

Patient Specific Simulation of Portal Vein Blood Flow to Predict Postoperative Thrombosis in Bariatric Surgery

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DESCRIPTION

Sleeve gastrectomy has become one of the most widely performed bariatric procedures worldwide due to its effectiveness in treating morbid obesity and associated comorbidities. Despite its popularity and overall safety, postoperative complications can arise, including bleeding, leakage and less commonly, vascular events such as Portal Vein Thrombosis (PVT). PVT is a rare but potentially life-threatening condition characterized by the formation of a thrombus in the portal vein, leading to impaired hepatic blood flow, portal hypertension and liver dysfunction. Understanding the underlying mechanisms and risk factors contributing to PVT following sleeve gastrectomy is critical for improving patient outcomes and computational modeling and simulation offer powerful tools for this purpose.

The complex pathophysiology of portal vein thrombosis involves multiple factors, including hemodynamic alterations, hypercoagulable states, endothelial injury and surgical trauma. Sleeve gastrectomy alters intra-abdominal pressure and venous flow dynamics, potentially contributing to stasis in the portal venous system. Additionally, postoperative inflammation, dehydration and patient-specific conditions such as obesity, diabetes and underlying liver disease can further increase the risk of thrombosis. Traditional clinical investigations provide valuable information but often cannot isolate the precise mechanical and hemodynamic contributions to thrombus formation. This is where modeling and simulation techniques play a pivotal role, enabling researchers to replicate and study complex physiological environments in silico.

Computational Fluid Dynamics (CFD) is one of the most effective approaches for simulating blood flow and vascular behavior in the portal system. By reconstructing patient-specific anatomical geometries from imaging data such as scans, CFD models can quantify flow velocity, pressure gradients and wall shear stress throughout the portal vein. These parameters are critical because regions of low velocity and low shear stress are prone to thrombogenesis according to Virchow's triad, which emphasizes stasis, hypercoagulability and endothelial injury as

the key contributors to thrombosis. Simulation studies can therefore identify localized zones where flow stagnation may occur postoperatively, providing insight into why certain patients develop PVT while others remain unaffected.

In addition to hemodynamic modeling, Finite Element Analysis (FEA) can be employed to assess the mechanical effects of sleeve gastrectomy on surrounding vascular structures. The procedure involves the resection of a significant portion of the stomach, which can alter intra-abdominal pressure distribution and induce subtle shifts in the orientation of veins and mesenteric structures. FEA allows for evaluation of stress and strain on the portal vein wall, which may predispose the endothelium to injury and subsequent thrombus formation. By combining CFD and FEA in an integrated framework, researchers can achieve a comprehensive understanding of both flow dynamics and mechanical forces, facilitating the identification of risk factors that are difficult to measure in vivo.

Patient-specific modeling also offers the advantage of simulating different surgical scenarios and interventions. For example, simulations can assess how variations in patient hydration, body positioning, or perioperative anticoagulation influence portal vein hemodynamics. Virtual trials using these models can inform clinical decision-making by predicting which patients are at higher risk for PVT and which intraoperative strategies may minimize that risk. Furthermore, these computational approaches enable sensitivity analysis, helping clinicians determine the relative contribution of various factors such as BMI, liver stiffness, or preexisting coagulopathy to thrombus development.

The integration of modeling and simulation with clinical data is an emerging paradigm in precision medicine. By combining postoperative imaging, laboratory markers of coagulation and hemodynamic simulations, clinicians can generate predictive models for PVT risk stratification. This approach has the potential to transform postoperative care, allowing for personalized anticoagulation protocols, early diagnostic monitoring and targeted interventions before significant complications develop. Moreover, simulation studies can guide

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the design of future surgical techniques and devices, optimizing anatomical outcomes and minimizing vascular compromise.

CONCLUSION

In conclusion, portal vein thrombosis is a serious but under recognized complication of sleeve gastrectomy that arises from a complex interplay of hemodynamic, mechanical and patient-specific factors. Modeling and simulation techniques, including computational fluid dynamics and finite element analysis, provide valuable insights into the potential causes of PVT by

replicating the physiological environment of the portal venous system. These tools enable identification of regions susceptible to thrombosis, evaluation of surgical impacts on vascular structures and prediction of individual patient risk. By integrating computational modeling with clinical practice, healthcare professionals can improve postoperative outcomes, develop preventive strategies and enhance the overall safety of bariatric surgery. As computational capabilities continue to advance, modeling and simulation will increasingly become essential components of personalized surgical care and vascular risk management.