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PELVIC STRENGTH AFTER MAJOR AMPUTATION OF THE SACRUM

An Experimental Study

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Major sacral resections up to the level of S 1 and even higher have been performed. This has raised the question of the degree to which such operations weaken the pelvic ring. Fifteen cadaver pelves, including the fifth lumbar vertebra, were loaded to failure, five unresected, five after resection of the sacrum between S 1 and S 2, and five after resection about 1 cm below the promontory. The weakening of the pelvic ring amounted to approximately 30 per cent with the former type of resection and 50 per cent with the latter. Taking into consideration the calculated normal load on L 5 in upright standing it seems safe from this study to allow patients to stand with full weight-bearing at an early stage postoperatively after submaximal resection of the sacrum.

Key words: pelvis; sacrum; stability; amputation

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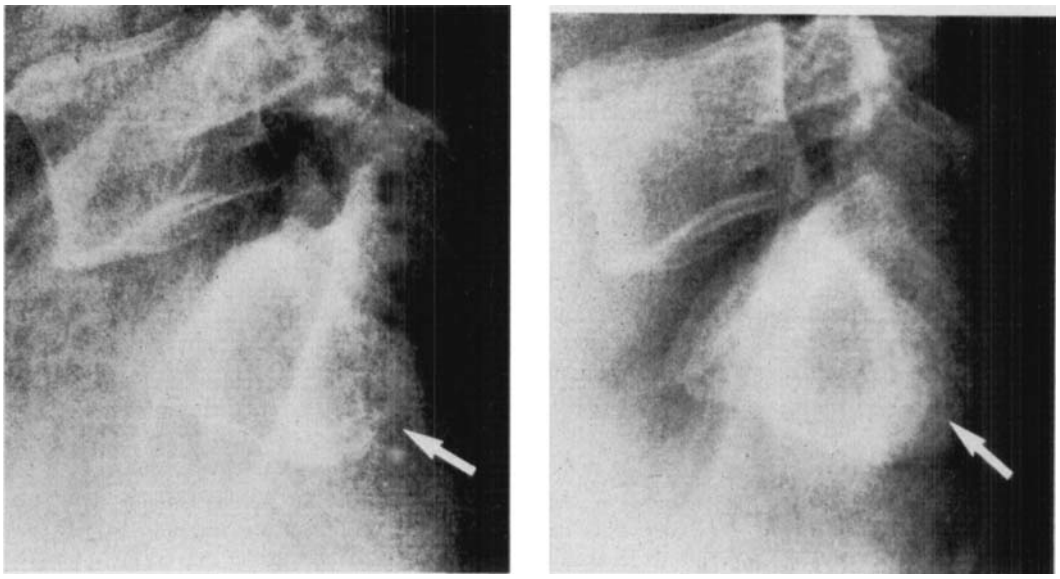
Tumors in the sacrum are often discovered at a relatively late stage and may reach a considerable size before coming under surgical treatment. The possibilities for radical removal of large sacral tumors, without doing a hemicorporectomy, are limited by the necessity to preserve, or reconstruct, a strong connection between the lumbar spine and the pelvic skeleton. The uppermost part of the sacrum with the corresponding parts of the sacroiliac joints should, if at all possible, be preserved. To our knowledge no investigations have been published that give information about how large a part of the sacrum can be removed without jeopardizing the strength of the pelvic ring. However, MacCarty et al. (1952) and Localio et al. (1967) have reported sacral resections up to the S 1 level with uneventful recoveries. Hays (1953) even performed a resection through the first sacral segment, leaving half of it as a bridge between the iliac bones, and the patient managed with a short leg brace. Evans & Lissner (1959) have carried out static vertical load tests on eleven specimens consisting of intact lumbar spine and pelvis and found the maximal load to be 290–1350 pounds (1290–6008 N, mean value 3514 N). Their material included both embalmed and unembalmed specimens. The localization of the injury at specimen failure was not given.

During recent years five patients with large sacral tumors have been operated



a b

Figure 1. Lateral radiograms of the L 5–S 1 region of a middle-aged male patient 2 weeks (a) and 2 years (b) after resection of the sacrum through the lower part of the S 1 vertebra. Note the skeletal adjustment: cortical appearance (arrow in b) of the osteotomized, initially cancellous (arrow in a) surface of the S 1 vertebra.

upon in our department. The whole of the sacrum was removed except for the first sacral segment to a varying extent. Adjacent iliac bone was removed on both sides so that the patients lost a large part of the sacroiliac joints and their ligaments. All these patients recovered well from the operation and it was possible to mobilize them to walking, initially with the aid of a stroller or crutches. These observations led to the present study. The purpose was to try to clarify to what degree the pelvis is weakened by a major sacral resection, including various parts of the sacroiliac connections, and to evaluate the retained strength in relation to the estimated normal load. This information should be helpful in determining whether patients with these sacral resections should be allowed to stand and walk with full weight-bearing at an early stage postoperatively. Later in the postoperative course there should be less problem as it is well known that a change of loading conditions will induce bone remodeling and adaption of skeletal strength. This is generally referred to as Wolff's law. In accordance with this law radiographic evidence has been obtained from the patients referred to above to suggest that the strength of the pelvic ring increases with time after the operation (Figure 1).

The anatomy and statics of the sacroiliac region have been described by several authors (e.g. Schunke 1938, Weisl 1954, Kopsch 1955, Solonen 1957, Hollinshead 1969). The posterior part of the pelvic skeleton can be looked upon as an arch with the base of the lateral pillars in the acetabuli. The sacrum, which takes up the body load, is the key stone of the arch. A downward movement of the sacrum is prevented by its wedge-shape and the unevenness of the sacroiliac joint surfaces. Separation of the pillars is prevented anteriorly by the pubic symphysis and posteriorly by

Table 1. Material and results in experimental study on pelvic strength.
Age, sex, body weight (BW), ultimate compressive load (UCL), calculated load in upright standing (P), "excess" strength (UCL/P), and diagnosis are given.

	No.	Age	Sex	BW (kg)	UCL (Newton)	P (Newton)	UCL/P	Diagnosis
Unresected	1	51	F	40	4611	569	8.1	Chronic pyelonephritis bilaterally with uremia + Circulatory insufficiency.
	2	56	F	64	3630	883	4.1	Collagenosis + Pulmonary embolism (Steroid treatment last 6 months).
	3	74	M	?normal stature	5297	–	–	Myocardial infarction + Pulmonary embolism.
	4	82	F	44	4905	628	7.8	Advanced arteriosclerosis + Cardiac insufficiency.
	5	85	M	60	5837	834	7.0	Bilateral bronchopneumonia + Cerebral arteriosclerosis.
				Mean value:	4856 (SD 824)			
Resection	6	43	M	?normal stature	5592	–	–	Bronchopneumonia + Hemorrhagic pancreatitis.
A	7	60	F	61	1619	844	1.9	Cancer of the uterus + Uremia + Circulatory insufficiency.
(below S 1)	8	61	F	50	1079	706	1.5	Aortic aneurysm.
	9	68	F	70	> 4905 •	961	> 5.1	Cardioarteriosclerosis + Myocarditis.
	10	74	M	44	3237	628	5.1	Advanced cardioarteriosclerosis.
				Mean value:	3286 (SD 971)			
Resection	11	29	M	?athletic	5101	–	–	Brain tumor.
B	12	59	M	76	2315	1040	2.2	Myocardial infarction + Advanced arteriosclerosis.
(through S 1)	13	63	F	50	1570	706	2.2	Congestive cardiomyopathy.
	14	66	M	80	1962	1099	1.8	Vascular lesion of the brain stem + Advanced cardioarteriosclerosis.
	15	69	F	?thin and lean	1472	–	–	Myocardial infarction + Cardioarteriosclerosis.
				Mean value:	2484 (SD 1500)			

• ultimate value could not be registered on account of technical failure.

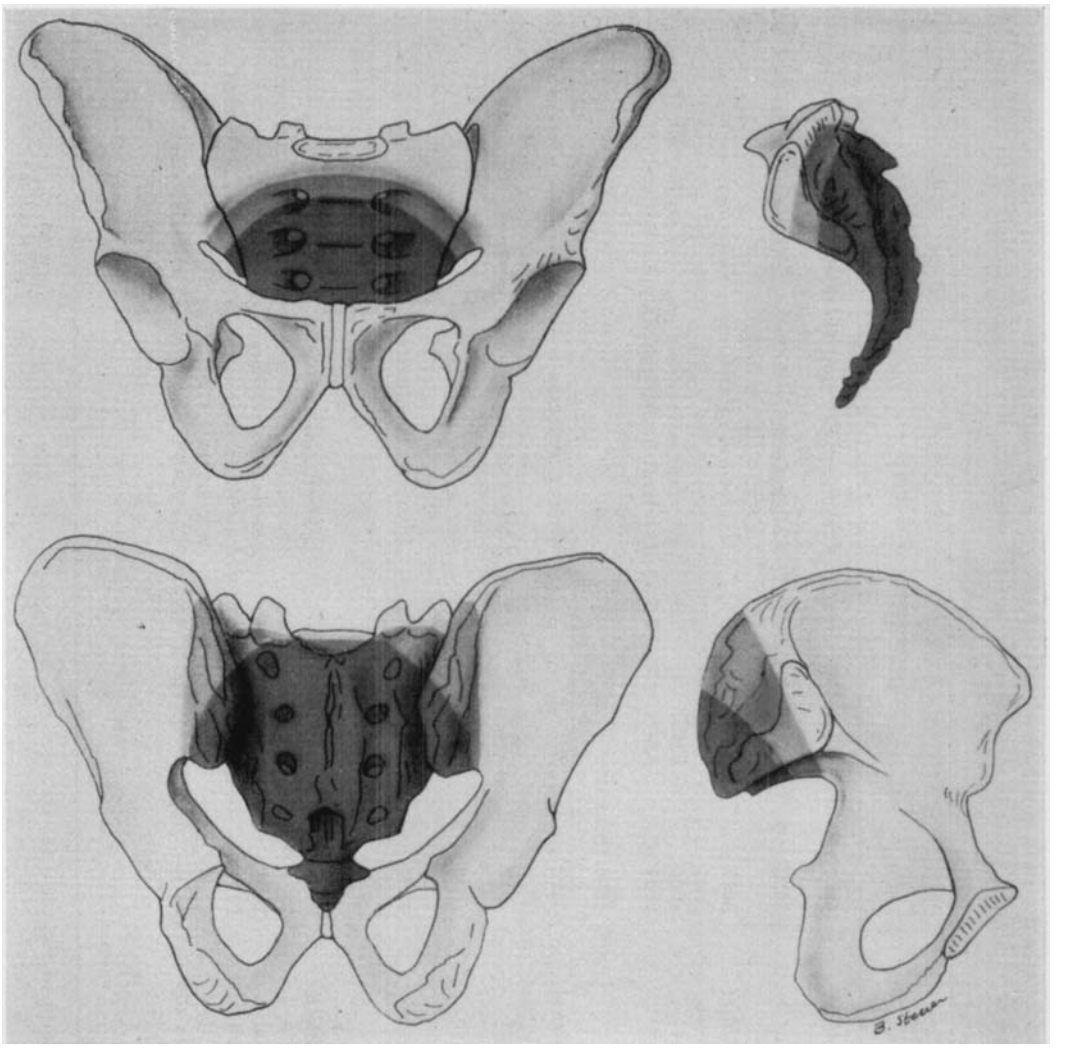


Figure 2. Schematic drawings of resections performed in this study. Resection A: darkest fields. Resection B: less dark fields also included.

the sacroiliac ligaments. The interosseous sacroiliac ligaments also serve as suspensors for the sacrum. On vertical loading of the sacrum these ligaments tighten and the posterior parts of the iliac bones are thereby pulled together so that the sacrum is squeezed between them. The interosseous sacroiliac ligaments also check the forward-downward movement of the upper part of the sacrum which takes place as a result of the vertical load. Thus, for several reasons the arch is dependent for its strength on the strong interosseous sacroiliac ligaments.

MATERIAL

Fifteen cadaver pelves were used (Table 1). They consisted of the pelvic ring with the fifth lumbar vertebra and had been roughly cleaned of soft tissues with the exception of the ligaments which were left intact. The specimens were kept in the deep-freeze and were allowed to thaw at room temperature in moist wrappings 12–24 hours before testing. This treatment has previously been shown not to alter the physical

properties of bone or collagen (Sedlin & Hirsch 1966, Hirsch & Galante 1967).

The pelves were divided into three groups with five specimens in each. In the first, no resection was made. In the second, sacroiliac resection was performed according to alternative A (see below) and in the third, according to alternative B (see below). The specimens originated from patients who had died of diseases that did not directly involve the skeleton. The age distribution was fairly wide, 29–85 years, but the age composition of the various groups was quite similar (Table 1). The causes of death were predominantly cardiovascular diseases. Two cases of uremia were included (nos. 1 and 7) and one patient had received steroid treatment during the last 6 months before death (no. 2). It was not possible to establish the exact duration of premortal bed-rest from the medical records. A major difference in this respect between the various groups was, however, unlikely.

Resection A (Figure 2, darkest fields)

Anteriorly the resection comprised the whole of the sacrum except for the first segment. Thus, the resection line ran between the bodies of S 1 and S 2 and through the anterior opening of the first sacral holes. Posteriorly the resection also comprised parts of the first sacral segment, including the posterior opening of the first sacral holes and the entire posterior wall of the sacral canal. From each iliac bone a posterior part, adjacent to the resected portion of the sacrum, was included. In this manner about one third of the sacroiliac joint with corresponding ligaments was removed on both sides.

Resection B (Figure 2, less dark fields also included)

Anteriorly the first sacral segment was divided approximately 1 cm below the promontory and superior to the first sacral holes. Posteriorly the body of S 1 was divided only a few millimeters from the lumbosacral disc. A considerably larger part of each iliac bone than in Resection A was included so that only about half the sacroiliac joint with corresponding ligaments remained on each side (anterosuperior part).

Figure 3. Close-up view of specimen under test conditions.

METHOD

The ischial tuberosities and the inferior pubic rami of the pelves were fixed in epoxy resin (Plastic Padding®) in a metal box in a position corresponding to upright standing (Boyd et al. 1958). The specimens were loaded on the L 5 vertebra in a standard material testing machine, Alwetron Model T-2000, with a deformation speed of 5 mm/min (Figure 3). A strain gauge load cell transducer of 9810 N (1000 kp) with an accuracy of ± 1 per cent (according to the manufacturer) was used. The load and the time were registered on an x-y-recorder over a measuring bridge and an amplifier. The specimens were x-rayed before and after testing.

To make it possible to judge the clinical significance of the experimental data the hypothetical load in upright standing was calculated according to Nachemson & Elfström (1970), who have shown that the load on lumbar discs in upright standing may be calculated using the formula $P = 6 + 2.2\,W$, where W is the part of the body weight exerting load upon the disc. This has been estimated by Ruff (1950), who found that approximately 60 per cent of the body weight lies above L 5. The calculated loads according to the above formula are given in Table 1.

Prior to failure testing, two specimens in each group (nos. 1, 5, 9, 10, 11, 13) were loaded one to three times up to approximately twice the estimated normal load in upright standing to find out if any permanent tissue damage occurred with these loads. Eventually all specimens were subjected to ultimate compressive loads.

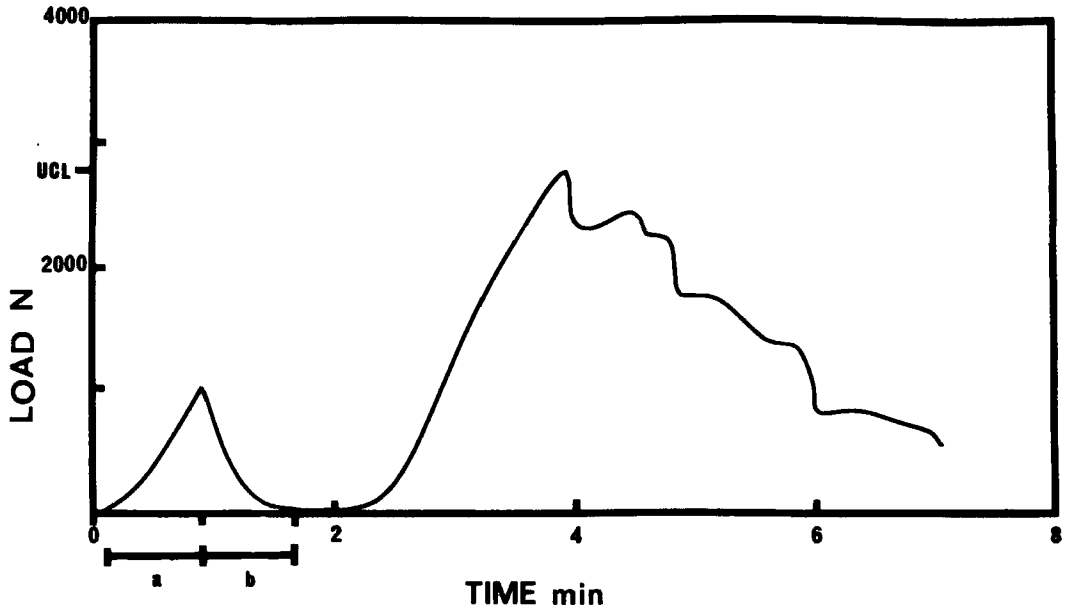


Figure 4. Load-time diagram of specimen no. 10 (resection A). Preliminary test to approximately twice the estimated load in upright standing revealed no residual deformation (a = b).

RESULTS

The result of the preliminary tests with loading up to approximately twice the estimated normal load in upright standing did not show any significant residual deformation. Thus, the unloading resulted in recovery of the deformation which was about 5 mm.

In the test to failure the mean ultimate compressive load in the group of unresected pelves was 4856 N (standard deviation 824 N). The specimens resected according to A had a mean ultimate compressive load of 3286 N (standard deviation 1971 N) and those resected according to B 2484 N (standard deviation 1500 N). The ultimate compressive load of each specimen is given in Table 1. A typical graphic recording of a load test (specimen resected according to A) is shown in Figure 4.

All specimens fractured through the lateral part of the sacrum relatively close to the sacroiliac joints, first on one side and then on the other. The fracture localization was difficult to observe in the specimens after unloading when the sacrum returned to almost its original position due to the elasticity of the obviously uninjured sacroiliac ligaments. If the deformation was allowed to continue well past the point of maximal load the fractures became more obvious and in resected specimens the S 1 vertebra or its remains eventually split. Permanent dislocation of the sacroiliac joints did not occur in any specimen. Figure 5 shows fracture localization in unresected and resected specimens.

DISCUSSION

The sacroiliac junction is very strong. Thus, the failure occurred in the lateral parts of the sacrum in unresected as well as resected specimens and the deformation curves also indicated a very low degree of permanent deformation of the soft tissues. The lowest value of ultimate compressive load in the group of un-

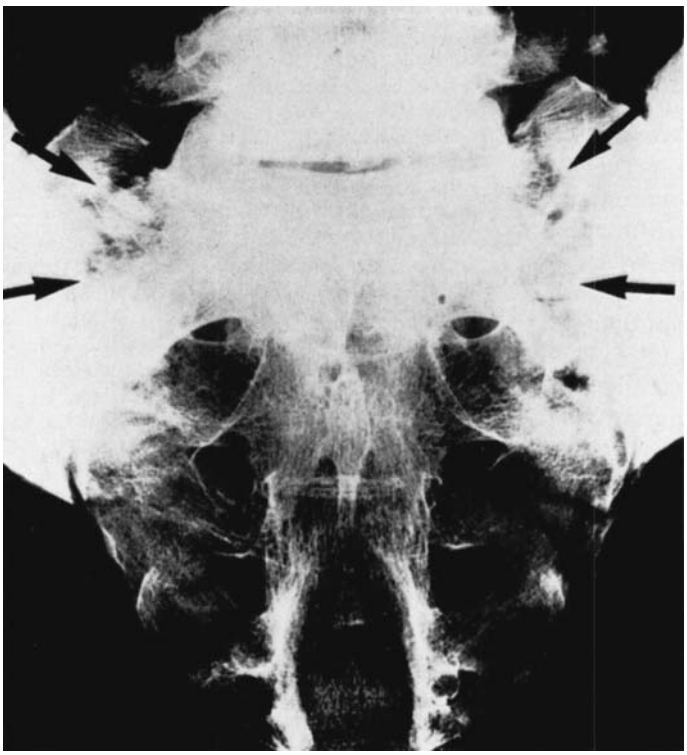
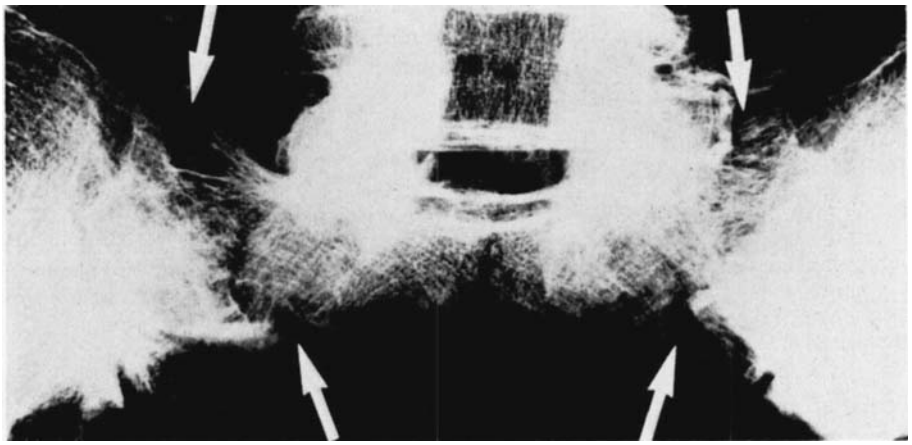


Figure 5. Radiograms of specimens showing fracture localizations. The initial fractures are indicated by arrows. a. Unresected specimen.

b. Resected specimen (through S 1).



resected specimens was noted in the steroid-treated patient (no. 2).

In this limited material the weakening of the posterior arch of the pelvis after Resection A (below S 1) was approximately 30 per cent and after Resection B (through S 1) approximately 50 per cent, as calculated from mean values. Information regarding the normal load *in vivo* on the pelvic ring is needed to evaluate our results and to judge whether the resections leave sufficient residual strength in the pelvic ring to allow early postoperative weight-bearing. It should be borne in mind that the load at a certain vertebral level is greater because of mus-

cular activity, than the weight of the overlying part of the body. Nachemson & Elfström (1970) have shown that the load varies depending on posture, movements, etc.: ordinary slow walking increases the load by about 15 per cent, jumping on the floor and coughing by about 40 per cent, straining with erect posture by about 50 per cent, and straining with sitting posture by 5–35 per cent.

In the cases in which information on the body weight was available (11/15) a good margin was found between the calculated load in upright standing and the load at failure, as seen from the calculated "excess" strength of the specimens in Table 1 (UCL/P). Thus, the test strength was 4–8 times the calculated load in upright standing in the unresected group, 1.5–5 times after Resection A, and approximately twice the calculated load after Resection B.

From this study it seems safe, with regard to residual strength of the pelvic ring, to allow patients to stand with full weight-bearing at an early stage postoperatively after submaximal resection of the sacrum including adjacent iliac bone.

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