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Real 3D Visualization of the Circumflex Artery Surrounding the Mitral Annulus

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Abstract

Background The circumflex coronary artery is located close to the mitral annulus. Consequently, it is not immune to iatrogenic damage during mitral valve procedures. Our objective was to visualize the circumflex artery from a surgeon's point of view, emphasizing its proximity. Furthermore, comparing it to coronary angiograms might support preoperative planning.

Methods Ten adult human hearts preserved in 4% formaldehyde solution were investigated (left coronary artery injected with contrast agent). After performing coronary angiographies from LAO (left anterior oblique) 40/cranial 20, RAO (right anterior oblique) 10/cranial 40, and true lateral projections, anatomical preparations were performed. Images were captured throughout the full course of the circumflex coronary artery from multiple angles. Finally, the mean distances were measured in every 5 mm between the investigated artery and the annulus of the mitral valve.

Results Three-dimensional model of the circumflex coronary artery and its surroundings was successfully achieved from a left atrial surgical viewpoint. The main branches were identified on the coronary angiograms. The closest distance was measured under the region of the left auricle (2.02 ± 0.69 mm; 1–3.1 mm). Afterward, the circumflex artery was observed to make a loop away from the annular region.

Conclusion Our observations show correlation with previous anatomical studies and case reports addressing iatrogenic lesions on the circumflex coronary artery. Based on all these, we could determine a "danger zone" on the vessel. The simultaneous evaluation of the anatomical preparations and the angiograms might improve the acknowledgment of this vulnerable region serving to avoid any damage to the coronary artery.

Keywords
- ► anatomy
- ► mitral valve surgery
- ► coronary artery

Introduction

Due to its proximity to the mitral annulus, the circumflex coronary artery is susceptible to injury during mitral valve procedures. In functional and degenerative mitral regurgitation—which are the most frequent mitral valve diseases—the preferred choice of treatment is mitral valve repair or mitral valve replacement.[1–3] The surgical method during both operations consists of suturing around the mitral annulus to implant either the annuloplasty ring in mitral valve repair or the artificial valve in case of mitral valve replacement. The

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iatrogenic damage on the circumflex coronary artery during these procedures has been reported by some authors to occur in 0.5%,[4] while others have revealed the prevalence in 1.8%.[5] There are new commonly used percutaneous approaches as well, such as implantation of the Cardioband device. During these interventional treatments, between 12 and 17 anchors are deployed in a C-shaped form around the posterior mitral annulus from the anterolateral to the posteromedial commissure.[6] Additionally, mitral valve diseases are frequently associated with atrial fibrillation, for which the methods of treatment are novel percutaneous left atrial appendage closure procedures which also threaten the mentioned vessel.[7] Despite the great number of procedures mentioned earlier, the occurrence of complications on the circumflex coronary artery is rare in numbers. However, there are several case reports discussing the issue, which highlights the importance of being aware of this severe life-threatening risk.[8–12]

In the review of literature, there are various studies addressing this topic. Some of them stressed the proximity of the examined arteries by measuring the mean distances at fix points on anatomic preparations,[13–15] while others evaluated intra- and perioperative imaging technologies to avoid iatrogenic complications.[16–18] Our study is aiming at emphasizing the proximity of the circumflex coronary artery to the annulus of the mitral valve by creating a three-dimensional (3D) model of the investigated region under exact anatomical conditions. Moreover, comparing coronary angiograms to anatomical preparations—as a radioanatomic correlation study—can help prevent any devastating injuries to the circumflex artery.

Materials and Methods

In our research, 10 fresh adult human hearts (weight ranging from 290 to 670 g) removed from the chest by sectioning through the large vessels were studied. All the investigated hearts were free from any anamnestic or macroscopically observable pathological lesions that could have had any effect on our results. The cadavers (six males and four females; age ranging from 53 to 90 years) had been donated to the institution of the first author with the purpose of medical education and research.

Coronary Angiographies

Prior to the anatomical fixation, the left coronary artery was cannulated and subsequently injected with pure esophageal barium sulfate contrast agent (Microtrast, Guerbet, Roissy CdG Cedex, France). After 5 weeks of fixation in 4% formaldehyde solution, coronary angiographies were performed (Innova 2100IQ, General Electric, Boston, United States). All the hearts were examined with the same three image exposure modes (LAO 40/cranial 20, RAO 10/cranial 40, and true lateral) as demonstrated in ►**Figs. 1–2** to **3**, "C–E."

Anatomical Preparation

In purpose of the proper anatomical preparation and visualization of the circumflex coronary artery, irrelevant parts of the hearts were removed. Thus, sectioning in an apicobasal direction with a plane going through the borders of the A1–A2 scallops and the P2–P3 scallops of the mitral valve, left atriotomy and ventriculotomy were performed. The anatomical preparation was performed in a rectangle shape following the rules of layering anatomical preparation. The bottom of the oblong was by the line of the mitral annulus, while the top border was the inferior edge of the left auricle. The left and the right borders of the rectangle were determined based on the coronary angiograms adjusted to reveal the full course of the investigated vessel.

Following, regardless of the level differences and the enclosed angles between the investigated structures, the closest distances were measured in every 5 mm between the circumflex coronary artery and the annular tissue starting from the anterolateral commissure of the mitral valve to the cleft between the P2–P3 scallops on each studied heart.

3D Imaging

Colored photographs were taken (EOS 5D Mark II, Canon, Tokyo, Japan) from a surgical point of view from multiple angles, which allowed to create exact 3D modeling. Additionally, we integrated and paired the coronary angiograms with the anatomic preparations.

Results

The circumflex coronary artery was successfully made visible from a surgeon's point of view. 3D imaging models based on real anatomical preparations were successfully created to demonstrate exact anatomical conditions of hearts with each dominance pattern, such as right coronary dominance (►**Appendix A**), balanced coronary dominance (►**Appendix B**), and left coronary dominance (►**Appendix C**). (*PDF viewer which is able to open interactive 3D content is required. Instructions for opening in Adobe Acrobat Reader DC: 1. Download and open the PDF file. 2. Enable 3D content on the yellow pop-up bar by Options – Trust this document. 3. Clicking on the question mark in the upper left corner opens the interactive 3D model.*)

The main branches of the left coronary system with special regard on the circumflex coronary artery were evaluated as well as identified on both the coronary angiograms and the anatomical preparations on a heart with right (►**Fig. 1B–E**), balanced (►**Fig. 2B–E**), and left coronary dominance (►**Fig. 3B–E**).

In each preparation—independently from the dominance pattern—the proximity of the circumflex artery to the mitral annulus was measured to be the closest accordingly to the P1 scallop (2.02 ± 0.69 mm; 1–3.1 mm). This certain area was observed to concur anatomically with the orifice of the left auricle, as illustrated in ►**Fig. 1–3**, "B." Following, the circumflex artery tended to make a significant loop away from the mitral annulus (8.97 ± 4.1 mm; 4.2–15.5 mm). Throughout the full course of the examined vessel, significant intermediate atrial or any other branches (more than 2 mm diameter) were not observed between the circumflex artery and the annular tissue.

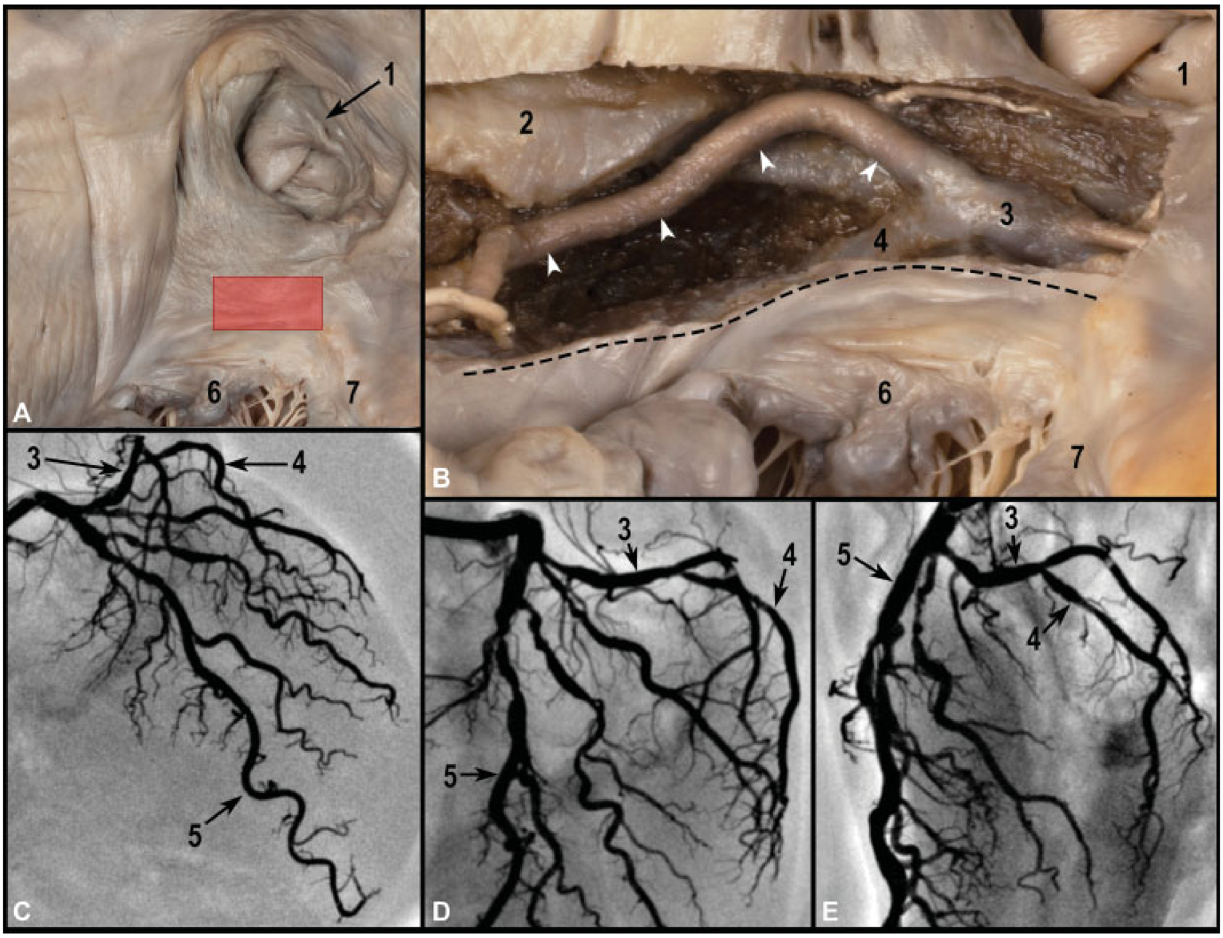

Fig. 1 Anatomical preparation of the circumflex artery compared with coronary angiograms on a heart with right coronary dominance. (**A**) The intact anatomical structure of the mitral valve and the mitral annulus in the left atrium. The vulnerable region is highlighted with a red rectangle. (**B**) The anatomical surrounding of the circumflex coronary artery. The main course of the artery is highlighted with white arrows. The mitral annulus is indicated by an interrupted line. (**C**) Coronary angiogram by RAO 10/cranial 40 projection. (**D**) Coronary angiogram by LAO 40/cranial 20 projection. (**E**) Coronary angiogram by true lateral projection. 1, left auricle; 2, coronary sinus; 3, circumflex coronary artery; 4, left marginal coronary artery; 5, left anterior descending coronary artery; 6, posterior cusp of the mitral valve; 7, anterior cusp of the mitral valve.

Finally, regarding the coronary dominance, five hearts presented with right coronary dominance (50%), three hearts with balanced dominance (30%), and two hearts presented with left coronary dominance (20%).

Discussion

Coronary angiography is part of the preoperative care serving the operator team to diagnose the coronary status beside the given mitral valve disease.[19] Though 3D imaging of the coronary vessels is achievable by switching between different viewpoints, the exact environmental relationship to the mitral valve cannot be revealed. Coronary computed tomography angiography is available for preoperative diagnostics, too. This method can solve the previous limitation by being able to visualize not just the full course of the coronary system but the anatomical surrounding as well, which might result more precise preoperative planning. With regard to the intra-operative screening, coronary angiography is performed as a standard routine while using Cardioband delivery system. Following the implantation of the first anchor, coronary angiography is performed to preclude any devastating vascular injuries to the circumflex coronary artery.[20,21] Despite the exact intraoperative screening during this catheter-based mitral annuloplasty, direct eye control is not available. On the contrary, open heart surgery allows direct eye control; however, intraoperative angiography is not accessible. Consequently, iatrogenic damage to the questionable vessels might be revealed with a delayed diagnosis in the postoperative terms. Though coronary angiography is not accessible during open heart surgery with median sternotomy, performing transesophageal echocardiography with modified midesophageal long axis might be an adequate method to preclude vascular injury to the circumflex artery.[22,23] In our study, we chose coronary angiograms as a reference to identify the examined coronary system. In addition, by having the anatomical preparations performed, real surgical point of view was achieved. Thus, we could extend the gold standard angiograms with a complete disclosure of the vicinity. Hereby, the simultaneous evaluation can result another viewpoint in risk assessment for the purpose of helping the surgeon to avoid any iatrogenic complications.

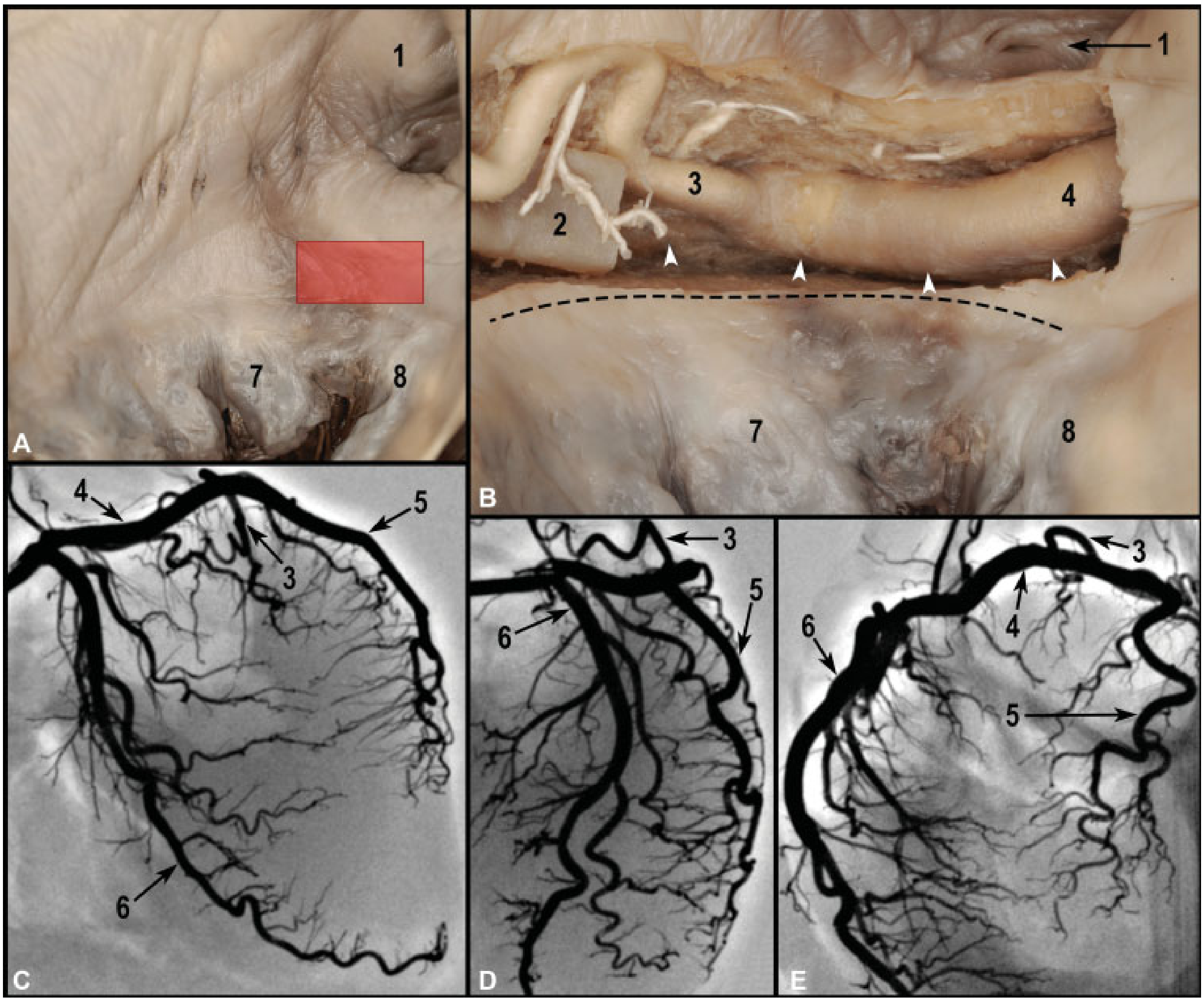

Fig. 2 Anatomical preparation of the circumflex artery compared with coronary angiograms on a heart with balanced coronary dominance. (**A**) The intact anatomical structure of the mitral valve and the mitral annulus in the left atrium. The vulnerable region is highlighted with a red rectangle. (**B**) The anatomical surrounding of the circumflex coronary artery. The main course of the artery is highlighted with white arrows. The mitral annulus is indicated by an interrupted line. (**C**) Coronary angiogram by RAO 10/cranial 40 projection. (**D**) Coronary angiogram by LAO 40/ cranial 20 projection. (**E**) Coronary angiogram by true lateral projection. 1, left auricle; 2, coronary sinus; 3, left marginal coronary artery; 4, circumflex coronary artery; 5, posterolateral coronary artery; 6, left anterior descending coronary artery; 7, posterior cusp of the mitral valve; 8, anterior cusp of the mitral valve.

Regarding the proximity of the circumflex coronary artery to the annulus of the mitral valve, our data correlated with the results presented in previous articles.[13–15,24,25] These publications emphasize the risk of iatrogenic injury to the circumflex artery by measuring the mean distances at several points of the mitral annulus on the examined hearts. The measurement technique, we performed between the investigated structures, was similar to the methods described in previous articles. However, the importance of being aware of the proximity and mean distances in numbers is essential, we believe visualizing it from a surgeon's point of view might stress the proximity even more.

Taking into consideration the review of literature in a particular segment of the circumflex artery, special attention is advised. Previous case reports suggest that iatrogenic lesions secondary to mitral valve surgery might occur in the mid-portion,[26,27] but concordantly to our results mainly in the proximal segment of the investigated coronary artery.[28–30] This certain proximal critical region is marked in ►**Figs. 1–2** to **3**, "A" with a red rectangle as "danger zone." We observed a retraction on the left atrial wall under the orifice area of the left auricle. We believe this condition might play an important role in the proximity and vulnerability of the circumflex artery under this critical area.

The limitations of our study were, first of all, the small number of cases. Therefore, we could not draw exact conclusion on pattern of coronary dominance. However, 3D visualization of anatomical preparations of each dominance pattern was performed from a surgical viewpoint. Thus, it might increase the awareness of the susceptibility of the circumflex artery more effectively than quantitative results. Second, despite the fact that the full course of the circumflex artery was made visible on anatomical preparations, this method cannot be performed in vivo. Finally, having the examined hearts ex situ removed from the cadavers, moreover, the cannulation of the left coronary artery from the aortic root

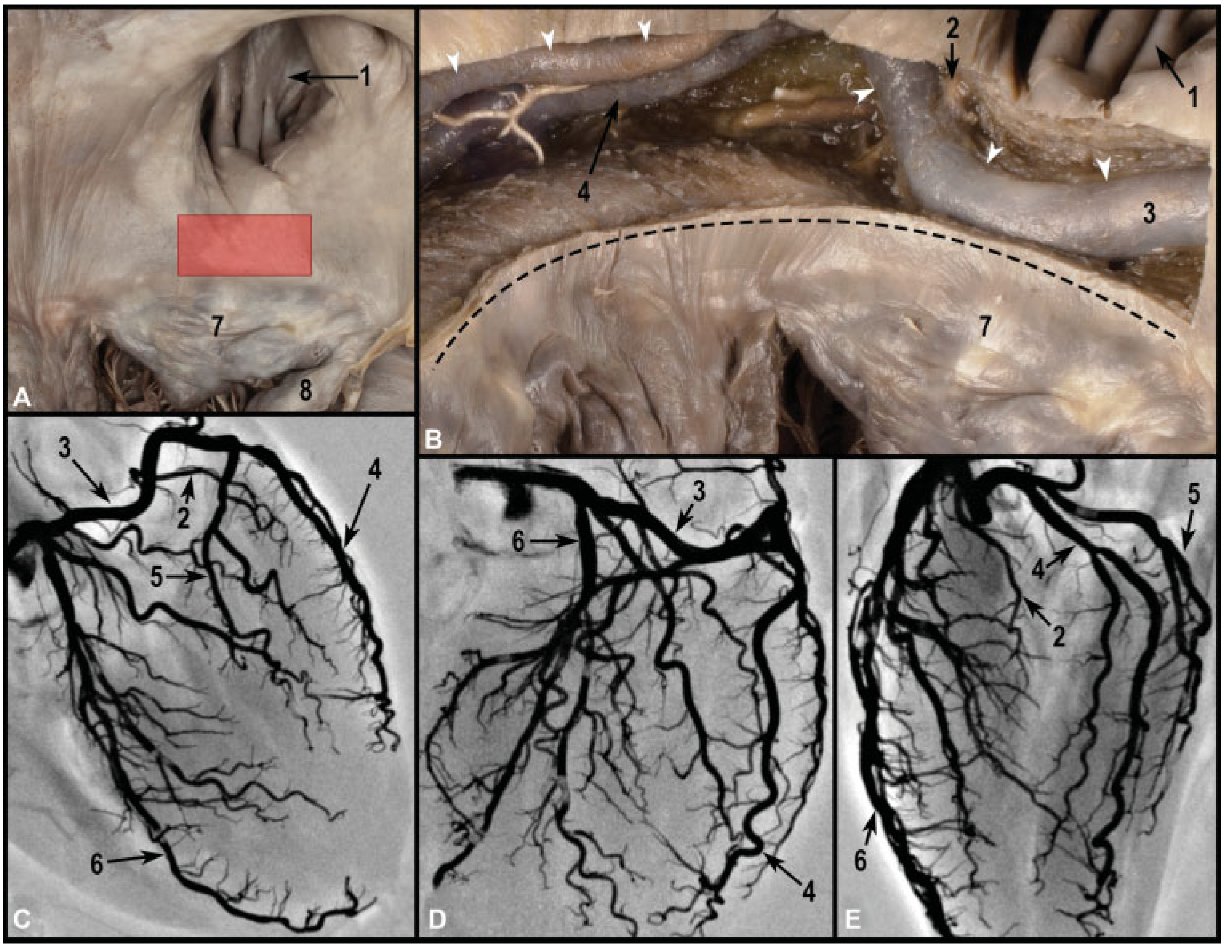

Fig. 3 Anatomical preparation of the circumflex artery compared with coronary angiograms on a heart with left coronary dominance. (**A**) The intact anatomical structure of the mitral valve and the mitral annulus in the left atrium. The vulnerable region is highlighted with a red rectangle. (**B**) The anatomical surrounding of the circumflex coronary artery. The main course of the artery is highlighted with white arrows. The mitral annulus is indicated by an interrupted line. (**C**) Coronary angiogram by RAO 10/cranial 40 projection. (**D**) Coronary angiogram by LAO 40/ cranial 20 projection. (**E**) Coronary angiogram by true lateral projection. 1, left auricle; 2, left marginal coronary artery; 3, circumflex coronary artery; 4, posterolateral coronary artery; 5, posterior descending coronary artery; 6, left anterior descending coronary artery; 7, posterior cusp of the mitral valve; 8, anterior cusp of the mitral valve.

hardened the application of the standard projections for the circumflex artery on the coronary angiograms. Thus, in purpose of more exact and more efficient identification of the main arteries in concern, other projections were chosen.

Conclusion

In conclusion, we believe this additional point of view and 3D visualization might help understand the anatomical vicinity of the affected annular region below the endocardial layer with special regard to the nearby circumflex coronary artery. Therefore, this research might contribute to avoid and reduce the incidence of iatrogenic complications resulting improved postoperative life expectancy.

Disclosures

The authors declare outside interests were not involved in neither the collection, analysis, and interpretation of the data nor the design of the study. Furthermore, the authors had freedom to fully disclose all results. Finally, no grants were received from any funding agencies in the public, commercials, or not-for-profit sectors.

Authors' Contribution

B.F.: project development, data collection, data analysis, manuscript writing; A.O.: data collection, data analysis; L.B.: data collection, project development; G.B.: project development; G.R.: data collection; T.R.: project development, data collection, data analysis, manuscript writing.

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Conflict of Interest

None declared.

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