Discover current perspectives on competitive flow from leaders in the cardiac surgery and cardiology fields. Learn how to assess competitive flow in the O.R. and consider interventions to optimize CABG patient outcomes.

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Symphony 1
Ultrasonic imaging analysis of competitive flow
The future of graft verification procedures

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Competitive flow may be seen when grafting is performed on coronary vessels with low-grade stenosis. Clinically, competitive flow is assumed to occur frequently in CABG, as coronary arteries with a luminal area stenosis of 50-70% are often grafted. Most studies on graft function have shown better long-term patency when they are directed distally to severe stenoses rather than beyond non-significant lesions. However, there is limited knowledge of the underlying pathophysiological and biomechanical mechanisms of competitive flow in CABG.

Coronary blood flow
Coronary blood flow is inversely related to the peripheral vascular resistance. The vascular resistance is very low in the epicardial coronary arteries. Only a minimal pressure drop exists between the ascending aorta and the distal end of healthy major coronary arteries. The arterioles (resistance arteries) adjust coronary blood flow according to the metabolic demands of the myocardium through the metabolic, neurogenic and vascular control systems (autoregulation). The coronary arteries provide stable myocardial perfusion when the systolic pressure ranges between 50 - 180 mmHg, allowing a relatively constant blood flow. An estimated 70% diameter reduction, equivalent to a 90–95% decrease in luminal area, is required to decrease the basal, resting coronary blood flow. During exercise, the coronary flow is already impaired when the internal diameter is reduced beyond 30%.

The coronary flow pattern is pulsatile due to the myocardial contraction and relaxation. Most of the coronary flow occurs in the diastolic phase of relaxation, most pronounced for the left coronary artery. The right coronary artery has a more equal volume flow both in systole and diastole. The flow pattern in a bypass graft should mainly be diastolic as in a coronary artery. There is a poor correlation between mean volume flow and the quality of the anastomosis (Nordgaard et al 2009). Different transit time flowmetry (TTFM) indicators have been introduced for the quality assessment in CABG:

a) Mean graft flow (> 15 – 20 ml/min)
b) Pulsatility index (PI < 5)
c) Diastolic filling % (DF % > 50)
d) Insufficiency % (retrograde flow) (< 5)

Wall shear stress and endothelial dysfunction
The vascular endothelium acts as control system by determining the vascular tonus through vasoactive mediators. The blood flow induced wall shear stress (WSS) increases the release of vasoactive
mediators from the healthy endothelium, particularly the vasodilatory molecule nitric oxide (NO). However, in rough damaged endothelium such as in patients with atherosclerosis, the release of NO is reduced and the release of the vasoconstrictive endothelin-1 is increased [Opie et al 2004]. The blood flow through arteries is mostly laminar with a parabolic profile: the highest blood velocity in the centre and the lowest velocities close to the vessel wall. The laminar blood flow may be considered as a series of layers that move with different velocities, but in the same direction. The friction between these layers generates the shear stress of blood. The WSS is the friction of blood flow against the vessel wall.

Experimental coronary flow research
In an experimental porcine model with off-pump CABG our research group studied different aspects of coronary graft flow. We aimed to analyse the influence on graft flow from competitive flow and stenotic anastomosis, as well as different WSS that may trigger endothelial dysfunction and subsequent graft failure. TTFM of the LIMA graft were recorded under four flow conditions (Fig. 1, A-D). By applying computational fluid dynamics, WSS in a 3-D LIMA-LAD model were investigated during the three different competitive flow conditions (A-C) as presented in figure 1.

Fig. 1. A schematic layout of four flow conditions.
A. No competitive flow; the proximal LAD totally occluded (baseline condition).
B. Partial competitive flow; mimicking grafting distal to a significant LAD stenosis.
C. Fully competitive flow, mimicking a non-significant LAD lesion
D. Stenotic anastomosis, mimicking a surgical error at the toe of the anastomosis, with zero competitive flow from proximal LAD.

Results
Competitive flow reduced the mean LIMA graft flow more than by a stenotic anastomosis, which was 75 % ± 11 % luminal stenosis as measured by epicardial ultrasound. Reduction of graft flow due to competition was particularly evident during diastole. The PI and retrograde flow were more increased by competitive flow than by stenosis. The DF-% was substantially reduced during competitive flow compared with both stenosis and baseline.

High competitive flow resulted in substantially lower WSS and more oscillatory shear stress in the LIMA graft compared to other flow conditions. Partial competitive flow resulted in WSS values that were similar to the non-competitive flow condition.

Comments
Competitive flow reduced the LIMA graft flow, mainly because of decreased diastolic flow, whereas the systolic flow remained unchanged. PI and retrograde flow also increased under full competitive flow. The LIMA graft flows were not significantly altered by a 75 % ± 11 % stenosis of the lumen of the anastomosis. The question how to distinguish competitive flow from a severe stenotic anastomosis is an important issue because both conditions may alter the graft flow, comparable to graft dissection, kinking, torsion and spasm, as well as high coronary resistance due to small target vessels. TTFM graft flow and pattern may be difficult to interpret. In on-pump CABG a manoeuvre to evaluate the LIMA-LAD graft is to perform TTFM prior to removal of the aortic clamp. If the LIMA flow decreases substantially following removal of the aortic clamp, competitive flow may be present. If competitive flow is suspected later, a trick is to clamp or snare the proximal native flow while measuring the graft flow. If a significant competitive flow is present, the temporary occlusion of the native flow will induce an increase of graft flow. Epicardial ultrasound may discriminate between stenosis and competitive flow [Haaverstad et al 2002] [Lovstakken et al 2008].

Vein graft failures are believed to be the most common reason for recurrent coronary symptoms following CABG. At approximately 10 years, 50 % of all SVGs are occluded, and half of the remaining grafts are expected to be severely narrowed due to atherosclerosis. A characteristic lesion observed in the LIMA is the “string phenomenon”, a longitudinal narrowing of the LIMA lumen to less than 1 mm over a length of 3-5 cm or more. Competitive flow in the LIMA is believed to cause the “string phenomenon”, which is considered an early sign of graft failure and occur in about 2 % of CABG patients.

The shear stress induced by blood flow on the endothelium triggers its biochemical responds and is probably a major contributor to endothelial function. An unfavourable WSS induces endothelial dysfunction, which may cause vascular disease such as intimal hyperplasia and atherosclerosis. At high competitive flow, such as when a graft is placed distal to a non-significant coronary stenosis, very low and oscillatory WSS was found. This unfavourable WSS may explain the LIMA “string phenomenon” and reduced graft patency due to competitive flow.

Conclusions
Transit time flowmetry (TTFM) cannot detect technical failures in the anastomoses unless they are haemodynamically significant. However, competitive flow influences the TTFMs early and substantially. Unfavourable and oscillatory wall shear stress (WSS) seen during high competitive flow may cause damaging effects on the endothelium, inducing endothelial dysfunction. Thus, competitive flow may cause the LIMA “string phenomenon” and reduced long-term patency of coronary bypass grafts.

References
TTFM identifies competitive flow in the operating room

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Although preferred conduits for coronary artery bypass graft surgery (CABG), competitive flow may diminish the efficacy of arterial grafts. Vein grafts suffer almost no competitive flow 1, but their limited lifespan precludes them from being acceptable long-term conduits. Because of their reactive muscular makeup, flow in arterial grafts rises and falls as is needed, hence competitive flow may interfere with longevity of arterial grafts. Use of transit-time flow measurement (TTFM) in the operating room identifies grafts with competitive flow. Testing for competitive flow involves placement of a proximal snare (silastic loop) on the native coronary artery 1-2 cm above the distal anastomosis. After initial TTFM of the bypass graft, the silastic loop is then snared to occlude any competing flow down the native coronary artery. The three parameters (flow PI and DF) are then re-measured. Upon review of 120 off-pump CABG surgeries with 98% arterial grafts, and analysis of TTFM values of bypass grafts before and after snaring of coronary arteries proximal to the anastomosis, 3 patterns emerged: 1) Flow increase and PI decrease 2) Flow and PI stay approximately the same 3) Flow decrease and PI increase or minimal change.

This first pattern (increased flow and decreased PI) occurs most often in grafted vessels with moderate stenosis (60-70%) indicating competitive flow from the native coronary artery. By occluding the natural flow, downstream resistance is decreased allowing increased flow in the conduit. The second pattern (minimal change in flow and PI) occurs in severely stenosed (80-90%) coronary arteries because there is very little native flow. The third pattern of decreased flow and changed PI is seen in three clinical scenarios: a) the suboptimal graft: this pattern is one of markedly decreased flow and significantly elevated PI to above the acceptable value (P < 5) and occurs because before snaring, the majority of the forward flow was coming from the native coronary. Without the snare, the graft flow looks falsely good with flow only retrograde into the native coronary. Proximal snaring unmasks sub-optimal grafts. Other scenarios of decreased flow and PI change (which may be minimal) include b) coronary arteries that are either occluded completely or c) that have very proximal disease with a significant amount of myocardium (eg. in a very proximal 90% stenosis of an LAD artery with many septal perforators and diagonal branches) supplied retrograde from the anastomotic site. Placement of the snare occludes retrograde run-off, thereby reducing flow but not altering PI to the point of unacceptability.

To summarize: competitive flow is an important entity in arterial grafting that becomes readily apparent and unmasked by the snare test. The three patterns of Flow and PI values reflect the degree of stenosis in the native coronary artery grafted and the pattern of disease in the artery. TTFM is an invaluable tool in the use of arterial grafting and can help direct the conduit choice according to severity of coronary disease for individual coronary arteries and systems.

Reference
What is the impact of competitive flow on distal coronary and graft flow?

Nikolaos Tsirikos-Karapanos, MD, PhD, FETCS

After the monumental publication from Cleveland Clinic, regarding the influence of the internal mammary artery on ten year survival in 1986, the left internal mammary artery to left anterior descending (LIMA-to-LAD) anastomosis became the golden standard in coronary artery bypass surgery (CABG). Further clinical research revealed that an important factor affecting early arterial graft patency is competitive flow (CF) from the native coronary artery.

In the present study, transit time flow measurements (TTFM) were used to investigate the impact of LAD competitive flow (LAD-CF) on LAD distal coronary flow (LAD-DF) and on LIMA graft flow (LIMA-GF), in a swine model of a LIMA-to-LAD CABG.

In six swine, a standardized LIMA-to-LAD CABG was performed on the beating heart using the C-Port Distal Anastomosis System (Cardica). LAD blood flow was measured bilaterally to the LIMA-to-LAD anastomosis, in the LIMA and in the pulmonary artery (cardiac output, CO) along with the LIMA pulsatility index (LIMA-PI) and the left ventricular pressure (LVP) using the VeriQ multi-channel flow and pressure monitor (Medistim). Pre-CABG measurements were followed by post-CABG measurements at five levels of LAD-CF: 100%, 75%, 50%, 25% and 0% after gradually snaring down a snare placed proximally of the LAD-CF flow probe.

Pre-CABG CO and LVP remained unchanged post-CABG. LAD-DF was reduced significantly post CABG. Reduction of the LAD-CF (at 75%, 50%, 25% and 0%) resulted in significant increase of LIMA-GF, reduced PI with simultaneous increase of LAD-DF.

What is FFR and should you insist on it for all your CABG patients?

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Key Points for Fractional Flow Reserve (FFR):
- FFR is function based
- As compared to visual assessment of lesion severity, use of FFR led to less revascularization and improved outcomes at 1 and 2 years
- FFR-guided PCI decreases costs
- Current guidelines grant FFR a Class IIA indication for assessing intermediate lesions
- Role of FFR pre-CABG is unknown

References

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To the best of our knowledge, this is the first study where blood flow was directly and simultaneously measured in all the components of the LIMA-to-LAD anastomosis. TTFM, apart from its proven valuable use in clinical research, is a powerful tool for use in cardiovascular translational surgical research.

References
2. Sabik JF, Blackstone EH. Coronary artery bypass graft patency and competitive flow. JACC 2008; 51:126-8
6. Tsirikos Karapanos N, Suddendorf SH, Li Z, Huebner M, Park SJ, Joyce LD, Daly RC. The off-pump implantation of an apicoaortic valved graft is safe and has no negative impact on coronary flow and hemodynamics. Innovations 2011; 6:298-304