points over ten times samples under the load 500N. Error bars represent standard errors.

the "PS" moved significantly only in transversal plane (P<0.05), but not in vertical plane (P=0.926). A more detail comparison example under the load 500N was shown in *Figure 5*.

Discussion

Treatment of malignant pelvic tumor is a tough challenge to patient's functional recovery, especially for those tumors of Type I-IV, which has the largest range of resection and difficult surgical technique of reconstruction. With the developing modular hemipelvic endoprosthesis, it appeared couples of advantages, such as good match of prosthesis, reasonable design, early exercise postoperatively (8). However, there were still debates about how to solve the problem of high loading at the connection between prosthesis and residual sacrum (9,10). Although new design of additional pedicle screw-rod system on the hemipelvic endoprosthesis, it is necessary to study its security and reasonability biomechanically.

As known, for normal pelvis, the stress concentrated on the superior edge of acetabulum, arcuate line, sacroiliac joint, sacral midline and the super area of the greater sciatic notch (11). The force is predominantly transferred along the sacroiliac joint onto the rest of the pelvic bone towards the superior edge of the acetabulum and the pubic symphysis. Within the whole pelvic ring, the hip bone still has the tendency to move laterally and downwards. The implanted pelvis with hemipelvic prosthesis seems to have similar stress concentrate (12), but due to its metal viscoelasticity, the prosthesis would be stiffer, which is in agreement with the results in our study—higher displacement at healthy side in both transversal plane and vertical plane. From the orthopaedic point of view, we should take it into consideration whether it may cause potential discrepancy or is just a normal compensatory, and attention to the potential complication at pelvic healthy half should be paid. It will be interesting to include the investigation on the physiology and pathology of the healthy half of pelvis with prosthesis in futural clinical studies.

The pedicle screw-rod system is an elastic fixation system, using for solving the problem of the instability between prosthesis with screw and residual sacrum. Without screw-rod system, as before, the stress at the root of sacral screw is high, and would be worse when the bone strength of the residual sacrum is not good or there are large defects in sacrum. These problems keep puzzling orthopaedic surgeons. However, the prosthesis in combination with screw-rod system seems to figure out these problems, showing the advantage that it can transfer the high stress from the root of sacral screw to the screw-rod system. Note that, many other surgeries in the lumbo-pelvic area have been taking advantage of it (13-15). The prosthesis we used is just in light of these previous studies, no matter if it was applied in trauma or other diseases.

Since the implanted side gets stiffer, the contralateral side (healthy side) has to suffer more deformation under the axial loading from the lumbar, as the results shown (*Figures 3* and 4, *Table 1*). Then the other problem appeared, that is, whether the rod is strong enough to bear the loading in the daily life for those patients who got pelvic tumor at Type I-IV and underwent such reconstruction surgery. Further finite element simulation should be applied to calculate how much the loading on the rod is and to what extent the rod fails.

The other drawback in this study is that only standing position on double feet was simulated. Since the loading distributions were similar at different positions: standing on two feet, standing on the foot of the affected side, and sitting (12), we only measured at one position. Further studies would include more positions and daily locomotion.

Conclusions

The pelvis of Type I-IV defect implanted with modular hemipelvic endoprosthesis showed asymmetric displacement under loading, where healthy side displaced more. The implanted pelvis plus screw-rod system showed less displacement at implanted side but more at contralateral side in comparison with those without screw-rod system. The screw-rod system strengthen the stiffness of the connection of the prosthesis and the residual sacrum, cause more deformation of the contralateral side, but the rod may bear more loading per se.

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