Stability Behavior of Human Tibias After Bone Removal—Comparative Examination in 15 Cadaver Tibia Pairs

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Purpose: To obtain scientific information on the loss of stability of tibias after removal of bone grafts, we performed a comparative study of 15 freshly preserved adult cadavers to determine the axial breaking loads of the operated and nonoperated tibial heads.

Materials and Methods: From all cadavers, 1 tibia was randomly selected from which the maximum possible amount of cancellous bone was harvested. The respective contralateral side remained untouched. After maceration, the proximal tibias of each cadaver were removed bilaterally and adjusted to precisely equal lengths. Using a Zwick universal testing machine, the tibial heads were loaded by an axial force until fracture. As the final breaking load, the force value was recorded when the first distinct decrease in the feed-force curve was observed. To compare the mean breaking loads of the operated and nonoperated control tibias, a t test for related samples at $P = .05$ was used.

Results: The mean breaking load for the donor tibias was 3,767 N and was significantly lower than that of the control side with an average of 5,126 N. This finding was independent of age and gender.

Conclusions: Bone removal from the proximal tibia leads to a significant reduction of the axial load capacity. Therefore, we recommend partial loading of up to one half of the body weight during the first postoperative week. For an additional 5 weeks, patients should bear their full body weight on the affected leg only when walking normally and on flat ground.

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Many pathologic conditions in the maxillofacial region are associated with varying degrees of bone loss leading frequently to the necessity of bone grafting. Cysts, atrophy of the edentulous ridge, congenital bony defects, such as alveolar clefts, and bony defects due to tumor resection or trauma are the major indications for bone transplantation.1-5 Replacement of the missing hard tissue by bone transplants has developed into a standard surgical procedure, with the amount of bone needed dependent on the size and geometry of the defect.4,5 Grafting techniques that provide the atrophic edentulous posterior maxilla with an adequate bone stock for osseointegrated implants have been gaining more and more importance. This especially applies to sinus floor elevation, as first described by Tatum6 at the 1976 Implant Meeting (Birmingham, AL) and reported subsequently by Boyne and James,7 which has become an undisputed standard preimplantology procedure for the maxilla. Countless alternative grafting materials have been researched and used; however, despite the continu-

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uous progress and recent developments in bone-substitute technologies, the autogenous bone graft remains the reference standard for bony reconstruction and rehabilitation in the orofacial region.\[^{8-13}\] It offers distinct advantages because of its osteoinductive, osteoconductive, and immunologic properties.\[^{14-16}\] The iliac crest is the most widely used extraoral donor site for autogenous bone grafts.\[^{5,13}\] Nevertheless, the proximal tibia is also a reliable bone graft donor site\[^{17}\] and has been gaining in popularity for maxillofacial bone defects.\[^{2,3,11,13,18-20}\] The surgical procedure is comparatively simple and can be performed with the patient under local anesthesia. In addition, a sufficient amount of cancellous bone can be harvested with only minimal morbidity.\[^{2,5,11,17}\] In contrast, the cortical bone available from this donor site is essentially limited to the access window. However, published reports have provided inconsistent information regarding tibial stability after bone graft removal and mobilization of the operated leg.\[^{2,5,17,19,20}\] In the present study, we determined and compared the axial load capacity of operated and nonoperated tibial heads in freshly preserved human cadavers.

**Materials and Methods**

A total of 15 freshly preserved human cadavers, 9 male and 6 female, with a median age of 76.8 years (range 51 to 94) were included in the present study. From each cadaver, 1 side was randomly selected to harvest a purely cancellous transplant from the proximal tibia using the bone lid method described by Jakse et al.\[^{11}\] (Fig 1). The respective contralateral side served as the control and remained untouched.

**SURGICAL PROCEDURE AND BONE GRAFT HARVESTING**

First, the important anatomic landmarks, such as the articular cavity, tibial tuberosity, and medial tibial margin, were identified and highlighted after randomization on the intervention side (Fig 2A). An incision line of about 3.5 cm was drawn from craniomedially to caudolaterally according to the oblique fibers of the pes anserinus, with the proximal limit 2 cm below the articular cavity. After the pes anserinus had been exposed by sharp and blunt dissection, a cortical lid, 1.8 × 1.5 cm, was prepared as described by Jakse et al.\[^{11}\] Incisions were made through the pes anserinus corresponding to the design of the planned bone lid whose cranial and caudal sides should run parallel and whose lateral side should run perpendicular to the fibers of the pes anserinus (Fig 2B). Medially, the pes was not incised; thus, the cortical lid was prepared using a microbone saw, and different chisels remained retained at its medial base (Fig 2C). Subsequently, the maximum possible amount of cancellous bone was collected with variably sized spoon excavators.

**DETERMINATION OF AXIAL BREAKING LOAD**

For paired comparisons of the axial load capacity, the proximal tibias of each cadaver were bilaterally removed using an oscillating saw subsequent to maceration. Using the bone saw and a dental model trimmer, the tibia heads of the cadavers were adjusted until they had exactly equal lengths and smooth bottom surfaces parallel to the tibial plateau. Thus, identical anatomic prerequisites for the intervention and control sides were provided. To apply an axial force to the prepared specimens, a computer-aided Zwick universal testing machine (Zwick, Ulm, Germany) was used comprising a load frame (Fig 3A) and personal computer with the appropriate software (Fig 3B). The tibial heads were loaded by a planar metal loading plate with a preload of 10 N, and a specimen feed of 0.6 mm/s (Fig 4A) until fracture occurred (Fig 4B), with the feed-force curve displayed on the personal computer screen. The fracture event itself became apparent by a noticeable cracking sound and a distinct decrease in the feed-force curve. To ensure symmetric force introduction and to avoid small area
FIGURE 2. A, Incision line (blue arrow) with important neighboring anatomic landmarks preoperatively marked on left-side cadaver shank. B, Pes anserinus after dissection of overlying soft tissue and incisions corresponding to planned bone lid. C, Medially retracted cortical lid providing access to bone marrow of tibia head.

peak loads, the unevenness between the tibial plateaus and the loading plate were equalized with a silicon mass (Silaplast, Detax GmbH, Ettlingen, Germany) (Fig 4). The force value at the first marked decrease in the feed-force curve was registered as the resulting breaking load (Fig 5).

STATISTICAL ANALYSIS

In addition to an explorative data analysis, a t test for related samples was performed to statistically compare the measured axial breaking loads. The influence of gender on the results was examined using an unpaired t test. A P value less than .05 was considered significant. For assessment of age-dependence, Pearson's correlation analysis was done. Statistical computations were performed using the Statistical Package for Social Sciences, version 14, for Windows XP (SPSS, Chicago, IL).

Results

The breaking loads of the operated and control sides yielded a rather heterogeneous distribution, with a comparatively wide spread of values (Fig 6, Table 1).

As expected the mean fracture load was significantly greater for the nonoperated control tibias with a mean value of 5,126.4 N. In contrast, the operated sides had an average load capacity of 3,766.9 N (Table 2). Thus, bone graft removal from the proximal tibia resulted in a significant loss of load capacity with tibial stability reduction to 73.5% compared with the nonoperated side. This result was not dependent on gender (P = 0.321) or age (r = −0.96; Fig 7) as determined by the unpaired t test and Pearson’s correlation analysis for the differences of the respective values of both sides.

However, in 2 cases, bone removal did not result in a decline in the axial fracture load, and the lowest measured load capacity for the operated tibial heads was 1,034 N, corresponding to a static load of >100 kg of body weight.

For tibias with (r = −0.103, Fig 8) and without (r = −0.031) bone graft removal, the determined fracture loads were relatively constant for the observed age interval without any significant age ef-
fect. In addition, gender dependence on the breaking loads could be statistically ruled out for both sides (Table 3).

Discussion

Whereas bone grafting from the proximal tibia is a frequently applied and proven procedure, the postoperative decrease of tibial stability has not been systematically examined. Therefore, the published data lack final recommendations concerning the postoperative load capacity and mobilization, and the information given is often not precise.

Although unrestricted weight bearing as usual has been advocated, especially when a comparatively small amount of bone has been harvested using trephines, most investigators have advocated immediate loading with body weight. However, athletic and other physical activities involving extreme stress to the operated leg should be avoided for 4 to 8 weeks. This applies in particular to patients from whom large cortical grafts have been harvested such as with cortical windows, because in such cases, fractures can be expected to occur in 12% of the operated tibias. According to a more conservative approach, patients should bear only partial weight on the operated leg for up to 6 weeks postoperatively. In general, only a few cases of proximal tibial fracture after bone graft removal have been reported. However, the amount of underreporting could be considerable, because these fractures often do not require surgical treatment.

In the present study, we have shown that the stability of the proximal tibia subsequent to bone graft removal is significantly reduced, irrespective of age and gender. An axial force of at least 1,034 N, which corresponds to a load of 105.4 kg, was necessary to induce a fracture in the donor tibia. On average, a force of 3,766.9 N or 384 kg led to the fracture event. As reported by Morrison, the joint forces transmitted to the proximal tibia by the articular surfaces during normal walking range from 2 to 4 times the body weight (mean 3.03). In more intense activities, such as climbing stairs, even stronger forces reaching more than 4 times one’s body weight, depending on the knee flexion angle, can be generated. Additional investigations have revealed that during isokinetic knee extension, compressive forces with peak magnitudes of 5 to 9 times one’s body weight are exerted on the tibia. Comparing these values with the results of our study (Table 1), one can conclude that even during normal walking, forces can develop that could result in a fracture of the tibia at least in the early postoperative period. More intense activities

![FIGURE 4](image)

**FIGURE 4.** A, Loading of donor tibia head using planar metal plate with silicon mass squeezed between plate and tibial plateau. B, Control side tibia immediately after fracturing.


![FIGURE 5](image)

**FIGURE 5.** First marked decrease in feed-force curve [red arrow], corresponding to breaking load.

such as climbing stairs increase the risk of fracture considerably.

One limitation of our study was the relatively older age of the examined cadavers; nonetheless, the attained fracture loads did not exhibit age dependence in the investigated age interval. In addition, sinus lifting surgery, one of the most important indications for harvesting autogenous cancellous bone grafts, is regularly performed in elderly patients.

The results of our study have shown that bone graft removal from the proximal tibia is associated with a significant increase in fracture risk. The acquired data suggest that partial loading of up to one half of the body weight in the first week after surgery is advisable. Subsequently, for the following 5 weeks, the donor leg should bear the full body weight during normal walking on flat ground. For all activities involving more stress to the operated leg (eg, climbing stairs),

![Comparison of the breaking loads](https://example.com/figure6)

**Table 1. Survey of Breaking Loads for Operated and Nonoperated Control Sides**

<table>
<thead>
<tr>
<th>Pt No.</th>
<th>Age (yr)</th>
<th>Gender</th>
<th>Operated Side</th>
<th>Control Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>94</td>
<td>Female</td>
<td>1,034</td>
<td>3,090</td>
</tr>
<tr>
<td>2</td>
<td>67</td>
<td>Male</td>
<td>2,635</td>
<td>4,414</td>
</tr>
<tr>
<td>3</td>
<td>88</td>
<td>Male</td>
<td>2,890</td>
<td>4,508</td>
</tr>
<tr>
<td>4</td>
<td>53</td>
<td>Male</td>
<td>2,674</td>
<td>3,526</td>
</tr>
<tr>
<td>5</td>
<td>78</td>
<td>Male</td>
<td>1,684</td>
<td>3,257</td>
</tr>
<tr>
<td>6</td>
<td>69</td>
<td>Female</td>
<td>6,044</td>
<td>4,234</td>
</tr>
<tr>
<td>7</td>
<td>88</td>
<td>Male</td>
<td>4,931</td>
<td>5,375</td>
</tr>
<tr>
<td>8</td>
<td>75</td>
<td>Male</td>
<td>9,962</td>
<td>14,009</td>
</tr>
<tr>
<td>9</td>
<td>89</td>
<td>Female</td>
<td>2,725</td>
<td>4,214</td>
</tr>
<tr>
<td>10</td>
<td>93</td>
<td>Male</td>
<td>3,529</td>
<td>3,385</td>
</tr>
<tr>
<td>11</td>
<td>71</td>
<td>Male</td>
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<td>6,243</td>
</tr>
<tr>
<td>12</td>
<td>76</td>
<td>Male</td>
<td>3,905</td>
<td>7,345</td>
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<td>13</td>
<td>84</td>
<td>Female</td>
<td>5,125</td>
<td>5,390</td>
</tr>
<tr>
<td>14</td>
<td>51</td>
<td>Female</td>
<td>2,795</td>
<td>3,789</td>
</tr>
<tr>
<td>15</td>
<td>76</td>
<td>Female</td>
<td>3,716</td>
<td>4,139</td>
</tr>
</tbody>
</table>

**Table 2. Statistical Comparison Between Operated and Control Sides**

<table>
<thead>
<tr>
<th>Side</th>
<th>Breaking Load (N)</th>
<th>p Value</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operated</td>
<td>3,766.9 ± 2,132.7</td>
<td>.002</td>
<td>582.5-2,136.4</td>
</tr>
<tr>
<td>Control</td>
<td>5,126.4 ± 2,722.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data presented as mean ± standard deviation.

FIGURE 7. Relationship between breaking load differences of both sides and patient age with no significant correlation \( r = -0.96 \).


FIGURE 8. Points cluster to illustrate relationship between fracture load and patient age for operated tibias \( r = -0.103 \).


**Table 3. INFLUENCE OF GENDER ON LOAD CAPACITY**

<table>
<thead>
<tr>
<th>Side</th>
<th>Gender</th>
<th>Breaking Load (N)</th>
<th>( t ) Test</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operated</td>
<td>Male</td>
<td>4,118.3 ± 2,435.8</td>
<td>.455</td>
<td>-1,586 to 3,152</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>3,239.8 ± 1,639</td>
<td>.268</td>
<td>-1,424 to 4,703</td>
</tr>
<tr>
<td>Control</td>
<td>Male</td>
<td>5,782.2 ± 3,378.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>4,142.7 ± 748.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data presented as mean ± standard deviation.

stairs), partial weight bearing with one half of the body weight should be recommended.

References


