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# The Histopathological Examination of the Degeneration of Menisci in Osteoarthritic Knees Using an Adapted Bonar Score: Does Osteoarthritis Equally Influence the Lateral and Medial Menisci?

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**Citation:** Zabrzyńska, M.; Gagat, M.; Antosik, P.; Woźniak, Ł.; Kułakowski, M.; Elster, K.; Zabrzyński, J. The Histopathological Examination of the Degeneration of Menisci in Osteoarthritic Knees Using an Adapted Bonar Score: Does Osteoarthritis Equally Influence the Lateral and Medial Menisci? *Appl. Sci.* **2024**, *14*, 9659. https://doi.org/10.3390/app14219659

Academic Editor: Francisco Arrebola

Received: 4 September 2024
Revised: 12 October 2024
Accepted: 16 October 2024
Published: 22 October 2024

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**Abstract:** This study aimed to investigate the degeneration of the meniscal tissue in osteoarthritic knees and to adapt the Bonar score and its modifications to develop a microscopic examination. This study included consecutive patients who underwent total knee arthroplasty for symptomatic end-stage gonarthrosis. During the surgery, the menisci were completely dissected to preserve their original shapes. The samples were prepared using the hematoxylin and eosin (H&E) staining method and the Alcian blue protocol and were examined under light microscopy. The extent of histopathological changes was assessed based on the classical Bonar score assumptions. Additionally, in the second step of the examination, menisci remnants were evaluated using the modified Bonar score developed by Zabrzyński et al. The study involved 44 patients, from whom 83 samples of knee menisci were obtained. Histological examination of the meniscal specimens under a light microscope revealed tissue degeneration in all cases, in both the medial and lateral menisci. The mean classical Bonar score was 8.3571 and the mean modified Bonar score was 6.9398. There were no statistically significant differences in classical Bonar score assessment between medial and lateral menisci ($p = 0.3014$). There were no statistically significant differences in the modified-Bonar score assessment between medial and lateral menisci ($p = 0.3620$). We show that both menisci are implicated in the degenerative process, with high scores in the Bonar system, regardless of knee axial deformity. The Bonar score, along with its modifications, can be readily employed in the microscopic assessment of meniscus pathology.

**Keywords:** meniscus; osteoarthritis; Bonar score; modified Bonar score; varus knees; valgus knees

## 1. Introduction

The menisci of the knee are wedge-shaped fibrocartilaginous structures located between the femoral condyles and the tibial plateau [1]. Meniscal tissue primarily consists

of water and type I collagen, intermingled with cells. Collagen constitutes 75% of the dry mass and forms the foundational structure of the menisci [1–5] Fibrochondrocytes, the local cells within the meniscus, exhibit a variety of shapes. In the superficial layer, cells are fusiform or spindle-shaped, resembling fibroblasts, while the deeper layer comprises ovoid cells similar to chondrocytes [5,6]. Furthermore, these zones are distinguished by their vascularity, which determines the meniscus's healing capacity. The peripheral zone, known as the "red–red" zone, is the most vascularized, with excellent healing potential. The "white–white" zone, with limited healing potential, is avascular, and a "red–white" transition zone exists between them, displaying characteristics of both zones [2,6–8]. The menisci were previously regarded as embryonic remnants, despite their crucial role in maintaining the optimal biomechanical properties of the knee [9,10]. They are responsible for joint stability, viscoelastic properties, shock absorption, load transmission, and strain distribution [11]. In the past, studies suggested that meniscal tears could only be repaired in the red zone, but it is now widely recognized that healing can also occur in the white zone. Due to an increasing understanding of their unique role, there is great emphasis on meniscus repair rather than removal, owing to their critical role in joint congruence, kinematics, and joint longevity [12].

Synovial inflammation intensifies the process of joint destruction, which correlates with degeneration of joint tissues and increased pain [13]. Olivotto et al. observed that patients undergoing arthroscopic meniscectomy showed macroscopic low-grade synovitis in the suprapatellar pouch, and that this is an independent predictor of pre-operative worsening symptoms and pain [14]. Olivotto et al. emphasized that targeting synovial inflammation in patients undergoing meniscectomy might be an optimal strategy in order to prevent cartilage degradation and reduce pain and dysfunction [14].

Knee osteoarthritis is a common degenerative and chronic joint disease which can be described as malformation of joint tissues, causing pain, swelling, and stiffness. All of these factors create disability in daily living due to the chronic knee pain [15,16].

In the early stage of OA, cartilage damage also affects the meniscus and ligament integrity. The degenerated meniscus is often found in OA knees. On the other hand, in advanced OA, the presence of ruptured menisci is a strong factor contributing to the level of cartilage loss in knee OA [17].

Microscopically, menisci from osteoarthritic joints exhibit disruptions in architecture and the presence of cyst-like cavities in areas where matrix and cells should be, with these cavities lined by collagen fibers and elongated cells. The distribution of cells in pathologically changed menisci varies, including hypercellular, hypocellular, and acellular regions. Cells in meniscus pathology are often larger in size and can form clusters [18]. Degenerative lesions in the meniscus frequently coincide with articular cartilage damage, suggesting an early stage of osteoarthritis [17]. Ozeki et al. noted that it remains controversial whether meniscus pathology or osteoarthritis precedes the other [19]. Furthermore, healthy menisci are seldom found in knees with osteoarthritis; instead, meniscal tears are frequently observed in knees with pathological changes [17].

The Bonar score is the most commonly used semiquantitative scoring system for assessing microscopic alterations in tendons. It consists of four main variables: tenocyte morphology, accumulation of ground substance, neovascularization, and the architecture of collagen bundles [20,21]. Some authors have modified this system by incorporating additional variables, such as the number of inflammatory cells, cellularity, calcifications, and changes in tenocyte cytoplasm [22,23]. Although the Bonar score was initially designed for tendons, Park et al. introduced its use in the assessment of meniscus root pathology in knee osteoarthritis, noting similarities between the microstructure of the fibrous connective tissue of the meniscus roots and that of the tendons [24]. Excision of the meniscus root leads to the degeneration of articular cartilage, akin to the effects of total meniscectomy [24]. Consequently, removal of meniscal tissue in cases of degeneration increases the risk of osteoarthritis development due to heightened exposure to dynamic deformation in the knee joint [25].

Nevertheless, the microstructure of pathological menisci has not been fully explored. The similarity in histopathology between tendinous tissue and meniscal connective tissue underscores the potential for the employment of similar assessment systems to quantify microscopic alterations. Even so, the Bonar score has not been previously utilized for examining the entire structure of the meniscus.

We hypothesized that there would be substantial degeneration of meniscal tissue in osteoarthritic knees, a phenomenon which could be quantified using the Bonar scoring system. Furthermore, we believed that the Bonar score and its modifications could aid in assessing meniscal tissue alterations due to their similarity in pathology to tendinous tissue. As a result, this study aimed to investigate the degeneration of meniscal tissue in osteoarthritic knees and adapt the Bonar score and its modifications to facilitate microscopic examination.

## 2. Materials and Methods

The institutional Bioethics Committee of the Nicolaus Copernicus University in Toruń located at the Collegium Medicum in Bydgoszcz approved (approval number KB 131/2022) this study, which included consecutive patients who underwent total knee arthroplasty for symptomatic end-stage osteoarthrosis. The study was performed in accordance with the Declaration of Helsinki as to experiments involving humans. All patients provided written informed consent before participating in the study.

The inclusion criteria were the presence of severe unilateral idiopathic arthritis (Ahlbäck score of II or higher) and informed consent from the patient. The Ahlbäck grading of knee OA has five stages: score 1, narrowing of the articular space; score 2, obliteration or near obliteration of the articular space; score 3, bone attrition of less than 5 mm; score 4, bone attrition between 5 and 15 mm; and score 5, bone attrition greater than 15 mm [26].

The following exclusion criteria were selected: secondary OA, previous surgical procedures within the affected knee, severe deformity (>15 deg. valgus; >20 deg. varus), advanced OA in other joints, diabetes, and advanced atherosclerosis of lower limbs.

### 2.1. Preoperative Assessment

Patient demographic data, smoking status, preoperative ROM, and preoperative X-rays were recorded. Moreover, the clinical assessment included a physical examination to assess functional outcomes, as well as the administration of the visual analog scale (VAS) for pain.

### 2.2. Surgical Technique

All procedures were performed using an anteromedial approach; a tourniquet was applied in each case. In patients, the infrapatellar fat pad (IFP) was bluntly divided from the patellar ligament and resected using electrocautery. However, surgeons incised it at the medial border of the patellar ligament to gain exposure to the knee joint. In all cases, the anteromedial joint capsule was routinely released from the tibia. The surgeries were performed according to the mechanical alignment concept; femoral components were implanted using the posterior referencing technique, while the rotation of tibial components was established parallel to a line drawn from the posterior cruciate ligament to the medial third of tibial tuberosity. In all cases, the patella was neither resurfaced nor denervated, although large patellar osteophytes were removed if present. During the surgery, the menisci (both lateral and medial in each case) were completely dissected to preserve their original shapes.

### 2.3. Histopathological Assessment

The menisci remnants were fixed in 10% buffered fresh and sterile formalin. The samples were prepared using the hematoxylin and eosin (H&E) staining method and the Alcian blue protocol and were examined under light microscopy (Olympus BX46, Tokyo, Japan), using 5 μm sections (magnification levels: 20× and 40×). Alcian blue staining was employed with the explicit purpose of determining the presence of ground-substance

glycosaminoglycans. The microscopic evaluation was carried out by two experienced observers who specialized in connective tissue and were blinded to the identity of the samples. The extent of histopathological changes was assessed based on the classical Bonar score assumptions. This scoring system evaluates four main variables: fibroblast morphology, accumulation of ground-substance elements, neovascularity, and collagen architecture. A scoring range of 0 to 3 points was assigned to each variable, with 0 indicating normal tissue and 3 representing extreme pathology. An utterly normal tissue would score 0, while a severely degenerated tendon would score 12 [25]. Additionally, in the second step of the examination, menisci remnants were evaluated using the modified Bonar score developed by Zabrzyński et al. In this modified scoring system, the attributes of the neovascularization variable in the original Bonar scale were reversed. A score of three points was assigned to normal tissue with minimal occurrence of blood vessels (absence of neovascularization), two points were assigned for the incidental presence of capillary clusters of less than one per 10 high-power fields (HPFs; mild neovascularization), one point for 1–2 clusters per 10 HPFs (moderate neovascularization), and zero points for more than two clusters per 10 HPFs (abundant neovascularization).

### 2.4. Statistical Analysis

Descriptive statistics were used to summarize categorical and continuous variables, with categorical variables reported as counts and percentages and continuous variables reported as mean ± standard deviation. The distribution of variables was assessed for normality using the Shapiro–Wilk test. Correlations between the parameters studied were assessed using the Spearman-Rho correlation coefficient. Intergroup comparisons were performed using non-parametric tests such as the Mann–Whitney U test and analysis of variance. A $p$-value of less than 0.05 was considered statistically significant. All statistical analyses were performed using GraphPad Prism software (GraphPad 8.0.1 Software, Dotmatics, UK).

## 3. Results

The study involved 44 patients, from whom 83 samples of knee menisci were obtained. The demographic data is presented in Table 1.

**Table 1.** Summary of demographic and clinical characteristics of patients.

| Characteristics | Total | Meniscus | | $p$-Value |
|---|---|---|---|---|
| | | Medial | Lateral | |
| $n$ | 83 | 41 | 42 | |
| Valgus knees | 18 | 9 | 9 | |
| Varus knees | 65 | 32 | 33 | |
| Female | 29 | 27 | 28 | |
| Male | 15 | 14 | 14 | |
| Age | 65.56 (range 51–83; SD = 7.14) | 65.14 (range 51–81; SD = 7.15) | 65.97 (range 54–83; SD = 7.19) | $p = 0.9134$ |
| VAS | 6.83 (range 5–8; SD = 0.90) | 6.85 (range 5–8; SD = 0.90) | 6.80 (range 5–8; SD = 0.91) | $p = 0.9819$ |
| Classical Bonar score | 8.3976 (range 4–12; SD = 1.5613) | 8.4878 (range 4–11; SD = 1.6751) | 8.3571 (6–12; SD = 1.5113) | $p = 0.8657$ |
| Modified Bonar score | 6.9398 (3–11; SD = 1.7967) | 6.8049 (3–10; SD = 1.8469) | 7.0714 (3–11; SD = 1.7585) | $p = 0.9378$ |

Macroscopically, all examined menisci displayed signs of degeneration, including cracks, structural disorganization, and fractures. Histological examination of the meniscal specimens under a light microscope revealed tissue degeneration in all cases, in both the medial and lateral menisci.

The mean classical Bonar score was 8.3976 (range 4–12, SD = 1.5613). Among patients with a dissected medial meniscus, the mean classical Bonar score was 8.4878 (range 4–11, SD = 1.6751), while among those with a lateral meniscus issue, it was 8.3571 (range 6–12, SD = 1.5113) (Table 1). There were no statistically significant differences in classical Bonar score assessment between medial and lateral menisci, with those scores being 8.4878 and 8.3571, respectively ($p$ = 0.3014) (Figure 1A).

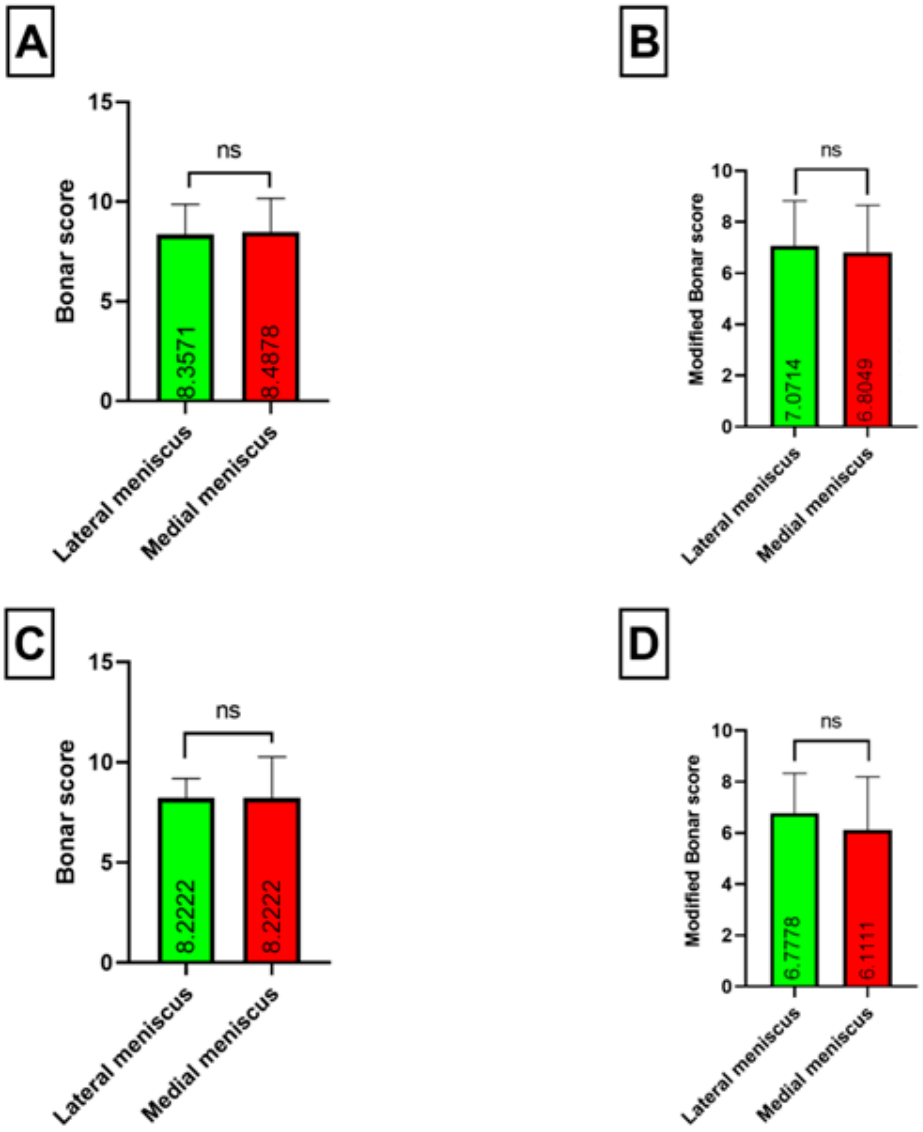



**Figure 1.** *Cont.*

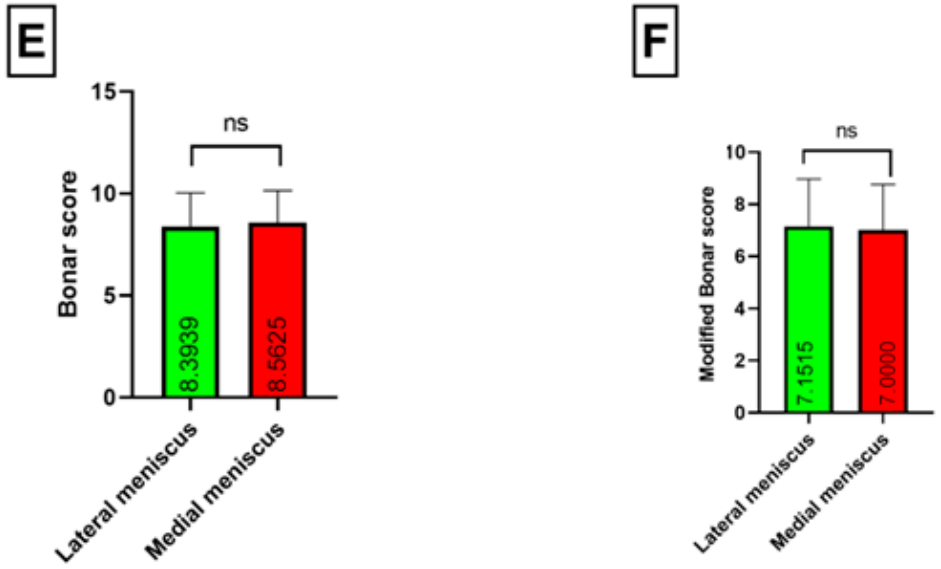



**Figure 1.** Summarized statistical analysis based on the Bonar score for the medial and lateral menisci. (**A**) Comparisons between the Bonar scores of the medial and lateral menisci in both deformity groups ($p$ = 0.3014). (**B**) Comparisons between the modified Bonar scores for the medial and lateral menisci in both deformity groups ($p$ = 0.3620). (**C**) Comparisons between the Bonar scores of the medial and lateral menisci in the valgus deformity group ($p$ = 0.4099). (**D**) Comparisons between the modified Bonar scores of the medial and lateral menisci in the valgus deformity group ($p$ = 0.2641). (**E**) Comparisons between the Bonar scores of the medial and lateral menisci in the varus deformity group ($p$ = 0.2868). (**F**) Comparisons between the modified Bonar scores of the medial and lateral menisci in the varus deformity group ($p$ = 0.4907).

The mean modified Bonar score, which includes the reversed neovascularization variable, was 6.9398 (range 3–11, SD = 1.7967). Similarly, there were no statistically significant differences in the modified-Bonar score assessment between medial and lateral menisci, with scores of 6.8049 and 7.0714, respectively ($p$ = 0.3620) (Figure 1B).

In valgus knees, there were no statistically significant differences in the classical Bonar score ($p$ = 0.4099) or its modification assessing both menisci ($p$ = 0.2641) (Figure 1C,D). Specifically, the mean classical Bonar score for the medial meniscus in valgus deformity knees was 8.2, and for the lateral meniscus, it was also 8.2. Regarding the modified Bonar score, the mean score for the medial meniscus was 6.1, and for the lateral meniscus, it was 6.7.

Similarly, in the varus deformity group, no statistically significant differences were observed in the Bonar score ($p$ = 0.2868) or its modification assessing both menisci ($p$ = 0.4907) (Figure 1E,F). Specifically, the mean classical Bonar score for the medial meniscus in varus deformity knees was 8.5, and for the lateral meniscus, it was 8.3. Regarding the modified Bonar score, the mean score for the medial meniscus was 7, and for the lateral meniscus, it was 7.1 ($p$ = 0.4907).

As shown in Figure 2A, we identified a relationship between chondrocyte morphology and gender in excised lateral menisci ($p$ = 0.0129). Specifically, males presented higher scores for altered chondrocyte morphology. However, there was no statistically significant difference between chondrocyte morphology and gender in the medial meniscus ($p$ = 0.4598) (Figure 2D). Moreover, a positive correlation was observed between age and chondrocyte morphology in the lateral meniscus ($p$ = 0.03622; Spearman r = 0.2801) (Figure 2B) but there was none for the medial meniscus ($p$ = 0.4380) (Figure 2E). No significant correlations were found between VAS score and chondrocyte morphology in either the medial or lateral meniscus (Figure 2C,F). Furthermore, there were no statistically significant differences in gender distribution when comparing the medial meniscus groups to the lateral meniscus groups (Figure 2G–I).

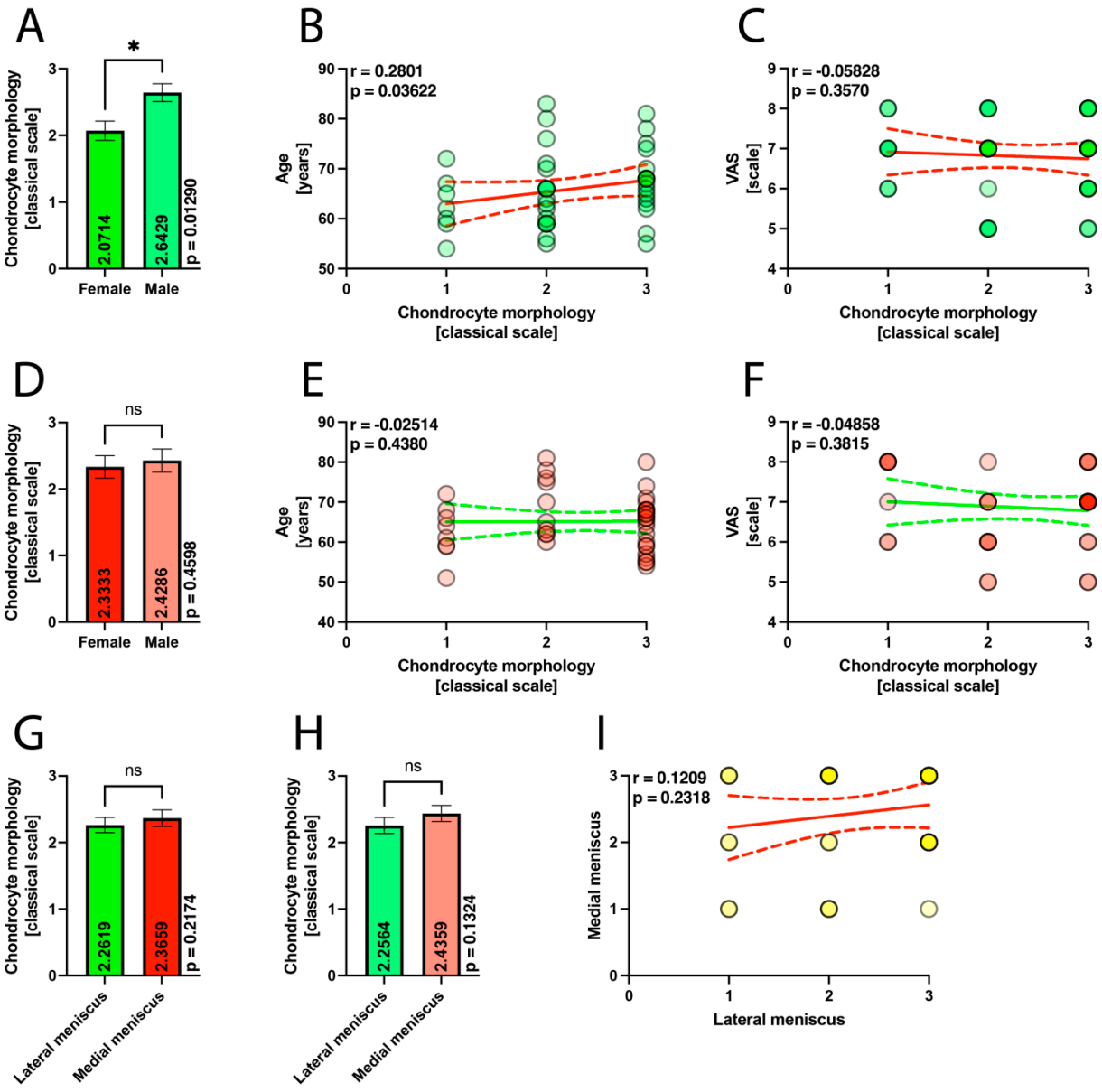



**Figure 2.** Summarized statistical analyses based on chondrocyte morphology, gender, age, and the VAS scale. (**A**) Comparison of chondrocyte morphology between gender groups, in the lateral meniscus. * $p < 0.05$ (**B**) Correlation between chondrocyte morphology and age, in the lateral meniscus. (**C**) Correlation between chondrocyte morphology and the VAS scale, in the lateral meniscus. (**D**) Comparison of chondrocyte morphology between gender groups, in the medial meniscus. (**E**) Correlation between chondrocyte morphology and age, in the medial meniscus. (**F**) Correlation between chondrocyte morphology and VAS scale, in the medial meniscus. (**G**) Comparison of chondrocyte morphologies of female participants, as to the medial and lateral menisci. (**H**) Comparison of chondrocyte morphologies of male participants, as to the medial and lateral menisci. (**I**) Correlation of chondrocyte morphology as to the medial meniscus and lateral meniscus.

Additionally, we noted that, in both the medial and lateral menisci, the vascularity variable showed no association with gender distribution, age, or VAS score, as illustrated separately in Figure 3A–F. Furthermore, there were no significant differences between the vascularity scores of lateral and medial menisci with respect to gender distribution, as shown in Figure 3G–I.

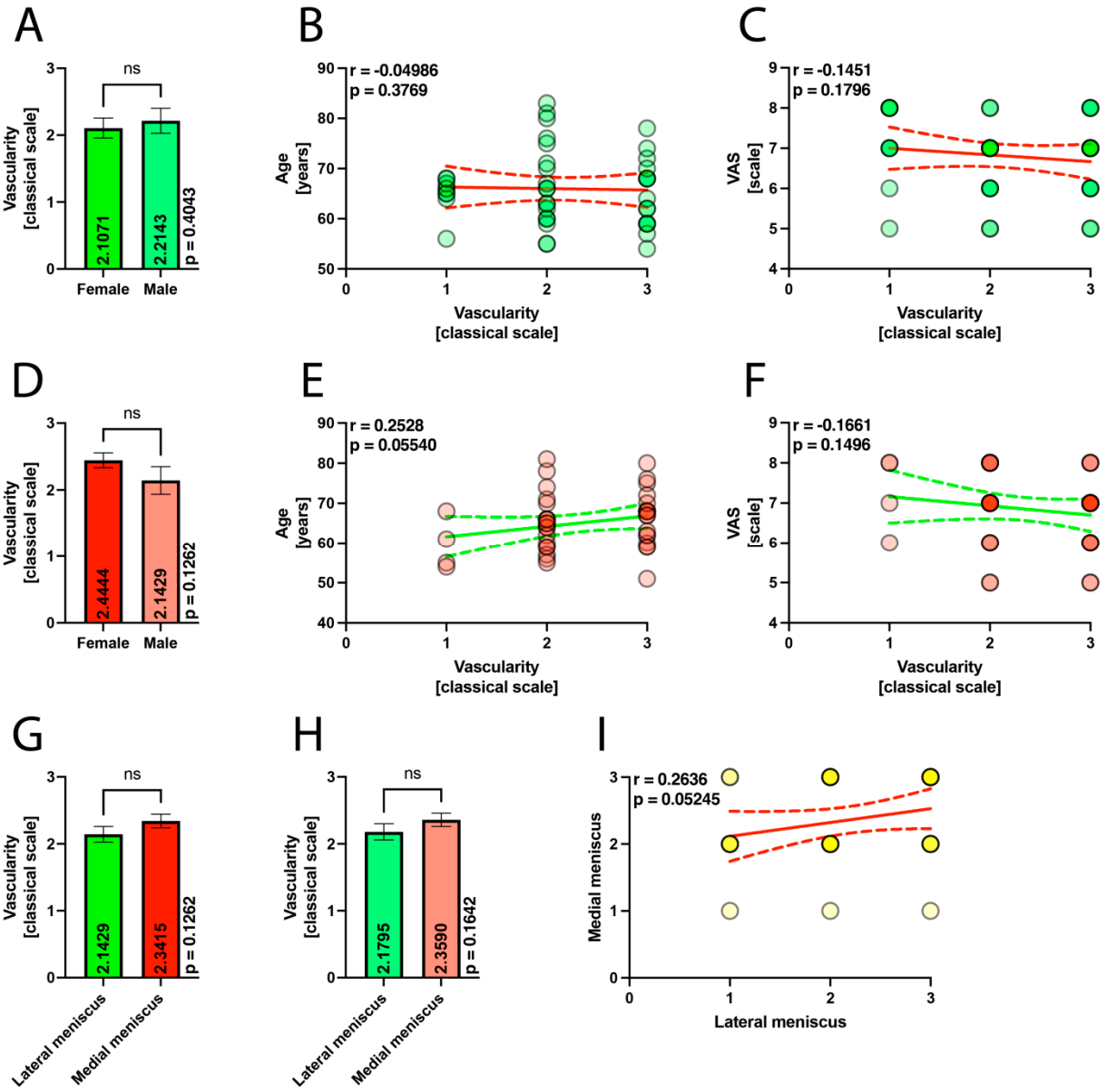



**Figure 3.** Summarized statistical analyses based on vascularity, gender, age, and the VAS scale. (**A**) Comparison of vascularity between gender groups, in the lateral meniscus. (**B**) Correlation between vascularity and age, in the lateral meniscus. (**C**) Correlation between vascularity and the VAS scale, in the lateral meniscus. (**D**) Comparison of vascularity between gender groups, in the medial meniscus. (**E**) Correlation between vascularity and age, in the medial meniscus. (**F**) Correlation between vascularity and the VAS scale, in the medial meniscus. (**G**) Comparison of vascularity, for female participants, as to the medial and lateral menisci. (**H**) Comparison of vascularity, for male participants, as to the medial and lateral menisci. (**I**) Correlation of vascularity as to the medial meniscus and lateral meniscus.

Furthermore, for both menisci, no correlation was identified between the modified neovascularization variable and gender, age, or VAS score, as illustrated in Figure 4A–F. Additionally, there were no statistically significant differences in the distribution of gender when comparing the modified vascularity scoring groups between the medial and lateral menisci, as presented in Figure 4G–I.

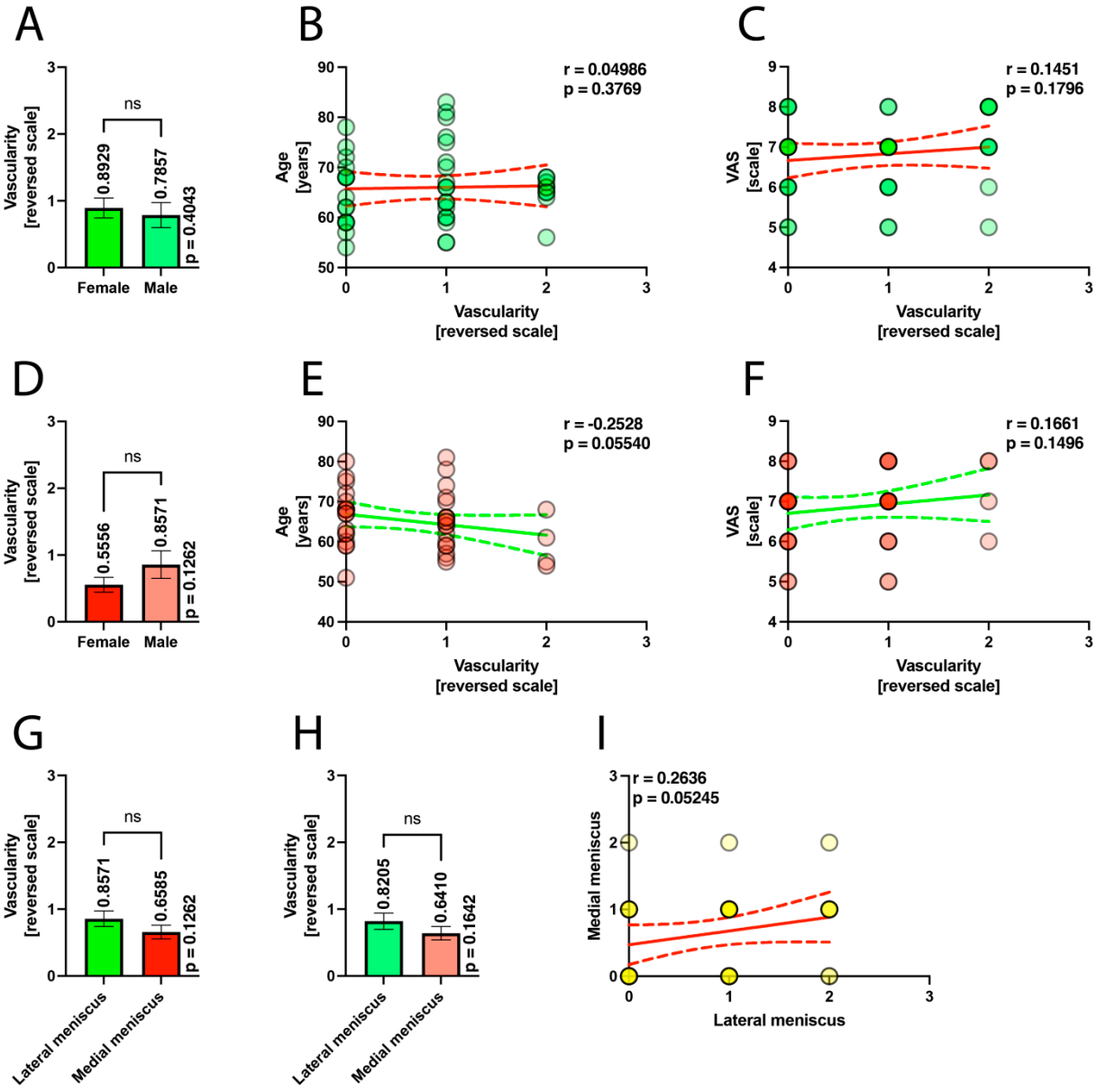



**Figure 4.** Summarized statistical analyses based on reversed vascularity, gender, age, and the VAS scale. (**A**) Comparison of reversed vascularity between gender groups, in the lateral meniscus. (**B**) Correlation between reversed vascularity and age, in the lateral meniscus. (**C**) Comparison of reversed vascularity and VAS scale, in the lateral meniscus. (**D**) Correlation between reversed vascularity and gender, in the medial meniscus. (**E**) Correlation between reversed vascularity and age, in the medial meniscus. (**F**) Correlation between reversed vascularity and the VAS scale, in the medial meniscus. (**G**) Comparison of reversed vascularity, for female participants, as to the medial and lateral menisci. (**H**) Comparison of reversed vascularity, for male participants, as to the medial and lateral menisci. (**I**) Correlation of reversed vascularity, as to the medial meniscus and lateral meniscus.

In both the lateral and medial menisci, the ground-substance variable exhibited no gender-based differences. Furthermore, it showed no correlation with age ($p$ = 0.4443 and $p$ = 0.1254) or VAS score ($p$ = 0.1081 and $p$ = 0.4345) in the lateral and medial menisci, respectively (Figure 5A–F).

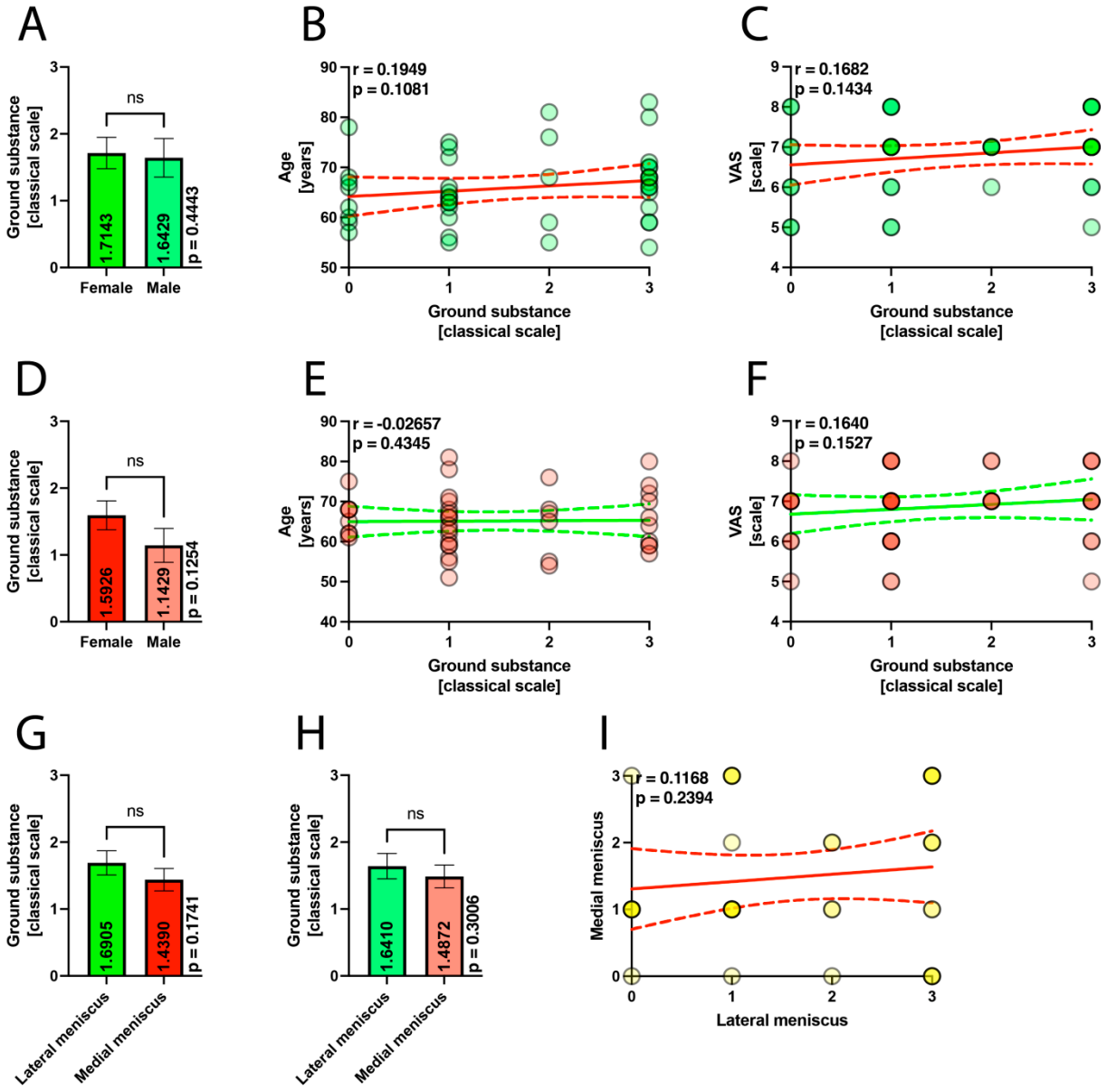



**Figure 5.** Summarized statistical analyses based on ground substance, gender, age, and the VAS scale. (**A**) Comparison as to ground substance between gender groups, in the lateral meniscus. (**B**) Correlation between the ground-substance variable and age, in the lateral meniscus. (**C**) Correlation between the ground-substance variable and the VAS scale, in the lateral meniscus. (**D**) Comparison of ground substance between gender groups, in the medial meniscus. (**E**) Correlation between the ground-substance variable and age, in the medial meniscus. (**F**) Correlation between the ground-substance variable and the VAS scale, in the medial meniscus. (**G**) Comparison of ground substance, for female participants, as to the medial and lateral menisci. (**H**) Comparison of ground substance, for male participants, as to the medial and lateral menisci. (**I**) Correlation of ground substance, as to the medial meniscus and lateral meniscus.

Moreover, when comparing males and females, there were no statistically significant differences in the ground-substance variable across the menisci ($p$ = 0.1741, $p$ = 0.3006, $p$ = 0.2394) (Figure 5G–I).

Regarding the collagen variable, as presented in Figure 6, for both of the menisci groups, there were no statistically significant differences in gender distribution ($p$ = 0.5299 and $p$ = 0.5099) (Figure 6A,D).

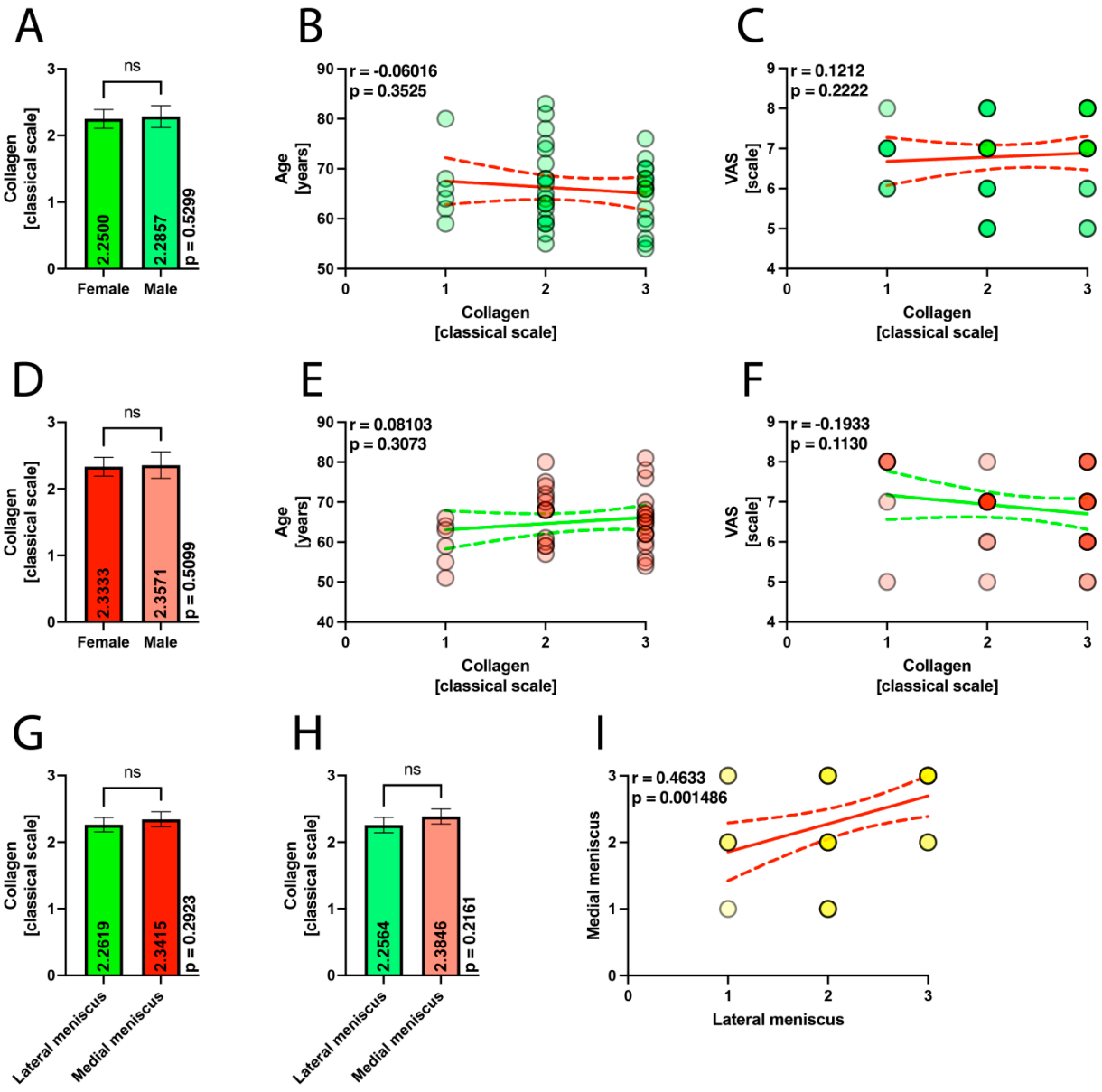



**Figure 6.** Summarized statistical analyses based on collagen composition, gender, age, and the VAS scale. (**A**) Comparison of collagen composition between gender groups, in the lateral meniscus. (**B**) Correlation between collagen composition and age, in the lateral meniscus. (**C**) Correlation between collagen composition and the VAS scale, in the lateral meniscus. (**D**) Comparison of collagen composition between gender groups, in the medial meniscus. (**E**) Correlation between collagen composition and age, in the medial meniscus. (**F**) Correlation between collagen composition and the VAS scale, in the medial meniscus. (**G**) Comparison of collagen composition, for female participants, as to the medial and lateral menisci. (**H**) Comparison of the collagen composition, for male participants, as to the medial and lateral menisci. (**I**) Correlation of the collagen composition, as to the medial meniscus and lateral meniscus.

Moreover, no correlation was observed between the collagen variable and either age ($p = 0.3525$ and $p = 0.3073$) or the VAS values ($p = 0.2222$ and $p = 0.1130$), for the lateral and medial menisci, respectively (Figure 6B,C,E,F).

When comparing the collagen variable between the lateral and medial menisci in terms of gender distribution, no statistically significant differences were found ($p = 0.2923$, $p = 0.2161$, $p = 0.1130$) (Figure 6G–I).

The classical Bonar score did not show any significant differences between the male and female groups when considering both the lateral and medial menisci separately ($p$ = 0.1086 and $p$ = 0.1385) (Figure 7A,D). Furthermore, in both menisci, age ($p$ = 0.06199 and $p$ = 0.2225) and VAS scores ($p$ = 0.2735 and $p$ = 0.1879) did not exhibit a correlation with classical Bonar values (Figure 7B–F). Additionally, there were no statistically significant differences in the distribution of classical Bonar scores between the lateral and medial menisci concerning gender classification ($p$ = 0.3014 and $p$ = 0.1615) (Figure 7G,H). Furthermore, we observed a statistically significant positive correlation between the morphologies of the medial and lateral menisci, as determined by the classical Bonar score (Spearman r = 0.3036; $p$ = 0.03014) (Figure 7I).

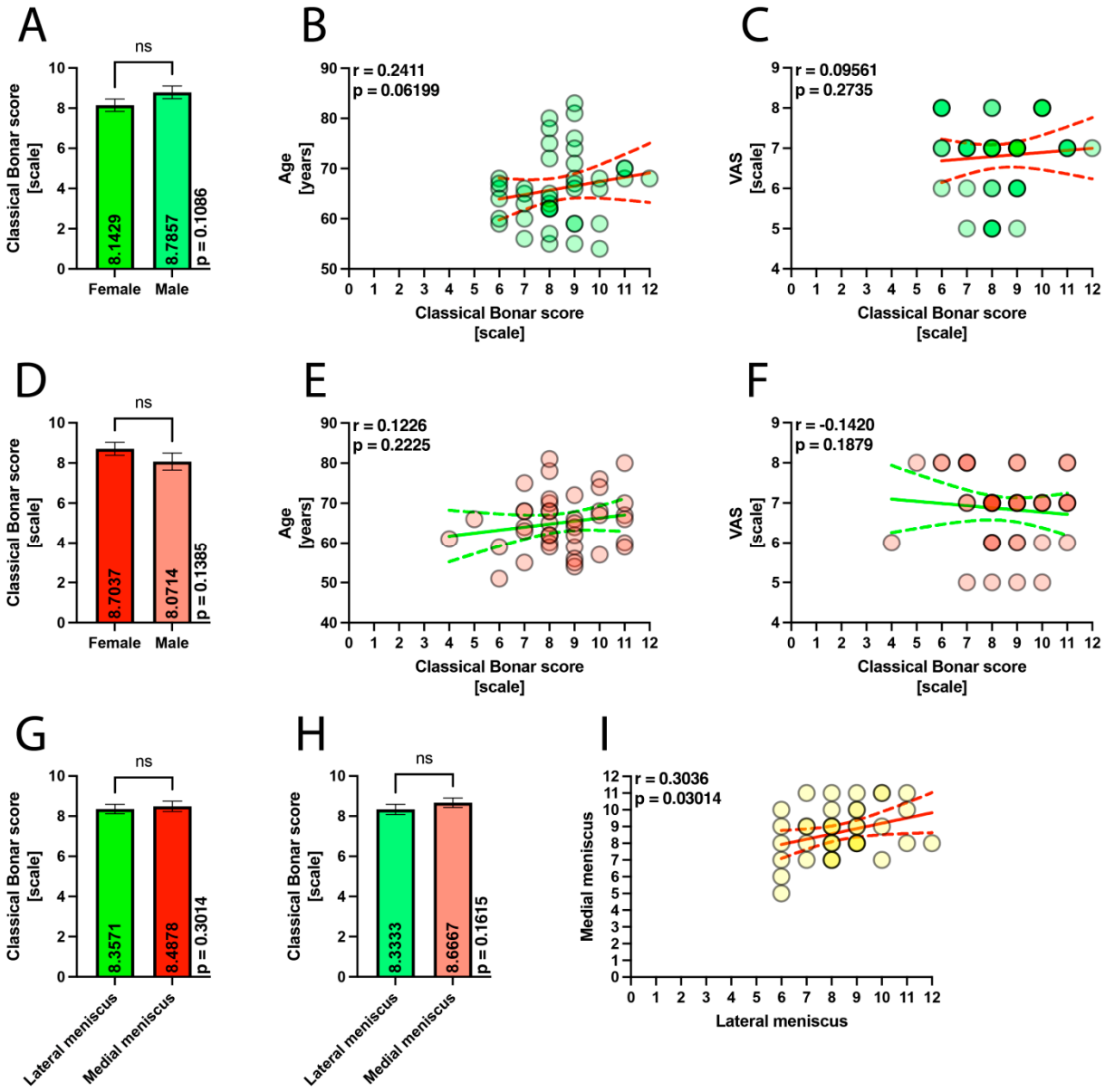



**Figure 7.** Summarized statistical analyses based on the classical Bonar score, gender, age, and the VAS scale. (**A**) Comparison of the classical Bonar score between gender groups, in the lateral meniscus. (**B**) Correlation between the classical Bonar score and age, in the lateral meniscus. (**C**) Correlation between the classical Bonar score and VAS scale, in the lateral meniscus. (**D**) Comparison of the classical Bonar score between gender groups, in the medial meniscus. (**E**) Correlation between the classical Bonar score and age, in the medial meniscus. (**F**) Correlation between the classical Bonar

score and VAS scale, in the medial meniscus. (**G**) Comparison of the classical Bonar score, for female participants, as to the medial and lateral menisci. (**H**) Comparison of the classical Bonar score, for male participants, as to the medial and lateral menisci. (**I**) Correlation of the classical Bonar score, as to the medial meniscus and lateral meniscus.

As for the modified Bonar score, we did not observe statistically significant differences between male and female groups in either the lateral or medial meniscus ($p$ = 0.2841 and $p$ = 0.4429), respectively. Additionally, there was no correlation found between age ($p$ = 0.05978, $p$ = 0.2632) and VAS scores, considering classical Bonar values in both menisci ($p$ = 0.09414, $p$ = 0.3944) (Figure 8A–F). Furthermore, there were no statistically significant differences in the distribution of the modified Bonar scores, across the lateral and medial menisci, concerning gender classification ($p$ = 0.3620 and $p$ = 0.4128) (Figure 8G,H). However, we did find a positive correlation between the classifications of medial and lateral menisci (Spearman r = 0.4199; $p$ = 0.003897) (Figure 8I).

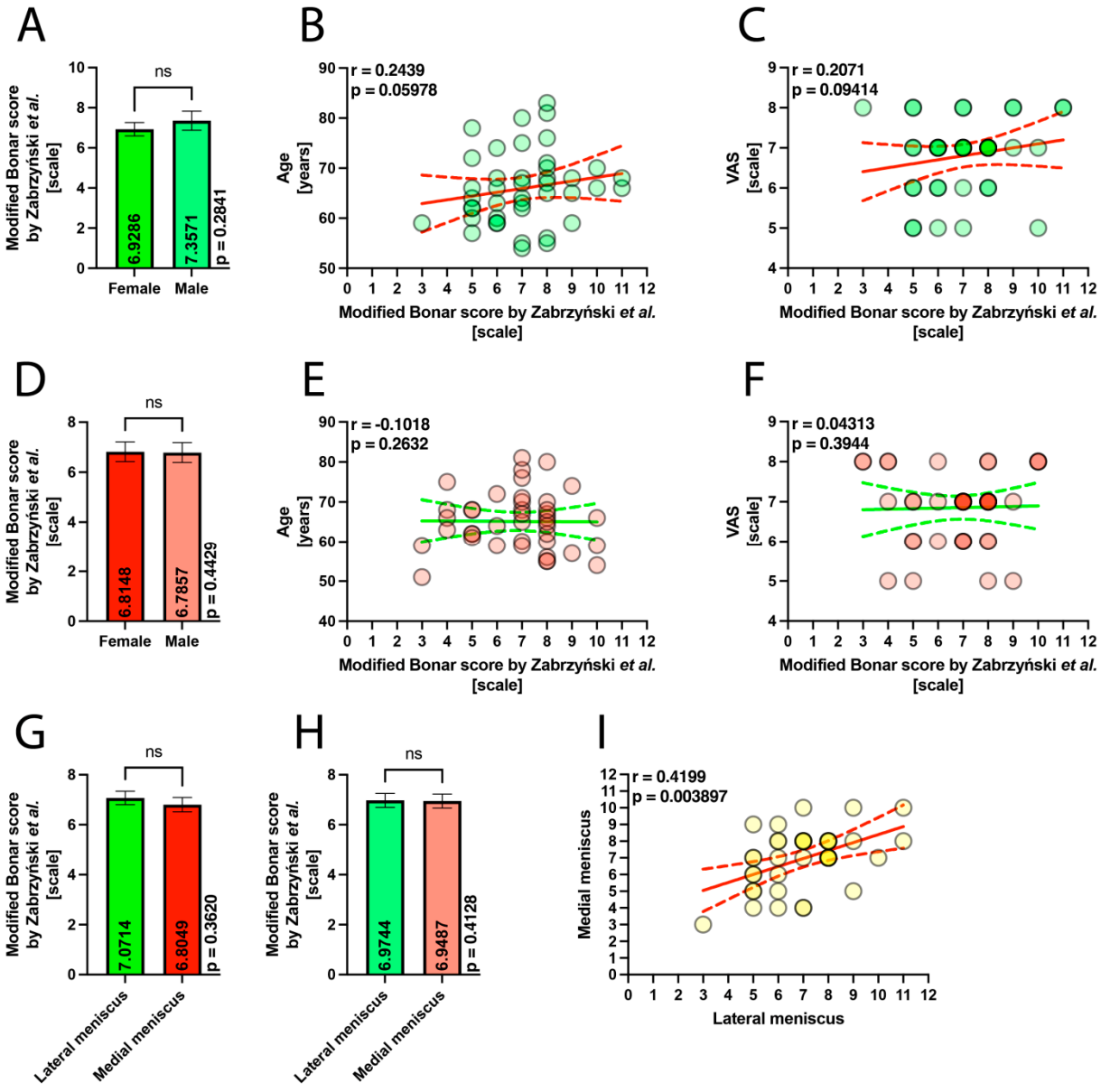



**Figure 8.** Summarized statistical analyses based on the modified Bonar score, gender, age, and the VAS scale. (**A**) Comparison of the modified Bonar score between gender groups, in the lateral meniscus.

(**B**) Correlation between the modified Bonar score and age, in the lateral meniscus. (**C**) Correlation between the modified Bonar score and the VAS scale, in the lateral meniscus. (**D**) Comparison of the modified Bonar score between gender groups, in the medial meniscus. (**E**) Correlation between the modified Bonar score and age, in the medial meniscus. (**F**) Correlation between the modified Bonar score and VAS scale, in the medial meniscus. (**G**) Comparison of the modified Bonar score, for female participants, in the medial and lateral menisci. (**H**) Comparison of the modified Bonar score, for male participants, in the medial and lateral menisci. (**I**) Correlation of the modified Bonar score as to the medial meniscus and lateral meniscus.

For both the lateral and medial menisci, there were no statistically significant differences in terms of age ($p = 0.1200$, $p = 0.06114$) or VAS score ($p = 0.2582$, $p = 0.1119$) between females and males, as shown in Figure 9A,B,D,E,G,H. Moreover, age and VAS values did not exhibit a correlation in either the lateral or medial menisci ($p = 0.4290$ and $p = 0.5000$) (Figure 9C,F–I).

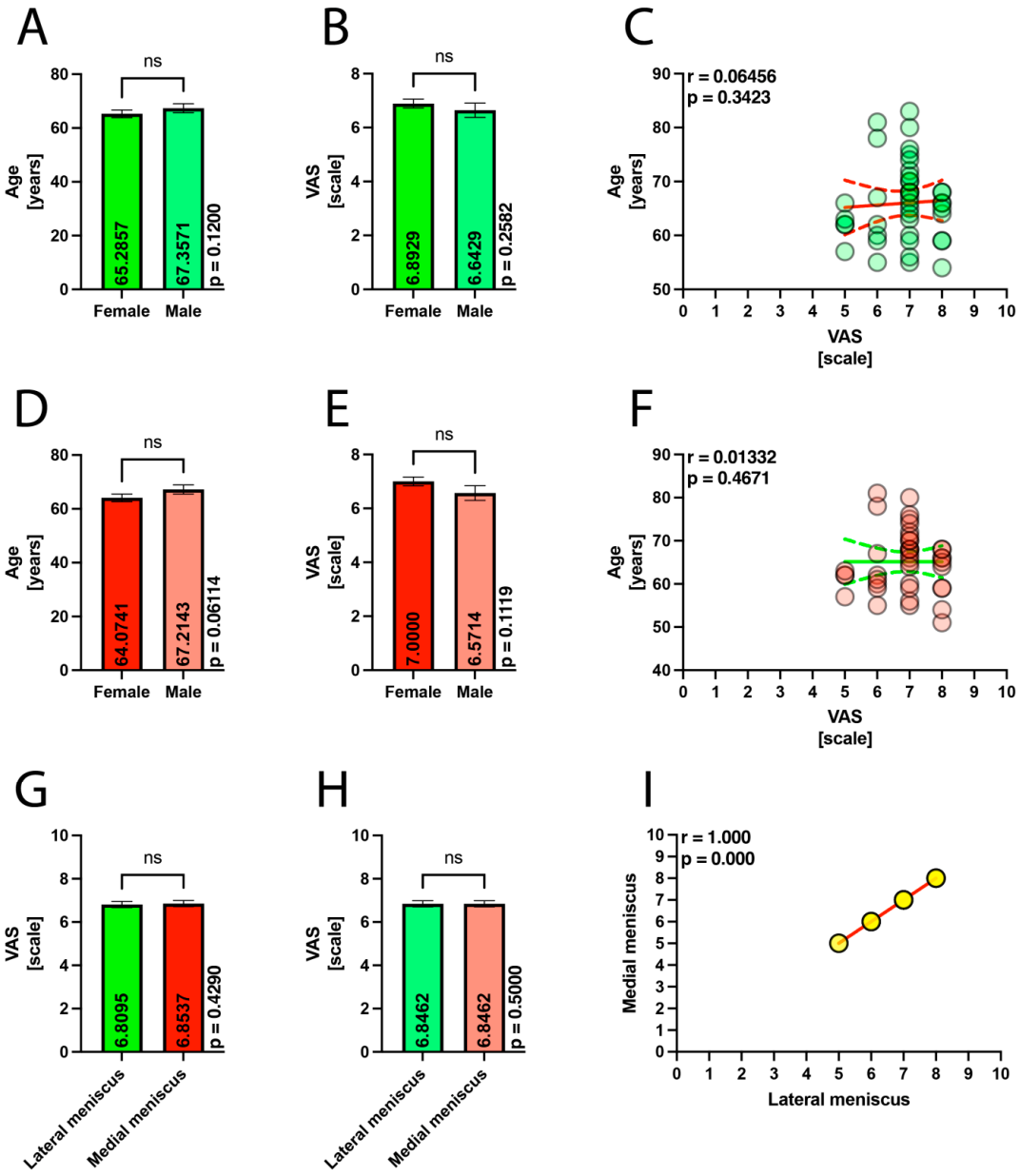



**Figure 9.** Summarized statistical analyses based on gender, age, and the VAS scale. (**A**) Comparison of age and gender, in the lateral meniscus. (**B**) Comparison of the VAS score and gender, in the lateral

meniscus. (**C**) Correlation between age and the VAS score, in the lateral meniscus. (**D**) Comparison of age between gender groups, in the medial meniscus. (**E**) Comparison of the VAS score between gender groups, in the medial meniscus. (**F**) Correlation between age and the VAS score, in the medial meniscus; (**G**) Comparison of the VAS score, for female participants, as to the medial and lateral menisci. (**H**) Comparison of the VAS score, for male participants, as to the medial and lateral menisci. (**I**) Correlation of the VAS score, as to the medial meniscus and lateral meniscus.

## 4. Discussion

While there exists a reasonable understanding of the microstructure of the menisci, to the best of our knowledge, this study represents the third attempt to quantify degenerative changes in the menisci of individuals with osteoarthritis using light microscopy. Other studies have investigated meniscus structure by electron microscopy. Previous investigations of meniscus structure also have relied on histological staining and polarized light microscopy [27–29]. Moreover, this study also constitutes another attempt to explore the use of the Bonar score in meniscus pathology.

Our study affirms a positive correlation when considering the presence of degeneration in the medial and lateral menisci of osteoarthritic knees. Another significant finding in our study was the application of the adapted Bonar scoring system, specifically designed for tendinous connective tissue. To our knowledge, this study is one of a series of studies to explore the use of the Bonar score in meniscus pathology [24]. But it is the second to apply the Bonar score comprehensively to assess the entire meniscus structure, along with modifications based on the work of Zabrzyński et al.

In our previous study we also used the Bonar score system in quantifying the pathological changes in meniscal tissue. We quantified the effect of nicotine on meniscal tissue, using the Bonar scoring system, and its modification, in microscopic examination [30]. That was our first attempt to explore the use of the Bonar score in meniscus pathology. Moreover, Park et al. also used the Bonar score in meniscus root pathology [24]. On the other hand, Pauli et al. developed their own grading-based, histopathological system. They added a main criterion, surface, and also evaluated the cellularity, collagen organization, and matrix staining (ground substance), before excluding the tenocytes and vascularity criteria [18].

The original Bonar scoring system is the most commonly employed established scale used to assess microscopic alterations in tendinous tissue [20–22,31,32]. The classical Bonar scoring system evaluates four main variables: cell morphology, accumulation of ground-substance elements, neovascularity, and collagen architecture [20]. Several researchers have adapted the classical Bonar score by incorporating additional variables to enhance diagnostic and microscopic evaluation. The most common modification involved adding a cellularity variable, based on local fibroblast counting [23,33–36]. Some studies also considered the morphology of intratendinous adipocytes [33,37] and the presence of calcifications as additional variables [33,37].

In our study, we adapted the Bonar quantitative scoring system, originally intended for tendons, to assess meniscal histology. Additionally, we opted to use the modified Bonar score. This score includes a reversal of attributes related to neovascularization. Zabrzyński et al. modified the Bonar scoring system with respect to the neovascularization process. They highlighted that, while new vessel formation can signify tissue regeneration and healing, it is well documented in advanced tendinopathies and considered a pathological phenomenon [38].

Regarding meniscal vascularity, numerous authors have explored this aspect in a macroscopic manner. Full vascularization occurs shortly after birth, and in mature menisci, blood vessels and nerves are confined to the peripheral 10–25% of the tissue. Contrarily, vascularization in the meniscus is approximately 10–30% at 10 years of age [6]. Some studies have reported a decrease in blood vessel counts with increasing age [39], and the presence of blood supply to tissue has been linked to healing and repair [9]. Additionally, Lin et al. suggested that the pediatric population exhibits greater intrinsic healing capacity for tears in what is traditionally considered the avascular zone of the meniscus, possibly due to vascularity extending beyond the generally accepted boundaries established in adult

studies [40]. On the other hand, Ashraf et al. demonstrated that high knee chondropathy is associated with increased meniscal vascularity, extending into the inner meniscal zone [28].

While the Bonar score system was initially developed for the assessment of patellar tendinopathy [23], and it primarily applies to tendons, Park et al. introduced the use of the Bonar score in meniscus root pathology in knees with osteoarthritis. They identified similarities between the fibrous connective tissue of meniscus roots and tendons in terms of microstructure [24]. In this study, we illustrated how the histopathological similarity between tendinous tissue and meniscal connective tissue can be leveraged in the adapted Bonar assessment system in order to quantify meniscus conditions.

Local meniscal cells, referred to as fibrochondrocytes, are a combination of fibroblasts and chondrocytes [41]. In the more superficial layer, these cells are fusiform or spindle-shaped, resembling fibroblasts, while ovoid cells more akin to chondrocytes are found deeper within the meniscus [5,6]. Tsuji et al. noted that an increase in cell size is a characteristic feature of senescent cells and is observed in aged menisci [42]. In our study, using the adapted Bonar score, we observed a positive correlation between age and chondrocyte morphology. The highest scores [29] indicated a predominance of increased size and round cells, as well as the presence of cell clusters. We also observed a correlation between chondrocyte morphology and gender, with men scoring higher than women for altered chondrocyte morphology. Furthermore, in addition to older age, male gender was associated with strong evidence indicating a risk factor for meniscus degeneration [43–45]. Englund et al. suggested that meniscus tears become more common with increasing age. Moreover, men had a higher prevalence of meniscal tears across all age groups [46].

In our study, there was no statistically significant correlation between the adapted Bonar score and the lateral/medial meniscus, nor was there one between the modified Bonar score and the lateral/medial meniscus, either when considering all knees or dividing them into valgus and varus knees. Generally, the medial meniscus is more frequently affected by the degeneration process [46–50]. The reasons for this difference in our study may stem from the fact that healthy menisci are rare in knees with pathological changes. Moreover, meniscus tears are typically found in knees with osteoarthritis [17,19]. The debate continues as to whether meniscus pathology or osteoarthritis develops first [19]. Meniscus tears can lead to articular cartilage degeneration, increasing the risk of osteoarthritis development [12]. Englund et al. suggested that the discovery of a degenerative meniscal tear could be considered an early indicator of osteoarthritis [51]. In these types of tears, osteoarthritis-related changes usually occur without significant injury [19]. However, in our study, meniscus degeneration was evident in both the medial and lateral meniscus. This could result from the fact that our population comprised 44 elderly patients with chronic knee conditions, including osteoarthritis and axial knee deformities. Pauli et al. also found that tears were frequently observed in both medial and lateral menisci in osteoarthritic joints [18]. Seitz et al. demonstrated a significant increase in biomechanical parameters (viscoelastic properties) of both menisci with the progression of joint degeneration, indicating advancing osteoarthritic degeneration. Despite differences in the pathologically affected zones and the stage of degeneration, their study revealed that both menisci are simultaneously impacted by osteoarthritis [52]. On the other hand, Englund et al. established a connection between meniscus damage and finger joint osteoarthritis, one which often coexists with knee osteoarthritis. They found that either the medial or lateral meniscus could be affected by the pathological process, although the medial meniscus was more extensively affected, with a prevalence of 27.6% compared to 12.4% [53].

The development of knee osteoarthritis in the medial knee area due to increased compressive forces in this compartment is associated with varus deformity. Conversely, the lateral area is linked to valgus deformity [54,55]. Our study demonstrated that both menisci undergo pathological changes, regardless of the type of axial deformity. There was no statistically significant difference between the classical Bonar score and its modification when assessing both menisci, whether in varus or valgus knees. This could result from the

fact that our patients had developed degeneration processes associated with chronic knee conditions—idiopathic arthritis.

Sharma et al. reported that among 110 varus knees, 18.2% exhibited medial damage, while 2.7% had lateral damage [54]. Habata et al. revealed that daily load stress on the knee in patients with axial alignment leads to degeneration of the medial meniscus in varus knees, eventually resulting in a meniscal tear [56]. The medial meniscus is more vulnerable due to its lower mobility compared to the lateral meniscus. The lateral meniscus lacks connections to the joint capsule or collateral ligaments and has only one disruptor of its mobility, the popliteal hiatus. Consequently, the lateral meniscus bears around 70% of the lateral load, in contrast to the medial meniscus, which carries only 50% [12,57]. Additionally, Nakagawa et al. observed that the progression of varus knee osteoarthritis initiates in the medial compartment of the knee, gradually encompassing the entire knee joint through further degenerative expansion [58]. In elderly patients with knee joint changes resulting from osteoarthritis, the degeneration process is widespread and may involve either the medial or lateral meniscus, regardless of axial deformity.

Several limitations were noted in this study. First, the sample size was modest, with female participants and varus deformities predominant. To create a more homogeneous population, strict exclusion criteria were applied to enhance its statistical power. Additionally, the use of the Visual Analog Scale (VAS) for pain assessment incorporates a subjective measure, and pain tolerance may vary among individuals. This could potentially introduce bias in our results concerning the VAS scale. Moreover, the samples were taken only from patients in the end stage of OA, which can influence the results concerning the equal impact of OA on the lateral and medial menisci, due to the fact that in end-stage OA, there is a high level of tissue degeneration.

Future analyses of the Bonar score in meniscus histopathology should be extended to conduct research on larger populations, with groups of men and women considered separately. Moreover, studies should be introduced utilizing different BMI-based groups. The future clinical applications of these findings could be linked with treatment decisions respecting unilateral versus total knee arthroplasty.

## 5. Conclusions

Our study's findings indicate that both menisci in osteoarthritic knees undergo degeneration. There is clear positive correlation found in the microscopic assessment of meniscus alterations when using scoring systems. Furthermore, regardless of knee axial deformity, both menisci are implicated in the degenerative process, recording high scores in the Bonar system. The Bonar score, along with its modifications, can be readily employed in the microscopic assessment of meniscus pathology.

**Author Contributions:** Conceptualization, M.Z. and M.G.; methodology, M.Z., P.A., Ł.W. and M.G.; software, M.Z.; validation, J.Z.; formal analysis, M.Z., M.G. and Ł.W.; investigation, M.Z., M.G. and P.A.; resources, M.Z. and M.K.; data curation, M.Z., M.K., Ł.W. and K.E.; writing—original draft preparation, M.Z. and M.G.; writing—review and editing, Ł.W., K.E. and J.Z.; visualization, M.Z. and P.A.; supervision, J.Z. and M.G.; project administration, M.Z. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** The study was conducted in accordance with the Declaration of Helsinki and approved by the local institutional Bioethics Committee of Collegium Medicum in Bydgoszcz, Poland (protocol code KB131/2022 and date of approval: 15 February 2022).

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** All data generated or analyzed during this study are included in this published article.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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