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Correlation of patellofemoral joint morphology with the size of chondromalacia patella based on MRI examination

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Abstract: Determine correlation between patellofemoral joint morphology and chondromalacia patella (CMP) size based on magnetic resonance imaging (MRI) examination. This study is an analytical observational study with retrospective approach. The sample consisted of patients aged 10-50 who underwent knee MRI. We evaluated patellofemoral morphological variables and compared them with the results of size CMP lesions. The total sample size was 63, comprising 47 samples that exhibited chondromalacia patella (CMP) and 16 samples without CMP. Significant correlations ($p < 0.05$) were observed between the trochlear sulcus angle (TSA), trochlear depth (TD), and lateral trochlear inclination (LTI) with the size of CMP. Specifically, a larger TSA angle was associated with a greater size of CMP, while smaller TD and LTI angles correlated with a larger size of CMP. In contrast, the patella-patellar tendon angle (PPTA), patella type, and Insall-Salvati ratio did not demonstrate any correlation ($p > 0.05$) with the size of CMP. There is a correlation between TSA, TD, and LTI with the size of CMP. No correlation was found between PPTA, patella type, and Insall-Salvati ratio with the size of CMP.

Keywords: *Chondromalacia patella (CMP), Lateral trochlear inclination (LTI), Trochlear sulcus angle (TSA), Trochlear depth (TD).*

1. Introduction

Knee pain can be classified into anterior, medial, lateral, and posterior types. Chondromalacia patella (CMP) is one of the findings observed in patients with anterior knee pain. CMP was first described in 1906 by Konrad Büdinger and refers to a medical condition where the cartilage beneath the patella (kneecap) is damaged [1]. A study reported that the prevalence of CMP is 20% among the total sample with patellofemoral pain [2]. Knee pain in young adults can lead to functional impairments in adolescents, limiting or disrupting daily activities and ultimately resulting in decreased academic performance [3], [4].

The pathology of CMP begins with softening, swelling, and edema of the articular cartilage, causing it to appear dull or even slightly yellowish. This condition typically starts on the medial side of the patella, or just below it, beginning as small sizes, approximately half an inch in diameter or more. It then progresses to cartilage fibrillation, cracking, and fragmentation in more advanced stages [5], [6], [7], [8]. MRI is the preferred modality for assessing articular cartilage, providing the best visualization on T2-weighted sequences where abnormal cartilage appears with high signal intensity [9], [10]. The Outerbridge classification is widely used for assessing cartilage lesions due to its straightforward, user-friendly, consistent nature through direct joint imaging, either using arthroscopy or open surgery. Outerbridge grade 1 is characterized by softening and swelling. Grade 2 describes partial cartilage layer defects with no more than 0.5 inches of crevice and no subchondral bone involvement. Grade 3 is characterized by cartilage cracks greater than 0.5 inches in diameter, extending down to the subchondral bone. Grade 4 involves cartilage erosion that exposes the subchondral bone.

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The modified Outerbridge classification proposes evaluating patellofemoral chondromalacia based on MRI features, along with macroscopic and arthroscopic aspects [11].

CMP often receives less attention from radiologists during knee MRI evaluations, as the focus tends to be on structures other than cartilage, such as bone, ligaments, tendons, and synovium, leading to the need for further CMP investigation. A body of literature has indicated an association between the morphology of the patellofemoral joint and CMP [12], [13]. This study will conduct a more in-depth analysis of MRI findings related to chondromalacia patella (CMP), specifically examining the correlation between the morphology of the patellofemoral joint and the size of CMP. To our knowledge, no similar studies have been conducted. This research is supposed to provide prognostic insights regarding the risk of pathological changes in patellar cartilage, allowing for earlier preventive and curative interventions.

We evaluated the morphology of the patellofemoral joint based on several parameters related to the patella, including the patella-patellar tendon angle (PPTA), patellar type, and Insall-Salvati ratio, which also assessed femoral parameters such as the trochlear sulcus angle (TSA), trochlear depth (TD), and lateral trochlear inclination (LTI). The size of CMP was calculated based on the number of patellar facet regions affected by CMP. Subsequently, a correlation analysis was performed for each of these morphological parameters of the patellofemoral joint in relation to the size of CMP.

2. Material and Method

Our study employed an observational analytical method with a cross-sectional design that retrospectively evaluates knee MRI examinations of patients at our hospital (RSUD Dr. Soetomo Surabaya) during a specified period, adhering to inclusion and exclusion criteria. The inclusion criteria are patients aged 10 to 50 who underwent MRI examinations. Exclusion criteria include patients with knee prostheses, those with knee flexion greater than 20 degrees, and any abnormalities (such as fractures, tumors, or congenital deformities) that involve patellofemoral structures and complicate the evaluation of morphological measurements.

3. MRI Technique and Data Collection

Data in Digital Imaging and Communications in Medicine (DICOM) format were collected from a 1.5T GE Brivo MR 360 MRI machine and a 3T Siemens Magnetom Skyra MRI machine, with slice thickness of 2-3 mm. All samples underwent morphological measurements of the patellofemoral joint, focusing on both patellar and femoral aspects. Analyses were performed on T2-weighted imaging and PD fat-suppressed sequences to determine the presence of CMP. For patients with CMP, an evaluation was conducted to count the number of patellar facet regions affected by CMP.

MRI findings of CMP vary according to the severity: grade I involves chondral swelling, inhomogeneity, and hyperintense signal with an intact surface; grade II is characterized by superficial ulceration, the formation of fissures, and fibrillation of the cartilage layer of no more than 50% thickness; grade III exhibits ulceration, fissures, and fibrillation involving more than half of the cartilage layer; and grade IV is defined where complete cartilage tears with subchondral bone exposure (see Figure 1) [14].

Figure 1.
MRI of chondromalacia patella. a. Grade 1, b. Grade 2, c. Grade 3, d. Grade 4 [15].

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The patella-patellar tendon angle (PPTA) measures the angle of the intersection of the imaginary line passing through the superior and inferior patellar poles and the line passing through the inferior pole of the patella to the tibial tuberosity (see Figure 2) [16]. According to Baumgartl, the patellar types are classified into four types (see Figure 3) [17].

The insall-Salvati ratio calculates the divided patellar tendon (PT) distance by the patellar length (PL) using the lateral view of the MRI (see Figure 2) [18]. The trochlear sulcus angle (TSA) is assessed by measuring the inclination of the lateral trochlear side relative to the medial side (see Figure 2) [18]. Furthermore, trochlear depth measures the maximum space between the hollowest part of the trochlear sulcus to the line connecting the most anterior and posterior edges of the medial and lateral sides (see Figure 2) [19]. Finally, lateral trochlear inclination (LTI) is measured on axial MRI as the angle formed between a line parallel to the lateral trochlear facet and a line parallel to the posterior femoral condyle on the same image (see Figure 4) [20].

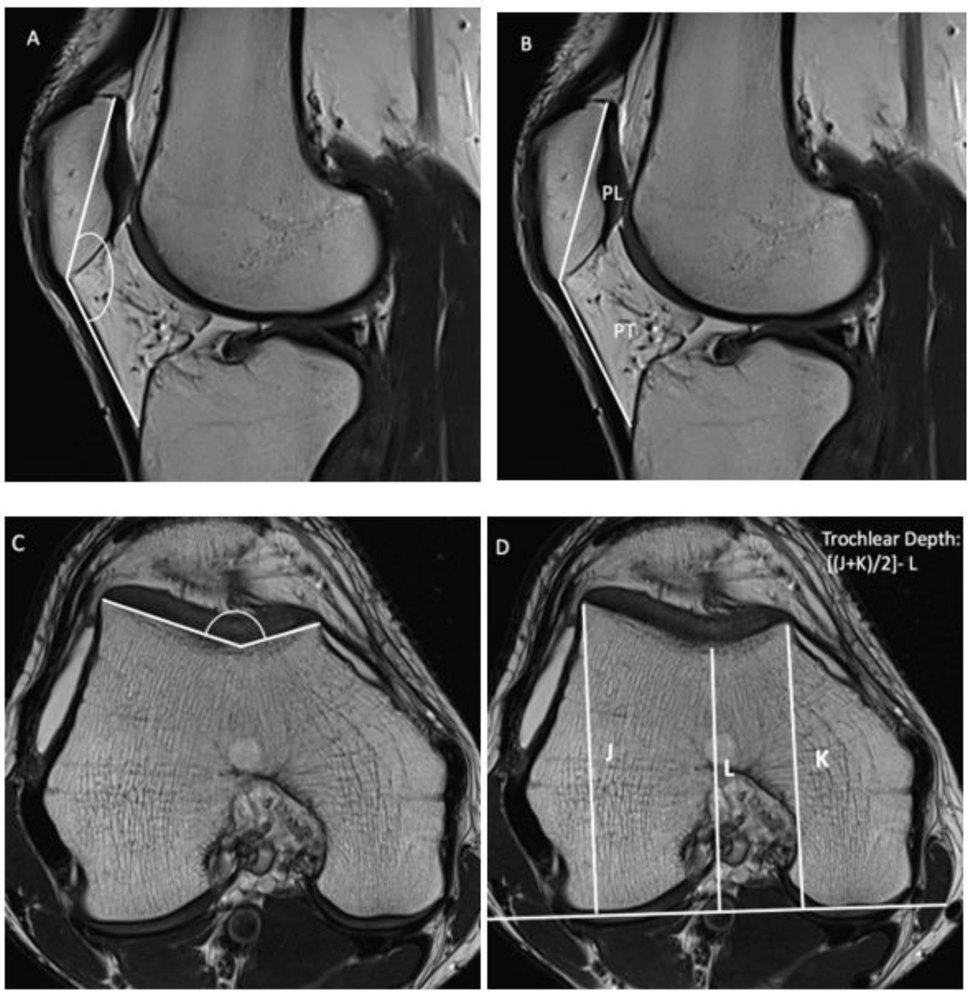

Figure 2.
a. Patella-patellar tendon angle (PPTA), b. Insall-salvati ratio (PT/PL), c. Trochlear sulcus angle, d. Trochlear depth.

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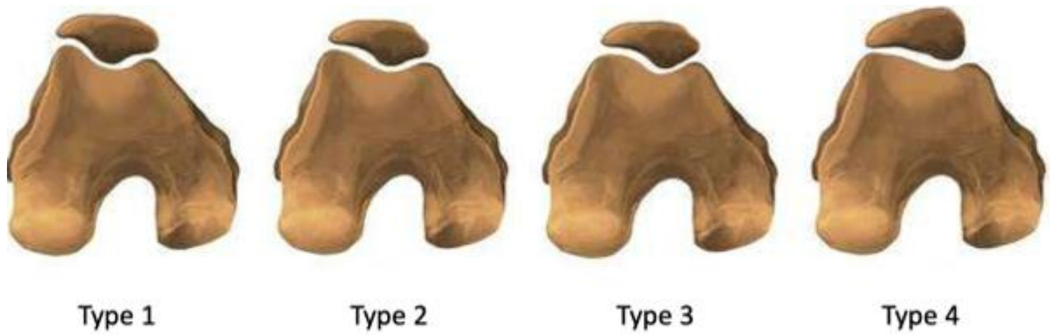

Figure 3.
Patellar types according to the Baumgartl classification.

Type 1: both the medial and lateral sides are concave and of equal length, type 2 : more prominent lateral side than the medial side and flat or concave medial side, type 3 : smaller and convex medial side, type 4 : lacks of medial side or central edge and is also referred to as the "jockey cap" [17]

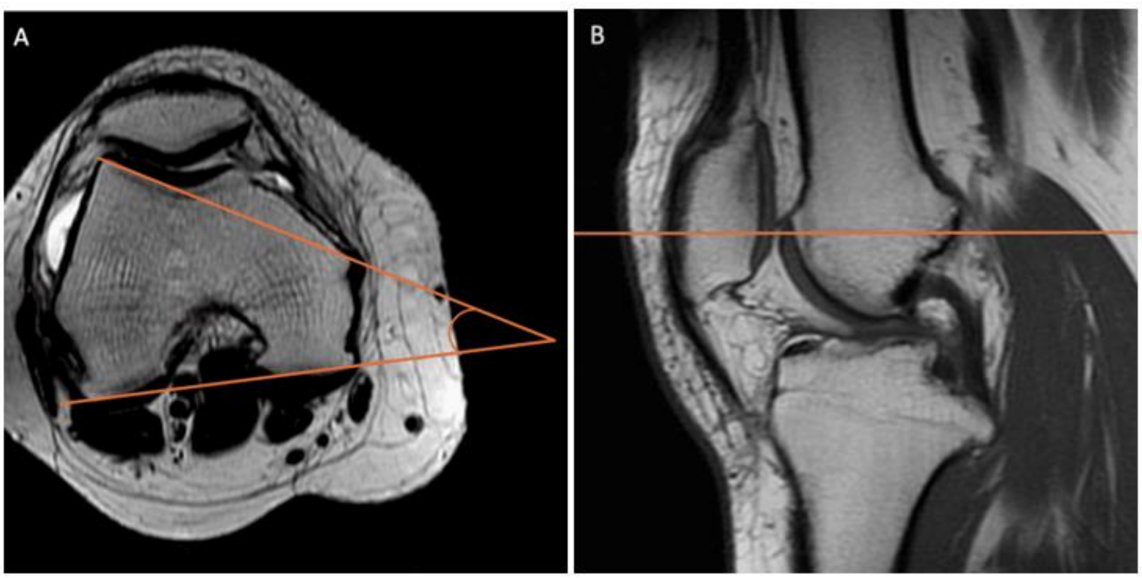

Figure 4.
Lateral trochlear inclination.

Lateral trochlear inclination (LTI), a. axial MRI, measurement LTI angle, b. sagittal MRI, level of measurement at the most proximal location of the trochlear cartilage

The size of lesion is calculated based on the number of patellar articular regions affected by CMP. The patellar articular surface is divided into seven facets, with a vertical prominence on the posterior patella dividing the patellar plane into medial and lateral halves. Furthermore, the patellar surface is split into seven facets: three horizontal pairs (proximal, middle, and distal) and an odd facet at the medial end on the posterior aspect of the patella (see Figure 5) [21].

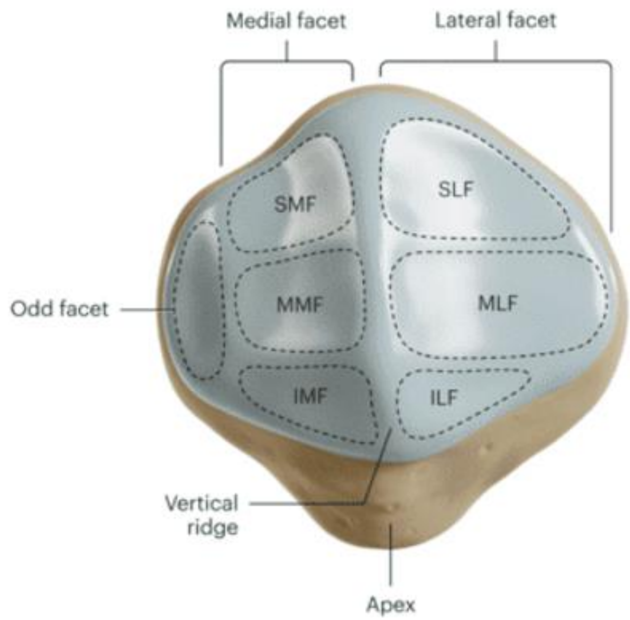

Figure 5.
Seven facets of patella [22].

4. Statistical Analysis

A Spearman correlation test was conducted to assess the association between the morphology of the patellofemoral joint and the size of CMP. Assuming a confidence interval of 95%, the findings were significant if the p-value was less than 0.05. The correlation coefficient was represented by ρ (rho), indicating the strength and direction of the relationship between the two studied variables.

5. Research Results

A total of 63 samples were selected based on the inclusion and exclusion criteria. It is noted that patients with more than one CMP lesion were counted for each lesion as a separate sample. The composition included 47 samples with CMP (74.6%) and 16 samples without CMP (25.4%). Descriptive data for the research variables can be found in Table 1. Descriptive data for the patellar regions with CMP lesions can be found in Table 2. Among the 47 samples with CMP, the smallest lesion was one region, while the largest was three regions. The most frequent finding was one region of lesion, occurring in 32 out of the 47 CMP samples (68.1%). The most affected region was the middle medial facet (MMF), with 15 samples out of 47 CMP samples (31.9%).

Table 1.
Descriptive data of research variables.

Variable	Total n= 63 (100 %)	Without CMP n=16 (25,4 %)	With CMP n=47 (74,6%)
Age			
11-20	15 (23.8%)	6 (40%)	9 (60%)
21-30	22 (34.9 %)	7 (31.8 %)	15 (68.2 %)
31-40	12 (19 %)	2 (16.7 %)	10 (83.3 %)
41-50	14 (22.2 %)	1 (7.1 %)	13 (92.9 %)
Sex			
Male	40 (63.5 %)	11 (27.5 %)	29 (72.5 %)
Female	23 (36.5 %)	5 (21.7 %)	18 (78.3%)
PPTA	143.65^o (SD $\pm$ 8.28^o)	144.55^o (SD $\pm$ 10.97^o)	143.34^o (SD $\pm$ 7.26^o)
Patella type			
Type 1	7 (11.1 %)	2 (28.6%)	5 (71.4 %)
Type 2	50 (79.4 %)	10 (20%)	40 (80%)
Type 3	6 (9.5 %)	4 (66.7 %)	2 (33.3%)
Type 4	0 (0%)	0 (0%)	0 (0%)
Insall salvati ratio	0.99 (SD $\pm$ 0.17)	1.00 (SD $\pm$ 0.19)	0.99 (SD $\pm$ 0.17)
TD	0.57 (0.28-1.11) cm	0.72 (0.41-1.11) cm	0.55 (0.28-0.99) cm
TSA	144.26^o (115.61^o-157.56^o)	138.27^o(115.61^o-154.98^o)	145.59^o(123.11^o-157.56^o)
LTI	20.66^o (SD$\pm$$4.26^o$)	23.57^o (SD$\pm$$4.3^o$)	19.67^o (SD$\pm$ 3.81^o)
Lesion's size			
1 regio			32 (68.1 %)
2 regio			13 (27.7 %)
3 regio			2 (4.3 %)

Table 2.
Data of patellar regions with CMP lesions.

Patella's region	Total
Superior medial facet	12 (25.5 %)
Middle medial facet	15 (31.9 %)
Inferior medial facet	7 (14.8 %)
Superior lateral facet	6 (12.7%)
Middle lateral facet	13 (27.6 %)
Inferior lateral facet	7 (14.8 %)
Odd facet	4 (8.5 %)

The results of the correlation analysis (Table 3) indicate that trochlear depth (TD) has a significant correlation with the size of chondromalacia patella (CMP) ($p<0.05$). This finding suggests that a smaller TD value is associated with an increased size of CMP. Similarly, the trochlear sulcus angle (TSA) exhibits a significant correlation with the size of CMP ($p<0.05$), indicating that a larger TSA is associated with a greater size of CMP. Furthermore, lateral trochlear inclination (LTI) shows a significant correlation with the size of CMP ($p<0.05$), where a smaller LTI value corresponds to a larger size of CMP. In contrast, the patella-patellar tendon angle (PPTA), patellar type, and Insall-Salvati ratio do not demonstrate a significant correlation with the size of CMP.

Table 3.
Correlation test of patellofemoral joint morphology with the size of CMP.

	Variable	Result	Correlation coeficient (ρ)
1	PPTA	$p > 0.05$	-0.15
2	Patella type	$p > 0.05$	-0.1
3	Insall-salvati ratio	$p > 0.05$	0.11
4	TD	$p < 0.05$	-0.37
5	TSA	$p < 0.05$	0.24
6	LTI	$p < 0.05$	-0.33

6. Discussion

The most significant proportion of CMP was comprised of the age group of 41-50. Additionally, the percentage of females experiencing CMP is greater than that of males. Repeated physiological stress contributes to the development of osteochondral lesions [23]; this aligns with the repetitive physiological stress associated with aging. Women are more susceptible to patellar cartilage lesions, and the prevalence increases with age [24]. Females have a larger normal Q angle compared to males, and a larger Q angle may exaggerate the patellar lateral forces by means of the bowstring effect. Hip position influences the dynamic Q angle or medialization of the knee, causing the patella to track laterally relative to the femoral trochlea. This results in excessive patellofemoral joint pressure, which can lead to patellofemoral pain [21] and CMP [5], [6], [7], [8]. Repeated physiological stress leads to the development of osteochondral lesions [23].

The characteristics of the size of CMP lesions revealed that the most frequent occurrence was in one region, with the middle medial facet (MMF) being the most affected size. Wiles et al. noted that almost all adult knees show some pathological changes, commenting that "these are generally limited to a small portion of the patella." They observed that the medial border of the medial side is the most common site for such cartilage changes [25].

Trochlear depth (TD), trochlear sulcus angle (TSA), and lateral trochlear inclination (LTI) show significant correlations with the size of chondromalacia patella (CMP). Specifically, a smaller TD value, a larger TSA, and a smaller LTI are associated with an increased size of CMP. For example, one patient in this study exhibited a large TSA (144.260), a shallow TD of approximately 0.45 cm, and a low LTI (16.72), resulting in four CMP lesions, three of which had a size of two facet regions, which aligns with the significant relationships among these three parameters and the size of CMP. Outerbridge et al. describe the characteristic appearance of CMP as a small, uninterrupted size of cartilage near the middle medial facet of the patella, measuring approximately one centimeter in diameter. This size may appear slightly swollen, possibly discolored, and soft, exhibiting a punctate or "pitted" quality when touched with a blunt instrument. From these early lesions, there is a gradual progression associated with increasing severity, characterized by fissures on the cartilage surface and deep splitting along the cartilage columns. The enlarging size develops as the damaged surface continues to erode, ultimately exposing the subchondral bone and allowing the lesions to spread across the entire patellar surface [26]. Decreased trochlear depth (TD) is a primary cause of patellar lateralization. A shallow sulcus can lead to unbalanced weight distribution on the patellofemoral joint surface during knee movement, followed by an elevated constraint on the joint and, subsequently, CMP[27]. A trochlea that is relatively flat and lacks depth may also cause uneven surface load distribution on the patellofemoral joint upon knee movement, leading to patellar instability and, consequently, the development of patellar cartilage defect, as reported in previous studies. The articular cartilage degeneration is attributed to excessive mechanical constraint on both of the patellofemoral surfaces [28]. In this study, CMP is more frequently observed in samples with a flatter lateral femoral trochlea, indicated by smaller

LTI values. This is because the lateral femoral trochlea plays a pivotal role in averting extreme lateral displacement of the patella following the contraction of the quadriceps muscle. Quadriceps muscle contraction exerts its force on the flat patella in a lateral direction, leading to increased pressure of the lateral femoral condyle to the patellar surface in knee flexion and, subsequently, cartilage erosion in the patellofemoral joint [28].

PPTA, patellar type, and the Insall-Salvati ratio do not correlate with the size of CMP in our study [29]. The patellar type, which involves cross-sectional imaging, has been discussed in research by Endo Y. In this study, we did not find a significant correlation between chondromalacia and the distance of the medial and lateral facets and the facet distance ratio calculated at three levels through the patella [30]. A limited study about the Insall-Salvati ratio found a relationship between patella alta and CMP, suggesting that patella alta contributes to mal-tracking and patellofemoral mismatch. In contrast, Dowd and Bentley identified a correlation between patella alta and patellar instability but did not find a correlation with CMP[31].

Since there is no previous research on the size of CMP lesions, we consider this value to serve as a standard for the correlation between the morphology of the patellofemoral joint and the size of CMP. This could provide an objective, clear, and accurate measurement parameter.

7. Limitation

As a retrospective cross-sectional study, we did not analyze the time interval between the measurement of patellofemoral morphology and the onset of CMP. Additionally, the sample in this study was not specifically focused on individuals with anterior knee pain, and there was no analysis of correlations with comorbidities or factors related to occupation, activity, or mode of injury.

8. Conclusion

Our analysis indicates significant correlations between TSA, TD, and LTI and the size of CMP. Specifically, a smaller TD value, a larger TSA, and a smaller LTI are associated with increased CMP size. In contrast, PPTA, patellar type, and the Insall-Salvati ratio show no correlation with CMP size. These findings suggest that specific aspects of trochlear morphology have a quantifiable relationship with the size of patellar cartilage damage, potentially offering valuable prognostic and treatment-planning insights.

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