

Bi-directional Spectral Doppler Waveform Analysis Used in Reversal of Coronary Artery Disease: A Case Study

John-Lloyd Santamarina, B.S., Alexander Castellanos, M.D.

Keywords: bi-directional Doppler waveform analysis, reversal of coronary artery disease, peripheral artery disease and coronary artery disease, global assessment, biofeedback

Poem by Patient (Case Study)

There was an old lady named Tink
Whose arteries went on the blink,
They filled up with plaque
Caused a mean heart attack
Blocked the blood and she went to the brink

The emergency room said...Oh No!
In the ambulance now you must go...
To French Hospital she went
Where they put in a stent
Which started the blood to re-flow

Then she went to her doctor and he
Sat her down and said listen to me
Don't just stop getting worse
Shift it down to reverse
Watch your diet and WALK and you'll see

Start with half hour three times a day
To help all this plaque fade away
The blood then can flow
Your heart then can go
It is working.....What can I say?

It's not enough to talk the talk
You literally need to walk the walk

- H.S.

I. Abstract

Introduction: This case dramatizes the complex nature of standard of care in the evaluation and treatment of acute coronary artery disease. Concerns over the invasiveness and costs of standard procedures have led to the search for alternative methods that allow earlier recognition of vascular disease.

Bi-directional spectral Doppler waveform analysis is a proposed approach in this study.

Case Presentation: In this case, the patient had long been evaluated in the office with a non-invasive tool (the ultrasound) diagnosing vascular disease. Patient had also been placed in a lifestyle program for its reversal. Through patient's choice she failed to follow those recommendations and had stopped reporting for evaluation. A few months later, she had an acute coronary syndrome, forcing her to be evaluated by standard of care protocol using invasive evaluation and intervention methods: angiograph and stent placement on her arteries, respectively. But, even with these invasive procedures, the left coronary artery was discovered to have severe plaque rupture and thrombus that the interventional cardiologist had no option other than to defer intervention to avoid further disruption. Thus the patient returns for treatment with primary doctor, who emphasizes lifestyle protocol, and using Doppler analysis on a weekly basis to track and measure progress.

At six weeks, she returned to the interventional cardiologist, where re-catheterization showed resolution of plaque and clot, therefore not necessitating stent, angioplasty, nor by-pass surgery.

Discussion: The study provides evidence in the following: the effectiveness of lifestyle management, supported by Doppler analysis; the strength of Doppler analysis as a biofeedback tool; and the application of Doppler analysis as a "global" assessment tool for vascular health, measuring posterior tibial and dorsalis pedis as representations of coronary artery disease.

Doppler analysis has its limitations in procedure and interpretation. Further research and resources are therefore necessary to elevate its status as a non-invasive, non-radioactive, and inexpensive assessment tool, that can also be used as a supplement to medical treatment thru biofeedback principles.

II. Introduction

Standard of health care for coronary artery disease follows this pattern: onset of symptoms (e.g. chest pain, heart attack, or stroke), diagnosis of disease, commencement of treatment.

Traditional diagnostic procedures may involve cardiac catheterization, intravascular ultrasound, electrocardiogram, coronary computed tomography angiography, single photon emission computed tomography, and magnetic resonance imaging.⁸ Preferred methods for treatment are drug therapy, angioplasty, stent placement, or by-pass surgery.¹³

But, due to the rising costs of healthcare⁶, multiple concerns over invasive procedures⁷, and the persistence of Heart Disease as one of the leading causes of death¹², U.S. and AHA has been searching for alternative methods that are less invasive and less costly.⁴ There are even studies that claim there is a shortage of

cardiologists, particularly interventionalists,³ but many believe that we should actually be promoting primary and proactive care. This case study proposes a solution: Bi-directional spectral Doppler waveform analysis for the “global” assessment of vascular disease (i.e. coronary, cerebral, renal, peripheral), used in early recognition, and for applying biofeedback principles to increase the efficacy of treatment, especially that of lifestyle interventions.^{10,14}

Doppler analysis is non-invasive technique⁹ typically used to analyze Peripheral Arterial Disease (PAD)², however studies have shown a correlation between the endothelial function of the peripheral arteries and of the coronary arteries.¹⁵ Therefore, Doppler analysis is applied as the “global” assessment tool that provides analysis of overall arterial health and early detection of arterial disease.¹

Doppler analysis is also used as a supplement to medical treatment (drug therapy, lifestyle intervention, etc.) thru the application of biofeedback principles. Biofeedback is the process of looking at signals from the body (i.e. heart rate, blood pressure, weight, etc.) to give an insight into a person’s health.¹¹ These signals are used to elicit appropriate responses, like enforcing positive habits and foregoing negative ones. Doppler analysis provides such responses, by giving an insight into arterial health and allowing continual patient engagement.

III. Case Presentation

a. Complaint

Patient is an 80-year-old Caucasian woman presented with acute coronary artery disease.

Patient has been followed in the office since 1994. She has had no prior history of ischemic heart disease, chest pain or myocardial infarction, however she did present several cardiac risk factors, such as obesity, hypertension and dyslipidemia. Doppler analyses have been done to evaluate arterial health, **diagnosing vascular disease**. A lifestyle program had been recommended with the goal of reversing her cardiac risk factors and **vascular disease**. However, thru patient’s choice, she failed to follow her exercise routine, and had stopped reporting for routine Doppler analysis. A few months later, she had an acute coronary syndrome, forcing patient to be evaluated with invasive evaluation and intervention.

Cardiac catheterization was performed and showed a wide degree of plaque formation over the right and left coronary systems, 80-90% and 70-80% stenosis, respectively. The right coronary artery was subsequently treated with the placement of a drug-eluting stent. However, the left coronary system was discovered to have severe plaque rupture and thrombus. The cardiologist therefore advised deferment of intervention (angioplasty, stent, and by-pass) for two weeks, to avoid further disruption. At this point, patient returned to the primary physician’s office for treatment.

Physical examination found that patient had a blood pressure of 148/80 mmHg; cardiac exam was normal; her EKG revealed regular rhythm, with no murmurs; she had a pulse of 60 bpm, with decreased pulse at the dorsalis pedis; a respiration rate of 16 breaths/min, temperature of 98°F; and a weight of 157 lbs. Patient had full range of motion. She didn’t have any bruits over the neck, and her chest was clear. Her neurological exam presented normal. She was in good spirits,

and was in no apparent distress, aside from experiencing minor headaches. Patient did however mention, “feeling dumb.” These symptoms were suspected to be secondary to the medications she was on (specifically the beta blockers). She was diagnosed with acute coronary artery disease, hypertension, being overweight and sedentary, with stent treatment of the right coronary, but residual stenosis in the left coronary artery.

b. Management

Patient was strongly recommended to re-address her cardiac risk factors. Lifestyle intervention, involving nutritional changes and an exercise program, was reinstated along with the Doppler analysis. Patient was placed on a low protein, no dairy product nutritional plan. Patient also agreed to start walking for 1 hour, three times a day, at a very slow and careful pace to prevent overexertion. Vigorous exercise may increase the risk of myocardial infarction or sudden cardiac death because of the patient’s underlying vascular disease.¹⁶

Doppler analysis was done on her lower extremities, right and left posterior tibial and dorsalis pedis.

Biofeedback principles were applied through the following: patient is interactive with procedure by performing deep breathing, showing how breathing and relaxation techniques can influence endothelial function of the arteries, thus fortifying patient participation. The analysis of the peripheral arteries was interpreted following guidelines listed in Table 1, and explained to the patient in hopes of reinforcing the positive habits as prescribed through the lifestyle intervention.

Previously scheduled reassessment with cardiologist was pushed back to six weeks, giving patient ample time to respond to medical treatment. Near to weekly Doppler Analyses were performed for six weeks (patient missed one session).

c. Outcome

A comparison of the analysis on 6/13/11 and 9/19/11, as seen in Figures 3 and 4, shows definite decrease in peak velocities of all waveforms (especially apparent with the first waveform). The triphasic waveforms observed during the earlier analysis had become biphasic, and Figure 5 shows that the width of the 2nd waveform has decreased. According to previously mentioned guidelines, these all equate to severe decline of endothelial health of the arteries, and may explain why the patient experienced chest pain on 8/20/11. This was explained to the patient and she began to follow prescribed diet and exercise regimen.

It is apparent in figures 1 and 2 that health improved drastically in just 1 week after patient started following regimen. The peak velocities of the 1st and 2nd waveforms have both increased, with the 1st waveform’s velocity almost reaching optimum (30 ± 10 cm/s). The widths of both waveforms increased as well. The patient continued with her lifestyle intervention and positive results remained apparent thru the analysis done on 10/5/11. At this point, the waveform had even returned to its normal triphasic form, as seen in Figures 1 and 2.

Figure 1, however, shows a noticeable dip in the peak velocity of the 1st waveform on 10/19/11. The waveform’s width has also decreased marginally.

Possible explanations are: precision of the ultrasound probe's angle of insonation has not been perfected; or this study was done two weeks after the last study, therefore patient may have veered slightly from the regimen.

Despite this, other factors still establish overall improvement of health, factors like the increase in velocity and width of the 2nd waveform, and the persistence of a 3rd waveform. This is supported by Figures 6 thru 8. The analysis done on 10/17/11 as compared to the analysis from 9/19/11 clearly shows improvement in all fronts: width, velocity and number of waveforms. Figures 9 thru 11 even show that the waveforms of the patient on 10/19/11 had surpassed even the health status as depicted by the waveforms from before the episode.

Improvement was further exemplified by Figure 12. One of the patient's presenting risk factors was obesity; therefore her weight was recorded along with the Doppler analysis sessions. Figure 12 shows that patient progressively decreased weight after the initial analysis.

After approximately six weeks of medical treatment, patient returned to the cardiologist for a repeat catheterization to determine whether PCI or by-pass surgery will be performed on the left coronary artery. However, results of the assessment showed complete resolution of the ruptured plaque and thrombus, and the lesions, though apparent, were no longer flow limiting, and were deemed unthreatening. Neither PCI nor by-pass surgery was indicated to be necessary at the time.

Patient continues to follow the medical treatment (diet and exercise) and continues to exhibit improvement in weight loss, energy and vital signs, as apparent in Figures 1, 2 and 12 for the analysis done on 1/16/12.

IV. Discussion/Observations

This case presentation was unique in that there were coinciding angiogram and cardiac intervention methods that show a correlation with the vascular studies used in measuring improvement of endothelial function from lifestyle interventions.

Discovery of the stenosis of the coronary artery via catheterization concurred with the decline of arterial health as observed via Doppler analysis. Assessment of resolution also agreed with the improvement of health as observed with Doppler analysis. These provide supporting evidence in the correlation of the status of peripheral arteries to the coronary arteries; thus demonstrating the potential of Doppler analysis for the assessment and early recognition of coronary artery disease, included in the "global" assessment of overall endothelial function (i.e. coronary, cerebral, renal, peripheral, etc.)

Principles of biofeedback were apparent when patient continued to show improvement as weekly Doppler analyses were done, and when her health marginally declined when she missed one weekly session. Biofeedback was also observed through the deep breathing exercise performed when patient was initially tense, stabilizing the waveforms over the baseline (no figures shown). These demonstrate the benefits of Doppler analysis in improving the treatment efficacy of lifestyle intervention,^{10,14} when used as a biofeedback tool allowing constant patient participation, interaction and education.

Cost analysis of procedures done with patient (i.e. angioplasty, CT angiography, hospital admission, Doppler analysis), as shown in Table 4, suggests that standard procedures are exorbitantly more expensive than Doppler analysis.

These observations suggest that had patient persisted with her Doppler analysis prior to episode, the health decline could have been noted, and drastic steps could have been taken to prevent the manifestation of acute coronary artery disease. Patient could also have better complied with her previous exercise routine had Doppler analysis been done more frequently, preventing her health decline in the first place. Patient could also have reduced costs of health care by doing Doppler analysis instead of necessitating hospital admission and angiography.

Some limitations with Doppler analysis warrant discussion. Regularity of Doppler analysis is necessary to better provide continual patient engagement. The precision of the angle of insonation of the ultrasound probe needs to be addressed for better standardization. And the values of the widths and velocities of the waveforms need to be more completely calculated to provide better evaluation.

Overall however, this case study provides significant evidence in the remarkable potential of Doppler analysis as an inexpensive, nonradioactive, noninvasive “global” assessment and biofeedback tool for the reversal of vascular disease and its co-morbidities.

V. References

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VI. Appendix

# of Waveforms	Triphasic = Mild-No Obstruction (Fig 19 and 20) ⁴	Biphasic = Moderate Obstruction (Fig. 21) ⁴	Monophasic = Severe Obstruction (Fig. 22) ⁴
Peak Velocity (1st Waveform)	30 ± 10 cm/s = healthy artery ⁹	>40 cm/s or <20 cm/s = deteriorating artery	
Peak Velocity (2nd and 3rd Waveforms)	Increase in velocity = health improvement	Decrease in velocity = health decline	
Width	Increase in width = health improvement	Decrease in width = health decline	

Table 1. Waveform analysis understanding and observation

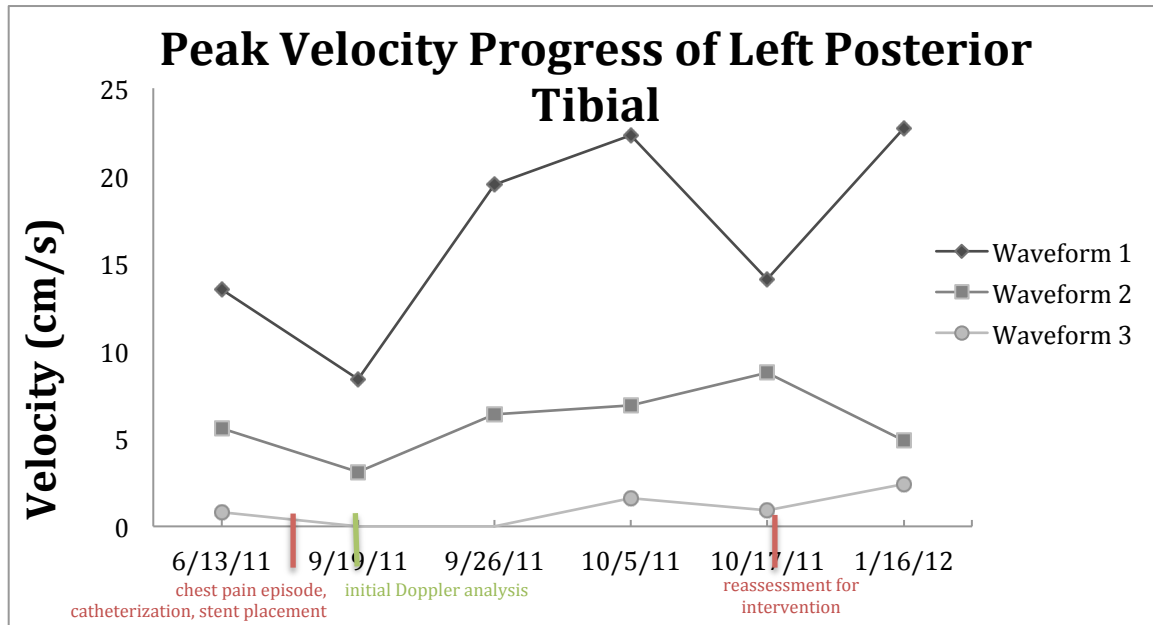


Figure 1. Peak Velocity Progress of Left Posterior Tibial Figure 1 shows peak velocity progress of waveforms 1-3 as observed from 6/13/11 to 1/16/12. An evident dip from 6/13/11 to 9/19/11 indicates deterioration of patient's health (signified by markedly lower velocities and presence of only biphasic waveforms). Following 9/19/11, a steady increase is apparent, demonstrating improvement of health. The sudden decrease in the wave velocity of waveform 1 that occurred on 10/17/11 can be implied as a decrease in health, but the continuing increase in velocity of waveform 2 and persistence of waveform 3 indicates overall improvement. This decrease can be accounted as random error; attributable to the process of reading (ultrasound scope) by experimenter, or that this test was done almost two weeks after the previous test and the patient may have veered slightly from her strict regimen.

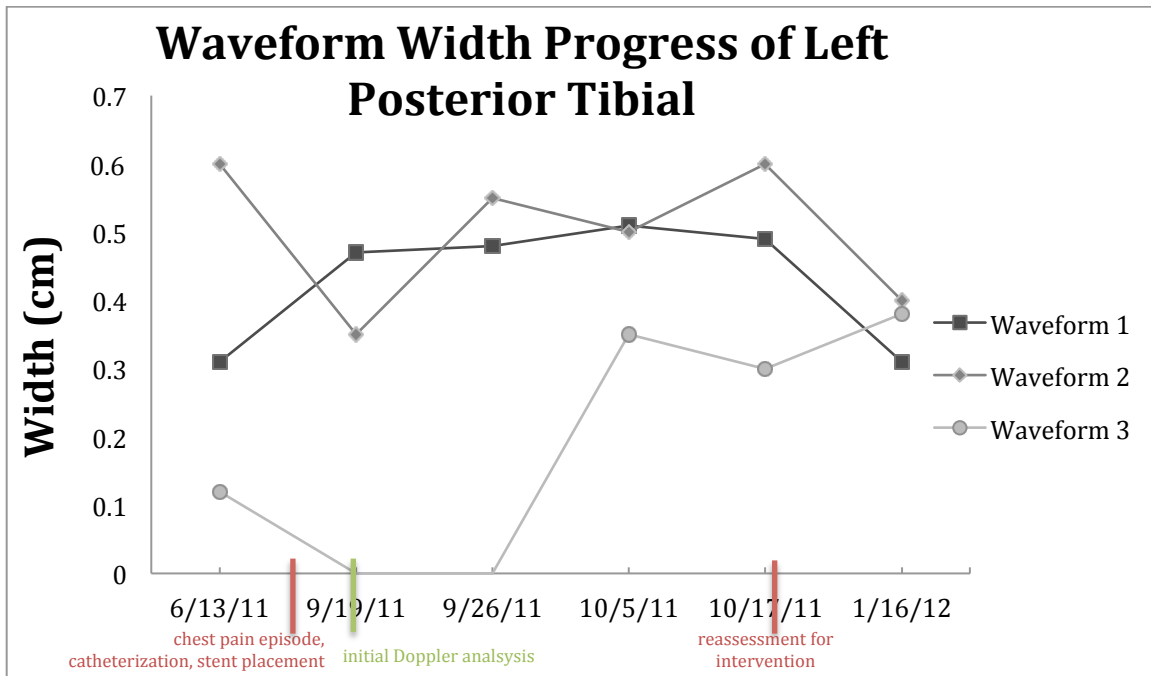


Figure 2. Waveform Width Progress of Left Posterior Tibial Figure 2 shows the width progress of waveforms 1-3. The decrease in number of waveforms from 6/13/11 to 9/19/11 shows a deterioration of patient's health, enforced by the large decrease in the width of waveform 2. The increase in width of waveform 1 infers health improvement, but with cross-referencing from Figure 1 and the previously mentioned statement indicates overall health decline. Following 9/19/11, a fluctuating increase and decrease in width ensues, however each reading is markedly higher than that of 9/19/11 (first study after incident) therefore health of patient can still be interpreted as having improved, and this is supported by the continuing presence of waveform 3 starting from 10/5/11.

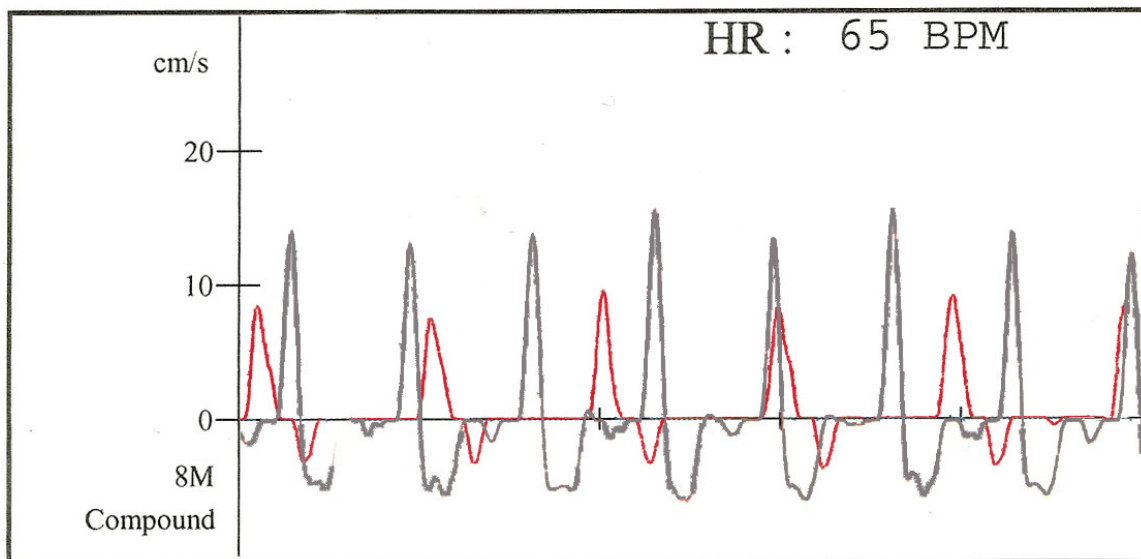


Figure 3. Waveform Comparison: Before and After Episode. The waveforms from the analysis done months prior the episode (6/13/11, shown in silver) is superimposed on the analysis done after the episode (9/19/11, shown in red). Waveforms from the later analysis are clearly smaller than the waveforms from before. The third waveform is no longer apparent in the later analysis as well.

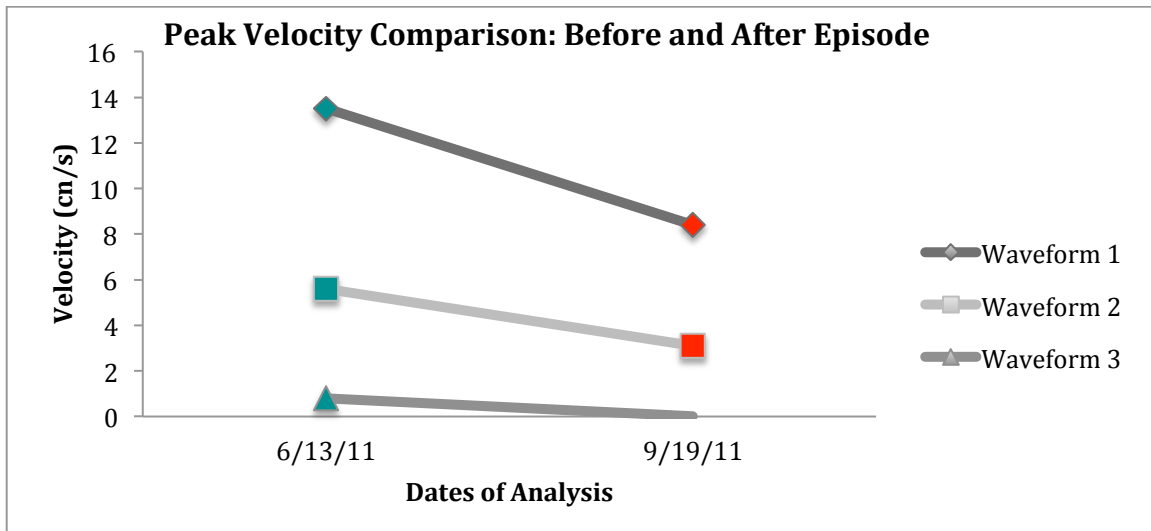


Figure 4. Peak Velocity Comparison: Before and After Episode. The velocities of all three waveforms of the left posterior tibial are compared from an analysis done before the episode of chest pain occurred (6/13/11) and after (9/19/11). Significantly lower velocities are evident with waveform 1 and 2, while waveform 3 disappeared altogether.

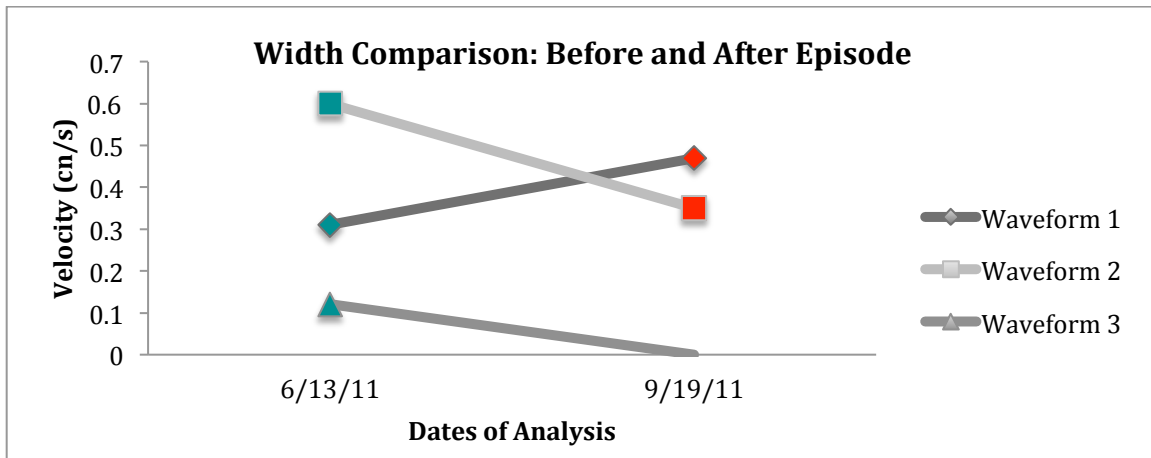


Figure 5. Width Comparison: Before and After Episode. The widths of all three waveforms of the left posterior tibial are compared from an analysis done before the chest pain episode (6/13/11) and after (9/19/11). The width of waveform 2 decreased significantly, while waveform 3 is no longer apparent. Waveform 1 however shows an increase in width. This discrepancy may be attributed to random error from precision of insonation.

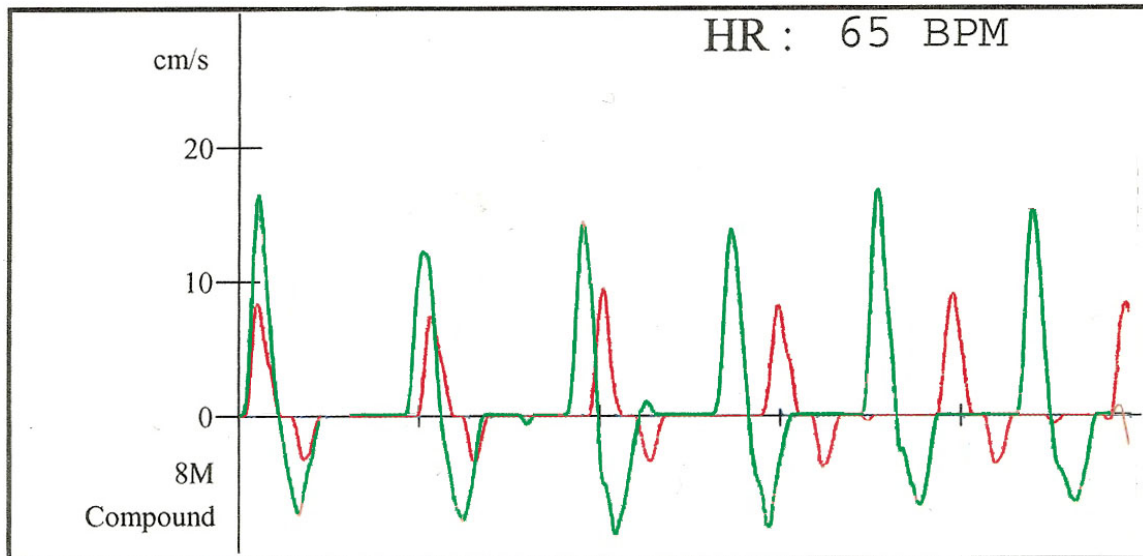


Figure 6. Waveform Comparison: After Episode and Before Reassessment: The waveform from the analysis done after the episode (9/19/11, shown in red) is superimposed over the analysis done before the reassessment with the cardiologist (10/17/11, shown in green). The later waveform clearly shows larger waveforms, especially with the 2nd waveform as compared to the analysis done after the episode. The 3rd waveform has resurfaced as well in the later analysis.

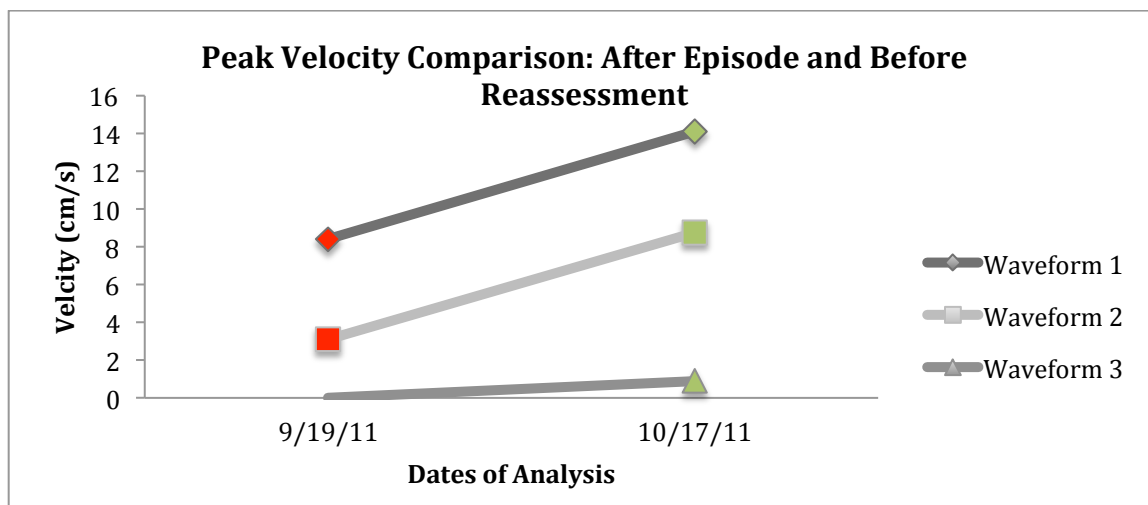


Figure 7. Peak Velocity Comparison: After Episode and Before Reassessment. The velocities of the three waveforms are compared from an analysis done after the chest pain episode and the analysis done before patient returned to cardiologist for reassessment. Waveforms 1 and 2 have increased drastically, while waveform 3 has evidently reappeared.

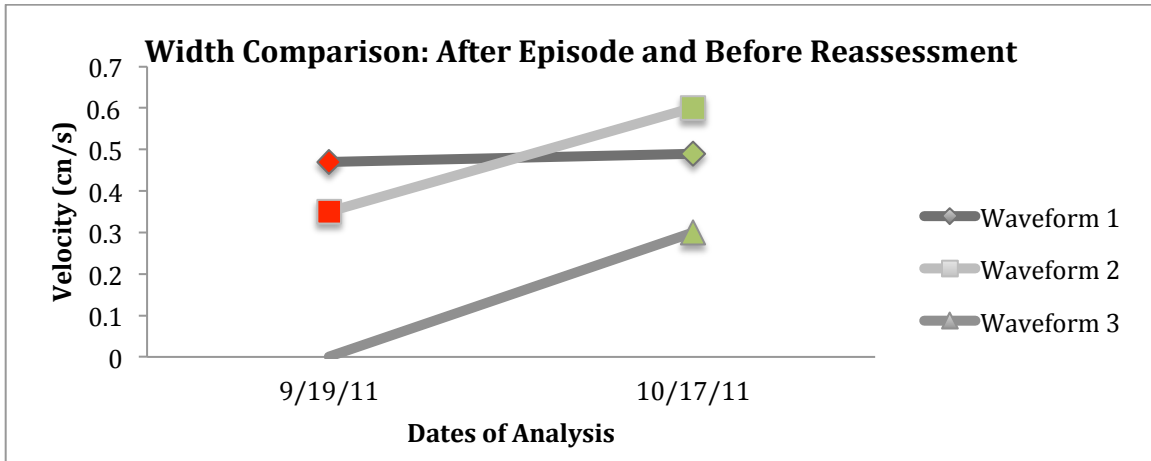


Figure 8. Width Comparison: After Episode and Before Reassessment. The widths of the different waveforms are compared, one from the analysis done after the chest pain episode, and the other before the patient returned to cardiologist for reassessment. Waveform 2 has increased in width significantly, while waveform 1 marginally shows increase. It is apparent that waveform 3 has reappeared as well.

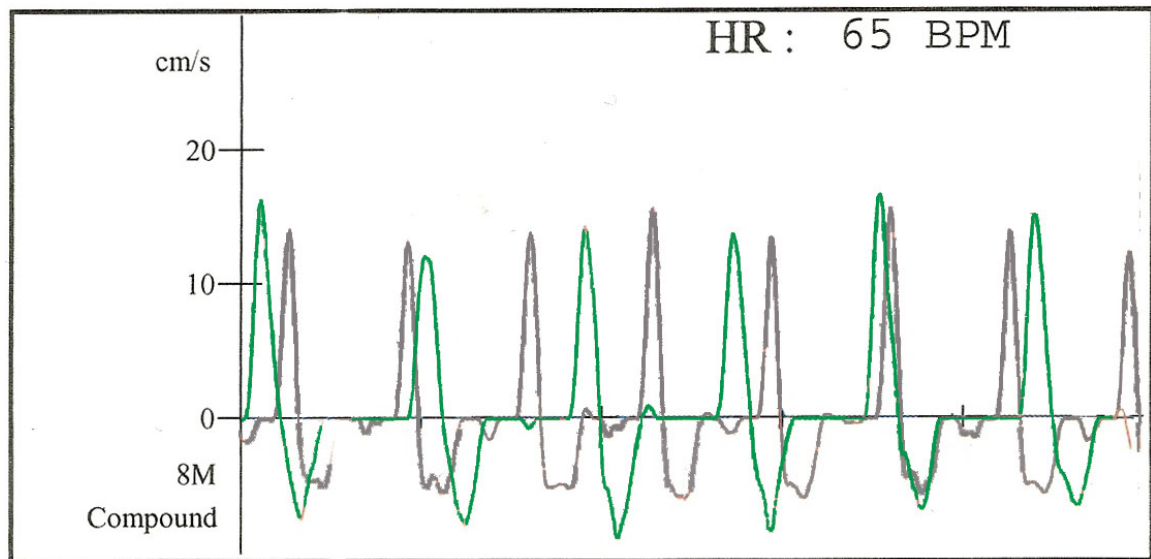


Figure 9. Waveform Comparison Before Episode and Before Reassessment. The waveforms from the analysis done before the episode (6/13/11, shown in silver) and from right before the reassessment (10/17/11, shown in green) were superimposed upon each other. The figure clearly shows that the later waveform has improved even more than the waveform before the episode.

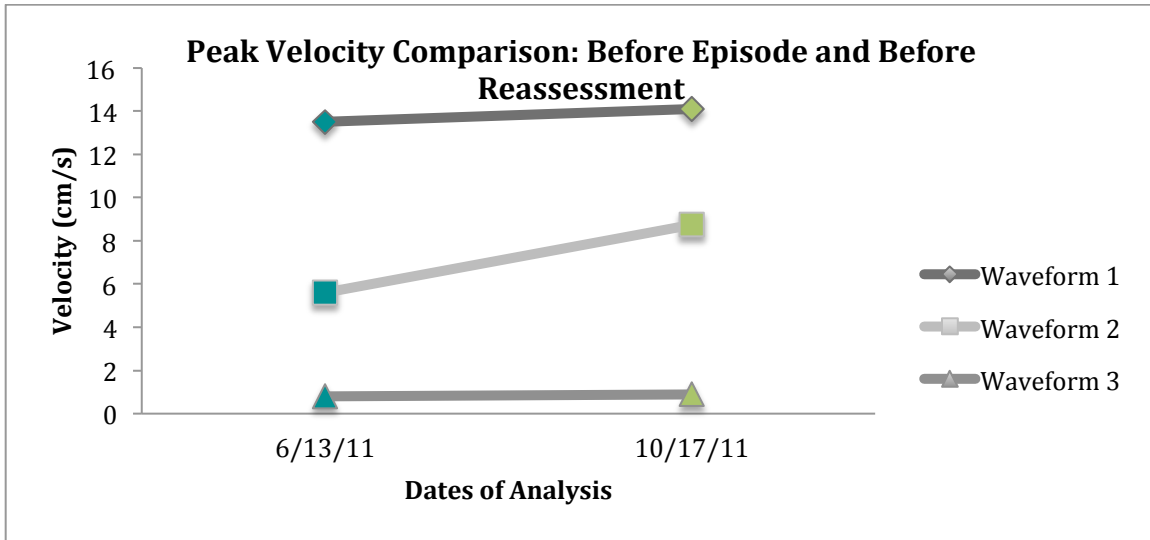


Figure 10. Peak Velocity Comparison: Before Episode and Before Reassessment. The velocities of the three waveforms were compared from the analysis done before the chest pain episode (6/13/11) to the analysis done before the reassessment with the cardiologist (10/17/11). The three waveforms have returned to their usual state, if not better than before, after just 6 weeks of medical treatment.

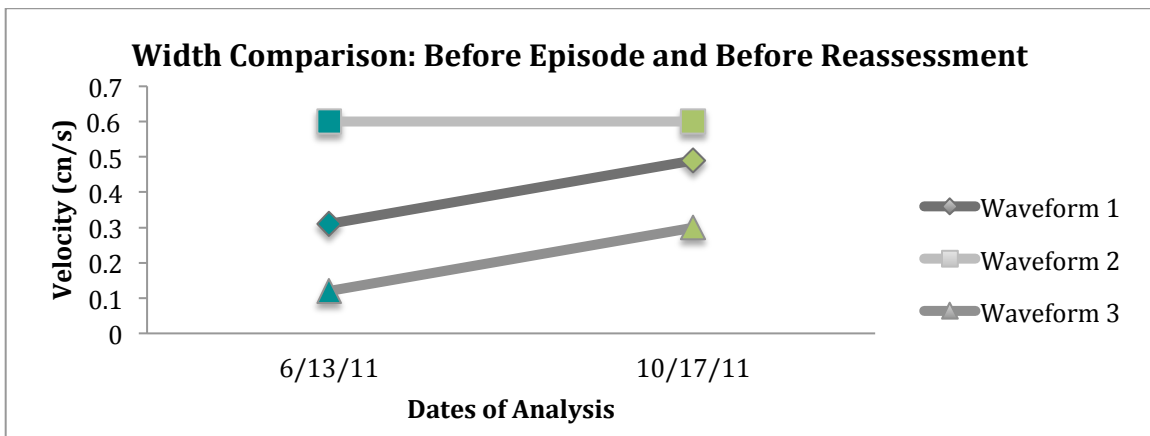


Figure 11. Width Comparison: Before Episode and Before Reassessment. The widths of all three waveforms are compared from before the chest pain to before the reassessment. The widths of waveforms 1 and 3 have increased while the width of waveform 2 very slightly decreased. This discrepancy may be attributed to random error from precision of insonation.

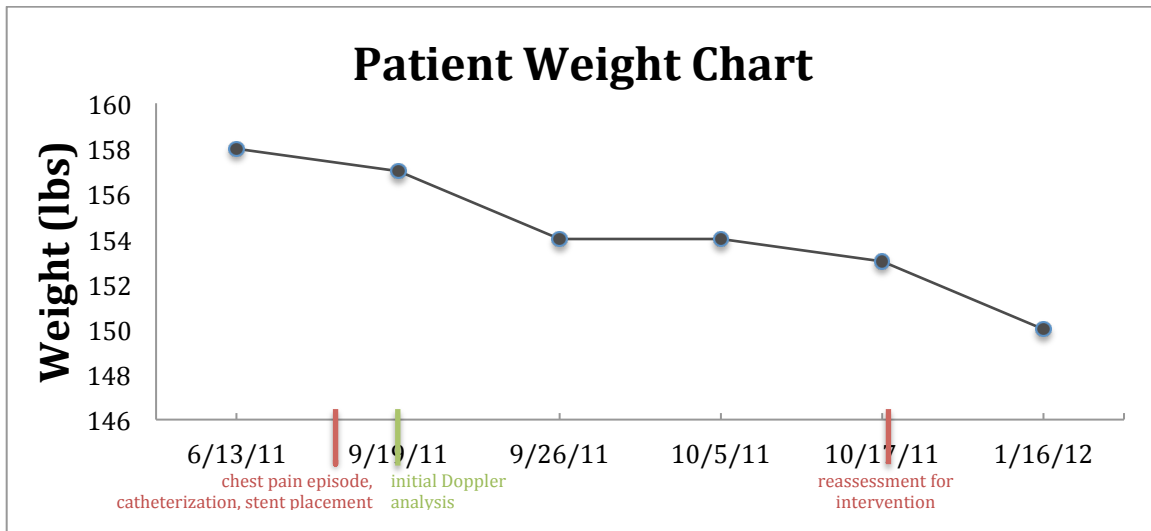


Figure 12. Patient Weight Chart Weight of the patient was tracked, to go along with the Doppler Waveform Analysis data. Patient distinctly shows to be decreasing weight after initial Doppler Analysis.

Test Date	Waveforms (#)	Velocity (cm/s)			Width (cm)		
		1 st Waveform	2 nd Waveform	3 rd Waveform	1 st Waveform	2 nd Waveform	3 rd Waveform
6/13/11	2.5-3	13.5	5.6	0.8	0.31	0.6	0.12
9/19/11	2	8.4	3.1	-	0.47	0.35	-
9/26/11	2	19.5	6.4	-	0.48	0.55	-
10/5/11	2.5-3	22.3	6.9	1.6	0.51	0.5	0.35
10/17/11	2.5-3	14.1	8.75	0.9	0.49	0.6	0.3
1/16/12	3	22.7	4.9	2.4	0.31	0.4	0.38

Table 2. Patient Vascular Study Data Table 2 shows data corresponding to the vascular studies done with patient from 6/13/11 to 1/16/12. Velocity of Waveform 1 were measured by the doppler ultrasound software. Other measurements (e.g. velocities of waveforms 1 and 2, width measurement of waveforms 1 thru 3 were measured by hand from the printed vascular studies (attached files) in correspondence to scale of measurements recorded by software.

Test Date	Weight (lbs)
6/13/11	158
9/19/11	157
9/26/11	154
10/5/11	154
10/17/11	153
1/16/12	150

Table 3. Patient Weight Data. Patient's data was tracked on the same dates as the vascular studies.

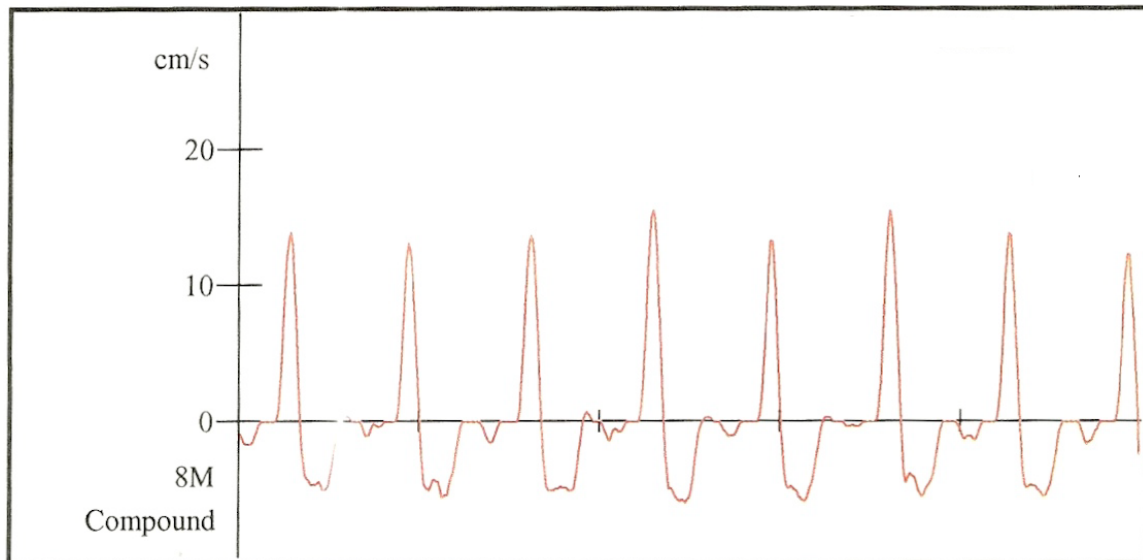


Figure 13. Doppler analysis of left posterior tibial from June 13, 2011

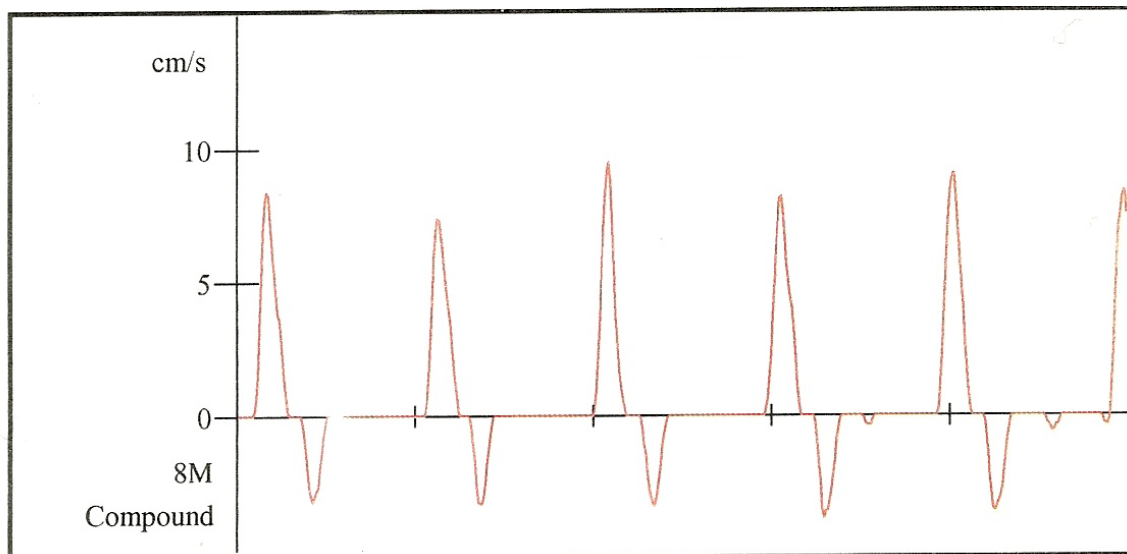


Figure 14. Doppler analysis of left posterior tibial from September 19, 2011

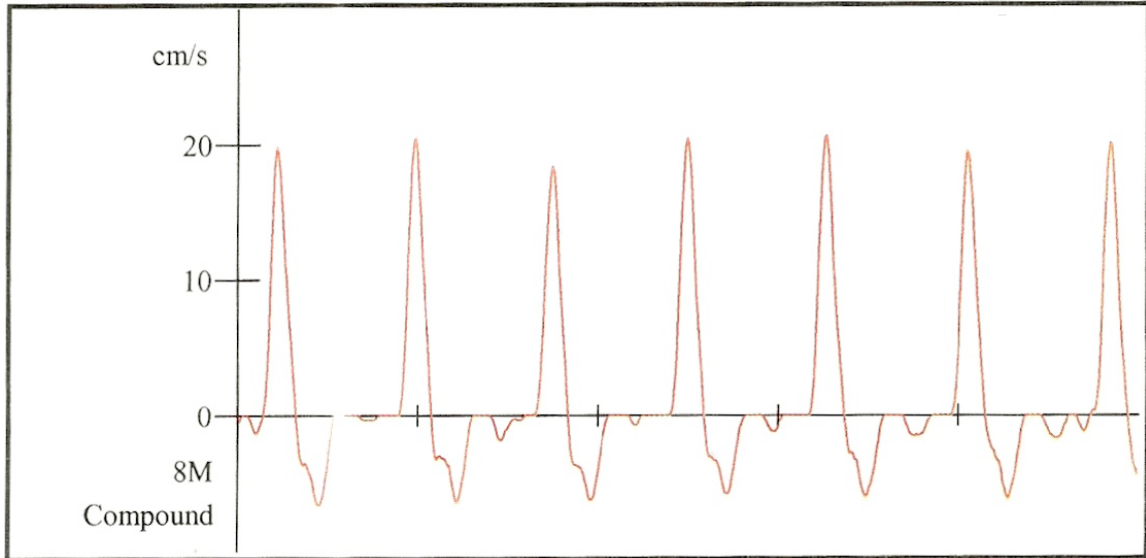


Figure 15. Doppler analysis of left posterior tibial from September 26, 2011

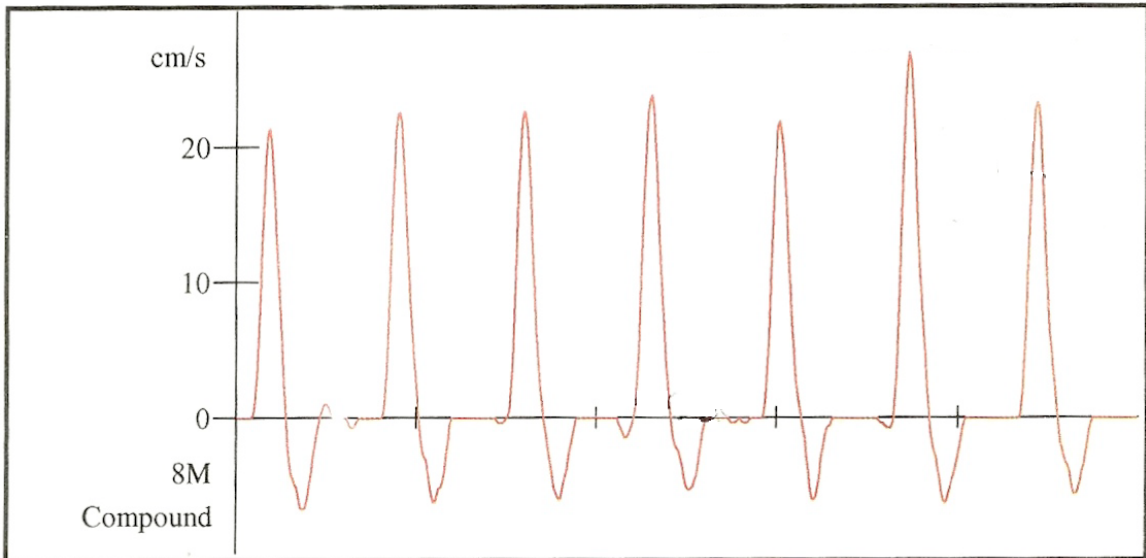


Figure 16. Doppler analysis of left posterior tibial from October 5, 2011

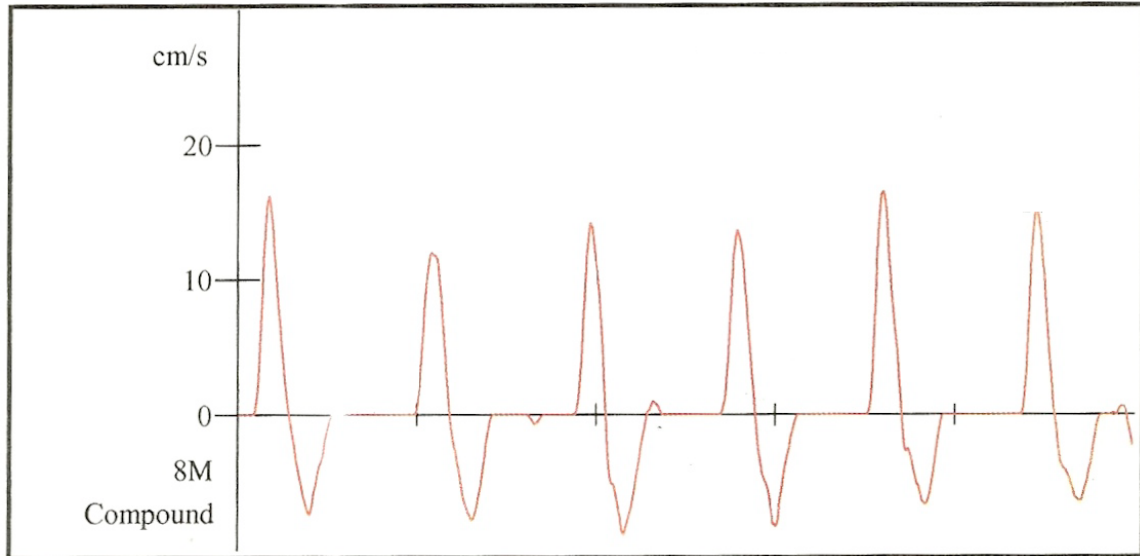


Figure 17. Doppler analysis of left posterior tibial from October 17, 2011

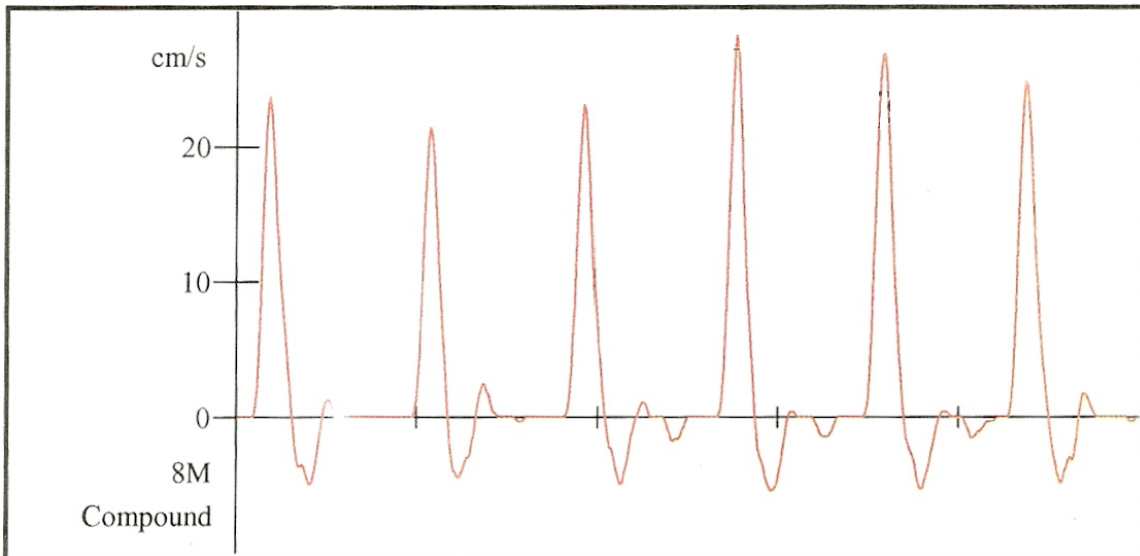


Figure 18. Doppler analysis of left posterior tibial from January 16, 2012



Figure 19. Model of normal artery as explained to patient

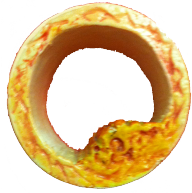


Figure 20. Model of mildly obstructed artery as explained to patient



Figure 21. Model of moderately obstructed artery as explained to patient



Figure 22. Model of severely obstructed artery as explained to patient

Procedure	Cost (Average)
1. Coronary Bypass Surgery	\$68,927
2. Coronary Angioplasty	\$19,931
3. Coronary Angiography	\$4,492
4. CT Angiography	\$520
5. Chest MRI	\$567
6. Echocardiogram	\$251
7. Chest Pain admission	\$3,082
8. Doppler Ultrasound	\$111
9. Office check-up	\$80

Table 4. Cost analysis of procedures done with patient. These numbers were national averages taken from the Healthcare Blue Book. Costs of the standard of healthcare procedures (1-7) amount to \$97,770. Costs of the Doppler analysis done with the primary care physician (8-9) amount to \$191.