



A morphologic evaluation of the sacroiliac joint and plate fixation on a pelvic model using a S1 pedicular screw, transiliosacral screws, and a compression rod for sacroiliac joint injuries

Sakroiliak eklem yaralanmalarında S1 pediküler vida-iliak plak/ iliosakral vida-kompresyon çubuğu uygulaması: Sakroiliak eklem morfolojik değerlendirilmesi ve model pelvis üzerinde uygulama

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Amaç: Sakroiliak eklemi oluşturan eklem yüzleri/fasies artikularisler ile komşu kemik bölgelerinin morfolojik ölçümlerini kuru kemik örnekleri üzerinde yaparak, bölgenin posterior iliak kanat üzerindeki izdüşümünü hesaplamak; sakroiliak eklem yaralanmaları için güvenilir bölge olarak değerlendirdiğimiz bu bölgeye uygulanan plak üzerinden transiliosakral vida ve S1'e pediküler vida kombinasyonundan oluşan sistemi pelvis modellerinde değerlendirmek.

Çalışma planı: Yirmi adet os koksa, 10 adet sakrumdan oluşan kuru kemik örneklerinde, sakrum lateralindeki ve iliak kanat medial yüzündeki eklem yüzleri, bölgelere göre posterior iliak kanat kemik kalınlıkları, S1 ile S2 foramina dış duvarlarının sakral eklem yüzüne olan uzaklıkları milimetreye duyarlı kompas ile ölçüldü. Lateral sakral kitlenin iliak kanat posterioruna uyan bölümündeki izdüşümü için plak tasarımı yapıldı. Pelvis modellerinde sakral foramina lateralinde kalacak şekilde plak üzerinden dört adet transiliosakral vida uygulandı. S1'e gönderilen pediküler vida ile plak iki ayrı tip yivli kompresyon çubuğuyla birleştirildi.

Bulgular: Eklem yüzüne ait ortalama değerler iliak kanat için taban uzunluğu 53.3 mm, yüksekliği 38.5 mm, eklem yüzü ön sınırının spina iliaca posterior superiora olan uzaklığı 56.2 mm; sakrum için taban uzunluğu 57.2 mm, yüksekliği 34.6 mm bulundu. Ortalama kemik kalınlıkları iliak kemiğin tüm bölgeleri için 19.2 mm, sakrumda S1 ve S2 foramina lateral duvarlarıyla eklem yüzü arasındaki uzaklık 21.7 mm bulundu. Bulunan izdüşüm için, taban orta noktasından çıkılan dik doğrunun, vida uygulamasında güvenilir bölge olduğu görüldü.

Çıkarımlar: Belirlenen izdüşüm bölgesine yerleştirilen plak üzerinden S1 ve S2 düzeylerinde sakral foramina lateralinde kalacak şekilde, sakral nöral ve çevredeki önemli yapılara zarar vermeksizin çoklu vida uygulanabilir. Plak/vida sistemine pediküler vida eklenmesiyle stabil bir tespit sağlanabilir.

Anahtar sözcükler: Kemik vidaları; kadavra; dislokasyon/cerrahi/radyografi; ekipman tasarımı; kırık fiksasyonu, internal/yöntem/enstrümantasyon; ilium/cerrahi; internal fiksatörler; pelvis/yaralanma/cerrahi/radyografi; sakroiliak eklem/yaralanma/cerrahi/radyografi; sakrum/cerrahi; bilgisayarlı tomografi.

Objectives: Morphological measurements were performed, of the articular surfaces and adjacent bone structures of the sacroiliac joint on dry bone specimens to determine the projection of the sacroiliac joint on the outer table of the posterior ilium. In addition, the effect of plate fixation using transiliosacral screws and a pedicular screw on S1 attached via a compression rod was evaluated on pelvic models to be applied in sacroiliac joint injuries.

Methods: Quantitative caliper measurements of dry bone specimens including 20 os coxae and 10 sacrum were made on the articular surfaces of the sacrum and the posterior ilium, thickness of the posterior iliac bone at different levels, and the distance from the outer walls of S1 and S2 foramina to the sacral facies articularis. After the construction of a plate matching the projection of the lateral sacral mass on the outer table of the posterior ilium, four transiliosacral screws were applied lateral to the sacral foramina on pelvic models. A pedicular screw sent to S1 was attached to the plate with a threaded compression rod.

Results: The mean values for the articular surface of (i) the posterior ilium were 53.3 mm (base length), 38.5 mm (height), and 56.2 mm (the distance from the anterior margin of the articular surface to the spina iliaca posterior superior); and (ii) the sacrum, 57.2 mm (base length), and 34.6 mm (height). The mean thickness of the posterior ilium was 19.2 mm, and the mean distance from the lateral walls of the sacral foramina at S1 and S2 levels to the articular surface was 21.7 mm. For the deduced projection, the perpendicular line from the middle of the base was found to be the safe zone for screw applications.

Conclusion: Through a plate applied matching the projection area, multiple screws may be sent lateral to S1 and S2 foraminal levels without damage to the sacral neural and surrounding vital structures. A stable fixation can be achieved by combining the plate/screw system with a S1 pedicular screw.

Key words: Bone screws; cadaver; dislocations/surgery/radiography; equipment design; fracture fixation, internal/methods/instrumentation; ilium/surgery; internal fixators; pelvis/injuries/surgery/radiography; sacroiliac joint/injuries/surgery/radiography; sacrum/surgery; tomography, X-ray computed.

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Sacroiliac joint dislocations constitute the most unstable group of pelvic ring injuries. In addition to posterior column injuries, disruption of the symphysis pubis or fractures in ischion or pubis bones (fractures of pelvic rami) may accompany injury. Hemipelvis is forced to rotate internally with vertical displacement.^[1-15] In vertically unstable pelvis injuries, it was observed that long-term follow up results were badly especially when an adequate reduction could not be achieved through traditional methods; nonunion, mal-union, heterotopic bone development, low back and sacral pain, scoliosis, gait disturbance with a limp, sitting problems, deformity in pelvis, leg-length discrepancy, limitation of daily life functions and severe neurologic sequelae may develop.^[7,9,14-16] The best results were obtained with internal fixation of pelvic complex. It was reported that application of posterior fixation together with anterior internal or external fixation methods would increase stability depending also on additional injuries as disruption of the symphysis pubis, superior and inferior pubic rami fractures (ischion and pubis bones fractures).^[1-17]

Sacroiliac joint can be approached from anterior or posterior for the internal fixation of posterior pelvic complex. Screw-plate can be applied with anterior approach.^[3,5,7,8,10,13,14,16] As posterior methods the following can be applied: double cobra plates,^[4,7,16] unilateral^[2,5,10,16] or bilateral (ilio-ilio) reconstruction plates^[7,12] and iliosacral cancellous screw,^[2,5,7,10,12,16] cannulated or non-cannulated iliosacral cancellous screw or lag screws,^[2,3,6-8,10,12,14] sacral rods/threaded compression rods,^[5,11,12,16] trans iliac-sacral-iliac bars,^[17] triangular osteosynthesis

(iliolumbar or lumbosacral fixation combined with transsacral, ilio-ilio plate or transiliosacral cancellous screw),^[18] combined use of S1 pedicular screw and the Galveston technique,^[1] S1-pediculoiliac fixation^[19] and percutaneous iliosacral screw guided by computed tomography (CT).^[3,4,9] Although they are not used so commonly as priority treatment nowadays, external fixator applications, which do compression temporarily or permanently with internal fixation or separately, have also been defined.^[3,5,10,12,14,15,20,21]

In posterior approach: necrosis and infection in the incision area on muscles and soft tissue; superior or gluteal artery, iliac veins, lumbosacral truncus, sympathetic chain and sacral root injuries may develop. In anterior approach to sacroiliac joint L5 and S1 nerve root injuries may develop.^[4,5,8,13,14,16,18,22] It was demonstrated in the anatomic studies carried out with human cadavers that this kind of injuries might occur as a result of screw insertion with incorrect technique or in wrong direction.^[23,25]

The largest part of lateral sacral mass (pars lateralis) which is located at the lateral of intervertebral foramina is sacral ala that belongs to S1. It includes an articular surface antero-inferiorly “facies auricularis” and a nonarticular surface postero-superiorly “tuberositas sacralis”. Its lateral appearance is like a triangle (Figures 1 and 2b).^[26,27]

In this study, sacroiliac joint, lateral sacral mass/pars lateralis and outer table of posterior ilium were evaluated morphologically on dry bone specimens provided from the department of anatomy (Figures 1 and 2). In the light of the data obtained; a

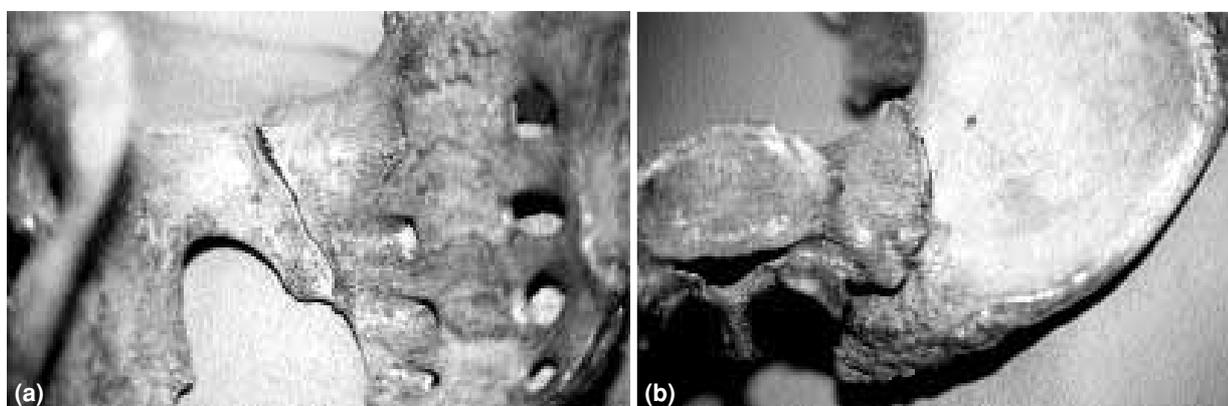


Figure 1. (a) Anterior, and (b) postero-superior view of right sacroiliac joint and lateral sacral mass in dry bone specimen that was made joint

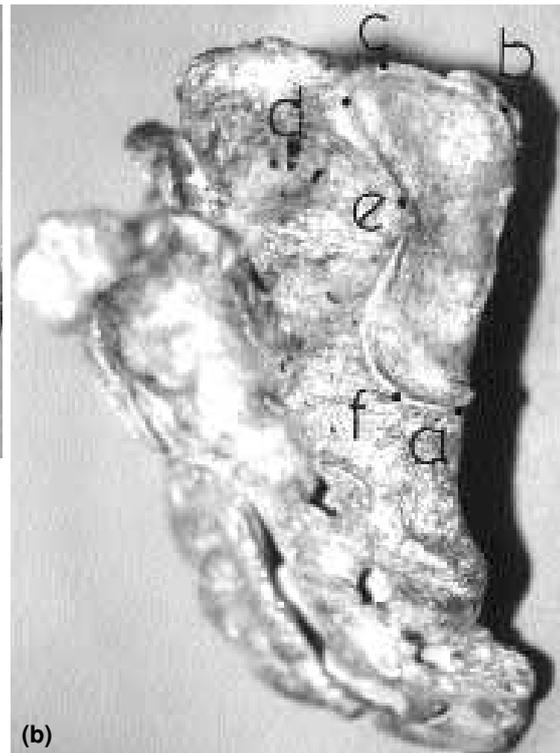
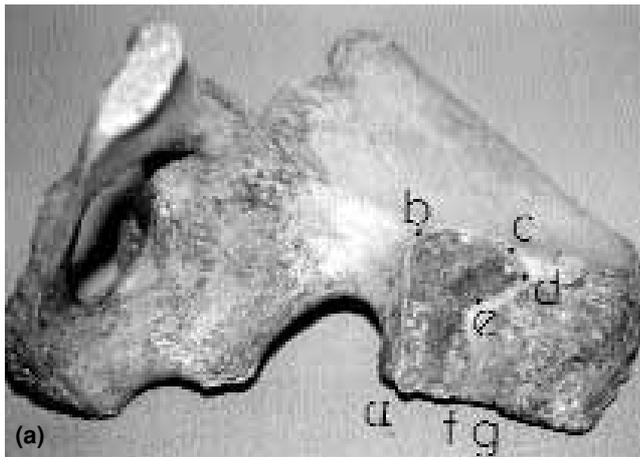


Figure 2. View of (a) facies auricularis and tuberositas iliaca in medial of the posterior iliac wing and (b) lateral sacral mass in dry bone specimens that constituting the half of right pelvis

(a) For the iliac facies auricularis, a is SIPI; g is SIPS; a-b is base length; b-d is height; c-g is the distance of front edge of articular surface to SIPS; e-f is the distance of posterior edge of articular surface to SIPI.

(b) For the sacral facies auricularis, a-b is base length; b-d is height/arm which is extending the sacral ala; e-f is the same distance on the iliac wing.

plate that matches the projection of the lateral sacral mass, which was stated to be a suitable and secure part to apply screw and also includes facies auricularis in its inferior part, on the outer table of the posterior ilium was constructed (Figures 3 and 4).^[2,14,26] Four screws were applied transiliosacrally from the holes that were linked to each other for free move-

ment, on the lateral of sacral foramina and in the lateral sacral mass. The system which was made up of two compression rods that would enable link between plate and pedicular screw by applying pedicular screw to S1 was evaluated on plastic pelvic models (Figures 4, 5, and 6).

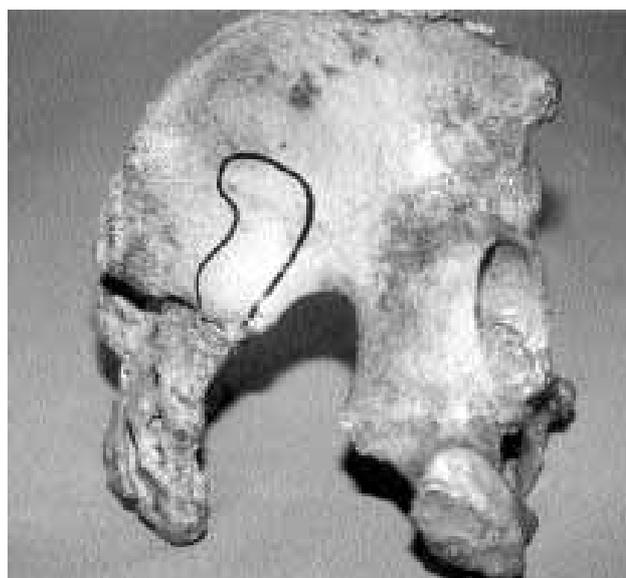


Figure 3. In the half of right pelvic that was made joint, projection of sacroiliac articular surface on posterior iliac wing



Figure 4. Parts that form the designed system: plates of two different lengths, cancellous screws that are applied transiliosacrally and screws with low profile heads, vertebral pedicular screws and cancellous screws for S1, connective two different type threaded rods and nuts that provide locking.

Table 1. Anatomic parameters “measurement values (mm)” of facies auricularis in the internal surface of iliac wing *

	Average	Range
Base length	53.3	44-62
Height	38.5	32-45
SIPS-anterior limit of articular surface	56.2	48-64
SIPI-posterior limit of articular surface	34.2	29-39
Width	18.6	13-23
Distance of base to ischiadic notch	7.2	6-11

* In 20 os coxae/ilia bone specimens; SIPS: Spina iliaca posterior superior; SIPI: Spina iliaca posterior inferior.

Materials and method

Dry bone specimens including 10 right, 10 left and totally 20 os coxae and 10 sacra were provided for the study from Inonu University Faculty of Medicine Department of Anatomy. Base lengths, heights and widths of facies auricularis on lateral of the sacrum and on medial of posterior ilium, which makes up sacroiliac joint, were measured on them. Quantitative caliper measurements of projection areas were carried out on lateral of the posterior ilium; distance from the outer walls of S1 and S2 foramina to facies auricularis of the sacrum in lateral, and bone thicknesses of articular surface of the medial side of posterior ilium and neighbour bone part, and the results were evaluated. Therefore, mean distance between outer wall of ilium and sacral neural foramina was found. For the measurements, the

Table 2. Anatomic parameters “measurement values (mm)” of facies auricularis in the sacrum*

	Average	Range
Its parallel base to long axis of sacrum	57.2	52-63
Its parallel height to upper edge (limit) of sacrum	34.6	29-42
Width “for all zones”	18.5	13-23

*In 10 sacra bone specimens.

longest distances of articular surfaces of sacrum and posterior ilium which constitute the sacroiliac joint were evaluated. When finding out the projection of articular surface on posterior ilium, distance of articular surface base to the edge (limit) between the greater ischiadic notch and spina iliaca posterior inferior (SIPI), and the distances of the front part of articular surface height to spina iliaca posterior superior (SIPS) and SIPI (Figure 2). It was determined that the area behind the greater ischiadic notch (Figure 3) was the most secure area to apply plate and screw without damaging the sacral neural structures and surrounding vital structures, in way nearly parallel to SIPS and SIPI.

In the light of these measurements, plate-iliosacral screw was applied from lateral of the posterior ilium which is a secure area and pedicular screw was applied to S1 by utilizing the available systems for the patients with sacroiliac joint injuries; the system designed by using threaded rod to connect them together (Figure 4) was evaluated on plastic pelvic models (Figures 5 and 6).

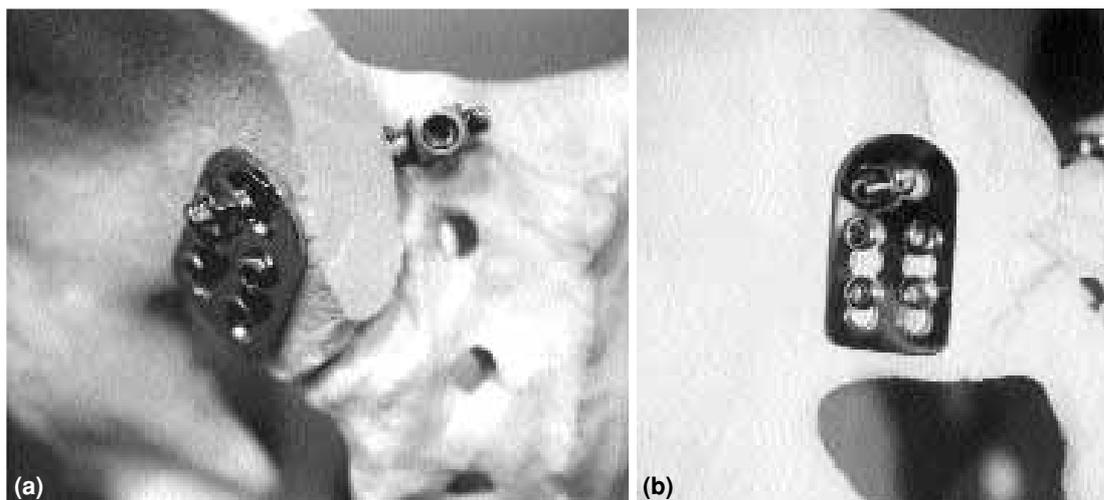


Figure 5. On the left posterior iliac wing, application made up of connected four screw holes (small size plate), transpedicular screw that is vertebral to S1, and bilateral threaded compression rod that provide the link between the plate and S1 screw; (a) postero-lateral and (b) lateral views. Posterior section of iliac crista was cut out to provide the view.

Table 3. Bone thickness according to zones (mm) *

	Average	Range
Iliac Bone		
Facies auricularis – anterior part	22.3	20-28
Facies auricularis – 2 cm in anterior of SIPI	17	14-21
In the section neighbour to facies auricularis	18.4	14-24
General average of all zones	19.2	14-28
Sacrum		
S1 foramen lateral border - facies auricularis / in the anterior	23.1	17-30
S1 foramen lateral border - facies auricularis / in the posterior	24.8	18-32
S2 foramen lateral border - facies auricularis / in the anterior	19.3	16-25
S2 foramen lateral border - facies auricularis / in the posterior	19.6	17-23
General average of S1 and S2	21.7	16-32

*In 10 sacra and 20 os coxae / ilia dry bone specimens; SIPI: Spina iliaca posterior inferior.

Results

The articular surface, which makes a joint with the sacrum in medial of the ilium called facies auricularis^[27] anatomically, was found to be about 7.2 mm (range 6-11 mm) superior the edge stretching between greater ischiadic notch and SIPI; the average base length was 53.3 mm (range 44-62 mm) and its average height stretching out towards tuberositas iliaca^[27] was 38.5 mm (range 32-45 mm). The average distance of anterior border (limit) of the part of facies auricularis that stretches out towards tuberositas iliaca to SIPS was measured as 56.2 mm (range 48-64 mm),

the average distance of its posterior border (limit) to SIPI was measured as 34.2 mm (range 29-39). Mean width of articular surface was 18.6 mm (range 13-23 mm) in all zones (Table 1, Figure 2a). The base of facies auricularis ossis sacri^[27] constituting the articular surface in the sacrum which stretches out along the sacrum long axis was meanly 57.2 mm (range 52-63 mm), its section close to the top joint surface that stretches out to sacral ala belonging to S1 was meanly 34.6 mm (29-42 mm), mean value of the width of articular surface was 18.5 mm (13-23 mm) in all zones (Table 2, Figure 2b).

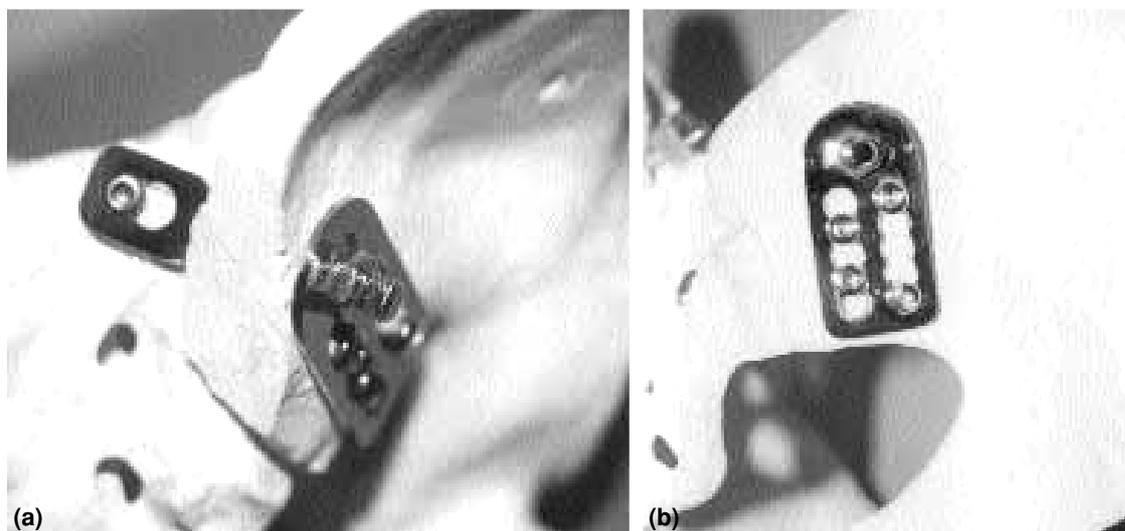


Figure 6. On the right posterior iliac wing, application made up of connected five screw holes on large size plate, which provides a link from the section flattened like a plate to S1 by means of a normal cancellous screw and the section that provides a link between this screw and the iliac plate is made up of a bilateral threaded compression rod; **(a)** postero-lateral and **(b)** lateral views. Posterior section of iliac crista was cut out to provide the view.

Thicknesses of bones were evaluated according to zones. Mean thicknesses of iliac bone were 22.3 mm (range 20-28 mm) in the anterior of part of facies auricularis that is close to the greater ischiadic notch, 17 mm (range 14-21 mm) in 2 cm anterior of SIPI; mean thickness of iliac bone matching tuberositas iliaca which is close neighbour to facies auricularis was measured to be 18.4 mm (range 14-24 mm). When this value was calculated as the average of bone thickness in all zones, it was found to be 19.2 mm (range 14-28 mm) (Table 3, Figure 2a).

Mean distances of lateral borders of S1 and S2 foramina in sacrum to the articular surface borders that make joint with ilium in the anterior and posterior surface were measured to be 23.1 mm (range 17-30 mm) in anterior surface and 24.8 mm (range 18-32 mm) in posterior surface for S1; 19.3 mm (range 16-25 mm) in anterior surface and 19.6 mm (range 17-23 mm) in the posterior surface for S2. When this value was calculated as general average for S1 and S2, it was found to be 21.7 mm (range 16-32 mm) (Table 3). In bone measurements, it was observed that even the values in the right and left sides of the same sacrum which didn't have any abrasion in the borders might be different (based on anatomic diversity).

Application

In the light of the measurements, a plate was designed to be applied onto the posterolateral surface of the ilium. On the plates, there were four and five screw holes that were parallel to each other and interrelated among themselves (connected holes), in two lines and parallel to long edge, and two interrelated screw holes that were in the outer convex side of the short edge/width. Plates were got constructed in two different dimensions in a way that their thickness was 2 mm, width was 28 mm, lengths were 49 and 55 mm so that they would be compatible to posterior ilium during screw up/fixation (and they would be shaped/formed if necessary) (Hipokrat Inc. Co., Turkey) (Figure 4)

Plates were applied on postero-lateral of iliac wing, nearly parallel to SIPS and SIPI, in a way that they were matching the projection of lateral sacral mass on posterior ilium, their base (short edge) was 5-10 mm above the edge between and SIPI and anterior border of their long edge didn't exceed greater ischiadic notch border. When the anterior edge of the

plate was placed at a mean distance of 40.6 mm to SIPI (distance of SIPI's articular surface base length to midpoint + half of plate width = 26.6 mm+14 mm) and 42.1 mm to SIPS (distance of SIPS's articular surface base length to midpoint + half of plate width = 28.1 mm+14 mm), the greater ischiadic notch limit that had been determined was not exceeded. Two cancellous screws were applied from the screw holes in the front part to S1 and two cancellous screws were applied from the screw holes on the back side to the zone between S1-S2; these four screws were applied in such a way that those which are close to the greater ischiadic notch were directed to the articular surface of sacrum, and those which are close to the crista were directed to the outer surface of joint (tuberositas sacralis) and they were applied in way that they exceeded the sacrum and iliac bone thicknesses and were far from the sacral foramina (Figures 5 and 6). As the iliac wing's mean thickness in all zones was evaluated to be 19.2 mm (range 14-28 mm) and the mean distances of lateral borders of S1 and S2 foramina to the lateral border (articular surface) of sacrum were evaluated to be 21.7 mm (range 16-32 mm), it was concluded that the mean distance of the lateral borders of the foramina walls to the outer surface of ilium was 40.9 mm (19.2 mm+21.7 mm). However, as age and gender discrimination was not carried out in the bone specimens that we obtained and as all of the sacra and os coxae were not specimens of the same pelvis, the bottom limit of iliac bone and sacrum thicknesses couldn't be determined definitely. By carrying out the CT examinations of bone specimens before application, the distance between the lateral borders of foraminal walls and iliac bone outer cortex was taken into consideration; it was adopted that the lengths of the screws must be so that they could not reach to the foramina of S1 and S2 and vertebral canal (canalis sacralis). It was planned that four or five cancellous screws could be sent from the holes on the plate in suitable specimens. The screws to be sent were designed in such a way that they would have lag effect (normal cancellous screw) or be buried in the hole on the plate and would not make steepness in the profile. Pedicular screw that was applied on S1 was sent in suitable axis towards the medial. Using polyaxial screws with multidirectional movement feature as pedicular screws facilitates the conformity of compression rod, which provides

the relation with the plate, with screw hole. Threaded bars/rods whose corresponding surfaces were smoothed were used so that the threads didn't deteriorate during the process of bending the rod that provides the relation between S1 pedicular screw and iliac plate. As another design, a normal cancellous screw was applied on S1 from the suitable one of interrelated two holes in the plate-shaped zone that fitted to the pedicle, which was located on the threaded rod that provides the relation with the iliac plate. Rods were constructed in different lengths so that they would be suitable for the distance between the iliac plate and S1. The fixation done in the iliac plate side was realized by means of nuts that were placed in the suitable one of interrelated two holes on the upper section and horizontal line of the plate and that could do compression (Figures 4, 5 and 6).

Discussion

It was reported that posttraumatic arthritis and persistent pain might develop after sacroiliac joint injuries, due to residual articular incongruity and chronic sacroiliac joint instability.^[14,15] Matta and Saucedo^[7] reported that malunion or nonunion was developed in 54% of the patients they treated conservatively. It was stated that in the injuries in this complicated ligamentous and bone zone, sacroiliac joint conformity and stability could be achieved by means of open reduction and internal fixation.^[1-19]

Posterior pelvic injuries are divided into three main groups such as fractures of the sacrum, fracture dislocations of the sacroiliac joint, and pure sacroiliac dislocations.^[15] Injury can be accompanied by ischion and pubis fractures (fractures of the pelvic rami) and disruption of the symphysis pubis.^[1-5,7-16] Surgical approach is planned according to the injury type. Plate-screw system that was designed in our study was planned to be used especially in cases with pure sacroiliac dislocation. However, it was thought that also the fracture in the posterior of the iliac bone could be fixated with the plate that was applied.

In sacroiliac joint injuries; open reduction and internal fixation can be realized by means of anterior^[3,5,7,8,10,13,14,16] or posterior^[1-12,14,15-19] approach. Sacroiliac joint can be reduced and fixated under direct view with anterior approach; moreover, potential lesion problem can be prevented by keeping away from posterior soft tissues. However, anterior approach requires retro-

peritoneal approach.^[2,7,13,14] It provides indirect reduction in sacroiliac joint fractures. It's easy to see and evaluate the upper section of the joint. However, when the plates are placed, the back side of the joint can be open.^[2,8] Because of its being close to L5 and S1 nerve root, there is potential risk of injury in the nerve.^[2,8,13,16]

The fixation that is done is weak to the stresses that affect from the cephalad direction and if there is fracture in the sacral ala, plate-screw cannot be applied from the anterior.^[8] Ebraheim et al.^[28] reported that in their anatomical study on cadaveric pelvic specimens where they applied anterior approach to sacroiliac joint, the zone that is 4 cm above the pelvic brim is the safe site/zone for L4 nerve branch and L5 nerve root. In sacroiliac joint injuries, open reduction applications from the posterior are simpler and safer. They provide suitable and adequate surgical view in sacroiliac joint and iliac wing fractures.^[1,2,8] The posterior approach allows for visualization the back of the joint directly, evaluation of the anterior section of the joint can be done by controlling with palpation, only indirectly.^[5,8,13]

It should be kept in mind that posterior approach is risky if there is another soft tissue injury in this site.^[4,5,8,9,13,16] Stabilization of the pelvis can be achieved with trans ilio-iliac threaded rods, trans iliac-sacral-iliac bars/rods, trans ilio-iliac reconstruction plates, double cobra plates, extraarticular plate-screw/lag screws, trans iliosacral screws, S1 pedicle screw-Galveston method, S1 pediculoiliac fixation and triangular methods.^[1,2,4-19] After posterior approach, necrosis and infection may develop in soft tissues in incision sites; and due to screw penetration to upper cortex or anterior of sacral ala, superior gluteal artery, iliac veins, lumbosacral truncus, sympathetic chain and sacral root injuries may develop.^[4,5,8,13,14,16,18,22-25] Licht et al.^[24] reported as a result of their studies on cadavers that common iliac artery and vein, sympathetic chain and lumbosacral truncus injuries may develop in pedicular screw applications on S1; common iliac vein, middle sacral artery, S1 and S2 nerve roots, sympathetic chain and rectum injuries may develop in pedicular screw applications in S2 and S3 levels; therefore, they said that the anterior cortical penetration not be used during sacral pedicular screw applications. In other anatomic studies, it was stated that sacral screw applications is not an easy and a benign procedure; it is necessary to apply adequate anatomic knowledge and careful surgical techniques in order to decrease anterior neurovascular and visceral injuries to

minimum levels.^[23,25] In the application of designed plates/transiliosacral screws, as screws were planned so that they will be in the bone structure in the lateral of S1 and S2 foramina, it was thought that sacral neural and surrounding vital structures will not be damaged by sending screws with suitable axis and lengths.

In applications from the posterior, it is important for a successful attempt of decreasing complications to determine the points in posterior ilium where screws will be sent correctly and to do sending in the right direction. Some studies suggested 2.5 cm lateral to SIPS and 2.5 superior to the greater sciatic notch as “the most suitable screw application/entrance point”.^[5,26] However, in the study of Ebraheim et al.^[29]; 3 to 3.5 cm anterior to the posterior border of the iliac crest in the sagittal plane, and 3.5 to 4 cm cephalad to the greater sciatic notch were described for placement of a single iliosacral screw to be sent to S1. Kraemer et al.^[6] and Matta and Saucedo^[7] applied the entrance/insertion point on the ilium for the screw to be sent to S1 located as 1.5 cm anterior to the crista glutea the midpoint between the iliac crest and the sciatic notch. Xu et al.^[26], who evaluated the projection of the lateral sacral mass on the outer cortex/table of the posterior ilium, described this zone as an isosceles triangle whose base is 5.4 mm (range 4-7 mm) superior the inferior edge, between the major sciatic notch and SIPI; mean base width is 56.8 mm (range 48-61 mm) and mean height that is drawn from the middle point of base is 61.4 mm (range 54-70 mm); and they stated that the line that is drawn vertically from the midpoint of the base to the apex of the projection/angle is the safe and suitable place to send transiliosacral screw. This line conforms to a distance that is in anterior on an average 30 mm (range 25-40 mm) from SIPS and on an average 27.4 mm (range 23-31 mm) from SIPI. They stated that in case that screw is sent from the inferior from this zone, the screw should be sent in horizontal direction in a frontal plan due to the concavity of the sacral ala; that screws sent from the superior area of the projection can be applied without harming joint by horizontal and slightly downwards directions because this zone consists mainly of non-articular surface. Borrelli et al.^[2] and Tile^[14] described lateral sacral mass as the safe and low risky zone. Mirkovic^[30] stated that applying screw from the very anterior according to the anatomic projection of lateral sacral mass is an inherent risk for the anterior

intrapelvic structures due to the anterior concavity of the sacrum; moreover, stated that screws sent to this zone may not be able to provide adequate biomechanical stability because the upper section of this projection is nonarticular structure and because of ligamentous structures. In S2 level, mean distance between the lateral surface (outer table) of the ilium and the lateral border of the sacral canal was determined to be 55.2 mm (range 49.5-60 mm) and it was suggested that screw should be sent 90 degrees vertical to the long axis of the sacrum and 60 degrees inclination towards anterior on the outer table (cortex) of the ilium.^[31] In the projection of articular surfaces (facies auricularis) that make up the sacroiliac joint, which we evaluate in our study, with an average value 26.6 mm (range 22-31 mm) that is midpoint of base length from SIPI and with an average value 28.1 mm (range 24-32 mm) distance from SIPS are similar to the safe zone described by Xu et al.^[26] Values that we measured as the height of articular surfaces are within non-articular zone (tuberositas sacralis) of lateral sacral mass. Distances from upper limits of screw holes that were penetrated for applying transiliosacral screw on plate to plates' inferior edge are 30 and 36 mm, respectively, on our plates of 49 and 55 mm lengths. These values conform to the zone within tuberositas sacralis of above described articular surface heights. As width of our plate is 28 mm, plate exceeds 14 mm to anterior and posterior when it's placed on this line; if the distance outside the screw holes on the plate is considered to be 5.5 mm, screws are located 8.5 mm anterior and posterior from the safe middle line. Furthermore, when the distance of 5-10 mm superior the greater sciatic notch postero-superior edge that will change according to anatomic features where the plate is placed, and 5.5 mm, which is the distance of first holes to plate's edge, are added, it is seen that the holes are 10.5-15.5 mm superior this edge. The zone where plate was placed and interrelated screw holes were similar to the points which were described as safe entrance points in screw application for the S1 and S2 pedicular distances by the other authors above. When short screw was sent from the holes of the plate in such a way that they would stay in the lateral of S1 and S2 foramina, bone structure in sacrum was not exceeded.

Anatomic and biomechanical studies were conducted in order to evaluate the stability of the screw

applied and investigate its relation with the bone strength of the zone it was applied on and insertion depth. Zindrick et al.^[32] reported that there's not significant difference in the stability of screws that are sent to 50% depth of vertebrae corpus and to the anterior cortex in such a way that they will not exceed the cortex; that they realized considerably stronger structure in the screws that exceeded the cortex (through cortex) compared to those that didn't exceed the cortex (to cortex); that cancellous screw that is sent until cortex provides more stable in the cancellous bone in the vertebrae corpus compared to cortical screw; and that pull-out force increases 32% when large diameter screw that exceeds cortex are used, in their studies which they conducted with 4.5 mm cortical and 6.5 mm full-threaded cancellous screws. The same authors stated that the S2 pedicle site has significantly weaker pull-out force values; that screws that will be directed to 45 degrees lateral towards sacral ala or towards medial in S1 pedicle provide stronger pull-out values. Kraemer et al.^[6] reported that long-threaded screw that is sent to sacral body has more pull-out strength than short-threaded screw that is sent to sacral ala and body; that short-threaded screw that is sent to sacral body has more pull-out strength than the short-threaded screw that is sent to sacral ala, in the biomechanical studies they conducted with 70 mm long, 16 mm and 32 mm thread-length cannulated cancellous screws, which they applied on cadaveric human pelvis iliosacrally. In the anatomic studies conducted, it was shown that bone density in S1 body level is 60% greater than that in the sacral ala; it was stated that as screw fixation is most dependent on the density of the bone, the screws sent to S1 object provide better fixation than those sent to sacral ala.^[22] Studies of Peretz et al.^[33] verify that trabecular structure of sacral body has greatest density, especially the trabeculae have their greatest density underneath the endplates, and that trabecular structure and bone density of sacral ala is less. However, while screws sent to sacral ala are safer in terms of neurovascular injury, those sent to sacral body have more complication risk.^[2,14,26] We applied cancellous screw from the interrelated screw holes on the plate that we designed in such a way that they will be on the lateral of sacral foramina (Figures 5 and 6). When screw lengths were calculated according to the distance between regional the outer table of the posterior ilium and sacral foramina, mean thickness of iliac bone for all zones was found out to be 19.2 mm (range 14-28

mm), general mean width of lateral sacral mass for S1 and S2 (the distance between the lateral border of foramina and edge "limit" of articular surface) was found out to be 21.7 mm (range 16-32 mm). We thought that screws whose length was found by adding the value 15 mm, which is a value under 16 mm that is the sub limit of general mean thickness value for S1 and S2, to this value measured after exceeding the iliac wing thickness will stay within lateral sacral mass and that they will provide adequate stabilization. (We believe that it's necessary and plan to do a biomechanical study on the strength of stabilization). Bone density and strength of lateral sacral mass is weaker in comparison to the bone structure of S1 body,^[22, 23] but as it is possible to send more than two screws through plate, we planned to send short cancellous screw in such way that it will stay lateral to sacral foramina or will not extend to pedicular zone. Measurements in CT scans to be done before operation due to anatomic variants will help calculate suitable screw length. Compression can be done when necessary by means of rod one surface of which is threaded which will be applied preferably between polyaxial transpedicular screw sent in medial direction towards S1 body and and plate (Figures 4 and 5) or a similar rod that is widened in such way that a cancellous screw can pass through it (in such way that it will act as plate) in its section that conforms to pedicle can also provide a link (Figures 4 and 6). Especially in thin people, decreased low profile screws whose head is smoothed (Figure 4) can be used in order to prevent plate and screw head to create high profile. In bilateral injuries, either system can be applied in both sides separately or it can be connected by means of a connection system. It can be considered as a disadvantage that there needs to be a large area of view on iliac wings in order to apply the system.

In the studies they conducted with pelvic CT in order to evaluate sacroiliac joint, Prassopoulos et al.^[34] detected six types of anatomical variants other than the normal condition. Before operation, axial CT scans can be examined in terms of anatomic differences in sacroiliac region and differences of bone structures; zone where plate will be placed, entrance places of screws and their directions, thickness of bone structure in that region/zone and depth/length of the screw to be sent can be determined. Therefore, probable complications will be kept at minimum level.^[17,26,29-31]

Consequently, through a plate applied matching the projection of lateral sacral mass on the outer table of the posterior ilium (posterior iliac wing), multiple screws may be sent lateral to S1 and S2 sacral foraminal levels without damage to the sacral neural and surrounding vital structures. Distance between the outer wall of sacral foramina and the outer cortex of the iliac wing at the same level can be found out by examining CT scans before operation and suitable screw length can be calculated. A stable fixation can be achieved by combining the plate/screw system with pedicular screw.

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