

The density of growth cartilage evaluation due to epiphysiodesis procedure

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Abstract

Introduction: Proper prediction of remaining lower limbs growth is crucial for determining the optimal timing of epiphysiodesis in patients with limb length discrepancies or the curvature occurred in knee joint occurred in children during rapid growth period. Several methods are commonly used in correction of such orthopedic problem. One of them is procedure of epiphysiodesis.

The main goal of the study was to evaluate changes in the density of growth cartilage at the distal end of the thigh bone following epiphysiodesis, and to compare it with the cartilage density on the side without screw placement in the same limb, as well as with the contralateral side.

Material and methods: The clinical study included 9 patients of both sexes (5 females and 4 males) who were treated at the Department and Clinic of Orthopedic Surgery, Medical University of Silesia in Katowice.

Results: The regions of interest marked on the X-ray images from which the average pixel value have been derived.

Conclusions: The conducted study demonstrated a statistically significant difference of over 50% the average pixel value between preoperative and postoperative measurements on the side where screws were placed ($p = 0.01$). Additionally, a significant difference of 50% was observed between the preoperative pixel value on the side designated for screw placement and the postoperative pixel value on the contralateral, non-operated side.

Keywords: X-ray images, density of growth cartilage, epiphysiodesis procedure

Introduction

The procedure of epiphysiodesis was described in detail by Bowen and Johnson in 1984¹. This procedure aims to correct limb length differences in growing children by stopping the growth of the longer limb, allowing the shorter limb to catch up by the time skeletal maturity is reached¹. The procedure is typically indicated when a child is projected to have an limb length discrepancies (LLDs) between 2 and 5 centimeters at maturity². Growth disorders affecting the axis of long bones and the spine represent a significant therapeutic challenge in the pediatric population, particularly in planning and implementing treatment strategies. Such deformities may result from congenital limb defects, metabolic bone diseases, osteomyelitis, or trauma. The treatment of growth disorders predominantly relies on surgical interventions. After skeletal maturity, osteotomies are performed, posing challenges in both execution and subsequent rehabilitation. These procedures often require the use of additional fixation materials such as

plates, screws, or external stabilizers to ensure proper correction and stabilization of the bones. In growing children with active growth plates, surgical procedures such as epiphysiodesis can be utilized to correct bone deformities. This technique involves partial or complete closure of the growth plate to modulate longitudinal bone growth.

The treatment of growth disorders in children primarily involves epiphysiodesis procedures, which can be categorized into two types: temporary and permanent, differing in the method of growth plate blockage. The first epiphysiodesis, involving the removal and inversion of a cartilage-bone block, was performed by Phemister in 1933, resulting in irreversible growth plate destruction³. In 1984, Bowen described a method of percutaneous cartilage removal as a form of permanent epiphysiodesis¹.

In 1949, Blount introduced the use of metal staples placed adjacent to the growth plate to temporarily arrest growth, allowing for their removal once the desired correction had been achieved⁴. In 2007, Stevens developed an innovative solution:

a plate with screws that enabled more dynamic, temporary growth plate blockage⁵.

Accurate prediction of remaining growth is critical for determining the optimal timing of epiphysiodesis in patients with limb length discrepancies. Several established methods are commonly used to estimate remaining growth and appropriately schedule the procedure, including the arithmetic “rule of thumb,” the multiplier method, and the Moseley straight-line graph.

The arithmetic method, commonly known as the “rule of thumb,” is based on standardized growth patterns observed in the pediatric population. It operates on the following assumptions:

- Girls typically cease growing at 14 years of age, while boys stop at 16 years⁶.
- The distal femoral growth plate contributes approximately 10 mm of growth per year⁶.
- The proximal tibial growth plate adds about 6 mm per year⁶.
- The discrepancy between limb lengths increases by roughly 3 mm annually⁶.

Measuring the density and structural properties of growth cartilage (also known as the growth plate) is critical in growth disorders. Accurate assessment of growth cartilage density and structural changes using radiographic (RTG) techniques is crucial for planning, monitoring, and evaluating the success of the procedure. Imaging is used for preoperative assessment and planning: e.g. hand and wrist X-ray (Greulich and Pyle or Tanner-Whitehouse method) is used to predict remaining growth potential, helping surgeons determine the optimal time for epiphysiodesis⁷. Standard X-rays of the knee, ankle, or other targeted sites help evaluate growth plate thickness, density, and symmetry before surgery. RTG helps identify premature growth plate fusion, misplacement of implants, or bone bridge formation, which can lead to angular deformities⁸.

The main goals of the study were to evaluate density changes of growth cartilage in further end of tight bone due to procedure of epiphysiodesis.

Materials and methods

The clinical study included 9 patients of both sexes (5 females and 4 males) who were treated at the Department and Clinic of Orthopedic Surgery, Medical University of Silesia in Katowice.

The characteristics of the patients are given in **Table 1**. All patients underwent a comprehensive clinical evaluation, including a detailed medical history and radiographic (X-ray) examination. The interval between consecutive X-ray examinations for the patients ranged from 6 to 8 weeks.

During surgery, the patient was placed in the supine position under general anesthesia. Next the preparation of sterile surgical area after locating the epiphyseal cartilage of the distal femur has been performed. Straight skin incision on the lateral, medial, or lateral and medial sides of the distal end of the thigh at the level of the epiphyseal cartilage has been done. Skin is cut of about 1 cm in length. The next steps were: bone

dissection with periosteal continuity preserved, measurement of the length of the plate, and insertion of a type “8” plate with temporary fixation using a Kirchner wire. An intraoperative X-ray confirmed the correct insertion of the plate. Two Kirchner wires were inserted into the holes of the type “8” plate, and their placement was inspected with X-ray to ensure they were parallel to the epiphyseal cartilage. Screw length was measured based on the length of the inserted Kirchner wires. After reaming the bone canal, two screws were inserted into the type “8” plate. A final X-ray confirmed correct screw placement.

Table 1. Characteristics of Study Patients.

Patient	Sex	Age [years]
1	M	11
2	F	12
3	M	14
4	M	12
5	F	13
6	F	11
7	F	12
8	F	10
9	F	5
$\bar{X} \pm \sigma$	-	11.11

All analysis were done by using ImageJ 1.52v software. The average bone/growth cartilage regions of interest density measurement were done by using the optical density parameter read from the X-ray images. The average voltage in AP (anteroposterior) and side X-ray images were set as $77,3 \pm 10,3$ kV with $55,3 \pm 21,2$ mAs and for knee joint the parameters were $73,5 \pm 8,3$ kV and $4,5 \pm 1,9$ mAs.

In order to compare the differences between the initial values of bone density parameters obtained before, due to procedure of epiphysiodesis and without the procedure the dependent samples Student's t-test or Wilcoxon's test have been used, depending on homogeneity of variances and normality of data distribution which were checked by using Levene' and Shapiro Wilk's tests, respectively. The significant statistical differences were considered with $p < 0,05$.

For the analysis, the following regions of interest (ROIs) were used:

- before surgery, on the side designated for screw placement, ROIs [3, 4, 5, 6, 9] (in the vicinity of the future screw insertion) were analyzed,
- before surgery, on the opposite (contralateral) side, ROIs [1, 2, 7, 8] (without screws) were analyzed,
- after surgery, on the side with screw placement, the same ROIs [3, 4, 5, 6, 9] were used,
- after surgery, on the opposite side without screws, the same ROIs [1, 2, 7, 8] were used for comparison.

This structure ensures that comparisons were made between matched ROIs across time points and sides. All ROI locations are indicated in **Figure 1**.



Figure 1. X-ray images of patient's knee joints before procedure of epiphysiodesis (a), one day after (b) and (c) as a side X-ray with a marked regions of interest from which the density parameters have been taken, where [1,2,7,8] - on the side opposite to screw fixation, [3,4,5,6,9] - in the vicinity of screws.

Results and analysis

The representative X-ray images of patient's knee joints before procedure of epiphysiodesis (a), one day after (b) and (c) as a side X-ray are presented in **Figure 1**.

There are regions of interest marked on the X-ray images from which the average density parameters have been derived - where [1,2,7,8] - on the side opposite to screw fixation, [3,4,5,6,9] - in the vicinity of screws. Calculated average density obtained from the growth cartilage are collected in the **Table 2** respectively.

To provide better insight into the problem, mean pixel values from ROI in the studied areas were analyzed using statistical methods.

For the analysis we used the following points:

- before surgery on the side where the screws will be inserted,
- before surgery on the opposite side where there will be no screws,
- after surgery on the side where the screws will be inserted,
- with screws after surgery on the side where there are no screws.

It was obtained the statistically significant difference of average pixel value from ROI before surgery on the side where there will be screws placed and average pixel value from ROI after surgery on the side with placed screws ($p=0.01$), what is presented in **Figure 2**. It was also obtained significant difference of the average pixel value from ROI before surgery on the side where there will be screws placed and average pixel value

Table 2. Average pixel value from ROI of the growth cartilage derived from studied regions of interest in X-ray images.

Patient	Average pixel value from ROI before surgery on the side where there will be screws placed	Average pixel value from ROI before surgery on the opposite side, where there will be no screws	Average pixel value from ROI after the procedure on the side where the screws placed	Average pixel value from ROI with screws after the procedure on the side where there are no screws
1	2093.04	2093.04	1170.92	1575.91
2	2085.17	2190.42	1246.91	1475.30
3	2562.21	2767.46	1098.14	1553.69
4	1939.02	2195.37	978.08	1381.82
5	2325.39	2196.60	1530.28	1592.7
6	1698.32	1993.35	1339.63	1709.20
7	1721.32	2307.90	1320.57	1413.14
8	1505.18	1718.19	1022.34	1470.91
9	1484.25	1521.79	2795.05	2645.94

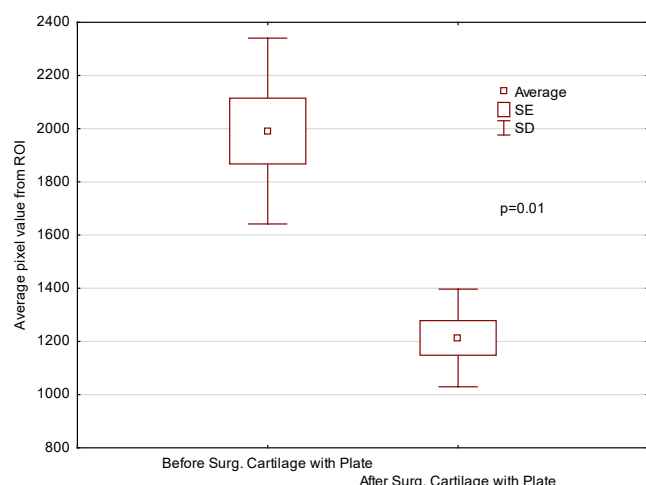


Figure 2. Difference in average pixel values from the region of interest (ROI) in the growth cartilage before surgery (Before Surgery: Cartilage with Plate) and after surgery (After Surgery: Cartilage with Plate) on the same leg, in the area between the placed screws.

from ROI after the procedure on the opposite side where there are no screws what is presented in **Figure 3**. Moreover, the average of cartilage density measured before surgery on the side where there will be screws placed was 10% significantly lower ($p=0.04$) than on the opposite side what is presented in **Figure 4**.

Discussion

Obtained results in the average pixel value from ROI changes seen in **Figure 2** may be connected with the effects of procedure performed on young organism. During epiphysiodesis, the insertion of screws requires drilling, which can disturb the bone's microarchitecture. This surgical procedure may trigger localized bone resorption and remodeling, resulting in a tem-

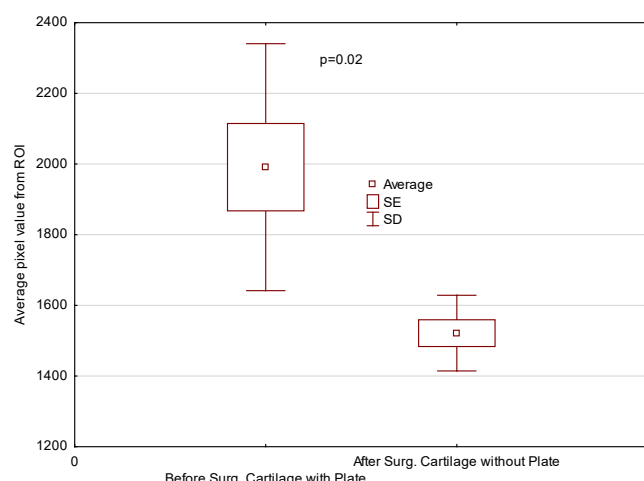


Figure 3. Difference in average pixel values from the region of interest (ROI) in the growth cartilage before surgery on the side designated for screw placement (Before Surgery: Cartilage with Plate) and after surgery on the opposite side without screw placement (After Surgery: Cartilage without Plate) in the same leg, at the distal end of the cartilage.

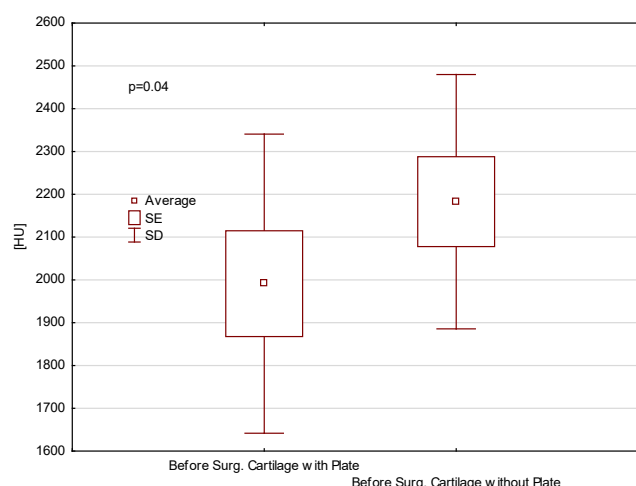


Figure 4. The differences between the average cartilage density before surgery on the side where there will be screws placed (Before Surg. Cartilage with Plate) and average cartilage density before surgery on the opposite side (Before Surg. Cartilage without Plate).

porary decrease in bone density at the screw placement site⁹. The insertion of screws affects the distribution of mechanical loads on the growth plate and surrounding bone. This alteration in stress patterns can initiate adaptive bone remodeling. Regions experiencing lower mechanical stress may gradually exhibit a reduction in bone density what may be seen in decrease of average cartilage density¹⁰.

On the other hand, the observed 50% higher the average pixel value on the side designated for screw placement prior to epiphysiodesis, compared to the contralateral side post-surgery, can be attributed to several biomechanical and biological factors, i.e. mechanical adaptation of the growth cartilage, inflammatory response and healing processes and early changes in endochondral ossification. In the first case the growth plate, or physis, is a dynamic structure responsive to mechanical stimuli. The insertion of screws during epiphysiodesis alters

the local mechanical environment, resulting in localized mechanical disruption. Insertion of screws can disrupt the local architecture of the growth plate, potentially causing immediate changes in mechanical stress distribution¹¹. Moreover fixation on one side may lead to compensatory changes in stress on the contralateral side, potentially affecting its density¹². The second issue is connected with process of surgical intervention which initiates an inflammatory response, what can influence the tissue remodeling and release of cytokines and growth factors, which can affect cellular activity and extracellular matrix composition¹³. It should also be noted that the surgical procedure can alter blood flow and initiate angiogenesis, which may affect nutrient delivery and waste removal, thereby influencing tissue density¹³. And at last the surgical intervention may accelerate or decelerate the maturation of chondrocytes, affecting the balance between cartilage and bone formation¹³.

It was also obtained that the average of cartilage density before surgery on the side where there will be screws placed was 10% significantly lower ($p=0.04$) than on the opposite side. This result appears to be consistent with clinical expectations, as the affected leg is likely to be used less due to pain. Consequently, the mechanical loading and forces acting on the bone are reduced, potentially leading to decreased bone density.

The growth plate, is a cartilaginous region located at the ends of long bones, serving as the primary site for longitudinal bone growth. This area is characterized by high metabolic activity and is regulated by various hormones and signaling compounds¹⁴. Within the growth plate, chondrocytes proliferate and undergo hypertrophy, creating a cartilaginous scaffold that is subsequently replaced by mineralized bone tissue

through endochondral ossification.¹⁴ This dynamic process can lead to regional differences in mineralization and bone density, as areas with more active chondrogenesis may exhibit lower mineral density compared to regions where ossification is more advanced¹⁴. It should be noted that variations in the rates of biological processes alone do not fully account for differences in bone density across the growth plate; mechanical loading and tension also play a critical role. In cases of valgus deformity, the affected cartilage experiences reduced mechanical stress, leading to lower bone density compared to a normally functioning leg¹⁴. Thus, the combined effects of these factors can result in changes in both cartilage and bone density.

Conclusion

The conducted study showed a statistically significant difference of more than 50% in the average pixel value between preoperative and postoperative measurements on the side with screw placement.

A significant difference of approximately 50% in the average pixel value was also observed between the preoperative measurement on the side designated for screw placement and the postoperative measurement on the opposite side, where no screws were placed.

Moreover, analysis of the average cartilage density before surgery revealed that the density on the side designated for screw placement was approximately 10% lower compared to the opposite, unaffected side.

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