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Original Article

The effect of drill hole location on load bearing capacity of long bones

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ABSTRACT

We investigated how load bearing capacity (LBC) of long bone differs with a bicortical drill hole in a compressive/tensile location vs. a neutral location.

Group I had a hole drilled through 0°/180° ([compressive at 0°/maximum tensile at 180°]), Group II at 90°/270° ([neutral]), and Group III at 135°/315° ([tensile at 135°/compressive at 315°]). Maximum load at failure and stiffness was measured.

A significant ([$p < 0.05$]) decrease in LBC of all Group I and Group III bones was observed. Loss of strength for Group II was statistically insignificant ([$p > 0.05$]). Changes in stiffness for both tibias and fibulas was not statistically significant ([$p > 0.05$]).

1. Introduction

The drilling of bone is a common practice in orthopedic surgery and is often employed for the treatment of fractures due to physical trauma. Depending on the individual, the process of healing a fractured bone can take from several months to years, based on the bone and type of fracture.[1–4] Excessive motion of the fractured bone components may cause delayed union or non-union.[2] Thus, to aid the fracture healing, the bones are often stabilized with intramedullary nails and plates secured with screws.[2] This technique involves a repositioning of the fractured bones to their normal alignment, at which point they are "screwed" and held together by metal plates secured to the surface of the bone.[5,6] The nature, location, and size of the drill holes used to secure these plates depend on the nature of the fracture and the size of the bones.[6–9] Although the necessity of surgical drill holes is recognized for its overall benefit in the healing process for patients, the impact these drill holes have on bone strength is a topic that has been the subject of numerous reports.

Multiple studies have confirmed a quantitative decrease in the strength of long-bone after drill hole placement. One study analyzing canine femurs reported up to a 55% decrease in the energy absorption capacity of the bone with the presence of 2.8-mm or 3.6-mm non-occupied drill holes.[10] Another investigation found that a non-occupied transcortical hole drilled into a femur reduced torsional strength by 60%.[11] A mean decrease in failure load of 40.4% was reported by a notable study observing the impact of non-occupied surgical drill holes in fibulas.[12] Even bone biopsy holes, traditionally smaller than drill holes used for internal fixation, can result in a significant reduction in femoral bone strength.[13] Additionally, a hole of larger width will generally reduce strength to a greater degree than a smaller sized drill hole.[13]

These findings leave little doubt that the presence of drill holes has significant implications on the integrity of healing bone.

2. Objectives/Aims

For this study, we question if the specific placement of these drill holes can be chosen to minimize the loss in bone strength that is typically associated with the existence of these holes. In many cases of internal fixation, implant removal after an expected successful fracture healing has resulted in a false sense of security: patients often return to their previously routine daily activities only to suffer another fracture due to the weakened state of the bone, in part due to the presence of surgical drill holes.[5] In a 2007 study, Saha showed that the location of unicortical drill holes in a Plexiglas® tube affected the load carrying capacity in a bending test.[14] Results indicated that the strength of the tubes was most negatively impacted when drill holes were located in zones where the tensile stress was maximum. However, this finding had not been corroborated in authentic human long-bone. Thus, the objective of this study was to investigate how the quantitative loss in strength of a long bone with a drill hole in a compressive/tensile location compares to the loss in strength of an identical long bone with a hole in a neutral location. We hypothesized that bones with drill holes located at tensile locations would be weaker compared to bones with

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drill holes at neutral locations. The ultimate aim was to offer some clarity on how much strength (as defined by load bearing capacity) a bone can lose with just a single surgical drill hole and whether or not this can be mitigated by choosing an optimal drill hole location.

3. Methods

Sixty-eight human embalmed cadaveric long-bones were obtained from the SUNY Downstate Gross Anatomy Lab (450 Clarkson Avenue, Brooklyn, NY 11203). With two exceptions, four bones were collected from each of the 18 available donor bodies: two tibias, and two fibulas. The ages of the bodies ranged from 59 to 100 years old with equal distribution of sex (9 male and 9 female). One body had amputated a leg prior to death, and another had significant surgical alteration to one leg that warranted exclusion from the study. Thus, only 2 bones were sourced from each of these two bodies and were used for initial testing of our equipment. Tibias and fibulas were chosen for inclusion due to availability and relative ease of access, in addition to their propensity for fracture in severe lower extremity trauma.

The bones from each donor body were kept together in individualized labeled plastic bags and stored in a refrigeration unit when not being tested/analyzed. The fibulas were disarticulated from their respective tibias and each bone was manually cleaned to remove excess tendon, ligament, and muscle tissue. Each bone was subsequently radiographed to spot any abnormalities not readily apparent to the naked eye. Length, diameter, and cortical thickness of each bone was measured by using a scale and a micrometer. Additionally, each fibula was cut in half in order to maximize the amount of bone material available for experimentation. Time constraints ultimately prevented the testing of distal fibula samples, but each proximal sample was tested.

Our methodology allowed us to test how differing the placement of an identical drill hole in two bones might impact their strength (defined as load bearing capacity). It was decided that for each experimental bone sample, the control bone counterpart would come from the contralateral limb of the same body, as this would eliminate any biological variables (i.e. age, sex, etc.) that may impact bone density, strength, or flexibility. The presence of such variables would inevitably impact results if the paired control and experimental bone were from different donors. Additionally, designating the left or right bone as either control or experimental was randomized via computer algorithm for each body.

One drill hole was drilled into each experimental bone, with the controls being unaltered in any way. For the tibias, the hole was drilled in the exact center of the bone using a 4.1-mm drill bit attached to an electric drill press. Fibulas were drilled 1/4 of the length from the proximal articulation (i.e. 1/2 the length of a fibula cut in half) using a 3.2-mm drill bit. Our drill holes were bicortical, meaning the drill bit travelled entirely through the bone and pierced both cortical layers with a defined entrance and exit point. Our rationale for employing a bicortical drill technique was to mimic established surgical procedures: standard internal fixation methods typically use bicortical drill holes. Additionally, prior research has shown that the mean thrust force applied by the average surgeon when using a drill bit of these sizes is roughly 110 N.[15] Therefore, since our drill allows force to be measured when drilling, we applied this same force when drilling our bones.

The holes were drilled in the same plane on each bone, with their location differing only by their placement along the circumference of that plane. The exact midline posterior tibia/fibula was designated as 0°. We divided the bone samples into three groups to test, each differing by their placement of the drill hole along the circumference. There was a total of 20 bones in each group: 10 control and 10 experimental (5 tibia and 5 fibula each). Group I had a hole drilled through 0°/180° (compressive at 0°/maximum tensile stress at 180°), Group II at 90°/270° (neutral), and Group III at 135°/315° (medium tensile stress at 135°/compressive at 315°) [Table 1 and Figs. 1 and 2]. Ages/sex of donor bones were evenly distributed amongst the groups. A statistical power analysis was performed to determine the necessary amount of bones to maintain the validity of our study: with an alpha of 0.05 and power of 0.80, the projected sample size needed per group was 15. Thus, our sample size of 20 per group was more than sufficient for our objectives.

Table 1
Summary of Groups. Each group contained 20 bones, 10 control (5 fibula + 5 tibia) and 10 experimental (5 fibula + 5 tibia). The control bones were unaltered and the experimental bones were drilled according to the group in which they were placed.

Group Number (N = 20)	Control (N = 10; 5 fibula and 5 tibia)	Experimental (N = 10; 5 fibula and 5 tibia)
Group I	Unaltered	Drill Hole at 0°/180° [Max compressive/tensile force]
Group II	Unaltered	Drill Hole at 90°/270° [Neutral]
Group III	Unaltered	Drill Hole at 135°/315° [Medium compressive/tensile force]

Drilled bones and their control counterparts were mechanically tested via a four-point bending test using a mechanical testing machine (Instron Model 1011®), as shown in Fig. 3. The four-point bend test was selected so that the central portion of the beam was subjected to a uniform bending moment. The bones were attached to a holding apparatus that ensured they maintained the same position when force was applied during each test. Tibias were tested with a beam span of 255-mm and an upper jig span of 50-mm. Measurements for the fibulas were accordingly adjusted to 100-mm and 20-mm respectively. Crosshead speed was maintained at 10-mm/min for all tests. All bones were placed with their anterior face down such that the force from the bend test apparatus was applied at 0° (i.e. the midline of the posterior surface.) Software recorded displacement and load bearing capacity in real time. All results were compiled into SPSS for final analysis. Statistical tests used were the two-sample *t*-test and ANOVA.

4. Results

Our experiment generated analyzable data that showed a statistically significant ($P < 0.05$) decrease in strength of all tibias and fibulas with a hole drilled at 0°/180° and 135°/315° compared to their respective control group (Tables 2A, 2B, 3A and 3B). Differences in strength between the control and drilled tibias and fibulas in the 90°/270° group was statistically insignificant ($P > 0.05$). For the 0°/180° group (where one hole was located at the maximum tensile stress region) and 135°/315° group (where one hole was located at a medium tensile stress region), tibias experienced average decreases in strength of 43.4% (± 6.5%) and 35.3% (± 25.7%) respectively [*Formula*: 100–(avg. experimental LBC/avg. control LBC *100)]. The failure load for the fibulas for these same respective groups showed a decrease of 34.6% (± 11.5%) and 27.9% (± 5.1%) in the load carrying capacity. ANOVA statistical analysis performed on all tibia and fibula data in each group indicated that the differences observed in the decrease in strength between drill holes placed at 0°/180°, 90°/270°, and 135°/315° was also statistically significant ($P < 0.05$). In addition to load bearing capacity, the stiffness for each sample was calculated by taking the maximum force prior to fracture (i.e. force at load bearing capacity) and dividing it by the displacement produced by such force. The results showed no statistical significance ($P > 0.05$) in the difference in stiffness between control bones and their experimental counterparts, indicating that the drill holes had no appreciable impact on overall stiffness of our samples.

Finally, when taking into consideration bone length, diameter, and cortical thickness of each of our samples, there was no significant finding that suggested any one of these parameters effected the relative loss in bone strength due to the drill hole. Though cortical thickness may have an impact on overall bone strength, having a thicker cortical layer did not prevent the drill hole from weakening the bone to the