Despite positive changes in lifestyle and the use of new pharmacological approaches to lowering plasma cholesterol concentrations, the frequency of cardiac death and coronary events continues to be high in Western countries. Many coronary risk factors have been identified, principally through population-based methods, but interestingly, fully half of all patients with coronary disease do not have any of the established coronary risk factors (ie, hypertension, hypercholesterolemia, cigarette smoking, diabetes mellitus, marked obesity, and physical inactivity). Further investigation of the cardiac risk factors has suggested links between various mechanical stresses and the site of lesion predilection and rupture. Local stresses may result in the induction of endothelial injury with consequent development of atherosclerosis and tearing soft plaque.

The coronary arteries are tethered to the epicardial surface of the heart and must move with each myocardial contraction. Through repeated observation of the motion of the coronary arteries and the location of plaque formation in diseased vessels, we formed the hypothesis that a critical movement pattern of the coronary arteries may result in localized stress points within the vessel and thus the development of atherosclerosis. The purpose of the present study was to analyze the motion of diseased coronary arteries and examine the correlation between these coronary movement patterns and the sites of identified lesions.

Methods
Using 100 consecutive angiograms performed from August 1999 to September 1999 we retrospectively analyzed the coronary artery movement (CAM) as well as the severity of obstruction. Coronary angiography, which was performed because of suspicion of ischemic heart disease, used standard techniques in multiple projections. The severity of obstruction was calculated by measuring with calipers the diameter of the stenotic area in relation to the adjacent normal artery in the view in which the stenosis was most severe.

We classified CAM into 10 patterns (Fig 1): (1) bend = coronary artery flexes into a single large curve; (2) multiple bend = coronary artery flexes into 2 or more curves; (3) compression = segmental length is shortened without vertical deviation of the artery; (4) displacement = location of the coronary artery shifts without change of segmental length or shape. Assessment of CAM was made for 6 segments from the left anterior descending artery and 3–5 segments from the left circumflex artery, and in total 673 segments were analyzed. Coronary arterial segments with the compression type had a significantly higher percent stenosis than those without it (Compression 57.9±29.4 % vs Bend 7.9±19.0 %, Displacement 4.3±13.0 %; p<0.00001). The compression type was seen frequently in the proximal and mid left anterior descending artery, ostial diagonal branch, obtuse marginal branch and mid left circumflex artery. The critical CAM (eg, compression pattern) may be an important mechanical stress inducing coronary atherosclerosis.

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(4) ostial compression = branch vessel movement opposes trunk vessel movement resulting in compression of the ostium; (5) lineal displacement = location of the coronary artery shifts in the longitudinal direction without change of segmental length or shape; (6) parallel displacement = position of coronary artery shift sideways without change of segmental length or shape; (7) hinge = artery makes an angular bend like a hinge during systole; (8) lever = lever action about the ostium; (9) crease = artery makes a crease; and (10) wave flex = artery shows wave motion.

These patterns were also grouped into 3 classes: (1) bend type = bend, multiple bend, hinge, crease and wave flex patterns; (2) compression type = compression and ostial compression patterns; (3) displacement type = lineal and parallel displacement, and lever patterns.

The CAM was estimated visually using at least 4 different views. First, a 2-dimensional (D) classification of the movement of segments was made in each view and the final classification of the movement was made using a synthesis of these views. For example, even though one segment shows the compression pattern in one view, if the other views show bend type, the movement type of the segment is classified as bend. When a segment shows compression pattern in all views, the movement pattern of the segment is classified as compression.

Assessment of CAM was made in 6 segments from the left anterior descending artery (LAD) (#5 left main, #6 proximal LAD, #7 mid LAD, #8 distal LAD, #9 first diago-
nal, #10 second diagonal) and 3–5 segments from the left circumflex artery (LCX) (#11 proximal LCX, #12 obtuse marginal, #13 mid LCX, #14 posterolateral, #15 posterior descending) in accordance with the AHA reporting system.13 The right coronary artery was excluded because right coronary angiography is usually performed in only 2 views. Cases with permanent pacemaker implantation or severe asynergy on the left ventriculogram, or segments showing severe calcification, muscular bridge or total occlusion were excluded from this study because these factors could lead to a misjudgment of the native movement.

Statistical Analysis
Data are presented as mean value ± SD. Differences in the mean values between subgroups were compared using an unpaired t test; p<0.05 was considered statistically significant.

Results
In all, we examined 673 segments. Fig 2–6 are coronary angiograms of the left coronary artery showing each CAM pattern, and Table 1 shows the frequency of each pattern and type of CAM and the segmental percent stenosis. The most common type of CAM was the bend type (56.5%), followed by the displacement type (29.4%); 14.1% of cases showed the compression type. Coronary arterial segments with the compression type had a significantly higher percent luminal stenosis than those without it (compression 57.9±29.4% vs bend 7.9±19.0%, displacement 4.3±13.0%; p<0.00001).

Fig 7 shows the frequency of each type of CAM in the segments. The compression type was seen most frequently in certain segments, such as the proximal and mid left anterior descending artery (#6,7), and then ostial diagonal branch (#9,10), obtuse marginal artery (#12) and mid left circumflex artery (#13).

Discussion
To our knowledge, this is the first classification of CAM and analysis of its relationship to lesion severity. The coronary arteries are always affected by the underlying myocardial contraction because they are tethered to the epicardial surface of the heart and the coronary artery segments show various kinds of movement depending on their anatomical distribution during the heart beat. We classified the CAM into 10 patterns and our results show that coronary arterial segments with the compression type of pattern (ie, segmental length is shortened without vertical deviation of the artery during systole) have a significantly higher percent stenosis than those without it. There were no significant differences of lesion severity among segments showing the other types of movement patterns. The compression pattern was seen frequently in the proximal and mid left anterior descending artery, ostial diagonal branch, obtuse marginal artery and mid left circumflex artery.

Atherosclerotic lesions on human vessel walls do not develop randomly, but localize at certain selected sites in the arterial tree, such as the outer wall of one or both daughter vessels at major bifurcations and T-junctions, which leaves the flow-divider free of lesions, and along the inner wall of curved segments. El Fawal et al reported the following sites of predilection for plaque rupture: the proximal and mid left anterior descending artery, the proximal and mid circumflex artery, and the second of 4 segments of the right coronary artery, which are similar sites to those found by us in the present study. Plaque rupture because of tearing of the fibrous cap at the shoulder of the plaque is thought to be caused by hemodynamic stress on the fibrous cap. Forces imposed on vascular tissues are known to be of 3 types, pressure, tension (stretch), and shear; and as one of the mechanical stresses on vascular tissue, the compression type of CAM may play an important role in the progression of coronary artery atherosclerosis. This special pattern of arterial motion may impose mechanical stresses on vascular tissue and cause endothelial injury or dysfunction, which is critical to the evolution, progression, and...
clinical manifestation of atherosclerotic vascular disease. Long-term, repetitive critical CAM during the cardiac cycle may weaken the deposited material and increase its vulnerability to rupture. Coronary angiography is the clinical standard for the evaluation of patients with suspected coronary artery disease, but it has limitations in the diagnosis of coronary artery stenosis. Vulnerable plaques may not have been seen, and a significant number of the episodes of disruption that precipitate infarction occur in coronary arteries that appear normal or only mildly stenotic on the angiogram. Intra-vascular ultrasonography (IVUS) may be better in demonstrating the presence and extent of atherosclerosis, because unlike contrast angiography, which does not predict the likelihood of an intact plaque rupturing, IVUS can indicate plaque vulnerability by an echo-lucent zone inside large eccentric plaque. However, as an IVUS study is expensive and time consuming, it is not possible to use it to examine all patients. Therefore, analysis of CAM could supply important information from conventional coronary angiography to detect sites within a coronary artery that have a high risk of developing stenosis or rupture because even if there was no significant stenosis on the coronary angiogram, the existence of the compression pattern of CAM may indicate a potential lesion.

Although much has been learned about the causes of coronary disease, fully half of all patients with this condition do not have any of the established risk factors. The anatomical distribution and movement patterns of the coronary arteries during the cardiac cycle differ among individuals and may be genetically inherited, which would explain why family history is a major coronary risk factors. We anticipate that the critical coronary movement will become one of the coronary artery risk factors.

Stent implantation has become the mainstay of coronary angioplasty and although less frequent than restenosis after balloon angioplasty, restenosis after coronary stenting is still a clinical problem. When stent restenosis occurs, the stenotic process usually involves the stent itself or its adjacent margins and neointimal hyperplasia has been indicated as the cause of in-stent restenosis; however, the cause of para-stent restenosis is still unknown. Based on the present results, stent implantation might change the segmental movement pattern and an iatrogenic critical movement may develop in the para-stent area resulting in development of a new lesion. Each experienced surgeon makes a decision the location of stent deployment, but further study is needed regarding the ideal site for stenting from the viewpoint of CAM.

Study Limitations
The present study does not have any follow up data and further study is needed to examine whether segments with the compression pattern of CAM more readily develop atherosclerotic lesions and whether each movement pattern changes with progression of the lesion.

Selective coronary angiography has inherent errors caused by viewing 3-D CAM in 2 dimensions. Therefore, assessing the CAM pattern visually has its limitations in accuracy. Several investigators have reported computer-assisted methods for estimation of 3-D coronary arteries from biplane projection data and we hope there will be further development in the technology of 3-D coronary angiography and in quantitatively analyzing the mechanical stress of the dynamic arterial wall.

References


