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Risk of Fracture at External Fixator Pin Hole After Lateral Tibial Plateau Fracture Plating

A Biomechanical Comparison of Different Screw Configurations

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Background: External fixation of tibial plateau fractures commonly provides temporary stabilization before definitive fixation with plate and screws. The purpose of this study was to determine if an external fixator pin hole distal to a tibial plate in a synthetic fracture model would increase the risk of fracture after fixation. Another objective was to determine the ideal configuration when placing tibial plate screws near an external fixator pin hole.

Methods: Thirty synthetic tibiae were tested and evenly divided into 5 groups. Tibial plateau plates were placed with 4 different screw configurations for the distal-most screw near the external fixator pin hole. The 5 groups tested were control (fixation with no external fixator hole), unicortical (distal fixation with a unicortical locking screw), bicortical (distal fixation with a bicortical locking screw), oblique (distal fixation with an oblique cortical screw angled 30° proximally from the external fixator hole), and hole-bridging (hole-bridging fixation in which the plate was placed bridging the external fixator hole). The bone surrogates were potted and tested using an Instron 8874 Testing System.

Results: There was a significant difference in failure load among the 5 groups ($p = 0.005$). The mean peak loads were 1,259 N (control), 835 N (unicortical), 831 N (bicortical), 943 N (oblique), and 993 N (hole-bridging). There was a higher failure load in the control group compared with the bicortical group ($p = 0.007$) and the unicortical group ($p = 0.007$). There was no difference in failure load between the control group and the hole-bridging group ($p = 0.16$) and the oblique group ($p = 0.067$).

Conclusions: External fixator pin holes distal to a tibial plateau plate may increase the risk of tibial fracture through the pin hole. This risk may be mitigated by placing the distal screw oblique and angled proximally away from the external fixator pin hole or by placing the external fixator pin proximally with subsequent bridging of the external fixator pin hole with the plate.

External fixators have been a widely used technique to fix fractures of long bones and are mainly used in a trauma setting but can also be used in deformity correction and arthrodesis[1,2]. External fixators primarily maintain the fracture's length, alignment, and rotation[1]. Compared with open reduction and internal fixation (ORIF) and intramedullary nailing, external fixation shows advantages, including simplicity, adjustability, and increased access for wound care and monitoring after the fixation[2]. An external fixator can be used in conjunction with ORIF and can serve as either permanent or temporary fixation[1]. In the latter case, the external fixator can allow soft-tissue healing and fracture stabilization, and ORIF can be performed following removal. Once the external fixator pins are removed, pin holes are left in the bone, leaving a substantial defect.

The use of external fixators comes with many risks, including neurovascular injury, compartment syndrome, nonunion or malunion, and infection, which can develop into osteomyelitis[1]. The defects created in the long bone also decrease the strength of the bone, increase stress in the region of the defect,

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and increase the risk of pathologic fracture, especially when exposed to torsional forces[3]. Several clinical studies have shown postoperative fractures related to pin holes. The rate of postoperative fracture through pin sites used for navigation can range from 0.06% to 4.8%[4]. Additionally, other studies have found that 16.7% to 18.2% of tibiae that had external fixator half-pins can have subsequent tibial fractures, as the pin hole acts as a stress-riser[5,6]. These authors also found that the pin fracture rate was much higher with large half-pins compared with tensioned fine wires[7].

A study assessing fractures of the calcaneus after external fixator pin removal found that the pin hole significantly reduced compressive load and the energy absorbed by the bone, and that all fractures were found to originate from the pin site and propagated outward[8]. The pin holes can create a stress-riser effect in the bone, reducing its load-carrying capacity[8]. A case study discusses a healthy patient who, 4 years after treatment of an open floating knee injury with a spanning external fixator then definitive fixation, developed a low-energy subtrochanteric proximal femoral fracture through the pin site of the external fixator[9]. An increasing pin hole diameter and increasing number of pin holes in the bone were shown to significantly decrease the amount of torsional force the bone can endure and subsequently increase the risk of fracture[3]. Given the evidence that the defects in long bones left by external fixator pin removal may create a stress-riser effect and increase the risk of fracture, we investigated the effect of different distal screw configurations in lateral tibial plates in proximity to external fixator pin holes on failure load, assessing the force needed to fracture the tibia. The purpose of this study was to determine if an external fixator pin hole distal to a tibial plate in a synthetic fracture model would increase the risk of fracture. Another objective was to determine the ideal configuration when placing tibial plate screws near an external fixator pin hole.

Materials and Methods

Thirty synthetic tibiae (absolute Tibia; Sawbones) were used for testing, 6 in each of the 5 experimental groups. Transverse metaphyseal proximal tibial fractures were first simulated with a saw using a standardized protocol, which has been previously described[10]. Fractures were made approximately 6 cm distal to the tibial plateau, and a fracture gap of 1 cm was created, similar to previous studies[11-13]. A 1-cm spacer was then placed in the fracture site, and tibial plateau plates were placed with different screw configurations for the distal-most screw near the external fixator hole (Fig. 1). The 5 groups tested were control (fixation with no external fixator hole), unicortical (distal fixation with a unicortical locking screw), bicortical (distal fixation with a bicortical locking screw), oblique (distal fixation with an oblique cortical screw angled 30° proximally from the external fixator hole), and hole-bridging (hole-bridging fixation in which the plate was placed bridging the external fixator hole) (Fig. 2). Each tibia was potted using epoxy resin in a 3 × 3-in (7.6 × 7.6-cm) aluminum box. Stainless steel, left, 8-hole, 4.5-mm LCP (Locking Compression Plate; DePuy Synthes) proximal tibial 154-mm-length plates were used for all of the synthetic tibiae. In the most proximal aspect of the plate, three 5.0-mm locking screws were placed in a converging fashion just below the articular surface of the tibial plateau. A 5.0-mm locking screw was placed in the third hole of the plate in an angled fashion in accordance with the manufacturer's technique manual; the angled hole at this position is designed to converge with the central locking screw in the proximal aspect of the plate. The proximal fragments of all 30 synthetic tibiae were fixed to the proximal tibial plate as detailed above. The remaining distal holes in the plate are combination holes that consist of a dynamic compression unit and a locking hole.

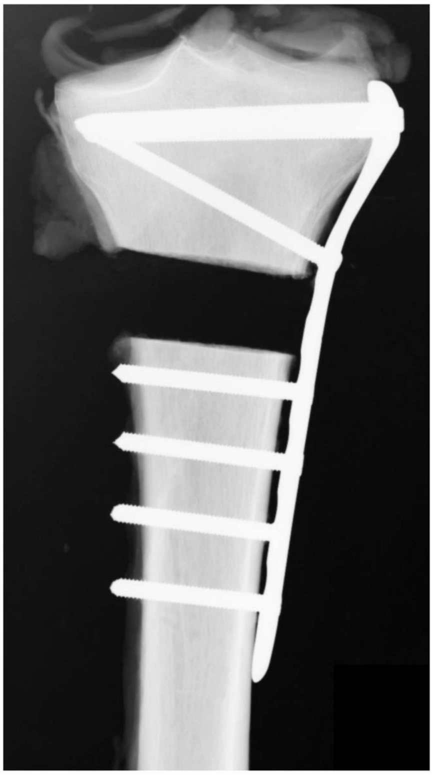

Fig. 1

Anteroposterior radiograph of the simulated metaphyseal fracture in a synthetic left tibia. The transverse fracture is 6 cm distal to the tibial plateau, with a 1-cm gap created at the fracture site. There is a lateral 8-hole proximal tibial plateau plate with 4 locking screws distal to the fracture and no external fixator pin hole in the tibia, representing the control group.

The control group utilized 5.0-mm locking screws in each of the 4 most distal combination holes in a bicortical fashion (Fig. 2). There was no external fixator hole placed at the distal end of the plate in this group; therefore, no stress-riser was present in the 6 synthetic tibiae in this group. The bicortical locking screw group utilized the same configuration as the control group (5.0-mm bicortical locking screws in the 4 most distal combination holes). In a real surgical situation, the bicortical screw will not always be close to the external fixator

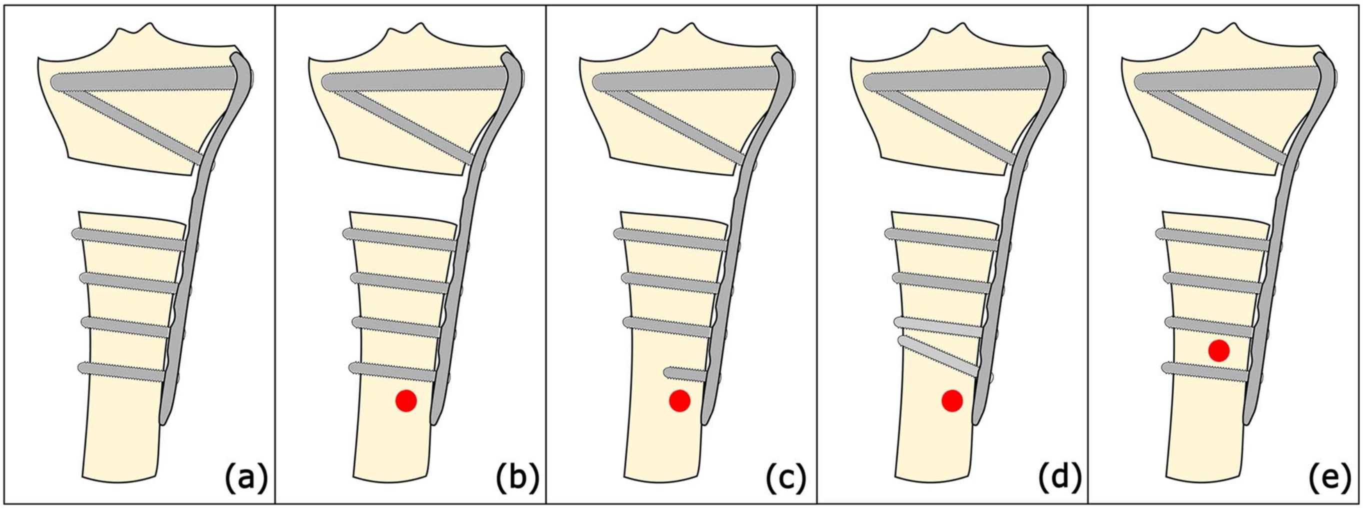

Fig. 2

Figs. 2-A through 2-E Illustration of 5 different configurations. A left tibia with a simulated fracture gap is depicted. The gray plate is lateral on the tibia, with locking screws in the proximal tibia. **Fig. 2-A** Control configuration with 4 distal bicortical locking screws and no external fixator pin hole. **Fig. 2-B** Bicortical configuration with an external fixator pin hole (red) just distal to the most distal screw, which is a bicortical locking screw. **Fig. 2-C** Unicortical locking configuration with the most distal screw being a unicortical locking screw. The external fixator pin hole (red) is just distal to the most distal screw. **Fig. 2-D** Oblique configuration with the most distal screw angled proximally from the external fixator pin hole (red). **Fig. 2-E** Hole-bridging configuration with the most distal screw distal to the external fixator pin hole (red).

hole, but this was done to be consistent among all of the samples in this group. Additionally, there is only a small distance between the screw holes in the plate, such that when filling several holes in a tibial plate, it is likely that at least 1 of the screws will be close to the external fixator pin hole. The unicortical locking screw group also used a 5.0-mm locking screw; however, it was placed in unicortical fashion, and the far cortex was not penetrated with the 4.3-mm drill-bit.

The oblique cortical screw group contained 5.0-mm locking screws in a bicortical fashion as detailed above; however, the most distal hole used a 4.5-mm cortical screw in the dynamic compression unit portion of the combination hole. This cortical screw was first predrilled with a 3.2-mm drill-bit oriented at a 30° angle from the external fixator hole. The 4.5-mm cortical screw was then placed in the 30° oblique orientation in a bicortical fashion.

The hole-bridging group utilized 5.0-mm locking screws in each of the 4 most distal combination holes in a bicortical fashion. However, this group contained an external fixator hole that was placed in between the 2 most distal 5.0-mm bicortical screws. A 5-mm drill-bit was used to simulate an external-fixation hole in each experimental group except the control group. The drill-hole was placed in the center of the synthetic tibia immediately adjacent to the distal end of the plate in the bicortical, unicortical, and oblique cortical groups. In the hole-bridging group, the external-fixation hole was placed in between the 2 most distal 5.0-mm bicortical screws (Fig. 2).

Each potted tibia had 1.5 inches (2.54 cm) of space between the epoxy resin and the distal end of the tibial plate. The epoxy resin was allotted a minimum of 12 hours to harden in order to ensure adequate fixation of the synthetic tibia. The aluminum box and distal tibia were secured with a C-clamp to the frame of the Instron mechanical testing machine.

Each group was then tested using an Instron 8874 Testing System with a bending apparatus, similar to previously described studies[14-16]. A posterior-to-anterior force was applied to the proximal tibia at a displacement of 0.5 mm/s until it broke (Fig. 3). This method of cantilever bending was utilized to create a worst-case scenario of shear forces across the cross-sectional area of the pin hole. Force-versus-displacement data were collected at 100 Hz and 0.1 N of load increments. The peak load of each sample was taken as its failure load. Fracture morphology was recorded for each sample.

Statistical Analysis

Numerical data such as failure load were compared across all 5 groups using ANOVA. Post hoc testing was performed with the Tukey honestly significant difference (HSD) test. Significance was set at $p < 0.05$.

An a priori power analysis was used to determine the number needed in each of the 5 groups, given that 10 pairwise comparisons were planned and based on initial pilot testing data of the control group and the bicortical group. Post hoc power testing was also performed.

Results

An a priori analysis determined that 3 samples in each group were required to achieve a power of 0.8.

Fig. 3

A lateral tibial plateau plate with locking screws has been applied to a synthetic proximal tibial fracture model. An external fixator hole has been drilled distal to the most distal locking screw in the plate. The Instron unit applied force directed from posterior to anterior on the proximal tibia.

There was a significant overall difference in failure load among the 5 groups (p = 0.005) (Fig. 4). There were significant pairwise differences in failure load between the control group and both the bicortical group (p = 0.007) and the unicortical group (p = 0.007) (Table I). There was no difference in failure load between the control group and the hole-bridging group (p = 0.16) and the oblique group (p = 0.067).

There was a difference in stiffness among the 5 groups (p = 0.019) (Table I). There was a significantly higher stiffness for the bridge group compared with both the unicortical group (p = 0.014) and the control group (p = 0.043). There was no difference in stiffness between the control group and the unicortical (p = 0.989), bicortical (p = 0.774), and oblique groups (p = 0.851). There was also no difference in the stiffness of the bicortical group compared with the hole-bridging group (p = 0.371), the oblique group (p = 1.0), and the unicortical group (p = 0.49). There was no difference in the stiffness of the hole-bridging group compared with the bicortical group (p = 0.371) and the oblique group (p = 0.294). There was no difference in stiffness between the oblique group and the unicortical group (p = 0.584).

The control group had a mixed mode of failure locations among samples, with 2 failures at the base of the potting, 1 distal to the plate, 2 screw fractures, and 1 other. All of the experimental groups fractured through the external fixator pin hole except for 1 sample in the bicortical group and 1 in the hole-bridging group that fractured distal to the hole. The was a significant difference in the mode of failure among the 5 groups (p = 0.034).

Discussion

In the treatment of complex long-bone fractures, temporary external fixation followed by definitive fixation with an implant is commonly used. The removal of external fixator pins leaves substantial defects in the bone and may create stress-risers. Evidence has shown that a pin-site hole significantly increases the risk of fracture originating from the pin site by decreasing the bone's overall strength.

In our study, we found that a large pin hole near the distal end of a tibial plate caused reduced failure load compared with the control group (with no pin-hole defect), indicating that less force is needed to fracture the bone. The bicortical and unicortical groups showed the lowest failure loads among the 5 groups. The oblique and hole-bridging groups showed failure loads similar to the control group. Based on these results, bridging the pin-site hole by placing the plate over the hole or configuring the most distal screw at an oblique angle pointed away from the hole should be considered if there is concern for fracture propagation. When placing an external fixator pin, surgeons should consider placing the proximal pin more proximally, so that their plate will overlap the pin hole or, if the plate stops at the pin hole, they should angle the distal screw proximally.

Juliano et al. tested compressive forces on human calcanei from which 6.0-mm external fixator pins had been removed and found a 22% reduction in compressive load at failure compared with their control calcanei with no pin holes[8]. They found that the calcanei with pin holes failed at forces that were similar to the forces encountered while walking or running[8]. Olcay et al. subjected sheep femora with varying numbers and sizes of holes to torsional forces and found that more holes in the bone and a larger hole diameter both increased the rate of fracture of the bone, with the hole diameter having a larger effect[3].

Speck et al. tested torsional forces on synthetic tibiae with 6-hole locking plates placed on the anteromedial tibia and 5.0-mm bicortical drill-holes at varying distances away from the distal end of the plate. The torsional force required to fracture the bone was measured. Two of their control groups (plated and unplated tibiae with no pin-hole defect) reached the capacity of the load cell without fracturing, so these groups were not included in their results when reporting torsional failure. They reported no significant difference in failure torque among the groups that did fracture[17].

Gee et al. tested anterior-to-posterior and medial-to-lateral forces on acrylic plastic tubing with varying external fixator half-pin obliquity and measured the force to fracture. They found that increasing obliquity of the half-pins resulted in lower forces needed to cause fracture and suggested that 0° half-pins used for external fixation will likely reduce the risk of

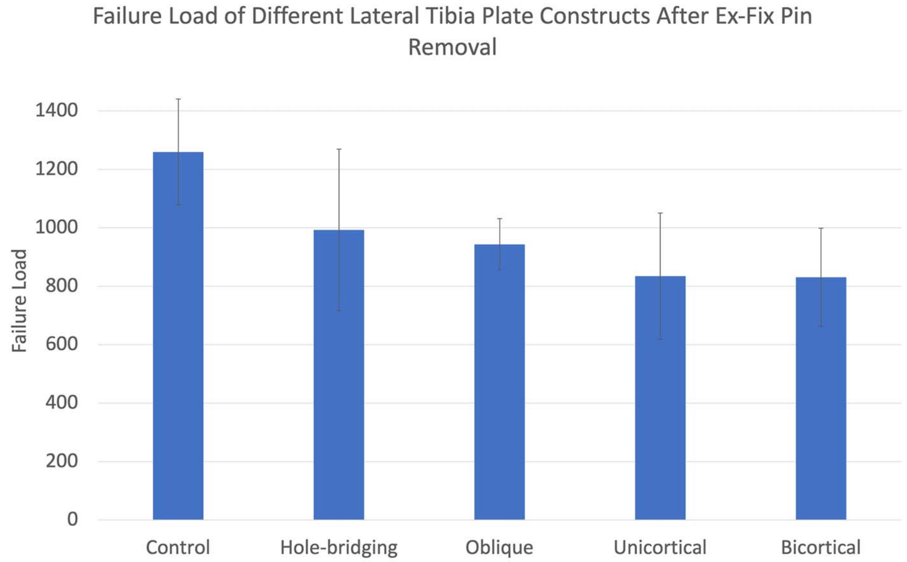

Fig. 4

Bar graph of the mean failure load (and standard deviation) for 5 different screw configurations. In each group, a lateral plateau plate was used to fix a proximal tibial fracture. Except in the control group, the tibia contained an external fixator (ex-fix) pin hole. There was a significant difference in failure load among the 5 groups (p = 0.005). There was a significant difference between the failure load of the control group and those of the bicortical group (p = 0.007) and the unicortical group (p = 0.007). There was no difference in failure load between the control group and the hole-bridging group (p = 0.16) and the oblique group (p = 0.067).

fracture after pin removal[18]. Their failure loads were approximately 750 to 790 N, which is similar to our groups with external fixator pin holes. Another study evaluating bending of tibiae containing a tibial plateau fracture fixed with a lateral plate and no pin hole demonstrated a mean failure load of 1,210 N, which is similar to our study group with no pin hole[15]. Finally, a study comparing intramedullary nailing with extramedullary plating demonstrated a failure load of approximately 1,400 N with plating[11].

TABLE I Mean Failure Load and Stiffness Among Various Screw Configurations for Lateral Tibial Plateau Plating After External Fixator Pin Removal*

Group	Failure Load *(N)*	Stiffness Value *(N/mm)*
Control	1,259 ± 181	41.5 ± 10.7
Bicortical	831 ± 168	47.5 ± 11.2
Unicortical	835 ± 216	39 ± 4.2
Oblique	943 ± 88	46.7 ± 7.1
Hole-bridging	993 ± 277	57.2 ± 10.2

*Mean failure load and stiffness, with standard deviation, of 5 different screw configurations for a lateral plateau plate on a proximal tibial fracture; except for the control group, all tibiae had an external fixator pin hole. There was a significant difference in failure load among the 5 groups (p = 0.005). There was a significant difference between the failure load of the control group and those of the bicortical group (p = 0.007) and the unicortical group (p = 0.007). There was no difference in failure load between the control group and the hole-bridging group (p = 0.16) and the oblique group (p = 0.067). There was a difference in stiffness among the 5 groups (p = 0.019).

Although there has not been an abundance of clinical studies showing the prevalence of postoperative fractures through external fixator pin holes, there have been several studies on fractures through pin holes used for arthroplasty navigation and external fixator half-pins. The rate of fractures can range from 0.06% to 4.8% through navigation pin holes[4] and from 16.7% to 18.2% through sites from which external fixator half-pins had been removed[5,6]. Other authors also found that the pin fracture rate was much higher with large half-pins compared with tensioned fine wires[7]. Additionally, case series have shown femoral fractures with navigation pins from low-energy mechanisms[19,20].

In a study comparing the biomechanics of bicortical and unicortical locking screws in proximal tibial periarticular locking plates, Dougherty et al. tested axial loads on cadaveric tibiae with osteotomy-stimulated bicondylar tibial fractures and plates with either 4 unicortical or bicortical locking screws proximally. They found that bicortical screw placement yielded higher maximum load before fracture compared with unicortical screws[21]. Stoffel et al. found that oblique distal screws in compression plates failed at higher loads compared with perpendicular distal screws and, thus, showed a higher fixation strength. The oblique screws in that study were angled away from the plate[22], where the oblique distal screws that we used in our study were angled toward the center of the plate and away from the pin site.

One common complication of external fixation is infection at the pin site. A cohort study analyzed if varying distances from the external fixator pin site to the definitive implant impacted the risk of infection[23]. They found that there was no significant difference in infection rate among the groups with different plate distances, including a group with an implant overlapping the pin site[23]. Laible et al. also studied patients who had sustained high-energy tibial plateau fractures and were treated with temporary external fixation with subsequent definitive internal fixation and found no significant difference in infection rates in patients with an implant overlapping a pin site compared with patients without overlap[24]. Another retrospective study also found no association between pin-site overlap and risk of infection after tibial pilon fracture fixation[25]. Although there may be surgeon concerns about overlapping the pin site with the plate, our data in conjunction with studies showing no increased infection support that overlapping of the pin hole is justified.

Our study had several limitations. The first limitation was that synthetic bone was used instead of human cadaveric bone. Although cadaveric bone is still a foundation of orthopaedic research, the fourth-generation synthetic bone models give an accurate representation of biomechanical properties of cadaver bone when subjected to axial, bending, and torsional loads[26]. The second limitation was that only a posterior-to-anterior force was tested on the synthetic tibiae when measuring failure load, and not other forces such as torsion, compression, tension, and shear forces in different directions. This was done because of limited supplies and to create a worst-case scenario, but further studies should test other force directions. A third limitation was that the pin-site hole in the hole-bridging group was in a superior location compared with the pin sites in the control, unicortical, bicortical, and oblique groups. We elected to do this to keep the tibial plate length constant in all groups, instead of using a longer plate to bridge the pin-site hole in the hole-bridging group. In a biomechanical study evaluating fixation strengths of different plate-and-screw configurations in synthetic bone, a longer plate with fewer screws endured greater loads before fracturing compared with shorter plates with more screws[22]. A longer plate, if needed, could be beneficial to bridge the pin-site hole to reduce the risk of fracture. Last, the synthetic bone does not account for healed pin holes, which may have consolidation around the pin track. Although it was not possible for this study to simulate that, the current model would be similar to a patient who is in the early postoperative period and could fall and fracture the tibia before the pin track has healed.

In conclusion, external fixator pin holes distal to a tibial plateau plate may increase the risk of tibial fracture through the pin hole. This risk may be mitigated by placing the distal screw obliquely and angled proximally away from the external fixator pin hole, or by placing the external fixator pin proximally with subsequent bridging of the external fixator pin hole with the plate. ■

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