Deformation Levels In Blood Droplets Created By Impact Events

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Abstract:

The purpose of this study was to consider the level of deformation evident in blood droplets created by dynamic events and verify if this deformation persists for any period of time. Were it to persist, such a deformation in the blood sphere could increase the level of error possible when determining the droplet's impact angle.

Blood droplets created using a trap device were photographed and measured. The oscillations (deformation from a prefect sphere) evident in the droplets were identified and graphed.

Although significant oscillations exist at the source of the blood's disruption, these oscillations do not persist and damp to less than 10 % of the droplet's diameter .05 seconds after disruption. Such deformation levels are unlikely to alter the ultimate shape of the resulting bloodstain.

Introduction:

One might initially ask, what relevance do shape deformations in blood droplets have on the discipline of blood stain pattern analysis? In the seconds in which a droplet exists in free flight, how can such oscillations/deformations change the resulting stain to the extent it would change an analysis?

Bloodstain analysts routinely attempt to establish impact angles of stains found in crime scenes. These angles assist in overall crime scene reconstruction by:

(1) Identifying the probable point of origin of the stain.

(2) Establishing parameters for possible and impossible events that might have created the stain.

The stain's impact angle is computed using the measured length and width of the stain in the following formula:

Width/Length = a and the ASN a = Impact Angle

Underlying this formula, is an assumption that a droplet of blood impacting a surface is in the form of a sphere. [1] If the droplet were to oscillate to a great degree, the deformation caused by such an oscillation could alter the resulting stain's shape and ultimately cause an inaccurate estimate of the length to width ratio.

This study will attempt to determine the true level of deformation evident in dynamic impact events and attempt to validate the basic underlying assumption: that blood droplets at impact are in a generally spheroid shape.

The Problem:

To determine what level of shape deformation exists in blood droplets created as a result of impact and if such deformations persist for any significant period of time.

Subproblem 1: To date, the measurement of oscillations or more properly the measurement of observed deformations in the sphere involve only large droplets (3.5 - 6 mm diameters spheres) produced by static means. [2] [3] What size of droplet should we expect to find in spatter created by impact and what level of deformation or oscillation will such droplets exhibit?

Subproblem 2: How quickly will such deformations damp as time from creation increases? Do such deformations persist for any significant period?

Hypothesis:

Blood droplets created as a result of dynamic impact events will display evident oscillations (deformations from a perfect sphere); but such oscillations damp quickly and do not persist long enough to significantly alter the spheroid shape of the droplet at impact.

Delimitations:

The droplets used as data are intended only to be representative of droplets created as a result of this impact event. The reader should not construe them to define a "normal" impact droplet.

This study properly considers the observed deformation evident in the droplet and not the true oscillation. The data shows individual droplets at a single point in time. The methodology did not allow for the evaluation of an individual droplet over time. Therefore the study makes no attempt to consider the frequency of the oscillation.

This study did not attempt to clarify the relationship or specific factors affecting a droplet's collapse as it relates to the lateral expansion of liquid in the droplet. This relationship may be of importance in understanding completely the relationship of the excess oscillation evident in the droplet and the level of deformation evident in the stain resulting from the droplet.

Definitions:

Sphere Size: As applied to the data, the term sphere size is an estimation of the perfect sphere size for a given droplet observed. This size is based on an average of the observed major and minor axis for each droplet.

Oscillation: Internal movement of the liquid droplet's mass, evident by deformation of the droplet from a perfect sphere.

Oscillation Amplitude: As applied to the data, the term oscillation amplitude is an estimation of the deformation evident in the droplet, expressed as a percentage of the droplet diameter. This estimate is based on subtracting the sphere size from the largest evident diameter of each droplet. The excess is then divided by the sphere size and converted to a percentage.

Assumptions:

1. The data used for this study captured only the deformation evident in the oblate phase of the droplet's oscillation. All photographs were exposed looking down onto the droplet from above. It is assumed the prolate phase is not significantly greater.

2. Some minor parallax error was introduced, based upon the manner of photography. Given the small field of view and the point of focus, this error is insufficient to change the conclusions drawn.

Review of Related Literature:

As the body of fluid dynamic research conducted on blood is quite small , one must consider that conducted on water. The nature of water and blood as fluids seems to allow for adequate analogy between the two, at least with regards to their relative behavior in motion.

Surface Tension Issues As It Effects Liquid Droplet Shapes

James E. McDonald, in discussing raindrops shapes, said:

> "One might begin by asking why a drop of water should bear any resemblance to a sphere at all. The answer is that surface tension always tends to reduce the surface of a free mass of liquid to the smallest area it can achieve. The smallest possible surface area is that of a sphere, and an isolated drop of liquid not distorted by external forces is pulled by its surface tension into a spherical shape." [4]

With regard to water droplet shapes he observed, McDonald noted:

> "the usual small sized droplet (less than a millimeter in diameter) is almost perfectly spherical, and a larger drop is a squat object resembling nothing so much as a hamburger bun." [5]

Dr. Alfred Carter supports McDonald's point on the correlation of shape and surface tension stating: "With regard to the spherical shape of liquid droplets, it can be explained entirely by the surface tension of the liquid." [6]

Oscillations and Their Effect of This Spherical Shape

If surface tension acts to hold a droplet to a spherical shape, what forces act against this process. Oscillations present in the mass of the droplet are the prime factor behind shape deformations and oscillations are caused by a variety of actions.

As McDonald noted, in his larger droplets, oscillations were evident to the extent he could physically observe and photograph them. Such oscillations occur naturally in rain drops, particularly those with larger diameters. They result primarily from collisions with other droplets. [7]

Ryan also observed water droplet oscillations and noted several items of interest. First with regard to deformations in shape, Ryan corroborated McDonald's observations, stating:

> " ... drops smaller than 0.5 mm radius are essentially spherical regardless of surface tension." [8]

Regarding droplet breakup, Ryan stated:

> "Thus , the current experiments lend further credence to the now generally accepted belief that raindrop size is limited by breakup caused by drop interaction rather than breakup from individual drop instability." [9]

As analysts have long understood, liquid droplets do not appear to spontaneously breakup as a result of droplet instability while in flight, not unless acted on by some force.

In an article in 1985, Dr. Kenneth Beard reported that he thought raindrop oscillations were related to collisions between larger, faster falling droplets with the smaller drizzle drops. [10] I asked Dr. Beard to comment on the specific question of oscillations in blood droplets. Dr. Beard stated:

> " Blood droplets should have initial oscillations of a rather large amplitude since the forces in the disruption process are not spherically symmetric. These oscillations will damp significantly in a fraction of a second for

> droplets of a few millimeters in diameter. Disruption of blood flow at the source of droplets should be the primary cause of oscillations since the forces from other influences are generally weaker (for example, that associated with air motions). It seems unlikely that droplets would collide far away from the source, to produce additional oscillations, because they become dispersed." [11]

With regard to the presence of oscillations and their damping in blood droplets, Dr.. Alfred Carter, when asked to comment on this agreed with Dr. Beard stating:

> " Liquid droplets when they are formed, can have some of the energy of formation appear as oscillatory motion in the mass of the liquid about the center of mass of the droplet.... Simple theoretical considerations predict that the oscillations will die out with a characteristic decay time [damping] which depends on viscosity, density, and surface tension." [12]

These oscillations result in a recurring shift of the mass of the liquid, which in turn results in deformations from a perfect sphere. It is the level of the deformation present at impact which may affect the bloodstain analyst's estimations. If at impact this remaining deformation were both large and captured in the measurement of the resulting stain, such a condition would upset the length to width ratio. This of course would result in a less accurate impact angle determination.

Methods:

The Data

The primary data for this project are measured length and widths of blood droplet spheres, created by a dynamic impact. All measurements are based on photographic images. The blood used was both freshly drawn whole blood and heparin treated. The heparin treated blood was always used within 30 hours of its collection. Data items are differentiated by blood source.

Selection Criteria of Data

A random selection process was created for the data, by setting the focus of the camera at various levels (all within a half inch distance of the target). Droplets photographically captured in the picture, which were in focus with clear boundary margins were included as data. This number was usually less than 20% of all droplets evident in the photograph. Selection was without regard to size, nature of oscillation or any other factor besides focus.

The Methodology

A mouse trap device was created, similar to those used in standard bloodstain pattern courses. See Annex A. This device created impact spatter, resulting in stains shapes ranging 5 mm and under. The jaws of the trap were held open 5.5 cm by an elastic band. The trap was closed using a 6 ounce weight, which slid down a tube and impacted the top jaw of the trap. The total distance the weight fell in each instance was 30 cm. The blood volume for each impact was 2-3 ml.

The flash was triggered using a mechanism like that described by Bevel and Conn.[13] See Annex B for details of this device. This trigger consists of a photo-transistor which requires a small beam of light to keep the circuit open. The device was placed in such a manner that the jaws of the mouse trap upon closing, interrupted the beam, thus initiating the flash.

Using two potentiometers (a course and fine control) on the flash trigger, the mechanism controls the timing of the flash allowing droplets to be photographed at various distances from the trap. The trap and a stop watch were taped using a Sony CCD F77 8 mm video camera with still frame capability, in order to establish the trigger to flash time of the settings used. This measure of time was also compared with the video tape speed as a method of corroboration. The tape speed was verified as 1/30 of a second per frame. When compared the two measurements were consistent, allowing a level of confidence for the time measurements described in this paper.

Once set up, photographs were taken of the droplets using a Canon AE1 camera, with a 50 mm Macro lens (1:3.5). The camera was set up directly over the stage area, with the film plane 25 cm from the target. A Nikon SB-E Flash provided illumination. The flash was set on the A setting while the camera was placed on "bulb" with the F-stop set at 5.6. A cable release controlled opening and closing of the camera shutter. Kodak ASA 400 color film was used for all photos.

Once exposed and developed, the photographs were numbered and evaluated. For each set of photographs a correction factor was set, correcting the picture to an actual mm scale. The individual droplets were measured along their primary axis. The sphere size was based on the average of these width and length measurements. After converting all measurements, a percentage of oscillation was computed.

The primary method of measurement was a MicroMike 20X magnifier, scaled to .002 inches. Throughout the research, random rechecks were made of the data to ensure quality measurements were obtained.

Treatment of the Data:

1. Three impact to flash times were used: +.01 , +.05 , and +.1 seconds. Respectively these times resulted in capturing droplet images 0-6 cm, 7-13cm, and 27-33 cm from the trap.

2. The long and short axis of droplets in photographs were measured, then averaged to determine an estimated perfect sphere diameter. See Figure 1. Where $(D + d^0)/2 = d$

3. This estimated sphere size (d) *was* subtracted from the longest axis (D) in the droplet, establishing the size of the excess deformation (e). Where $D - d = e$

4. This excess deformation was divided by the sphere size (d) and converted to a percentage. Where $((e / d)*100) = ep$

Example: Droplet Major Axis *(D)* = .66 mm
Droplet Minor Axis *(d°)* = .50 mm
(.50 + .60)/2 = .58 mm = Estimated Perfect Sphere Diameter *(d)*
.66 - .58 = .08 mm = Excess Deformation *(e)*
((.08/.58)*100) = 13% = Excess Oscillation or Deformation Percentage *(ep)*

5. Data items were grouped by droplet size as follows: .25 (<= .25 mm) ; .5 (.26 - .50 mm); .75 (.51 - .75 mm); 1.0 (.76 - 1.0 mm) ; >1 .0. The data items were then graphed accordingly.

6. Regression curves were established for both whole and heparin blood groups; however, no heparin blood was used at the +.01 impact.

Results:

Subproblem 1: What size of droplet should we expect to find in impact spatter and what level of deformation?

Impact events create free flight droplets with diameters of 1.9 mm and under, which at origin oscillate no more than .4*d*. (40% of the droplet's diameter). As expected smaller droplets had significantly lower levels of oscillation (.2*d*) at the source.

Figure 2 shows a histogram of droplet sizes evident in the 70 impacts created in the study. The absolute range of droplet diameters observed was between .16 mm and 1.9 mm. . Spatter resulting from these events were randomly measured.. The spatter stains were primarily 4 mm and under; however some 5 mm stains were found in the patterns.

The mean free flight droplet diameter for this study was .6 mm with a standard deviation of .3. This mean is only representative of this event. Impacts of different force would likely result in different overall numbers of droplets and droplet sizes. If one accepts that the majority of impact spatter stains are always 4 mm or below, then what is evident from this data is that the general upper limit for a free flight droplet in an impact event is 1.9 mm in diameter.

In looking at Figures 3 through 6, the regression curves plotted from the mean are probably not useful when considering this data. As they were selected randomly, the droplets are in varying stages of their individual oscillation phase. Not all were caught at the maximum level of deformation, which is what the study intended to consider. Therefore the high end of the data (the larger deformations evident), are a more important figure to consider.

Subproblem 2: How quickly will such deformations damp as time from creation increases?

For droplets with diameters of 1 mm and under, oscillations damp below the .1*d* level in nearly all droplets not later than impact +.05 seconds. Although the heparin treated blood followed closely the damping times of the whole blood, it was evident that heparin treated blood droplets tended to have slightly higher levels of deformation.

Figure 3 shows the .25 mm group. This group damps completely by Impact +.05 seconds. Only one exception was evident and this was a heparin treated droplet.

Figure 4 shows the .5 mm group. These droplets also fall below the .1*d* level by Impact + .05 seconds. Once again the only exception was a single heparin treated droplet. One tenth of a second following the event, this group's level of deformation is below .05*d*.

Figure 5 shows the .75 mm group. This group damps below the .1*d* level by Impact + .05 seconds. At .1 seconds this group is also displaying deformations below the .05*d* level.

Figures 6 and 7 show the 1 mm and over groups. Both groups appear to show significant damping by + .05 seconds (1 mm at .1*d* and the 1 mm and greater at .2*d*). Unfortunately, there were insufficient data items present to be confident of a continued damping effect as observed in the other groups.

Discussion:

Due to the small size of the free flight droplet involved in impact type events (2 mm diameters and under), such droplets do not appear to oscillate significantly for long periods. The smaller droplets show significantly smaller oscillations with faster decay times.

The deformations in shape resulting from these oscillations may well be significant at the source of the disruption (as much as 40% of the droplet's diameter). Away from the source a mere .05 seconds (which in this particular instance translated into a distance of 7 -13 cm), this deformation is generally 10% or less of the diameter. By +.1 seconds this deformation level is less than 5% of the droplet diameter.

It could be assumed that even this level of deformation has some minor effect on the length and width of the resulting stain, but this study indicates that blood droplets created as a result of dynamic impact events do strike the surrounding surfaces in generally spheroid shapes.

Conclusion:

The basis of most impact angle determinations in bloodstain pattern analysis continues to be the straight line geometry approach first established by Balthazard [14] and further refined using the Sin function by MacDonell and Bialousz. [15] The underlying assumption of this technique, specifically that a droplet of blood while in flight is spheroid, appears to be accurate in its end result.

In using the Sin technique, the analyst must consider that initially such droplets oscillate significantly. Close to the disruption it is possible these droplets impact as other than sphere shapes. The larger droplets resulting from the event will tend to have more significant oscillations present in them, which will last for longer periods.

Such considerations would suggest two responses when selecting stains to evaluate for impact angle determinations. First, select stains that are not too close to the probable disruption point. Second, select smaller stains if possible, as they result from smaller droplets which show significantly lower levels of deformation.

It's always been accepted in bloodstain pattern analysis that impact angle determinations are an "estimation". There is no reason to believe that the small deformations observed significantly change this estimation. So long as the analyst considers the initial effect of the disruption and uses this "estimation" for its intended purpose (establishing parameters of possible and impossible events), such estimations of impact angle continue to be both functional and useful.

References

[1] MacDonell, H. *Bloodstain Pattern Interpretation*, Laboratory of Forensic Science, Corning, NY. 1982

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[3] Raymond, M.A., Leisegang, J., and Smith, E.R. High Speed Cinematography Of Blood Droplets Deformation In Flight - Implications For Crime Scene Reconstruction. Advances in Forensic Sciences, Volume 4. International Association of Forensic Sciences.

[4] McDonald, James E. The Shape of Raindrops. Scientific American Volume 190 No. 2 February 1954.

[5] op. cit.

[6] Carter, A. L. Written correspondence. July 1992.

[7] Peterson, Ivars. Raindrop Oscillations - Raindrops Do More Than Just Fall; They Also Appear to Oscillate During Their Downward Plunge. Science News Vol. 127 March 1985

[8] Ryan, Robert T. The Behavior of Large, Low-Surface-Tension Water Drops Falling at Terminal Velocity in Air. Journal of Applied Meteorology Vol. 15 No. 2 Feb. 1976.

[9] op. cit.

[10] Peterson, Ivars. Raindrop Oscillations - Raindrops Do More Than Just Fall. They Also Appear to Oscillate During Their Downward Plunge. Science News Vol. 127 March 1985

[11] Beard, Kenneth V. Written correspondence , Sept 1989.

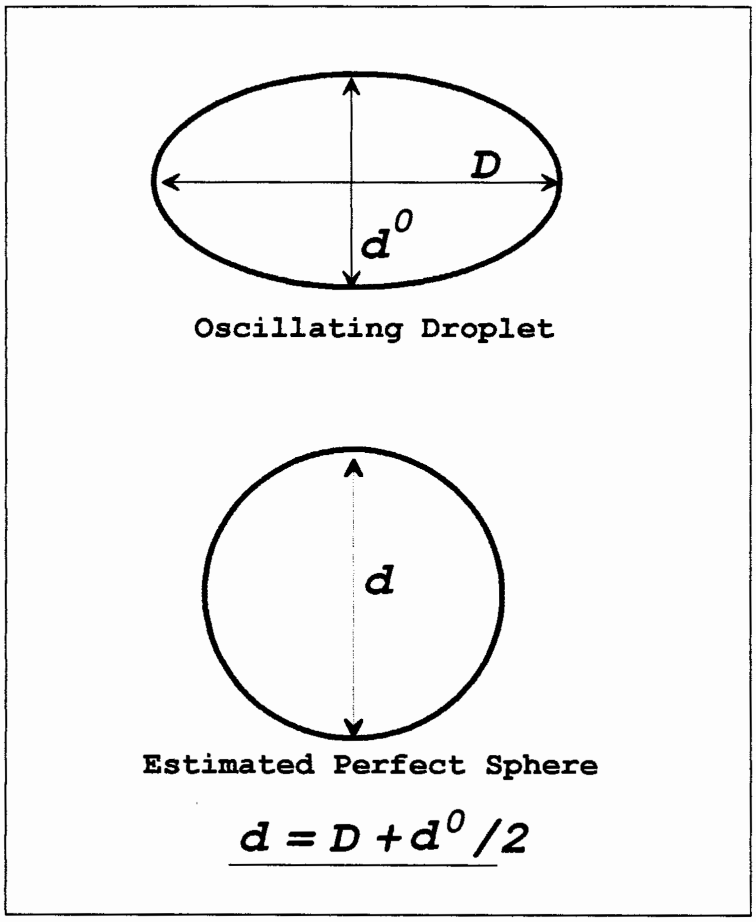
[12] Carter, Alfred L. Written correspondence. July 1992.

[13] Bevel, Tom, and Conn, Leonard. Stop Motion Photography of Bloodstains. International Association of Bloodstain Pattern Analysts News. July 1987

[14] Balthazard, Victor, Piedelievre, R., Desoille, Henri, and Derobert, L. Des Gouttes De Sang Projecte. XXII Congres De Medicine Legale. Paris, France, June 1939

[15] MacDonell, Herbert L. and Bialousz, L. Flight Characteristics and Stain Patterns of Human Blood. LEAA. 1970.

Figure 1

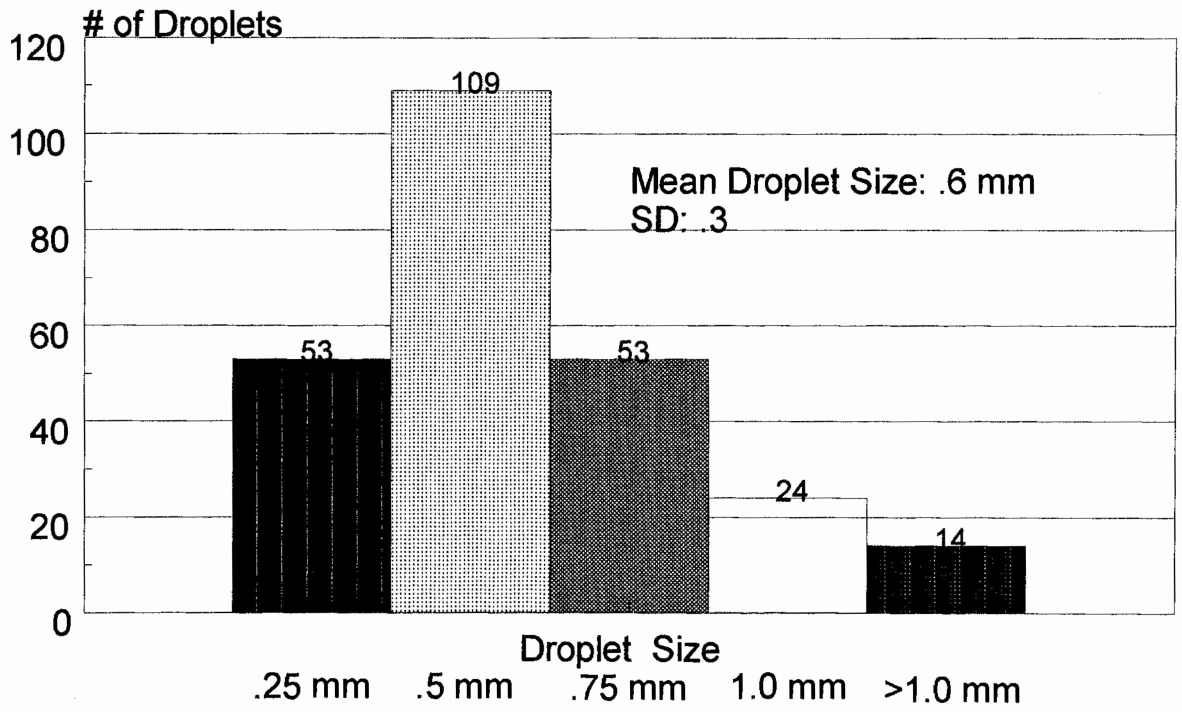


Oscillating Droplet

Estimated Perfect Sphere

$$d = D + d^0/2$$

Figure 2



# of Droplets
120
100
80
60
40
20
0
109
53
53
24
14
Mean Droplet Size: .6 mm
SD: .3
Droplet Size
.25 mm
.5 mm
.75 mm
1.0 mm
>1.0 mm

Figure 3

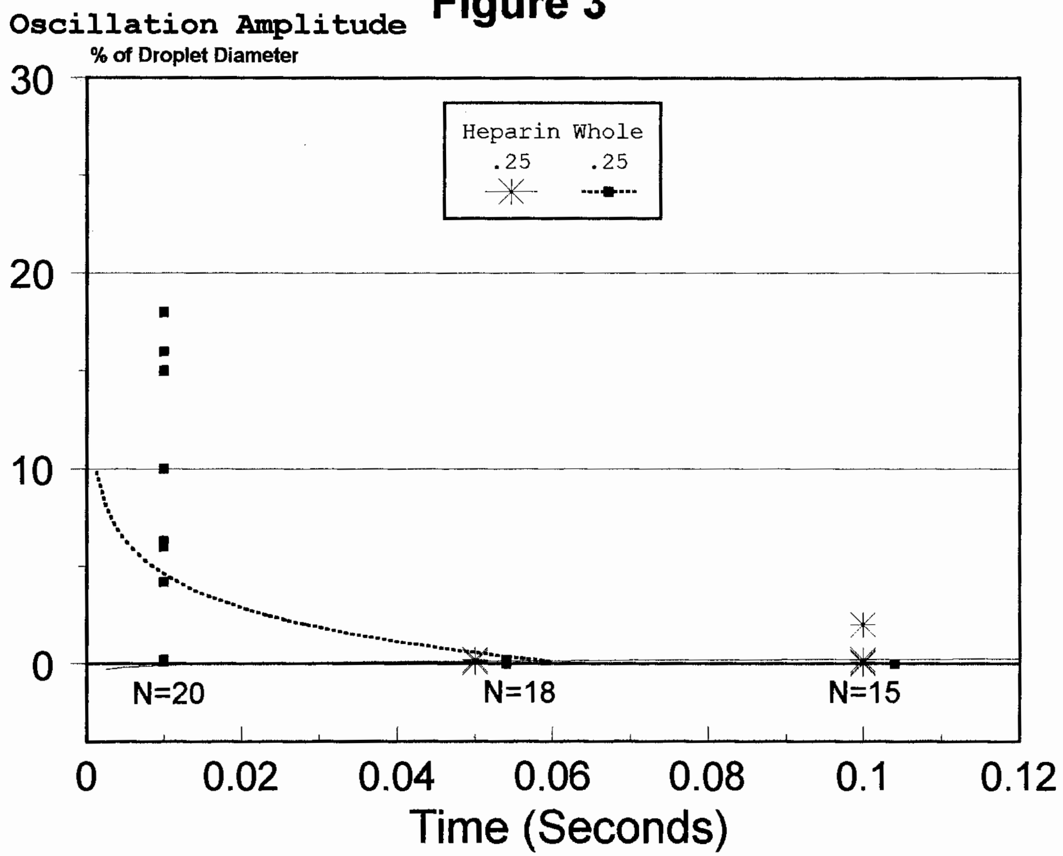

Oscillation Amplitude
% of Droplet Diameter
30
20
10
0
Heparin Whole
.25 .25
N=20
N=18
N=15
0
0.02
0.04
0.06
0.08
0.1
0.12
Time (Seconds)

Figure 4

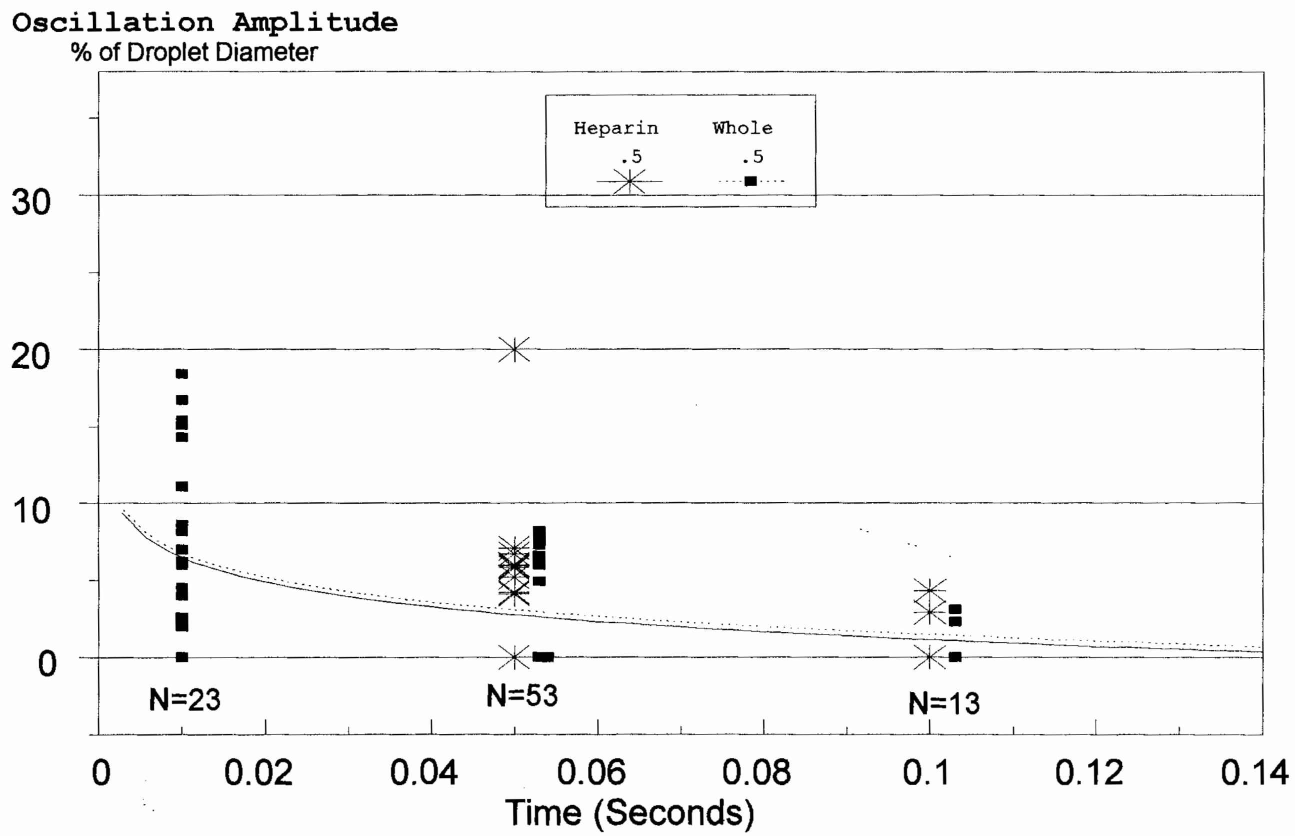
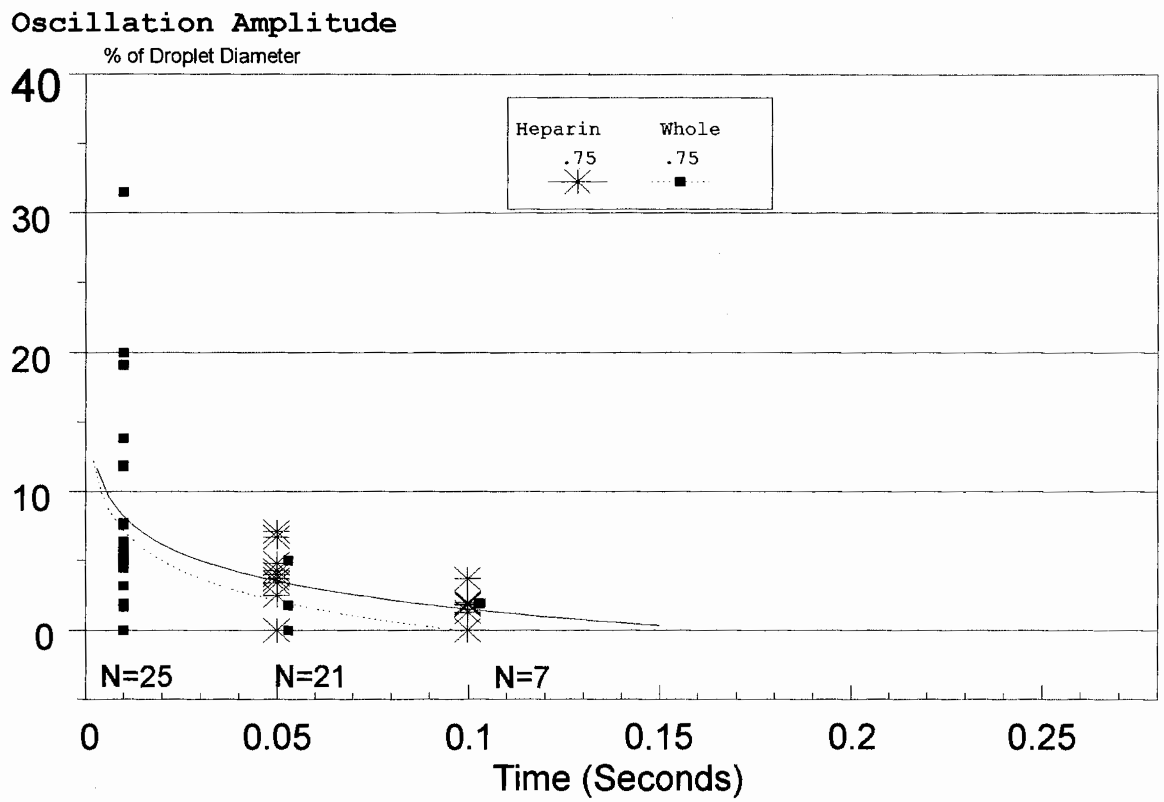

Oscillation Amplitude
% of Droplet Diameter
Heparin .5
Whole .5
30
20
10
0
N=23
N=53
N=13
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time (Seconds)

Figure 5



Oscillation Amplitude
% of Droplet Diameter
40
30
20
10
0
Heparin
.75
Whole
.75
N=25
N=21
N=7
0
0.05
0.1
0.15
0.2
0.25
Time (Seconds)

Figure 6

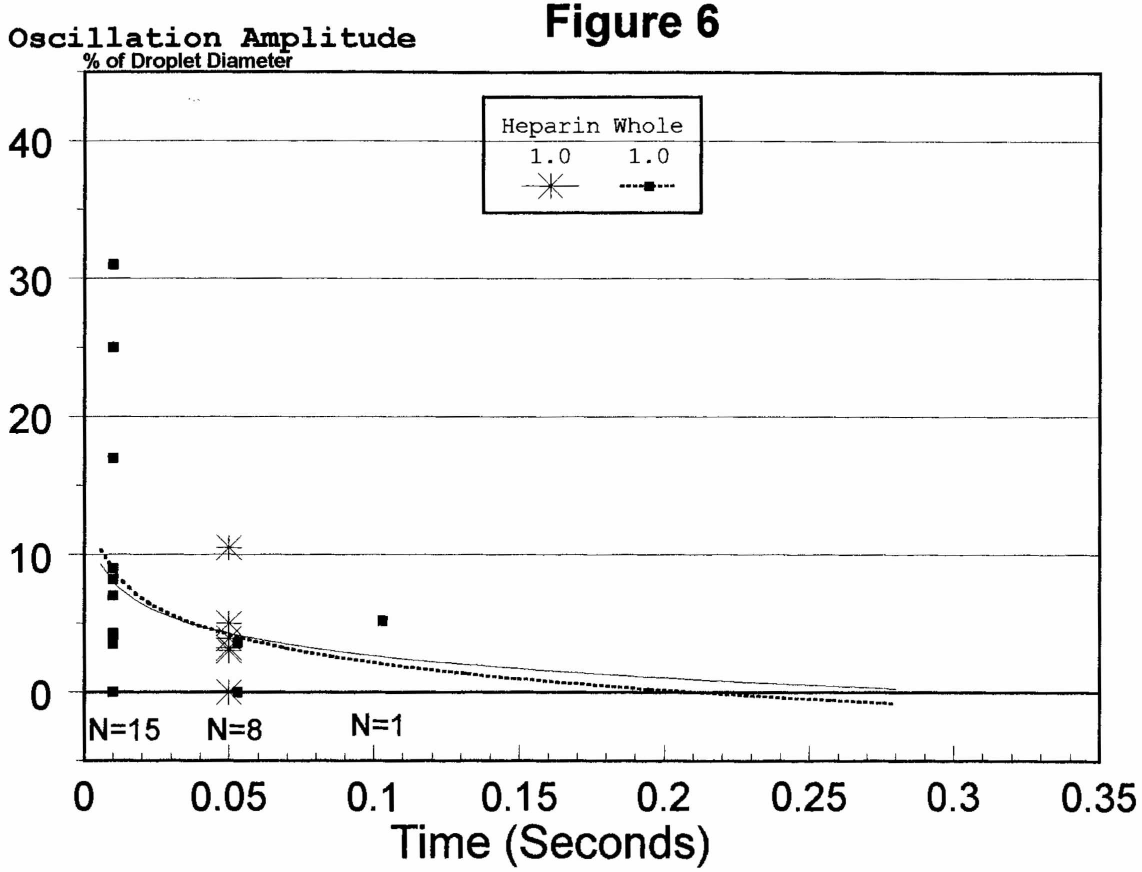
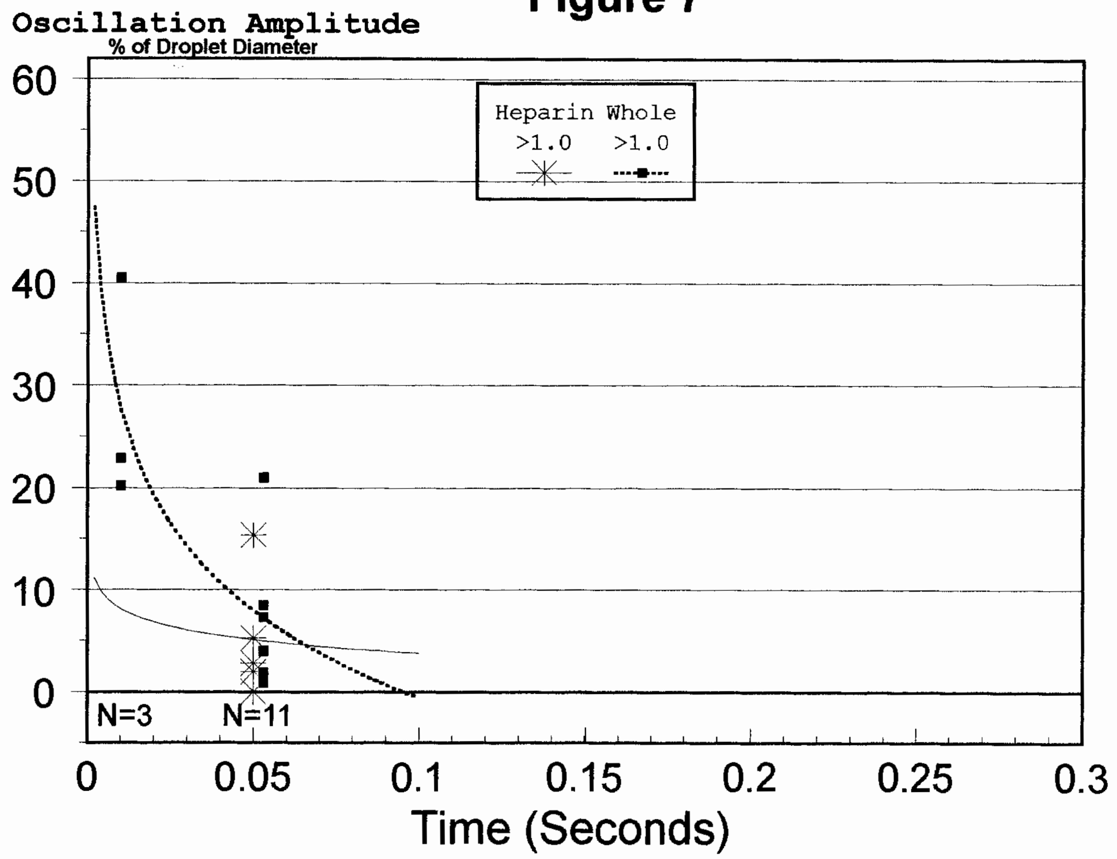
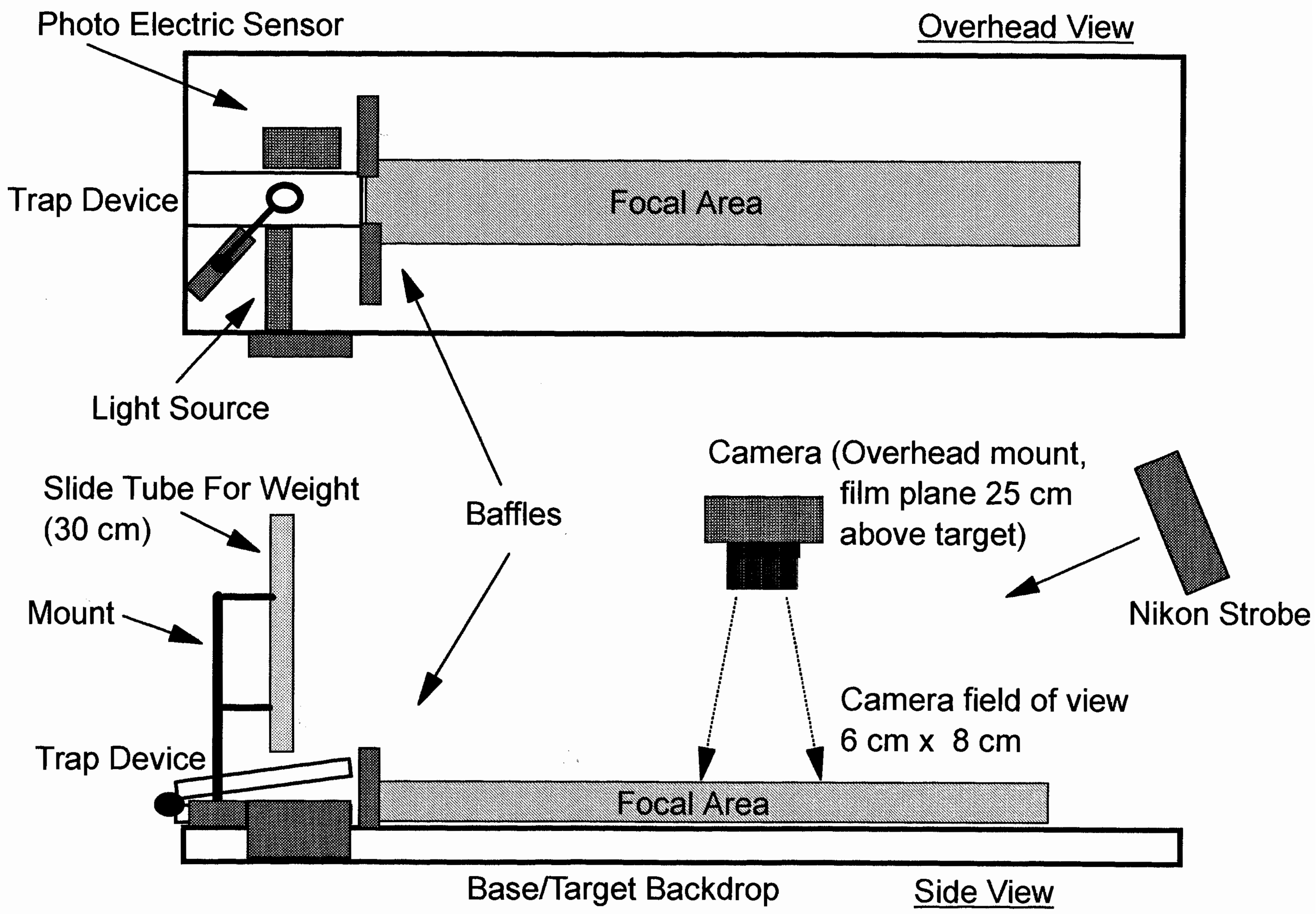

Oscillation Amplitude
% of Droplet Diameter
Heparin 1.0
Whole 1.0
40
30
20
10
0
N=15
N=8
N=1
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
Time (Seconds)

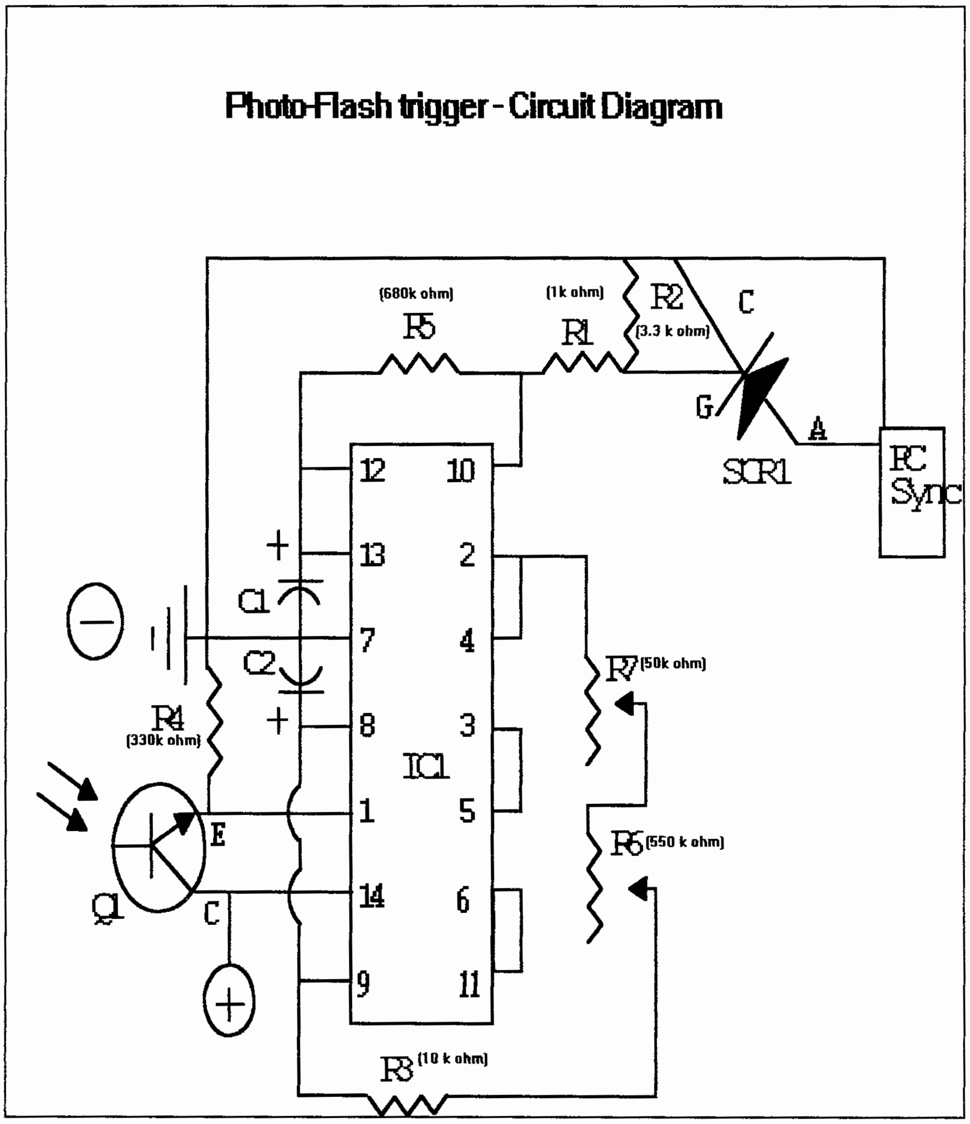
Figure 7


Oscillation Amplitude
% of Droplet Diameter
60
50
40
30
20
10
0
Heparin >1.0
Whole >1.0
N=3
N=11
0
0.05
0.1
0.15
0.2
0.25
0.3
Time (Seconds)

Annex A: Study Device Layout



Annex B: Photo-flash Trigger



Parts required for this device include:
3"X 2"X 1.5" plastic housing box.
3"X 2" perf. board
Q1 - Phototransistor RS-276-145
IC1 - 4093BCN or RCA SK4093B
SCR1 - C106D2 SCR or RCA SK 3598
R1 - 1K Ohm resistorR2 - 3.3K ohm resistor
R3 - 10K ohm resistor
R4 - 330K ohm resistor
R5 - 680K ohm resistor
R6 - 500K ohm potentiometer
R7 - 50K ohm potentiometer
C1, C2 1 mfd/35 Volt capacitors
Male PC sync cord