How the application of a traditional horseshoe with and without polyurethane sole packing effects the direction and position of the hoof capsule`s movement in response to ground reaction force

By

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Acknowledgements

This paper is dedicated to Joseph Raymond Moores, in the pursuit of excellence failure must become a friend.

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Abstract

Hypothesis

The application of a traditional horseshoe with and without the insertion of polyurethane sole packing will alter the direction and position of the hoof capsule`s movement in response to ground reaction force.

Aims

To find how the unshod hoof capsule flexes under load and the effect of the application of a horseshoe and polyurethane sole packing.

Background

Since Lungwitz`s (1891) research on hoof capsule morphology many researchers have adapted and enhanced the knowledge in this subject. Colles (1989) found frog contact effected heel motion. Roepstorf et al (2001) found hoof capsule movement peaked at specified stride positions.

Materials & Methods

10 cadaver limbs were trimmed to geometrical proportions, 4 measurement markers were placed medially and laterally at the widest point and at the point of hoof wall deviation at the seat of corn on the hoof wall parallel to the horn tubules 10mm proximal of the ground baring border and distal of the hairline. Measurements were taken between the markers when the feet were unloaded. The feet were then loaded in a pneumatic press at specified angles relevant to enrolment, mid stance and unenrolment at both walk and trot, measurements were retaken at each point. The feet were then shod with a open heeled unclipped concave shoe and attached with 6 nails to suit, before being retested. Then a soft density sole packing was injected onto the foot before being retested and removed ready for testing of a medium then hard density sole packing.

Results & Conclusion

It is apparent that in the healthy cob foot the unshod hoof capsule expands greatest palmar to the widest part of the hoof at the proximal aspect, the application of a shoe results in the hoof capsule expansion being greatest distally, thus the application of a shoe alters the hoof mechanism. However the insertion of a sole packing material does not revert the hoof capsule`s position of maximum expansion whilst shod to mimic that of the unshod hoof. Yet the overall hoof capsule expansion is increased as a shoe is applied and sole pack is inserted, with the increase in sole packing density increasing the hoof capsule expansion. Previous studies have suggested that the application of a shoe restricts the hoof capsule`s expansion, however this study has shown that the application of a shoe only alters the position of expansion within the hoof capsule, it is this researchers suggestion that previous studies have only measured across one position on the hoof capsule, therefore this alteration in position of expansion was misjudged as restriction of expansion.

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Chapter 1 Introduction

1.1 Rationale

It is thought that natural heel motion alters when the hoof is trimmed and shod, resulting in an alteration to the normal biomechanics found within the hoof. It is plausible that this biomechanical breakdown may create pathology within the hoof, thus creating an equine welfare concern by causing avoidable pain and shortening the equine`s working life. Therefore, it is paramount to assess how hoof capsule morphology is altered through the application of traditional horseshoes and polyurethane packing.

1.2 Anatomical structures of the foot:

It is important to understand the positioning of anatomical structures in and around the hoof before delving into the function of the hoof, the following diagrams point out the anatomical parts that are responsible for hoof capsule morphology. (Fig 1.1 and1.2)

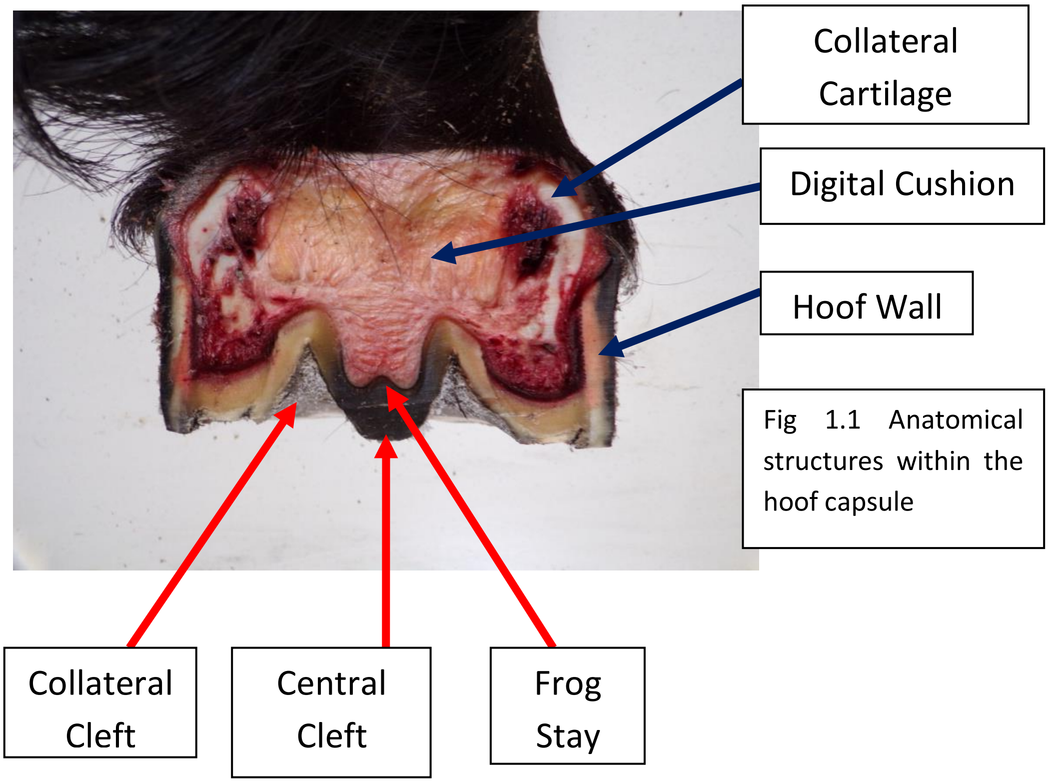


Fig 1.1 Anatomical structures within the hoof capsule

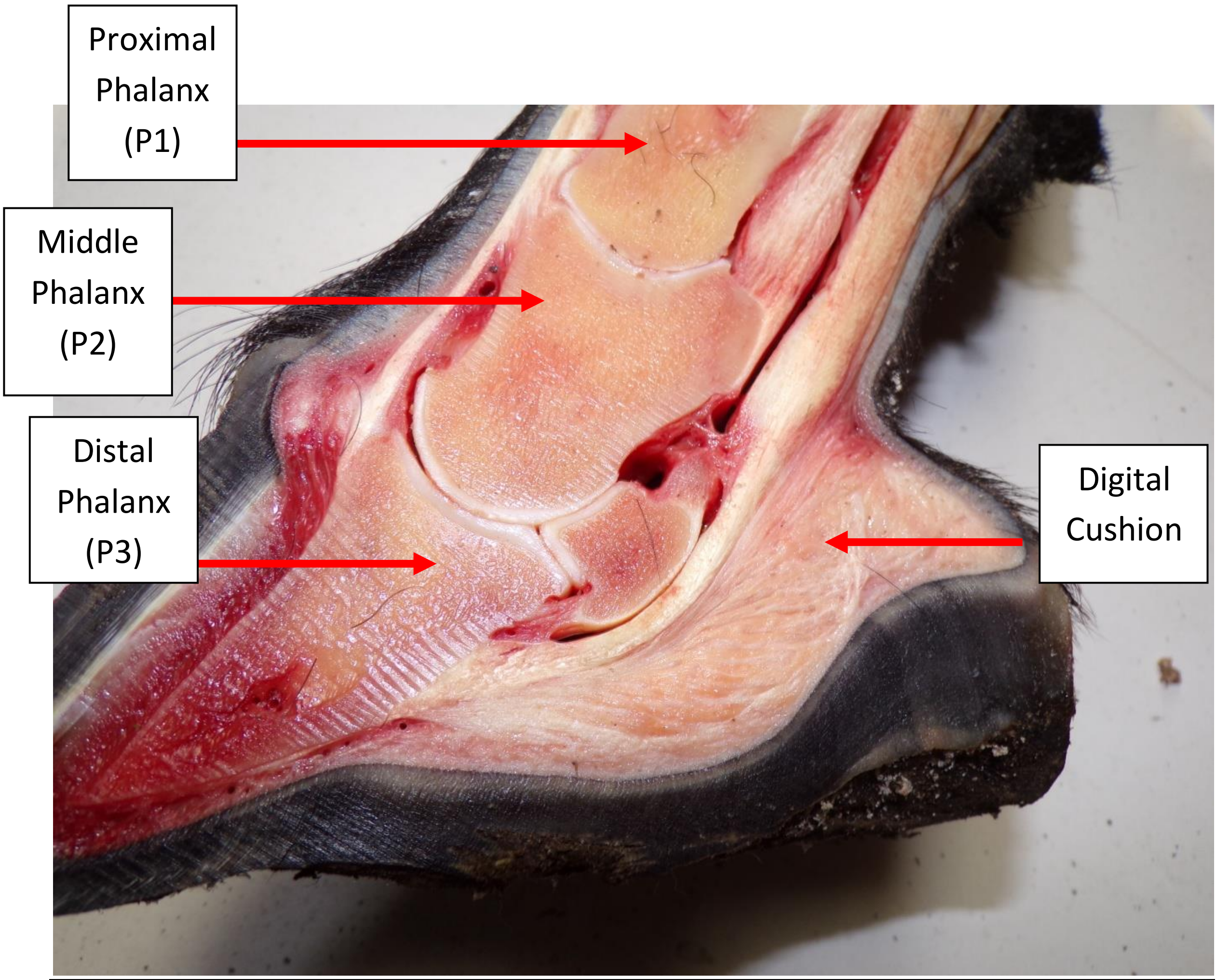


Fig 1.2 phalangeal bone column and the positioning of the digital cushion

1.3 The Hoof capsule`s morphological function

The morphology of the hoof capsule in the unshod hoof is aligned to share the weight distribution with the frog, this results in the ground contact surface of the frog being in line with the ground surface of the hoof wall. This creates a positive contact pressure on the frog when the hoof is in contact with the ground at the contact phase of the stride and a negative contact when the hoof is elevated at the swing phase of the stride, this is also known as a passive contact. This passive contact theory is believed to result in overall hoof capsule expansion as the descending load of body weight passes through the hoof capsule via the bony column onto the frog in the enrolment phase of the stride, resulting in an opposing ascending force known as the ground reaction force, this force pushes the frog stay into the digital cushion, compressing the digital cushion`s vertical height and expanding its horizontal width into the co-lateral cartilage. This movement of the collateral cartilages abaxially, expands the proximal hoof wall`s width, the vertical compression of the frog then results in the frog horizontally expanding coupled with the flattening of the solar arch results in the distal hoof wall expanding medially and laterally. (Fig 1.3)

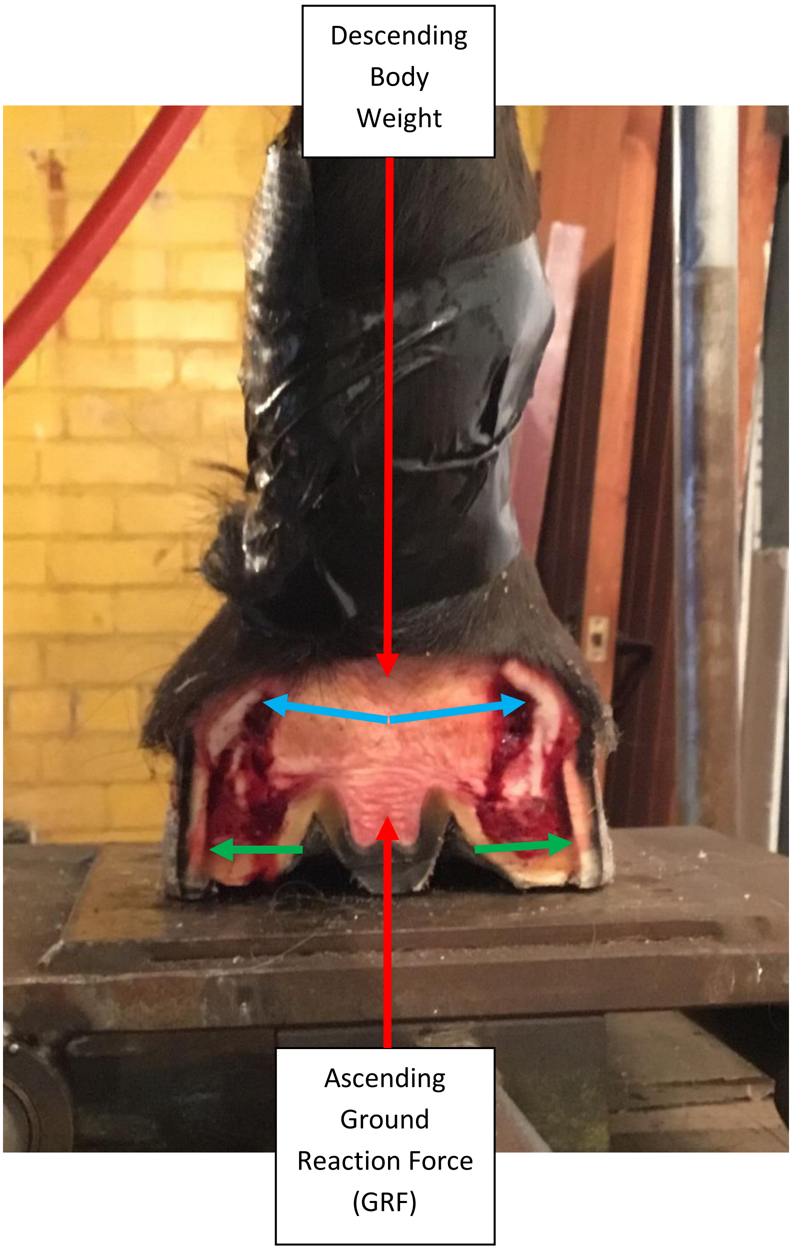


Fig 1.3 the passive contact theory, with the red arrows representing the opposing vertical forces, the blue arrows representing the horizontally expanding digital cushion, resulting in the co-lateral cartilages expanding, the green arrows representing the distal hoof capsule expansion in response to the frog compression and flattening of the solar arch.

The application of a shoe or over trimming of the frog results in the ground contact surface of the frog being elevated, and a void is created between the frog and the ground surface when the hoof is in the contact phase of the stride. This alteration removes the opposing ground reaction force, which results in the descending bony column migrating further distally within the hoof capsule and temporarily repositions the digital cushion with the underlying frog into the void, resulting in the collateral cartilages being dragged axially and distally, which results in the proximal hoof wall contracting medially and laterally. However, as the void is filled by these descending structures in addition to the solar arch which is flattening, the distal hoof wall expands medially and laterally. This is known as the negative pressure or decompression theory. (Fig 1.4)

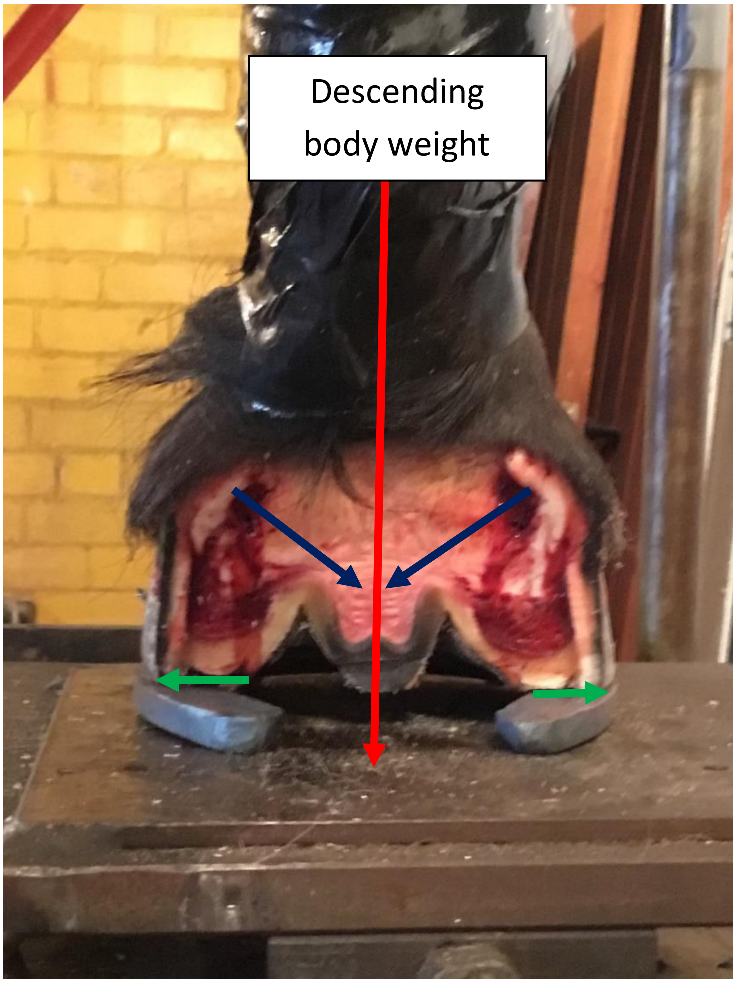


Fig 1.4 the negative hoof capsule loading, with the blue arrows representing the direction of collateral cartilage movement in response to the descending digital cushion caused by the loss of ascending GRF, the green arrows represent the distal hoof capsule expansion which is thought to be reduced however will remain in the same direction as flattening of the solar arch will still be present under load.

1.4 Historical concepts

The ideal horse`s foot shape has been questioned for many years, the first description was most likely made by General Xenophon around 360 BC, when even then attention was given to the frog, with the General insisting it should be in contact with the ground (Colles 1989). Miles (1846) first started the discussion about heel expansion which is now categorised under hoof capsule movement, as he suggested that attaching a shoe with excessive amounts of nails could interfere with normal hoof function. Lechner (1881) and Bayer (1886) described hoof deformation, they were quickly followed by Lungwitz`s (1891) work with a number of detailed experiments examining hoof movement, the work carried out by Lungwitz is the foundation of the four principal movements of the hoof mechanism Fig 1.5. Colles (1989) described these as, the lateral expansion of the quarters at the coronary band and plantar borders, presumably plantar border refers to the distal border or ground surface of the hoof wall, followed by the narrowing of the anterior half of the hoof at the coronary border resulting in the decrease in height of the foot with sinking of heels and the flattening, sinking, of the soles.

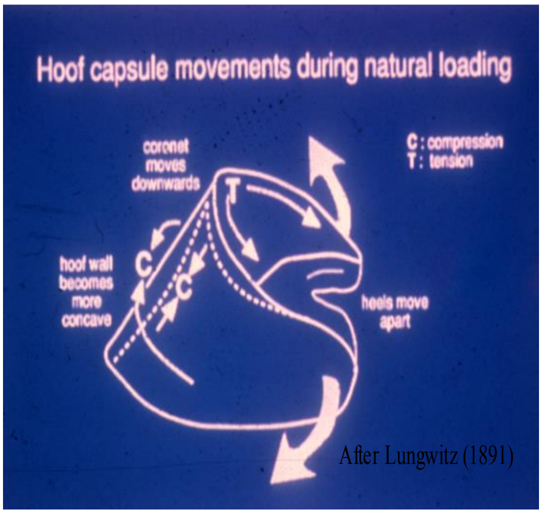


Fig 1.5. Illustration of Lungwitz`s (1891) diagram that represents his findings.

This was then confirmed by Akerblom (1930) who enhanced Lungwitz`s (1891) work by using a mechanical recording system attached to the wall of the hoof to record a paper trace. However Colles (1989) later suggested that Lungwitz (1891) was misguided when he stated that an upright hoof wall and heel is due to a lack of frog pressure and suggested that Lungwitz was looking at an upright or club foot (Colles 1989). Lungwitz`s (1891) research has been copied and modernised with more up to date measuring equipment. Knezevic (1962, 1963) and Zoerb and Leach (1978) looked into the movement of the hoof wall with the use of strain gauges. Whilst these researchers` work showed that the hoof wall deformed under load, it was Knezevic`s (1962, 1963) work that showed that strain gauges had a use in measuring hoof wall deformation.

Many researchers have noted that the natural hoof bares weight around its hoof wall, the sole bordering the hoof wall junction and the frog (Jackson 1997, Ovnicek et al 2003 and Hampson and Pollitt 2011), this is taught in modern day farriery schools. While there are several theories on how the hoof capsule supports the descending body weight and distributes the ascending ground reaction force, little is known on how or where the hoof capsule expands or contracts in reaction to these opposing forces. However, it is widely accepted that this instantaneous deformation of the hoof helps to reduce the shock wave travelling proximally through the limb, aids in the circulation of blood and recycling of lymph fluid (Butler and Butler 2004), thus changing the manner in which the hoof capsule deforms under load may have a detrimental effect on this percussive protection and fluid return systems.

2.1 Introduction

It is important to review previous literature and research studies prior to engaging in any further studies, as previous studies will shed light on what factual evidence is already known and how the studies were undertaken. When critically appraising past studies it is vital to assess whether the study was reliable and valid, if not then this information can be used to ensure future studies are more accurate and repeatable (Crombie 1996). The literature was sourced from Wiley online library, Google Scholar and the Equine Veterinary Journals. Key words searched for were hoof capsule, morphology, heel motion, ground reaction, frog and digital cushion.

2.2 Historical research into heel motion

Colles (1989) investigated the theory that frog contact was needed in heel motion, as prior to his work all previous research had proven was that heel motion occurred when the hoof was loaded and only anecdotal evidence and suggestions implied that frog contact had any effect. He also noted that all previous studies did not control the hoof shape or angle, so he set out to control this, with the aim of investigating frog pressure only and its effects. He used Knezevic`s (1962, 1963) and Zoerb and Leach`s (1978) studies as a base to create a piece of testing equipment that used strain gauges. The measurements were taken on live horses at trot, however the speed of trot was not controlled, which casts doubt on the reliability and validity of the research. All the horses where previously shod and at no point where they tested unshod in their normal state, this means the research did not have a baseline data set. It was suggested that the normal test was done on shod feet, that the frog was unloaded when the equine was static and loaded when in trot. He stated that this was checked when the horse was trotted and the frog made contact with the damp grass and then when trotted on a dry tarmac surface as the impression of the frog was clearly visible. This suggestion of normal ground contact contradicts to the researcher’s knowledge research done into hoof capsule morphology in wild equines

(Jackson 1997, Ovnicek et al 2003, Hampson and Pollitt 2011), also the idea of the frog trace from damp grass is ridiculous as the shoe would sink into the grass, casting doubt onto the method within the research. In order to eliminate the frog from the ground Colles (1989) attached a second shoe onto the original shoe, which even he noted might affect the limb flight and possibly affect strains within the hoof during the weight bearing stance phase, again adding further doubt on the reliability of his research. Whilst the study was inconclusive it was concluded that increasing frog contact pressure within weight bearing, alters the hoof wall which supports the reason for this study. It was even suggested that this frog contact alteration within farriery research should be done with caution, supporting the use of cadaver limbs within this study to remove any equine welfare implications. Thus there must be some grounds to the anecdotal suggestion that frog contact pressure effects hoof capsule motion. While his work was inconclusive he suggested two other ways the hoof capsule might expand, the wall may expand due to its conical shape or the frog may create internal pressure, expanding the hoof at the coronary band but contracting the hoof at the ground surface. Further studies are required but this initial work has helped future researchers create a more accurate test, even as he implies friction could have an effect on contraction and expansion, which emphasises the need for a Tarmacadam surface under the cadaver hoof in this research study.

2.3 Role of the frog in heel motion

Roepstorff et al (2001) expanded on Colles`s (1989) study, by creating a study that was simple in design and measured heel motion in vitro and in vivo. They also measured different areas of the heels in the cadaver limbs at both the proximal and distal points of the hoof wall, however they did not publish the measurements in two separate groups, but as an average measurement between the two, a more accurate analysis of the results was done in this research study. Testing on the cadaver limbs was done by loosely applying a wooden plinth to elevate the hoof in the press, it could be argued that this does not simulate the attachment of a shoe, so the shoe was attached in the traditional farriery method in this research study. The same method of increasing frog contact pressure that Colles (1989) used was utilised but again this did not simulate the normal ground contact pressure that is published in numerous other articles (Jackson 1997, Ovnicek et al 2003, Hampson and Pollitt 2011). However they improved on Colles` (1989) study, as they tested the cadaver limbs unshod. The in vivo test created similar results to that of the in vitro test, therefore it was suggested that cadaver limb testing is useful in assessing heel motion without the use of live specimens. The trimming prior to testing was done so that the frog was in contact with the surface in a non loaded situation, thus mimicking the normal ground contact pressure found by Jackson (1997), Ovnicek et al (2003) and Hampson and Pollitt (2011). Whilst their findings showed that heel motion occurs as expansion with or without frog contact pressure, they also noted that the expansion is increased in relation to frog contact pressure, but more interestingly that the proximal hoof wall expanded less than the distal wall but the coronary band expanded the most, this suggested that the soft tissue movement occurring is that of the collateral cartilage and then the digital cushion and the frog.

2.4 Variables that need considering in future research

The limb was mounted with the distal inter-phalangeal articulation centred vertically under the hydraulic ram (Colles 1989), which suggested that the angle of the limb was not correctly in line with the descending body weight at mid stance. As the limbs where dissected distal to the carpus, the suspensory ligament would have still been attached, however as with Colles (1989), clamping the deep digital flexor tendon, the superficial digital flexor tendon, common digital extensor tendon or the lateral digital extensor tendon was not mentioned, which would give an unnatural flexion to the carpo-metacarpal joint when loaded, this contradicts the suggestion that the in vitro results replicated that of the in vivo results. Similar to Colles (1989) no explanation was given on how much descending body weight was applied, and whether this simulated the situation in the live horses. The widest point proximal and distal in five limbs was measured and heel motion proximal and distal in the other five, even though the samples were taken on separate limbs both sets of measurements were used to produce an average, this would have been be more reliable if both sets were taken on all ten limbs. The study set out to create a simpler test for heel motion, whilst their measurements were easier to interpret than Colles (1989), it is this researcher's suggestion that the use of wires and electrical impulses make it difficult to reproduce. The in vivo test did give interesting findings that could be used in future studies, it was noted that maximum heel expansion occurs at 20% of the stance phase in walk and 30-35% in trot, along with the findings of maximum contraction being at 85% in walk and 80% in trot which could be used to get a more precise limb alignment in future in vitro studies.

Hobbs et al`s (2004) study measured the internal hoof strain using strain gauges and whilst the studies objective has no correlation to that of this study, Hobbs et al set the angle of MC3 in relation to the position of the stride and mimicked flexor tendon tie off with the use of cords and load cells. Thomason et al (1998) studied the effects of hoof capsule movement in relation to the alteration of stress and strains dorsal to widest part of the hoof, this means that their study did not measure the hoof capsule movement palmar to the widest part of the hoof but its effects on the hoof capsule that has attachment via the lamellar interface.

2.5 Summary

By reviewing historical research studies it was recognised that there was a need for further studies into hoof capsule movement and the hoof mechanism. By utilising these past research studies this research study was able to supply a defined trimming and preparation procedure, a loading simulation that replicates natural position and weight across both walk and trot, coupled with a more accurate and simplistic method of measuring. The collated results have also been more defined and analysed to show any differences or comparisons between the groups. All the above has enabled this research study to produce a firm baseline showing exactly how hoof capsule movement occurs in the unshod hoof and how it is affected by external variables.

Chapter 3 Methodology

3.1 Introduction

A methodology is crucial within a research project as it answers two vital questions on how the data was collected and how it was analysed. The methodology explains in detail the techniques used to collect process and analyse information to answer a set question or questions, which allows the reader to critically evaluate the validity and reliability of a study. A research study can either be qualitative or quantitative; a qualitative research study is an introductory exploratory research paradigm which gathers information on thoughts, opinions and feelings via a unstructured or partly structured data collection method, most commonly from individual/group communications, observations and discussions. A quantitative research study is a way of solving a problem by generating a numerical data set or a set of data that can be used within statistical analysis, this analysis allows the researcher to find patterns within the results (Crombie 1996). This research used a quantitative paradigm which allowed for a large quantity of numerical data to be collected and statistically analysed which created a set of results that were reliable and valid.

3.2 Aims and Objectives

The aim of the study was to give equine science a better understanding as to how the unshod hoof capsule flexes in reaction to descending body weight and ascending ground reaction force. These findings will give evidence based fact on how farriery interventions affect the biomechanical behaviour of the hoof capsule, which will encourage farriers throughout the industry to reassess their shoeing protocols regarding hoof capsule interface with GRF. Whilst also allowing for further research to be conducted into what mechanisms and structures are affected and how they are affected by this change in hoof capsule movement.

The objective of this study was to show how the hoof capsule expands or contracts and at which points this movement occurs on the hoof capsule. The study then moved on to show whether the application of a horseshoe and a horseshoe with a polyurethane sole packing alters the normal hoof capsule expansion and contraction.

3.3 Hypothesis

A hypothesis is a proposed explanation for an unknown occurrence, if a hypothesis is to be a scientific hypothesis then the method must be one that can be tested. (Crombie, 1996)

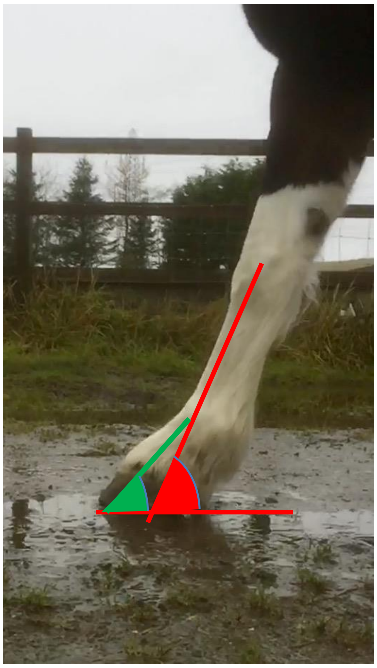
The hypothesis for this study was the application of a traditional horseshoe with and without the insertion of polyurethane sole packing will alter the direction and position of the hoof capsule`s movement in response to ground reaction force.

3.4 Materials and Method

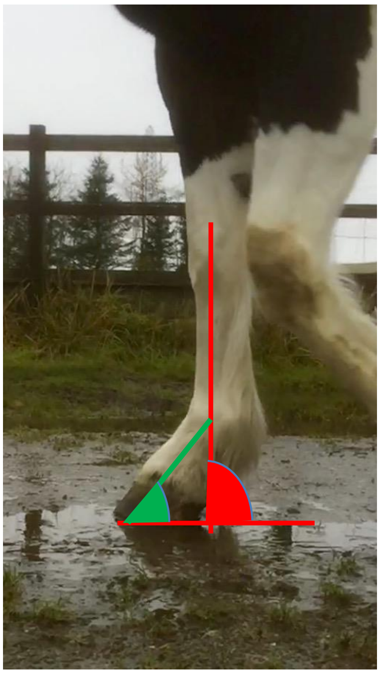
Ten cadaver fore limbs were obtained from a North West of England fallen equine company, the limbs had been previously dissected at the carpo-metacarpal joint, correctly wrapped and frozen by the collection company. The collection agency delivered the limbs in accordance with the Department for Environment, Food and Rural Affairs (DEFRA) transport of fallen animals legislation (2012), to the researcher`s forge and were stored in a locked chest freezer. All persons handling the limbs wore the following personal protective equipment when handling the cadaver limbs, disposable gloves and an apron. The limbs were selected as being free from any signs of pathology, had good hoof conformation, were previously unshod >6 months and could be suggestive of being from cob breeding with the widest part of the hoof being between 125mm and 175mm pre trim. Prior to testing the limbs were allowed to defrost over 24 hours and numerically labelled 1-10.

When the press had initial testing it was hoped that the descending body weight of the live horse could be simulated in the cadaver limb, by calibrating the press and calculating the ratio of PSI to descending body weight, however due to time restraints the researcher opted to simulate the angles of the limb in walk and increase the PSI to match the percentage increase in descending body weight between walk and trot, this was thought to be a reliable simulation as the tendon were held in place thus the limb angles would simulate that of a live horse. The angle of the third metacarpal (MC3) and the pastern at the moments of maximum heel expansion and contraction was found, this was done by videoing six horses, which were owned by the researcher and fitted the selection criteria for the cadaver limbs, as they walked over a level surface perpendicular to a slow motion IOS camera. Whilst wearing the correct PPE the handler was asked to walk and trot each horse along a straight line over a level Tarmacadam surface both ways, which allowed for easy viewing of both fore limbs. Still frames were taken at the moment the bony column decelerated to a stop upon enrolment, MC3 was perpendicular to the ground and when the heels elevated from the ground within unenrolment. Each frame was then printed out onto A4 paper which allowed the angle of MC3 and the pastern in relation to the ground surface to be found with the use of a protractor. The mean angle of MC3 and the pastern was then established at enrolment, mid stance and unenrolment for walk, (Fig 3.1). These set angles were then used to align the limbs within the press with the use of a Bosch PLL2 self-levelling cross line laser level and tripod.

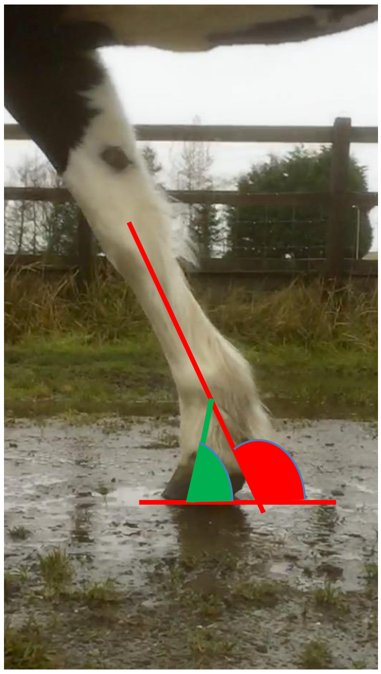
Limb alignment per



20% -
MC3: 68 degree
Pastern: 42 degree

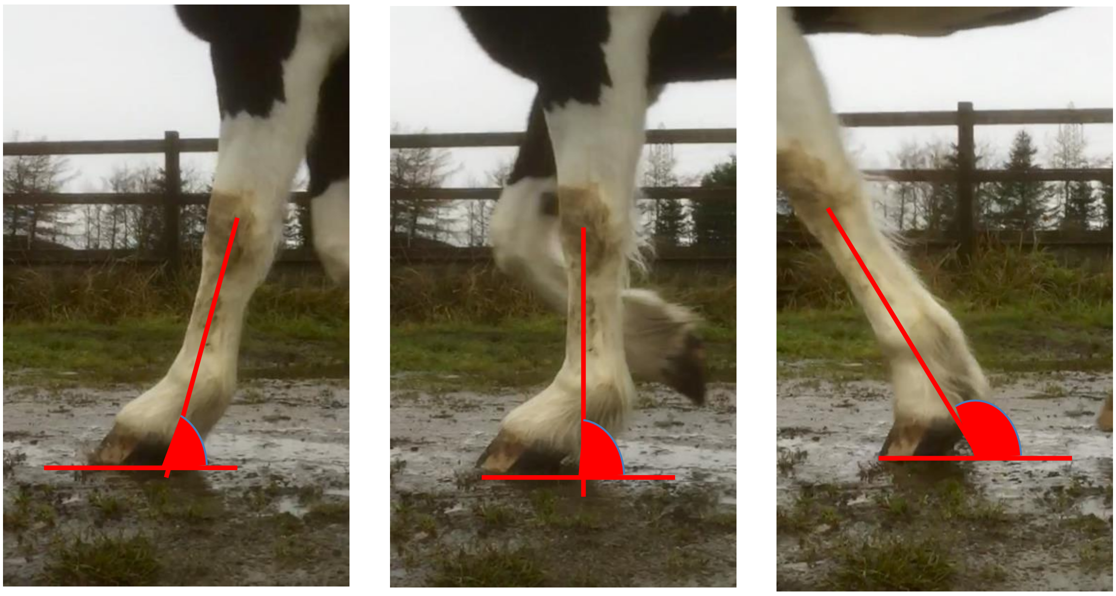


Mid-stance
MC3: 90 degree
Pastern: 58 degree



85% -
MC3: 115 degree
Pastern: 83 degree

Limb alignment per



32.5% - 71   Mid stance   80% - 113

Fig 3.1 and Fig 3.2 shows still images of one of the horses that were used to find the MC3 and pastern palmar angles in relation to the ground, at specified points throughout the contact phase of the stride at both walk and trot. The % given is that of the time following the contact phase of the stride, with the degree given for that moment in time.

The descending force also needed to be calibrated to find the force increase in percentage from walk to trot, this was done by using McGuigan and Wilson`s (2003) work on acceleration across the stride which was supported by Johnson`s unpublished (2017) pressure mat data for a horse over the contact phase of the stride at walk and trot. It was found that the descending force in trot at mid stance is 150% of the force at mid stance in walk, furthermore the descending force at enrolment is 45% of that at mid stance in trot, with the descending force at unenrolment is 40% of that at the mid stance in trot. It was then possible to increase the PSI by the above percentages to recreate the descending force through the hoof at trot across the enrolment, mid stance and unenrolment.

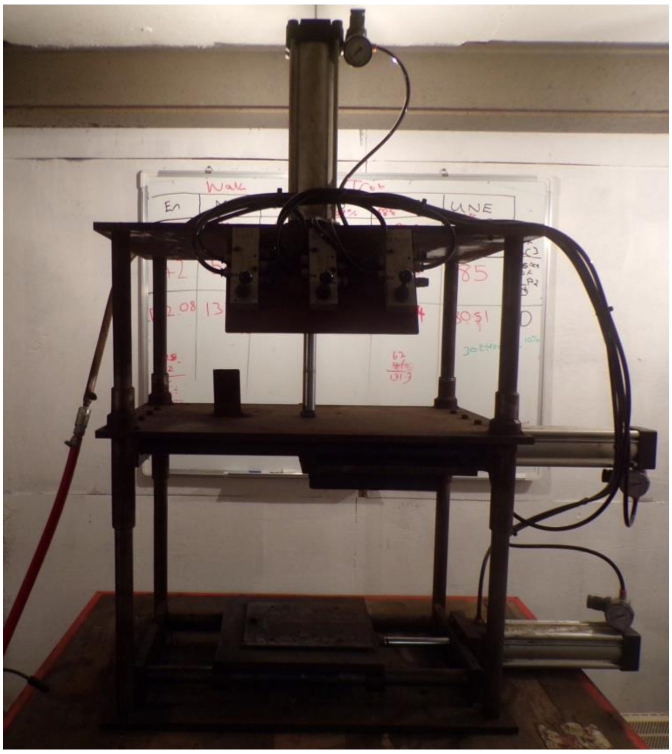


Fig 3.3 the pneumatic press

A pneumatic press is designed to mimic descending load on a cadaver limb via the vertical pneumatic ram, the two horizontal rams which are set at a lower psi are designed to allow the user to rotate the cadaver limbs to achieve limb angulations, thus mimicking the stride pattern of a live horse. The base plate upon which the ground surface of the hoof sits has a M12 socket screw fitted, this creates a stopper to restrict the slide of the hoof capsule under load. The base plate is also fitted with self adhesive anti slip safety tape that mimics the traction created by a Tarmacadam surface, Fig 3.3.

With the limb held vertically at mid MC3 in a bench vice, a 10.5mm hole was drilled centrally into the proximal articular surface of MC3 approximately 75mm deep into the medullary cavity with a battery operated drill, (Fig 3.4), ready for the insertion of the press adaptor screw. Both the flexor tendons and extensor tendons were tied off with a jubilee clip 30mm from the proximal aspect of the third metacarpal, to stabilise the flexion of the metacarpo-interphalangeal joint, (Fig 3.5).

Fig 3.4 shows the position and direction of the drill in preparation of the press adaptor socket

Fig 3.5 shows the press adaptor inserted and the jubilee clip that has been tightened to hold the tendons in position

The feet were then trimmed to geometrical proportions with a modified version of Caldwell et al`s (2010) trimming protocol for research, with the partially exfoliated sole being removed and the white line being excavated to reveal the excess depth of the hoof wall. The hoof wall was trimmed to the solar plane, rounded to remove any distortion and mirror the shape of the white line, with the distortion finally being dressed out. The frog was trimmed to remove any loose horn but still remain ground parallel with the ground bearing border of the heels. Marker points were then placed on the hoof with a coloured permanent marker, collaterally at specified points relating to external anatomical features. (Fig 3.6-3.7)

Fig 3.6 the trimmed hoof has been mapped with the widest point of the hoof being marked in blue and the anatomical position of the point of hoof wall deviation at the seat of corn being in green. This allows for a reliable and repeatable form of marker point positioning

Reference

Fig 3.7 final positioning of marker points, 10 mm proximal from the ground baring border and 10mm distal from the hair line, following the angle of the horn tubules from the mapped markers shown in Fig 3.6

Photographs were taken using an IOS digital camera positioned at the dorsal, lateral and palmar aspect, perpendicular to the press which was surrounded by a designated photo booth, measurements in millimetres (mm) were taken between the opposing collateral marker points on the hooves with a pair of Insize digital outside callipers, external callipers and digital verniers, (fig 3.8-3.9). All measurements were recorded by hand on a chart before being inputted into an excel spreadsheet and then inputted into Minitab version 18 for statistical analysis. Photographs and measurements were then taken with the limbs fitted within the press but not loaded, this data collection was done after each weight, position and intervention.

Fig 3.8 the measurement equipment used within this study

Fig 3.9 the measurement equipment used within this study

Each limb was then loaded and tested sequentially to the given angulations and descending body weight relevant to the limbs position at enrolment, mid stance and unenrolment at walk and trot. The hooves were then fitted with a handmade fullered concave unclipped shoe, of a section and size to produce a riding style fit. Then attached with six E slim nails that suited the shoe and driven in to establish a tight fit without the use of a block (Fig 3.10). The limbs were then reloaded and tested.

Fig 3.10 the shod hoof

The solar surface of the hoof was then lightly heated with a fan assisted heat gun to establish a firm adhesive bond with a Arthur Cottam`s soft sole pack, duct tape was used to create a dam at the open area between the heels. The soft sole pack was then injected into the inner perimeter of the shoe, to create a continuation of the ground bearing border throughout the caudal half with a slightly lowered surface in the dorsal half (Fig 3.11 and 3.12). Five minutes were taken to allow the packing to cure, before the tape was removed and the limb was tested. The packing was then removed, the same process and testing was undertaken using a medium and then a hard density sole pack and retested.

Fig 3.11 the shod hoof with hard sole packing

Fig 3.12 the shod hoof with medium packing

3.5 Reliability, Validity and Standardisation

It was important that this research was valid and that the measurements taken were precise with the results of this sample size being relevant to any sample taken throughout the world, this was done by using accurate measuring equipment that gave internal validity to the research by measuring exactly what they were supposed to measure and that the cadaver hooves had been put through a selection criteria, the hooves used were generalised beyond this immediate study and deemed similar to the hooves of the wider equine community thus the external validity was confirmed. It is also important that the research was reliable and repeatable by others whilst yielding the same result, this was done by simplifying the method with readily available equipment. Standardisation within quantitative research must ensure that each sample is treated and tested precisely in the same manner, this was done by ensuring that each limb underwent the same trimming, marking and loading processes with the type of intervention being applied in the same manner over the same amount of time.

3.6 Data Collection and Analysis

Measurements in millimetres (mm) and photographs were taken between the collateral markers of the hooves with a pair of Insize digital outside callipers, external callipers and digital verniers which allowed for accurate measurement within 0.01mm, these were retaken at each intervention. All measurements were recorded by hand on a chart before being inputted into an excel spreadsheet, the excel spreadsheet was used to produce tables with the difference between the baseline data, variants, limb positions, gait and measurement marker points, with the aid of imputing formulas within the spreadsheet these differences were able to be shown in a measurement mm form and a percentage form. The raw data was then inputted into Minitab version 18 to produce the basic statistics and p-values. Photographs were uploaded onto Kinovea software which enabled an overlapping timeline of hoof capsule movement between interventions.

3.7 Ethical Considerations

Cadaver limbs were sourced from a North West of England fallen equine collection company with the horses cause of death being unrelated to this study, they were previously frozen and delivered by the company in accordance with DEFRA transport regulations. They were stored in a secure freezer at the researcher`s forge and handled in the correct manner with the relevant PPE. Risk assessments were created and followed for storing and handling of the cadaver limbs. Once the research testing had been completed the cadaver limbs were returned to the freezer and awaited collection from the fallen equine collection company, who removed the limbs and disposed of them in accordance with DEFRA regulations. The Myerscough College Ethics Committee has granted approval for this study.

Chapter 4: Results

4.1 Descriptive statistics of raw data

The baseline data has been used below as an example of the basic descriptive statistics copied from Minitab version 18 showing the mean value, standard error of the mean and standard deviation of the ten cadaver limbs that were tested. The full list is shown in appendices 1. The baseline data taken at the unloaded UL stage at all four marker points are given. The variables are unshod US, shod S, shod with soft pack SP, shod with medium pack MP and shod with hard pack HP, along with their respective positions of enrolment walk EW, mid stance walk MsW, unenrolment walk UW, enrolment trot ET, mid stance trot MsT and unenrolment trot UT at each of the four marker points.

Statistics

Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
UL D-D	10	0	139.99	2.26	7.15	124.65	136.34	140.34	146.23	148.93
UL D-P	10	0	123.08	1.84	5.83	112.43	116.41	126.30	126.83	127.75
UL P-D	10	0	121.93	1.46	4.62	115.97	117.98	121.74	124.60	129.90
UL P-P	10	0	109.17	1.96	6.19	98.32	104.95	110.89	114.09	115.82

4.2 Statistic table with P-value in walk

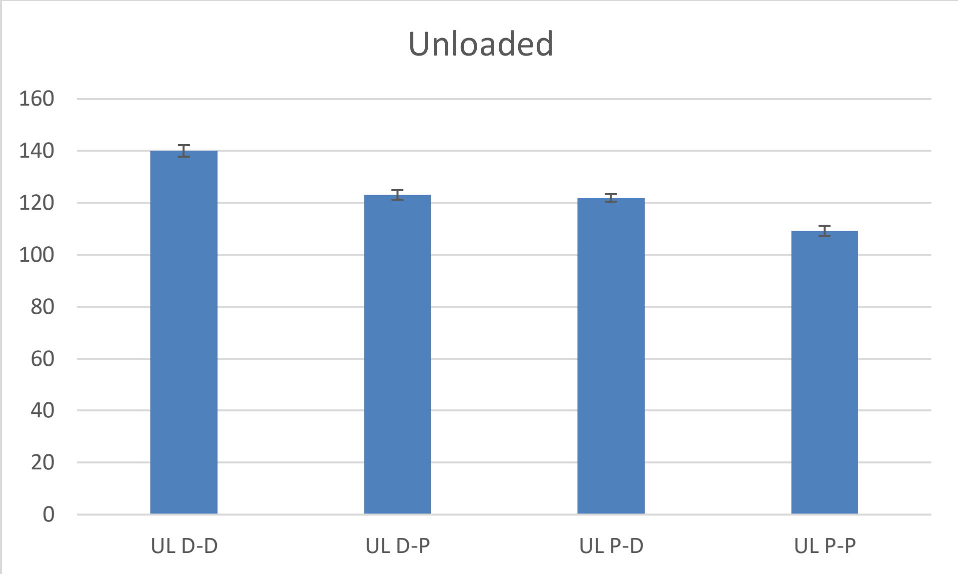
	Mean	StDev	N	AD	P-value		Mean	StDev	N	AD	P-value
WALK						WALK					
D-D						P-D					
UL	140	7.151	10	0.303	0.511	UL	121.9	4.621	10	0.399	0.294
US EW	142.5	7.812	10	0.233	0.725	US EW	124.3	4.305	10	0.319	0.472
US MsW	141.5	7.384	10	0.257	0.637	US MsW	123.8	4.255	10	0.329	0.447
US UW	140.5	6.875	10	0.262	0.619	US UW	122.4	4.737	10	0.697	0.047
S EW	143.4	7.666	10	0.205	0.82	S EW	125.1	4.15	10	0.335	0.43
S MsW	142.8	7.35	10	0.208	0.812	S MsW	124.6	4.376	10	0.353	0.387
S UW	141.6	6.668	10	0.263	0.617	S UW	123.3	4.393	10	0.452	0.214
SP EW	143.9	7.715	10	0.26	0.629	SP EW	125.5	4.345	10	0.554	0.114
SP MsW	143.2	7.45	10	0.263	0.617	SP MsW	125	4.366	10	0.621	0.075
SP UW	141.8	6.722	10	0.235	0.719	SP UW	123.6	4.132	10	0.374	0.343
MP EW	144.7	8.038	10	0.269	0.595	MP EW	126.1	4.511	10	0.489	0.17
MP MsW	144.1	7.671	10	0.269	0.596	MP MsW	125.5	4.478	10	0.43	0.245
MP UW	142	6.62	10	0.227	0.748	MP UW	123.8	4.205	10	0.304	0.509
HP EW	145.1	7.944	10	0.324	0.459	HP EW	126.6	4.464	10	0.372	0.346
HP MsW	144.5	7.893	10	0.303	0.51	HP MsW	126.1	4.239	10	0.458	0.205
HP UW	142	6.858	10	0.178	0.891	HP UW	124.1	4.319	10	0.303	0.511
D-P						P-P					
UL	123.1	5.83	10	1.303	<0.005	UL	109.2	6.186	10	0.514	0.144
US EW	126.1	5.789	10	0.919	0.012	US EW	112.1	5.46	10	0.62	0.075
US MsW	125.3	5.668	10	0.907	0.013	US MsW	111.1	5.228	10	0.688	0.049
US UW	125	5.661	10	1.033	0.006	US UW	110.2	6.07	10	0.82	0.022
S EW	126.1	5.662	10	0.588	0.092	S EW	112.1	5.056	10	0.443	0.226
S MsW	125.8	5.562	10	0.578	0.098	S MsW	111.6	5.305	10	0.301	0.514
S UW	125.2	5.304	10	1.114	<0.005	S UW	111.1	5.801	10	0.639	0.067
SP EW	126.8	5.63	10	0.482	0.177	SP EW	113	5.277	10	0.54	0.122
SP MsW	126.3	5.367	10	0.415	0.267	SP MsW	112.6	4.798	10	0.313	0.49
SP UW	125.1	5.093	10	0.931	0.011	SP UW	111.1	5.696	10	0.485	0.174
MP EW	127	5.399	10	0.342	0.415	MP EW	113.6	5.106	10	0.327	0.451
MP MsW	126.8	5.429	10	0.374	0.343	MP MsW	113.1	4.988	10	0.283	0.554
MP UW	125.3	5.102	10	0.731	0.038	MP UW	111.5	5.778	10	0.484	0.174
HP EW	127.8	5.215	10	0.328	0.45	HP EW	114.3	4.972	10	0.285	0.549
HP MsW	127.4	5.197	10	0.289	0.538	HP MsW	113.6	4.981	10	0.274	0.58
HP UW	125.6	5.117	10	0.701	0.046	HP UW	111.8	5.742	10	0.526	0.134

4.3 Statistic table with P-value in trot

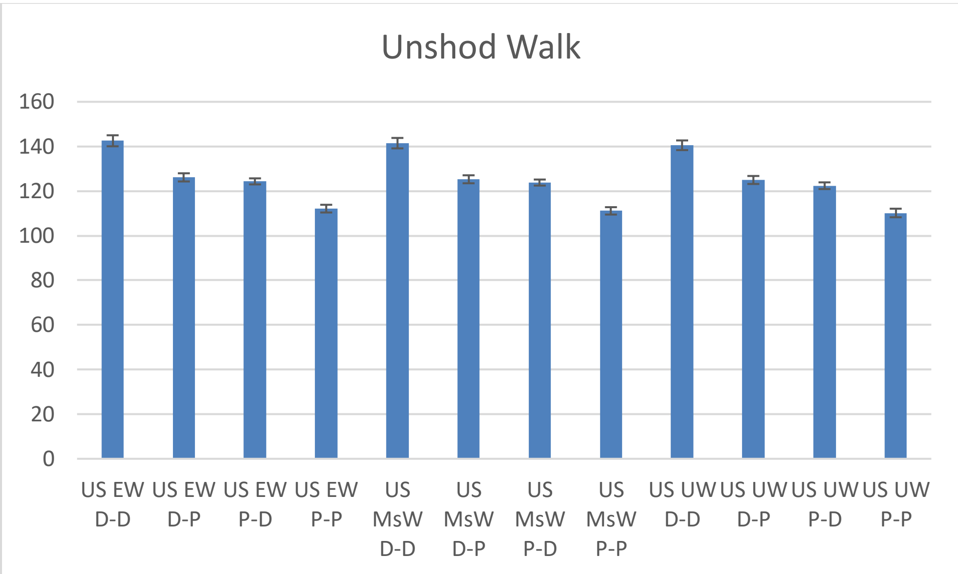
	Mean	StDev	N	AD	P-value		Mean	StDev	N	AD	P-value
TROT						TROT					
D-D						P-D					
UL	140	7.151	10	0.303	0.511	UL	121.9	4.621	10	0.399	0.294
US ET	143.2	7.901	10	0.174	0.898	US ET	125.4	3.896	10	0.327	0.45
US MsT	142.2	7.695	10	0.235	0.717	US MsT	124.4	4.086	10	0.353	0.389
US UT	140.7	6.897	10	0.24	0.701	US UT	122.8	4.51	10	0.407	0.28
S ET	143.6	7.721	10	0.24	0.698	S ET	125.5	4.302	10	0.343	0.411
S MsT	143	7.624	10	0.225	0.753	S MsT	124.9	4.293	10	0.42	0.26
S UT	141.6	6.581	10	0.28	0.563	S UT	123.3	4.545	10	0.368	0.355
SP ET	144.4	7.65	10	0.246	0.677	SP ET	126.1	4.354	10	0.523	0.136
SP MsT	143.7	7.592	10	0.229	0.742	SP MsT	125.4	4.2	10	0.618	0.077
SP UT	141.8	6.654	10	0.257	0.639	SP UT	124.4	6.359	10	0.804	0.024
MP ET	145	8.218	10	0.274	0.581	MP ET	126.5	4.657	10	0.522	0.137
MP MsT	144.3	7.843	10	0.255	0.645	MP MsT	125.9	4.384	10	0.559	0.111
MP UT	142.1	6.717	10	0.207	0.815	MP UT	123.8	3.949	10	0.36	0.373
HP ET	145.7	8.145	10	0.309	0.503	HP ET	127.1	4.526	10	0.47	0.19
HP MsT	144.8	8.667	10	0.343	0.412	HP MsT	126.5	4.526	10	0.473	0.187
HP UT	142.3	6.647	10	0.192	0.86	HP UT	124.2	3.953	10	0.383	0.324
D-P						P-P					
UL	123.1	5.83	10	1.303	<0.005	UL	109.2	6.186	10	0.514	0.144
US ET	126.7	5.653	10	0.861	0.017	US ET	113	5.445	10	0.617	0.077
US MsT	125.6	5.645	10	0.757	0.032	US MsT	112	5.26	10	0.686	0.05
US UT	125	5.565	10	1.054	0.005	US UT	110.4	5.774	10	0.601	0.085
S ET	126.6	5.579	10	0.623	0.074	S ET	112.5	5.489	10	0.556	0.113
S MsT	126	5.597	10	0.662	0.058	S MsT	112.1	5.272	10	0.459	0.204
S UT	124.7	5.05	10	1.314	<0.005	S UT	110.5	5.809	10	0.695	0.047
SP ET	127	5.506	10	0.487	0.172	SP ET	113.4	5.363	10	0.482	0.177
SP MsT	126.3	5.265	10	0.466	0.195	SP MsT	113.1	5.225	10	0.458	0.206
SP UT	124.7	4.802	10	1.161	<0.005	SP UT	110.9	5.693	10	0.466	0.195
MP ET	127.6	5.477	10	0.341	0.416	MP ET	114.2	5.101	10	0.296	0.523
MP MsT	127	5.504	10	0.407	0.281	MP MsT	113.3	5.137	10	0.256	0.642
MP UT	125	4.652	10	1.071	<0.005	MP UT	111.5	5.827	10	0.502	0.156
HP ET	128	5.356	10	0.292	0.533	HP ET	115.1	5.138	10	0.255	0.643
HP MsT	127.5	5.329	10	0.275	0.578	HP MsT	113.9	5.017	10	0.244	0.685
HP UT	125.2	4.522	10	0.946	0.01	HP UT	111.7	5.722	10	0.455	0.21

The tables in 4.2 and 4.3 were produced in excel with the statistical values copied from the Minitab version 18 probability plot graphs and the connecting data sheet, see appendices 2.

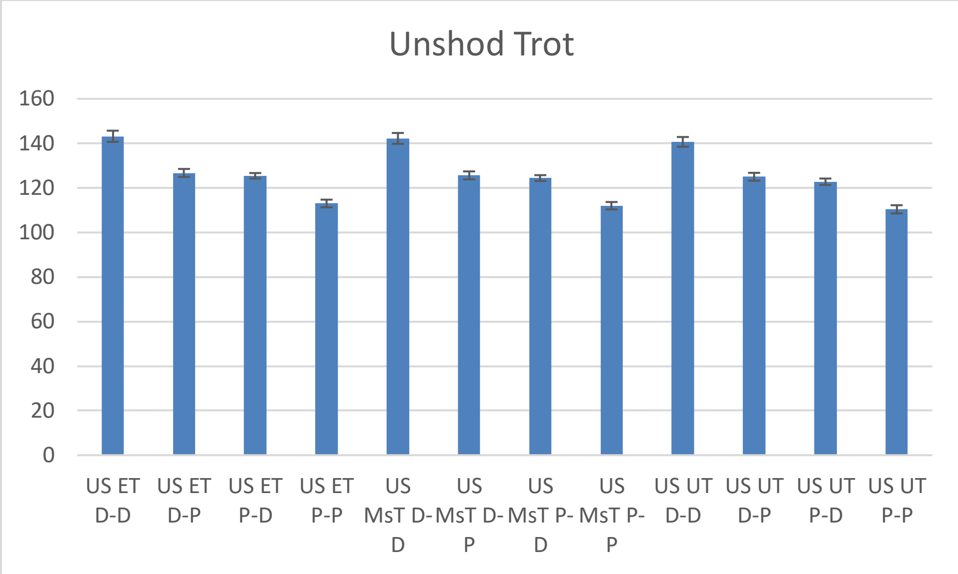
4.4 Bar charts with standard error of the mean



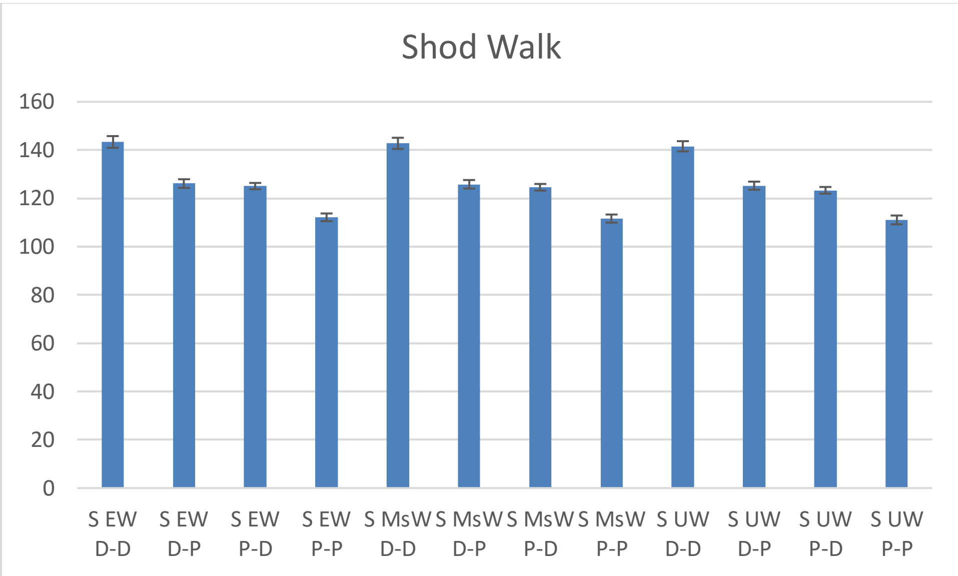
Graph 4.1 baseline data bar chart of the mean measurements mm of the cadaver limbs at the unloaded state across each marker point, with the standard error of the mean inputted.



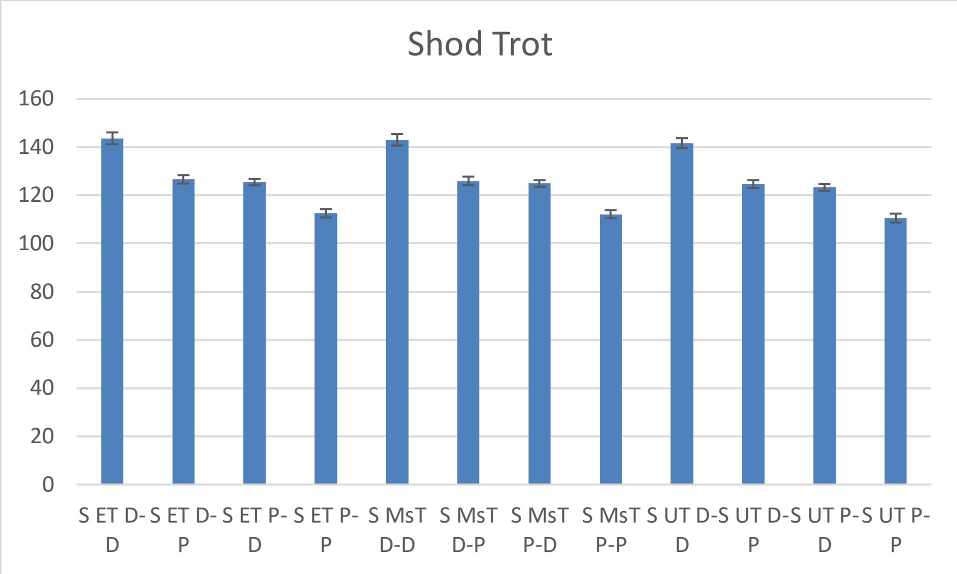
Graph 4.2 bar chart of the mean measurements mm of the cadaver limbs at the unshod loaded state of the three positions of the walk stride across each marker point, with the standard error of the mean inputted.



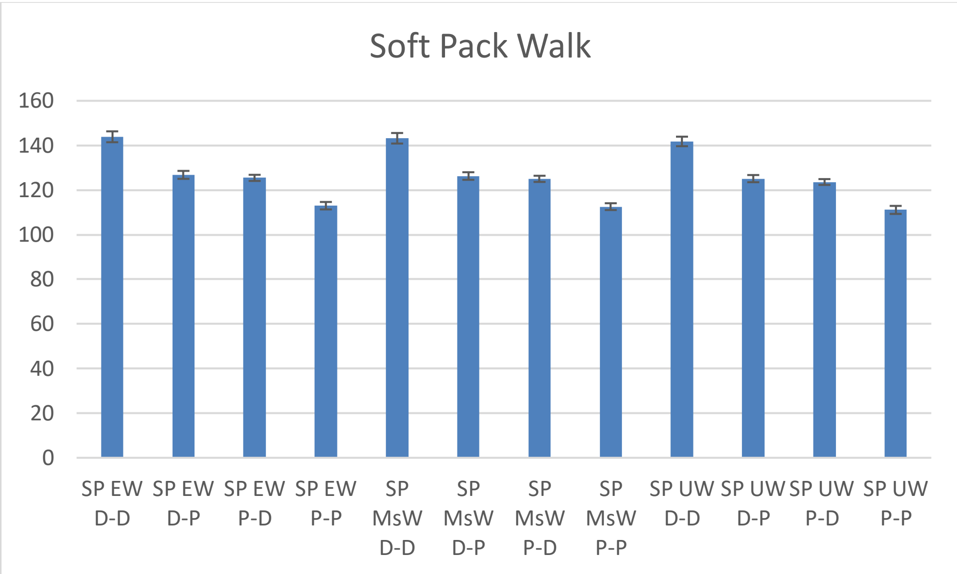
Graph 4.3 bar chart of the mean measurements mm of the cadaver limbs at the unshod loaded state of the three positions of the trot stride across each marker point, with the standard error of the mean inputted.



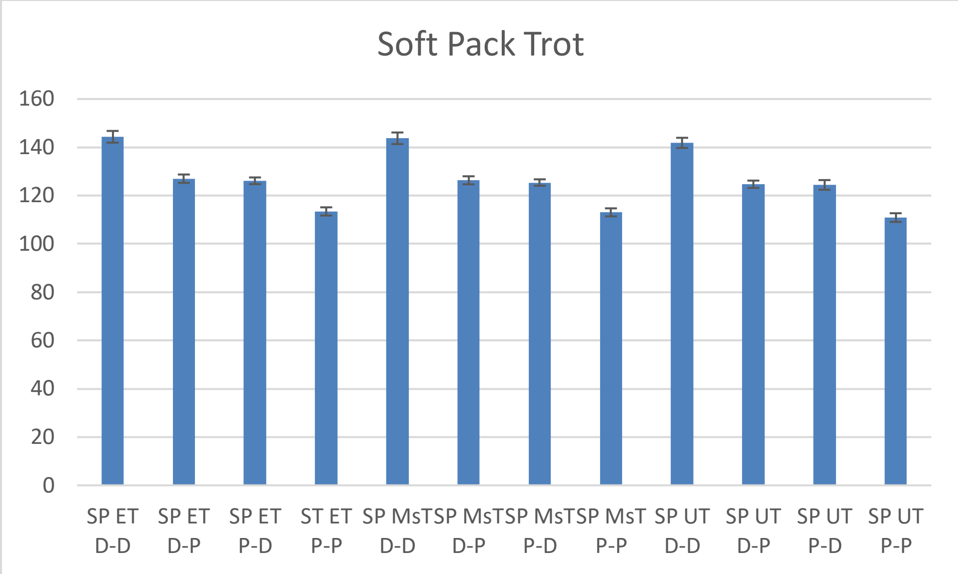
Graph 4.4 bar chart of the mean measurements mm of the cadaver limbs at the shod loaded state of the three positions of the walk stride across each marker point, with the standard error of the mean inputted.



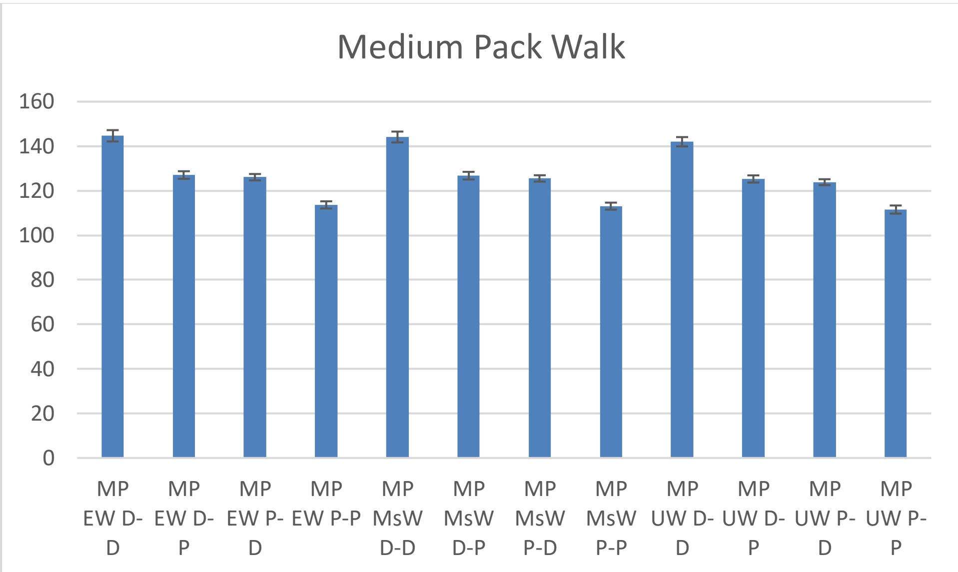
Graph 4.5 bar chart of the mean measurements mm of the cadaver limbs at the shod loaded state of the three positions of the trot stride across each marker point, with the standard error of the mean inputted.



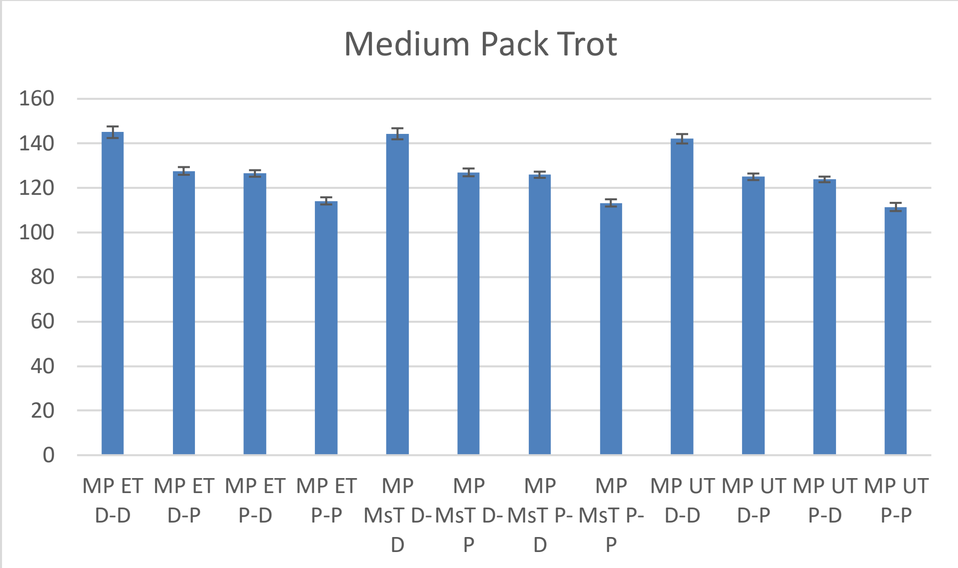
Graph 4.6 bar chart of the mean measurements mm of the cadaver limbs at the shod with soft pack loaded state of the three positions of the walk stride across each marker point, with the standard error of the mean inputted.



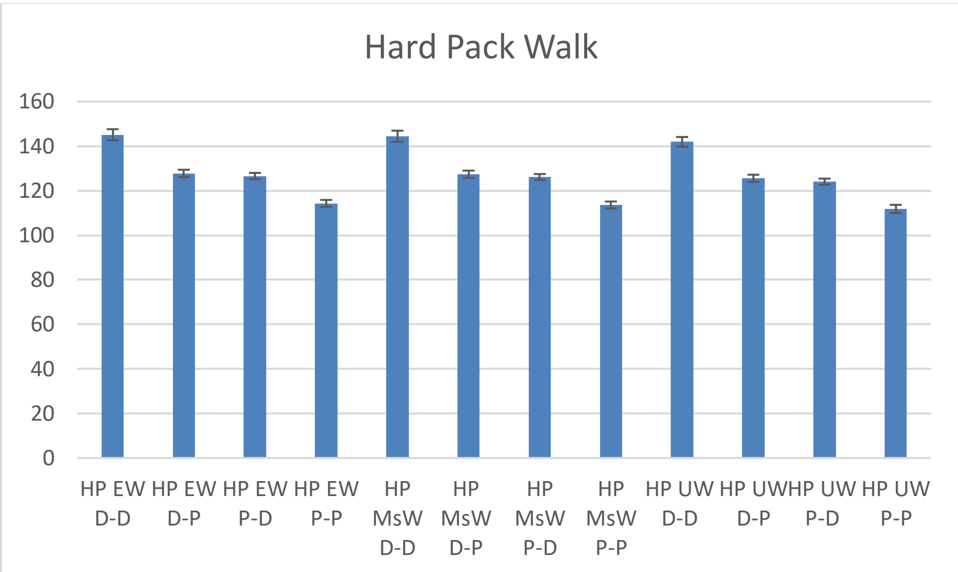
Graph 4.7 bar chart of the mean measurements mm of the cadaver limbs at the shod with soft pack loaded state of the three positions of the trot stride across each marker point, with the standard error of the mean inputted.



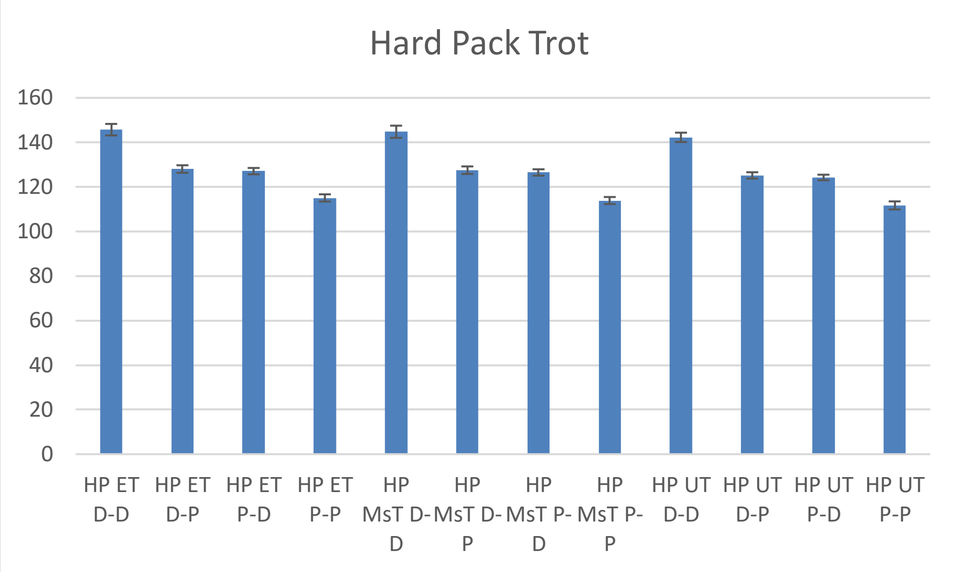
Graph 4.8 bar chart of the mean measurements mm of the cadaver limbs at the shod with medium pack loaded state of the three positions of the walk stride across each marker point, with the standard error of the mean inputted.



Graph 4.9 bar chart of the mean measurements mm of the cadaver limbs at the shod with medium pack loaded state of the three positions of the trot stride across each marker point, with the standard error of the mean inputted.



Graph 4.10 bar chart of the mean measurements mm of the cadaver limbs at the shod with hard pack loaded state of the three positions of the walk stride across each marker point, with the standard error of the mean inputted.



Graph 4.11 bar chart of the mean measurements mm of the cadaver limbs at the shod with hard pack loaded state of the three positions of the trot stride across each marker point, with the standard error of the mean inputted.

4.5 Metric and percentage difference from unloaded in walk

Average UL	D-D 139.989	D-P 123.075	P-D 121.929	P-P 109.174	Combined
UL-US Dif EW	2.534	3.048	2.395	2.939	2.729
%+/-	1.810142225	2.476538696	1.964257888	2.692032902	2.235742928
US-S Dif EW	0.852	0.012	0.754	0.036	0.4135
%+/-	0.608619249	0.009750152	0.618392671	0.032974884	0.317434239
UL-S Dif EW	3.386	3.06	3.149	2.975	3.1425
%+/-	2.418761474	2.486288848	2.582650559	2.725007786	2.553177167
S-SP Dif EW	0.497	0.663	0.374	0.838	0.593
%+/-	0.355027895	0.538695917	0.306735887	0.767582025	0.492010431
UL-SP Dif EW	3.883	3.723	3.523	3.813	3.7355
%+-	2.773789369	3.024984765	2.889386446	3.492589811	3.045187598
SP-MP Dif EW	0.778	0.235	0.614	0.64	0.56675
%+/-	0.555757952	0.190940483	0.503571751	0.586220162	0.459122587
UL-MP Dif EW	4.661	3.958	4.137	4.453	4.30225
%+-	3.329547322	3.215925249	3.392958197	4.078809973	3.504310185
MP-HP Dif EW	0.468	0.737	0.512	0.657	0.5935
%+/-	0.334311982	0.598821857	0.419916509	0.601791635	0.488710496
UL-HP Dif EW	5.129	4.695	4.649	5.11	4.89575
%+-	3.663859303	3.814747105	3.812874706	4.680601608	3.993020681

Table 4.1 shows the mean baseline data at the unloaded state across each of the four marker points, gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at enrolment walk EW.

Average UL	D-D 139.989	D-P 123.075	P-D 121.929	P-P 109.174	Combined
UL-US Dif MsW	1.468	2.201	1.88	1.935	1.871
%+/-	1.048653823	1.788340443	1.541880931	1.772400022	1.537818805
US-S Dif MsW	1.331	0.555	0.79	0.52	0.799
%+/-	0.950788991	0.450944546	0.647918051	0.476303882	0.631488867
UL-S Dif MsW	2.799	2.756	2.67	2.455	2.67
%+/-	1.999442813	2.239284989	2.189798981	2.248703904	2.169307672
S-SP Dif MsW	0.419	0.455	0.425	0.928	0.55675
%+/-	0.299309231	0.369693276	0.348563508	0.850019235	0.466896313
UL-SP Dif MsW	3.218	3.211	3.095	3.383	3.22675
%+/-	2.298752045	2.608978265	2.53836249	3.098723139	2.636203985
SP-MP Dif MsW	0.906	0.465	0.492	0.504	0.59175
%+/-	0.647193708	0.377818403	0.40351352	0.461648378	0.472543502
UL-MP Dif MsW	4.124	3.676	3.587	3.887	3.8185
%+/-	2.945945753	2.986796669	2.94187601	3.560371517	3.108747487
MP-HP Dif MsW	0.345	0.633	0.629	0.51	0.52925
%+/-	0.246447935	0.514320536	0.515873992	0.467144192	0.435946664
UL-HP Dif MsW	4.469	4.309	4.216	4.397	4.34775
%+/-	3.192393688	3.501117205	3.457750002	4.027515709	3.544694151

Table 4.2 shows the mean baseline data at the unloaded state across each of the four marker points, gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at mid stance walk MsW.

Average UL	D-D 139.989	D-P 123.075	P-D 121.929	P-P 109.174	Combined %+/-
UL-US Dif UW	0.52	1.885	0.458	0.985	0.962
%+/-	0.371457757	1.531586431	0.37562844	0.902229469	0.795225524
US-S Dif UW	1.07	0.289	0.944	0.914	0.80425
%+/-	0.76434577	0.234816169	0.774221063	0.837195669	0.652644668
UL-S Dif UW	1.59	2.174	1.402	1.899	1.76625
%+/-	1.135803527	1.7664026	1.149849503	1.739425138	1.447870192
S-SP Dif UW	0.203	-0.132	0.272	0.026	0.09225
%+/-	0.145011394	-0.107251676	0.223080645	0.023815194	0.071163889
UL-SP Dif UW	1.793	2.042	1.674	1.925	1.8585
%+/-	1.280814921	1.659150924	1.372930148	1.763240332	1.519034081
SP-MP Dif UW	0.206	0.16	0.227	0.431	0.256
%+/-	0.147154419	0.130002031	0.186173921	0.394782641	0.214528253
UL-MP Dif UW	1.999	2.202	1.901	2.356	2.1145
%+/-	1.42796934	1.789152956	1.559104069	2.158022973	1.733562334
MP-HP Dif UW	-0.036	0.284	0.234	0.294	0.194
%+/-	-0.025716306	0.230753606	0.191914967	0.269294887	0.166561788
UL-HP Dif UW	1.963	2.486	2.135	2.65	2.3085
%+/-	1.402253034	2.019906561	1.751019036	2.42731786	1.900124123

Table 4.3 shows the mean baseline data at the unloaded state across each of the four marker points, gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at unenrolement walk UW.

4.6 Metric and percentage difference from unloaded in trot

Average UL	D-D 139.989	D-P 123.075	P-D 121.929	P-P 109.174	Combined %+/-
UL-US Dif ET	3.21	3.657	3.52	3.853	3.56
%+/-	2.29303731	2.971358927	2.886925998	3.529228571	2.920137702
US-S Dif ET	0.413	-0.149	0.012	-0.538	-0.0655
%+/-	0.29502318	-0.121064392	0.009841793	-0.492791324	-0.077247686
UL-S Dif ET	3.623	3.508	3.532	3.315	3.4945
%+/-	2.58806049	2.850294536	2.896767791	3.036437247	2.842890016
S-SP Dif ET	0.741	0.417	0.678	0.949	0.69625
%+/-	0.529327304	0.338817794	0.556061314	0.869254584	0.573365249
UL-SP Dif ET	4.364	3.925	4.21	4.264	4.19075
%+/-	3.117387795	3.18911233	3.452829105	3.905691831	3.416255265
SP-MP Dif ET	0.654	0.626	0.358	0.752	0.5975
%+/-	0.467179564	0.508632947	0.293613496	0.688808691	0.489558675
UL-MP Dif ET	5.018	4.551	4.568	5.016	4.78825
%+/-	3.584567359	3.697745277	3.746442602	4.594500522	3.90581394
MP-HP Dif ET	0.704	0.417	0.585	0.866	0.643
%+/-	0.502896656	0.338817794	0.479787417	0.793229157	0.528682756
UL-HP Dif ET	5.722	4.968	5.153	5.882	5.43125
%+/-	4.087464015	4.036563071	4.226230019	5.387729679	4.434496696

Table 4.4 shows the mean baseline data at the unloaded state across each of the four marker points, gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at enrolment trot ET.

Average UL	D-D 139.989	D-P 123.075	P-D 121.929	P-P 109.174	Combined %+/-
UL-US Dif MsT	2.257	2.555	2.514	2.844	2.5425
%+/-	1.612269535	2.075969937	2.06185567	2.605015846	2.088777747
US-S Dif MsT	0.778	0.333	0.43	0.068	0.40225
%+/-	0.555757952	0.270566728	0.352664255	0.062285892	0.310318707
UL-S Dif MsT	3.035	2.888	2.944	2.912	2.94475
%+/-	2.168027488	2.346536665	2.414519926	2.667301739	2.399096454
S-SP Dif MsT	0.718	0.374	0.536	0.978	0.6515
%+/-	0.512897442	0.303879748	0.439600095	0.895817686	0.538048743
UL-SP Dif MsT	3.753	3.262	3.48	3.89	3.59625
%+/-	2.68092493	2.650416413	2.854120021	3.563119424	2.937145197
SP-MP Dif MsT	0.571	0.655	0.506	0.209	0.48525
%+/-	0.407889191	0.532195816	0.414995612	0.191437522	0.386629535
UL-MP Dif MsT	4.324	3.917	3.986	4.099	4.0815
%+/-	3.088814121	3.182612228	3.269115633	3.754556946	3.323774732
MP-HP Dif MsT	0.463	0.52	0.58	0.614	0.54425
%+/-	0.330740272	0.422506602	0.47568667	0.562404968	0.447834628
UL-HP Dif MsT	4.787	4.437	4.566	4.713	4.62575
%+/-	3.419554394	3.60511883	3.744802303	4.316961914	3.77160936

Table 4.5 shows the mean baseline data at the unloaded state across each of the four marker points, gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at mid stance trot MsT.

Average UL	D-D 139.989	D-P 123.075	P-D 121.929	P-P 109.174	Combined %+/-
UL-US Dif UT	0.695	1.943	0.862	1.238	1.1845
%+/-	0.49646758	1.578712167	0.70696881	1.133969626	0.979029546
US-S Dif UT	0.941	-0.363	0.519	0.125	0.3055
%+/-	0.672195673	-0.294942108	0.425657555	0.114496125	0.229351811
UL-S Dif UT	1.636	1.58	1.381	1.363	1.49
%+/-	1.168663252	1.283770059	1.132626365	1.248465752	1.208381357
S-SP Dif UT	0.209	0.044	1.11	0.353	0.429
%+/-	0.149297445	0.035750559	0.910365869	0.323337058	0.354687733
UL-SP Dif UT	1.845	1.624	2.491	1.716	1.919
%+/-	1.317960697	1.319520618	2.042992233	1.57180281	1.563069089
SP-MP Dif UT	0.232	0.301	-0.586	0.57	0.12925
%+/-	0.165727307	0.244566321	-0.480607567	0.522102332	0.112947098
UL-MP Dif UT	2.077	1.925	1.905	2.286	2.04825
%+/-	1.483688004	1.564086939	1.562384666	2.093905142	1.676016188
MP-HP Dif UT	0.195	0.165	0.409	0.237	0.2515
%+/-	0.139296659	0.134064595	0.335441117	0.217084654	0.206471756
UL-HP Dif UT	2.272	2.09	2.314	2.523	2.29975
%+/-	1.622984663	1.698151534	1.897825784	2.310989796	1.882487944

Table 4.6 shows the mean baseline data at the unloaded state across each of the four marker points, gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at Unenrolment trot UT.

4.7 Metric and percentage difference between proximal and distal markers in walk

Average	PROXIMAL	DISTAL
UL-US Dif EW	2.9935	2.4645
%+/-	2.584285799	1.887200057
US-S Dif EW	0.024	0.803
%+/-	0.021362518	0.61350596
UL-S Dif EW	3.0175	3.2675
%+/-	2.605648317	2.500706017
S-SP Dif EW	0.7505	0.4355
%+/-	0.653138971	0.330881891
UL-SP Dif EW	3.768	3.703
%+-	3.258787288	2.831587908
SP-MP Dif EW	0.4375	0.696
%+/-	0.388580323	0.529664852
UL-MP Dif EW	4.2055	4.399
%+-	3.647367611	3.361252759
MP-HP Dif EW	0.697	0.49
%+/-	0.600306746	0.377114245
UL-HP Dif EW	4.9025	4.889
%+-	4.247674357	3.738367005

Table 4.7 gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at enrolment walk EW, as an average of the two proximal markers and the two distal markers.

Average	PROXIMAL	DISTAL
UL-US Dif MsW	2.068	1.674
%+/-	1.780370232	1.295267377
US-S Dif MsW	0.5375	1.0605
%+/-	0.463624214	0.799353521
UL-S Dif MsW	2.6055	2.7345
%+/-	2.243994446	2.094620897
S-SP Dif MsW	0.6915	0.422
%+/-	0.609856256	0.32393637
UL-SP Dif MsW	3.297	3.1565
%+/-	2.853850702	2.418557267
SP-MP Dif MsW	0.4845	0.699
%+/-	0.419733391	0.525353614
UL-MP Dif MsW	3.7815	3.8555
%+/-	3.273584093	2.943910881
MP-HP Dif MsW	0.5715	0.487
%+/-	0.490732364	0.381160964
UL-HP Dif MsW	4.353	4.3425
%+/-	3.764316457	3.325071845

Table 4.8 gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at mid stance walk MsW, as an average of the two proximal markers and the two distal markers.

Average	PROXIMAL	DISTAL
UL-US Dif UW	1.435	0.489
%+/-	1.21690795	0.373543098
US-S Dif UW	0.6015	1.007
%+/-	0.536005919	0.769283417
UL-S Dif UW	2.0365	1.496
%+/-	1.752913869	1.142826515
S-SP Dif UW	-0.053	0.2375
%+/-	-0.041718241	0.18404602
UL-SP Dif UW	1.9835	1.7335
%+/-	1.711195628	1.326872535
SP-MP Dif UW	0.2955	0.2165
%+/-	0.262392336	0.16666417
UL-MP Dif UW	2.279	1.95
%+/-	1.973587964	1.493536705
MP-HP Dif UW	0.289	0.099
%+/-	0.250024246	0.08309933
UL-HP Dif UW	2.568	2.049
%+/-	2.22361221	1.576636035

Table 4.9 gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at Unenrolment walk UW, as an average of the two proximal markers and the two distal markers.

4.8 Metric and percentage difference between proximal and distal markers in trot

Average	PROXIMAL	DISTAL
UL-US Dif ET	3.755	3.365
%+/-	3.250293749	2.589981654
US-S Dif ET	-0.3435	0.2125
%+/-	-0.306927858	0.152432487
UL-S Dif ET	3.4115	3.5775
%+/-	2.943365891	2.742414141
S-SP Dif ET	0.683	0.7095
%+/-	0.604036189	0.542694309
UL-SP Dif ET	4.0945	4.287
%+/-	3.547402081	3.28510845
SP-MP Dif ET	0.689	0.506
%+/-	0.598720819	0.38039653
UL-MP Dif ET	4.7835	4.793
%+/-	4.1461229	3.66550498
MP-HP Dif ET	0.6415	0.6445
%+/-	0.566023476	0.491342037
UL-HP Dif ET	5.425	5.4375
%+/-	4.712146375	4.156847017

Table 4.10 gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at enrolment trot ET, as an average of the two proximal markers and the two distal markers.

Average	PROXIMAL	DISTAL
UL-US Dif MsT	2.6995	2.3855
%+/-	2.340492892	1.837062603
US-S Dif MsT	0.2005	0.604
%+/-	0.16642631	0.454211104
UL-S Dif MsT	2.9	2.9895
%+/-	2.506919202	2.291273707
S-SP Dif MsT	0.676	0.627
%+/-	0.599848717	0.476248769
UL-SP Dif MsT	3.576	3.6165
%+/-	3.106767918	2.767522475
SP-MP Dif MsT	0.432	0.5385
%+/-	0.361816669	0.411442402
UL-MP Dif MsT	4.008	4.155
%+/-	3.468584587	3.178964877
MP-HP Dif MsT	0.567	0.5215
%+/-	0.492455785	0.403213471
UL-HP Dif MsT	4.575	4.6765
%+/-	3.961040372	3.582178348

Table 4.11 gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at mid stance trot MsT, as an average of the two proximal markers and the two distal markers.

Average	PROXIMAL	DISTAL
UL-US Dif UT	1.5905	0.7785
%+/-	1.356340897	0.601718195
US-S Dif UT	-0.119	0.73
%+/-	-0.090222992	0.548926614
UL-S Dif UT	1.4715	1.5085
%+/-	1.266117905	1.150644808
S-SP Dif UT	0.1985	0.6595
%+/-	0.179543808	0.529831657
UL-SP Dif UT	1.67	2.168
%+/-	1.445661714	1.680476465
SP-MP Dif UT	0.4355	-0.177
%+/-	0.383334327	-0.15744013
UL-MP Dif UT	2.1055	1.991
%+/-	1.828996041	1.523036335
MP-HP Dif UT	0.201	0.302
%+/-	0.175574624	0.237368888
UL-HP Dif UT	2.3065	2.293
%+/-	2.004570665	1.760405223

Table 4.12 gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at Unenrolment trot UT, as an average of the two proximal markers and the two distal markers.

4.9 Metric and percentage difference between dorsal and palmar markers in walk

Average	DORSAL	PALMAR
UL-US Dif EW	2.791	2.667
%+/-	2.143340461	2.328145395
US-S Dif EW	0.432	0.395
%+/-	0.309184701	0.325683778
UL-S Dif EW	3.223	3.062
%+/-	2.452525161	2.653829172
S-SP Dif EW	0.58	0.606
%+/-	0.446861906	0.537158956
S-SP Dif EW	3.803	3.668
%+-	2.899387067	3.190988128
SP-MP Dif EW	0.5065	0.627
%+/-	0.373349218	0.544895957
SP-MP Dif EW	4.3095	4.295
%+-	3.272736285	3.735884085
MP-HP Dif EW	0.6025	0.5845
%+/-	0.466566919	0.510854072
MP-HP Dif EW	4.912	4.8795
%+-	3.739303204	4.246738157

Table 4.13 gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at enrolment walk EW, as an average of the two dorsal markers and the two palmar markers.

Average	DORSAL	PALMAR
UL-US Dif MsW	1.8345	1.9075
%+/-	1.418497133	1.657140476
US-S Dif MsW	0.943	0.655
%+/-	0.700866768	0.562110966
UL-S Dif MsW	2.7775	2.5625
%+/-	2.119363901	2.219251443
S-SP Dif MsW	0.437	0.6765
%+/-	0.334501254	0.599291372
UL-SP Dif MsW	3.2145	3.239
%+/-	2.453865155	2.818542814
SP-MP Dif MsW	0.6855	0.498
%+/-	0.512506056	0.432580949
UL-MP Dif MsW	3.9	3.737
%+/-	2.966371211	3.251123763
MP-HP Dif MsW	0.489	0.5695
%+/-	0.380384236	0.491509092
UL-HP Dif MsW	4.389	4.3065
%+/-	3.346755447	3.742632855

Table 4.14 gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at mid stance walk MsW, as an average of the two dorsal markers and the two palmar markers.

Average	DORSAL	PALMAR
UL-US Dif UW	1.2025	0.7215
%+/-	0.951522094	0.638928954
US-S Dif UW	0.6795	0.929
%+/-	0.49958097	0.805708366
UL-S Dif UW	1.882	1.6505
%+/-	1.451103064	1.44463732
S-SP Dif UW	0.0355	0.149
%+/-	0.018879859	0.12344792
UL-SP Dif UW	1.9175	1.7995
%+/-	1.469982923	1.56808524
SP-MP Dif UW	0.183	0.329
%+/-	0.138578225	0.290478281
UL-MP Dif UW	2.1005	2.1285
%+/-	1.608561148	1.858563521
MP-HP Dif UW	0.124	0.264
%+/-	0.10251865	0.230604927
UL-HP Dif UW	2.2245	2.3925
%+/-	1.711079798	2.089168448

Table 4.15 gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at Unenrolment walk UW, as an average of the two dorsal markers and the two palmar markers.

4.10 Metric and percentage difference between dorsal and palmar markers in trot

Average	DORSAL	PALMAR
UL-US Dif ET	3.4335	3.6865
%+/-	2.632198119	3.208077284
US-S Dif ET	0.132	-0.263
%+/-	0.086979394	-0.241474765
UL-S Dif ET	3.5655	3.4235
%+/-	2.719177513	2.966602519
S-SP Dif ET	0.579	0.8135
%+/-	0.434072549	0.712657949
UL-SP Dif ET	4.1445	4.237
%+/-	3.153250062	3.679260468
SP-MP Dif ET	0.64	0.555
%+/-	0.487906256	0.491211094
UL-MP Dif ET	4.7845	4.792
%+/-	3.641156318	4.170471562
MP-HP Dif ET	0.5605	0.7255
%+/-	0.420857225	0.636508287
UL-HP Dif ET	5.345	5.5175
%+/-	4.062013543	4.806979849

Table 4.16 gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at enrolment trot ET, as an average of the two dorsal markers and the two palmar markers.

Average	DORSAL	PALMAR
UL-US Dif MsT	2.406	2.679
%+/-	1.844119736	2.333435758
US-S Dif MsT	0.5555	0.249
%+/-	0.41316234	0.207475074
UL-S Dif MsT	2.9615	2.928
%+/-	2.257282076	2.540910832
S-SP Dif MsT	0.546	0.757
%+/-	0.408388595	0.66770889
UL-SP Dif MsT	3.5075	3.685
%+/-	2.665670671	3.208619722
SP-MP Dif MsT	0.613	0.3575
%+/-	0.470042503	0.303216567
UL-MP Dif MsT	4.1205	4.0425
%+/-	3.135713175	3.511836289
MP-HP Dif MsT	0.4915	0.597
%+/-	0.376623437	0.519045819
UL-HP Dif MsT	4.612	4.6395
%+/-	3.512336612	4.030882108

Table 4.17 gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at mid stance trot MsT, as an average of the two dorsal markers and the two palmar markers.

Average	DORSAL	PALMAR
UL-US Dif UT	1.319	1.05
%+/-	1.037589873	0.920469218
US-S Dif UT	0.289	0.322
%+/-	0.188626782	0.27007684
UL-S Dif UT	1.608	1.372
%+/-	1.226216656	1.190546058
S-SP Dif UT	0.1265	0.7315
%+/-	0.092524002	0.616851463
UL-SP Dif UT	1.7345	2.1035
%+/-	1.318740657	1.807397522
SP-MP Dif UT	0.2665	-0.008
%+/-	0.205146814	0.020747383
UL-MP Dif UT	2.001	2.0955
%+/-	1.523887471	1.828144904
MP-HP Dif UT	0.18	0.323
%+/-	0.136680627	0.276262886
UL-HP Dif UT	2.181	2.4185
%+/-	1.660568098	2.10440779

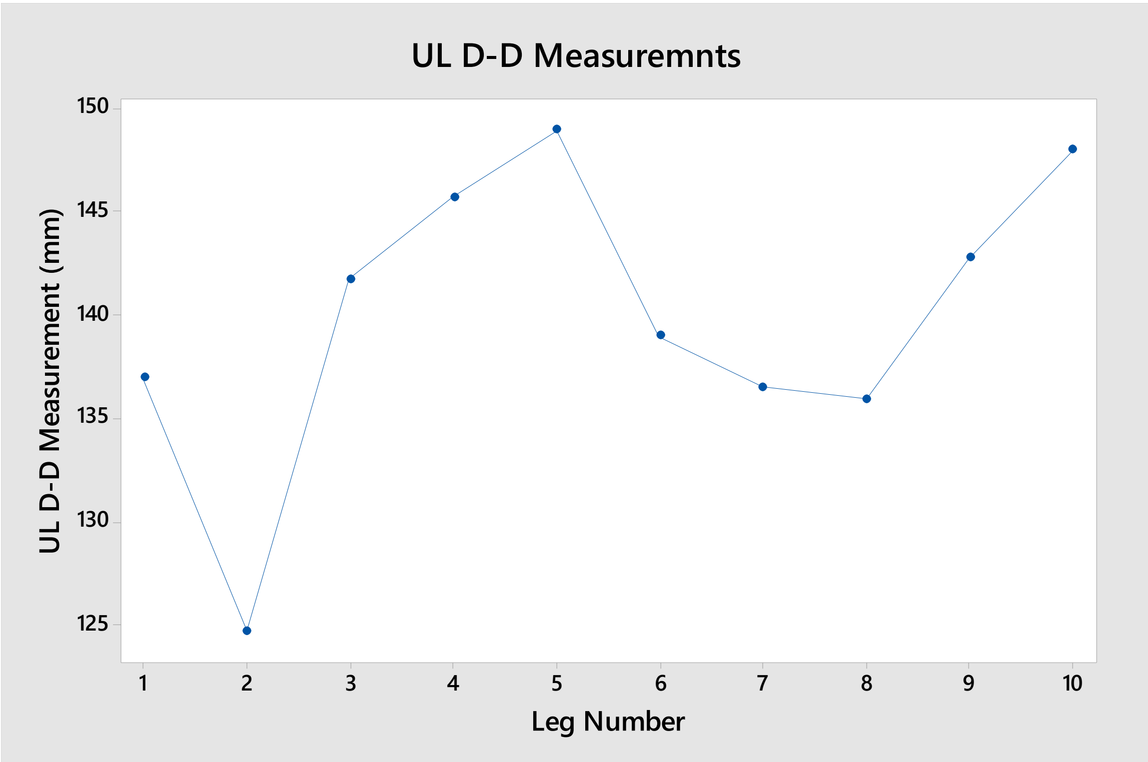
Table 4.18 gives the difference between each variable in mm and what that equates to in percentage % difference, including the difference between the unloaded baseline measurement and each variable in mm and percentage %, at Unenrolment trot UT, as an average of the two dorsal markers and the two palmar markers.

4.11 Overall hoof percentage difference from unloaded

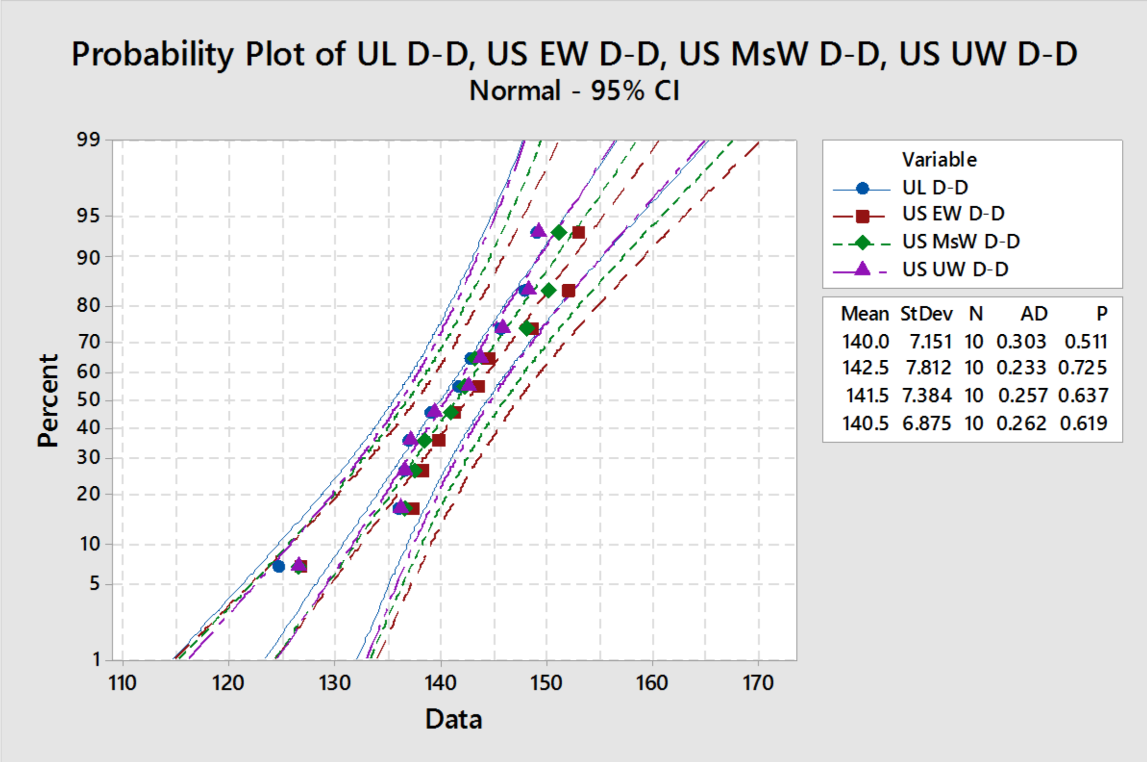
POSSITION/VARIANT	UNSHOD	SHOD	S PACK	M PACK	H PACK
EW	2.24%	2.55%	3.05%	3.50%	3.99%
MsW	1.54%	2.17%	2.64%	3.11%	3.50%
UW	0.80%	1.45%	1.52%	1.73%	1.90%
ET	2.92%	2.84%	3.42%	3.91%	4.43%
MsT	2.09%	2.40%	2.94%	3.32%	3.77%
UT	0.98%	1.21%	1.56%	1.68%	1.88%

Table 4.19 gives the combined average of all four marker point as a percentage % difference from the baseline data at the unloaded state.

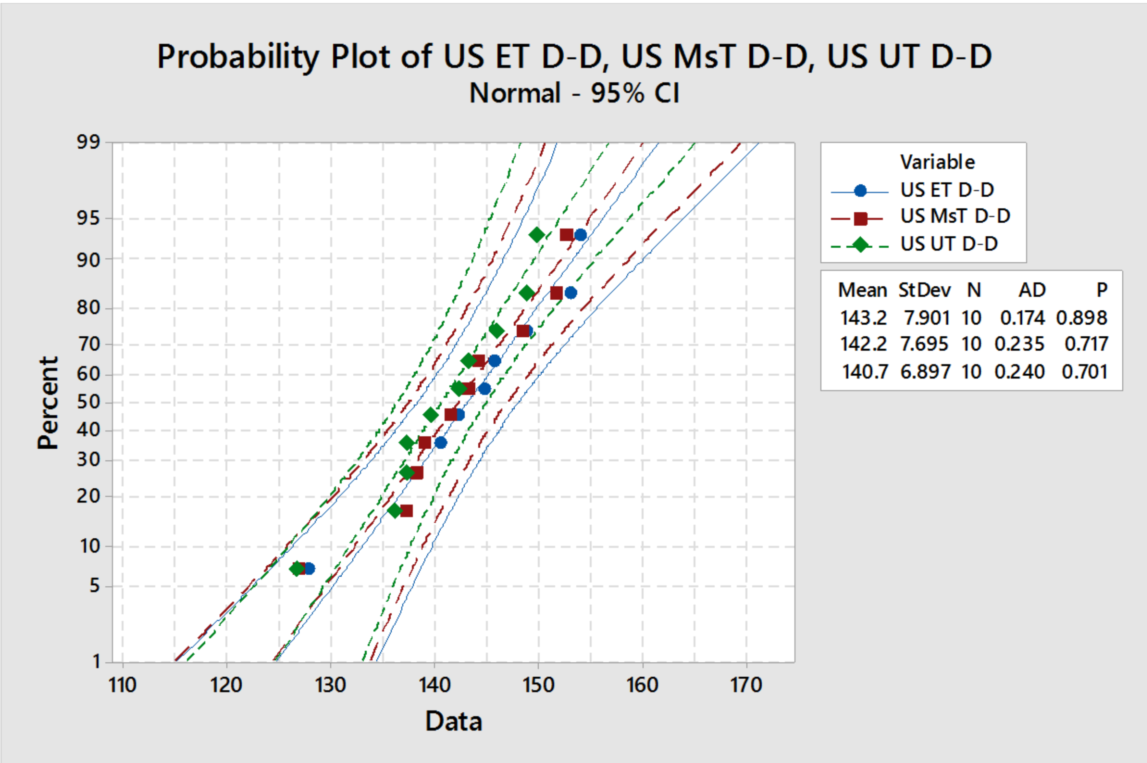
4.12 Minitab graphs



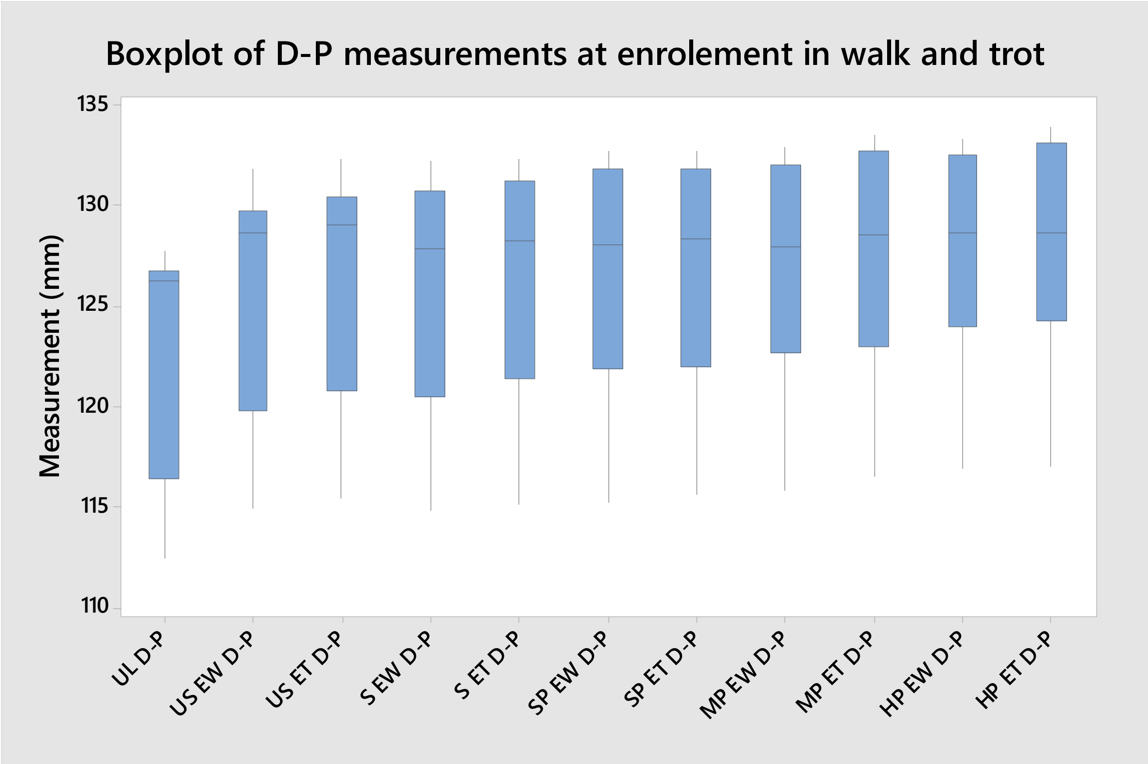
Graph 4.12 shows the individual base line measurements of each hoof for the dorsal-distal D-D marker point at the unloaded state, taken from Minitab version 18.



Graph 4.13 a probability plot graph and descriptive statistics for the dorsal-distal D-D measurements at the baseline unloaded state and the unshod loaded state at the three points of the stride in walk. Note the P-values are given in the data box.



Graph 4.14 a probability plot graph and descriptive statistics for the dorsal-distal D-D measurements at the unshod loaded state at the three points of the stride in trot. Note the P-values are given in the data box.



Graph 4.15 a box plot of the dorsal-proximal measurements of the baseline unloaded state, unshod loaded UL, shod loaded S, shod with soft pack loaded SP, shod with medium pack loaded MP and shod with hard pack loaded HP, at the enrolment stage of the walk and trot stride. Note the position of the mean line.

Chapter 5: Discussion and recommendations

5.1 Discussion

The descriptive statistics of the raw data in 4.1 shows a low standard of error which can also be seen in graphs 4.1-4.11, which adds reliability to the method of data collection. The standard deviation of the data in 4.3 is moderately large which could be due to limb number two having the smallest range of hoof measurements which can also be seen in graph 4.12. The P-values are mostly greater than 0.05 which could also be due to the range of hoof measurements, as is shown in the range on the box plot in graph 4.15. Both the standard deviation and P-values could be reduced by concentrating the hoof capsule size criteria and increasing the sample size.

The palmar hoof capsule expansion is greatest in the proximal two marker points compared to the distal two marker points between unloaded and unshod loaded. With a 0.69% greater expansion proximally at enrolment walk, 0.48% greater expansion proximally at mid stance walk, 0.85% greater expansion proximally at unenrolment walk, 0.66% greater expansion proximally at enrolment trot, 0.5% greater expansion proximally at mid stance trot and 0.76% greater expansion proximally at unenrolment trot. The ratio of palmar hoof capsule expansion between proximal and distal markers is altered when a shoe is applied, with the expansion being greatest at the distal markers, with a 0.59% greater expansion distally at enrolment walk, 0.34% greater expansion distally at mid stance walk, 0.23% greater expansion distally at unenrolment walk, 0.46% greater expansion distally at enrolment trot, 0.28% greater expansion distally at mid stance trot, 0.64% greater expansion distally at unenrolment trot.

There was no recognisable differences between the dorsal two marker points and the palmar two marker points, other than expansion was greatest at the palmar two marker points between unloaded and unshod loaded with enrolment walk being 0.19% greater, mid stance walk being 0.24% greater, however unenrolment walk had 0.31% greater expansion at the dorsal two marker points compared to the palmar two marker points. The ratio between the dorsal two marker points and palmar two marker points followed the same pattern in trot between unloaded and unshod loaded with enrolment trot being 0.58% greater expansion, mid stance trot being 0.49% greater expansion, yet at unenrolment trot the expansion was 0.12% greater at the two dorsal marker points compared to the palmar marker points.

The results show that overall maximum palmar hoof capsule expansion occurs at the enrolment stage of the stride, which agrees with the findings of previous studies. The palmar hoof capsule expansion decreases overall by 0.7% in walk and 0.83% in trot as the limb moves from the enrolment stage to mid stance between unloaded and unshod loaded. The palmar hoof capsule expansion reduces by 0.74% in walk and 1.11% in trot however remains present as the limb rotates further to the unenrolment stage, which contradicts the findings of previous studies that found heel contracture upon unenrolment. Palmar hoof capsule expansion is increased across all four marker points as the gait increases from walk to trot. Regardless of the intervention applied the palmar hoof capsule still expands greatest at enrolment and decreases as the limb rotates through mid stance towards unenrolment.

The application of a traditional open heeled concave unclipped shoe results in an increase in palmar hoof capsule expansion between unshod loaded and shod loaded at walk, with an overall average of 0.31% increase at enrolment walk, 0.63% increase at mid stance walk, 0.65% increase at unenrolment walk. However at trot the overall difference between the palmar hoof capsule expansion at unshod loaded and shod loaded results in a decrease in expansion of 0.08% at enrolment trot, however increases expansion by 0.31% at mid stance trot and 0.23% at unenrolment trot. The insertion of soft sole packing material further expands the overall palmar hoof capsule from the shod state by 0.5% at enrolment walk, 0.47% at mid stance walk, 0.07% at unenrolment walk, 0.58% at enrolment trot, 0.54% at mid stance trot and 0.35% at unenrolment trot. The insertion of medium sole packing material further expands the overall palmar hoof capsule from the shod state by 0.95% at enrolment walk, 0.94% at mid stance walk, 0.28% at unenrolment walk, 1.07% at enrolment trot, 0.92% at mid stance trot and 0.47% at unenrolment trot. The insertion of hard sole packing material further expands the overall palmar hoof capsule from the shod state by 1.44% at enrolment walk, 1.33% at mid stance walk, 0.45% at unenrolment walk, 1.59% at enrolment trot, 1.37% at mid stance trot and 0.67% at unenrolment trot.

5.2 Conclusion

In the healthy cob hoof with no pathology it is apparent that the unshod hoof capsule expands greatest palmar to the widest part of the hoof at the proximal aspect, the application of a shoe results in the hoof capsule expansion being greatest distally, thus the application of a shoe alters the hoof mechanism. However the insertion of a sole packing material does not revert the hoof capsule`s position of maximum expansion whilst shod to mimic that of the unshod hoof. Yet the overall hoof capsule expansion is increased as a shoe is applied and sole pack is inserted, with the increase in sole packing density increasing the hoof capsule expansion. The insertion of sole packing material in the shod hoof does not re-establish the normal hoof mechanism found in the unshod hoof. Previous studies have suggested that the application of a shoe restricts the hoof capsule`s expansion, however this study has shown that the application of a shoe only alters the position of expansion within the hoof capsule, it is this researchers suggestion that previous studies have only measured across one position on the hoof capsule, therefore this alteration in position of expansion was misjudged as restriction of expansion.

5.3 Recommendations

Care must be taken when deciding to apply a shoe to the unshod hoof as to whether the alteration in capsular mechanism may be detrimental to the integrity of the hoof capsule and the welfare of the equine. The amount of expansion created by the insertion of sole packing material must be taken into consideration when choosing which density of sole packing to apply. The amount of sole packing and its position within the inner margins of the shoe should also be taken into consideration however further research is needed to assess what effects the level and position of sole packing has on the hoof mechanism. A ratio of PSI equivalent to descending body weight should be established with the use of a force plate, this will allow accuracy in future research that utilises the pneumatic press as part of their research. Further research into the hoof mechanism must test at different positions around the hoof capsule including distal, central and dorsal. The selection criteria regarding the hoof capsular measurement should be concentrated into a smaller range along with a larger sample size to produce a more significant statistical result. The testing of different breeds should be incorporated for a better understanding of the hoof capsule`s mechanism throughout the equine population, including the testing of different hoof capsule conformations for example broken back hooves. Once a better understanding of how a generic shoe effects the equine hoof is gained researchers will be able to test further shoe variants such as clip position, shoe section and shoe type.

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All photographs and illustrations are researcher`s own unless specified.

<u>Appendices</u>

Appendices 1:

Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
UL D-D	10	0	139.99	2.26	7.15	124.65	136.34	140.34	146.23	148.93
UL D-P	10	0	123.08	1.84	5.83	112.43	116.41	126.30	126.83	127.75
UL P-D	10	0	121.93	1.46	4.62	115.97	117.98	121.74	124.60	129.90
UL P-P	10	0	109.17	1.96	6.19	98.32	104.95	110.89	114.09	115.82
US EW D-D	10	0	142.52	2.47	7.81	126.72	138.07	142.38	149.54	153.07
US EW D-P	10	0	126.12	1.83	5.79	114.94	119.79	128.66	129.75	131.93
US EW P-D	10	0	124.32	1.36	4.31	119.24	120.56	124.04	127.22	131.67
US EW P-P	10	0	112.11	1.73	5.46	102.06	108.29	113.96	116.34	117.58
US MsW D-D	10	0	141.46	2.34	7.38	126.45	137.30	141.54	148.55	151.18
US MsW D-P	10	0	125.28	1.79	5.67	114.55	119.05	127.79	128.85	130.95
US MsW P-D	10	0	123.81	1.35	4.26	118.72	119.80	123.49	126.63	131.16
US MsW P-P	10	0	111.11	1.65	5.23	101.02	108.02	112.72	115.16	116.20
US UW D-D	10	0	140.51	2.17	6.88	126.40	136.44	141.01	146.45	149.22
US UW D-P	10	0	124.96	1.79	5.66	115.28	118.10	127.56	128.98	130.32
US UW P-D	10	0	122.39	1.50	4.74	116.40	119.25	121.68	124.26	131.07
US UW P-P	10	0	110.16	1.92	6.07	98.39	107.06	112.07	114.65	115.81
US ET D-D	10	0	143.20	2.50	7.90	127.70	137.92	143.50	149.82	153.96
US ET D-P	10	0	126.73	1.79	5.65	115.39	120.80	129.12	130.48	132.34
US ET P-D	10	0	125.45	1.23	3.90	120.59	121.67	125.43	127.75	132.09
US ET P-P	10	0	113.03	1.72	5.44	103.69	108.88	114.53	117.87	118.15
US MsT D-D	10	0	142.25	2.43	7.69	126.75	137.89	142.32	149.22	152.64
US MsT D-P	10	0	125.63	1.79	5.64	114.45	119.90	127.89	129.27	131.53
US MsT P-D	10	0	124.44	1.29	4.09	119.37	120.66	124.19	127.04	131.57
US MsT P-P	10	0	112.02	1.66	5.26	102.13	108.65	113.66	116.09	116.90
US UT D-D	10	0	140.68	2.18	6.90	126.69	136.91	140.88	146.60	149.83
US UT D-P	10	0	125.02	1.76	5.56	114.98	118.46	127.57	129.08	130.03
US UT P-D	10	0	122.79	1.43	4.51	116.64	119.86	122.23	125.40	130.76
US UT P-P	10	0	110.41	1.83	5.77	99.75	107.45	111.69	114.62	116.68
S EW D-D	10	0	143.38	2.42	7.67	127.87	138.09	144.10	150.39	153.12
S EW D-P	10	0	126.13	1.79	5.66	114.81	120.54	127.85	130.79	132.26
S EW P-D	10	0	125.08	1.31	4.15	120.32	121.18	124.70	128.16	132.04
S EW P-P	10	0	112.15	1.60	5.06	102.79	108.47	113.61	115.48	118.69
S MsW D-D	10	0	142.79	2.32	7.35	127.95	137.82	143.45	149.63	152.15
S MsW D-P	10	0	125.83	1.76	5.56	115.01	120.10	127.50	130.56	131.85
S MsW P-D	10	0	124.60	1.38	4.38	119.33	120.78	124.12	127.55	132.07
S MsW P-P	10	0	111.63	1.68	5.30	102.06	108.49	112.18	116.22	118.19
S UW D-D	10	0	141.58	2.11	6.67	127.85	137.75	142.00	147.50	150.01

S UW D-P	10	0	125.25	1.68	5.30	115.46	118.98	127.85	128.96	129.85
S UW P-D	10	0	123.33	1.39	4.39	117.54	120.00	122.86	125.75	131.21
S UW P-P	10	0	111.07	1.83	5.80	100.36	107.56	112.38	115.75	116.62
S ET D-D	10	0	143.61	2.44	7.72	127.73	138.78	144.09	150.67	153.65
S ET D-P	10	0	126.58	1.76	5.58	115.08	121.36	128.32	131.28	132.35
S ET P-D	10	0	125.46	1.36	4.30	120.44	121.42	124.97	128.29	132.75
S ET P-P	10	0	112.49	1.74	5.49	103.15	108.42	114.11	116.29	118.97
S MsT D-D	10	0	143.02	2.41	7.62	127.67	138.02	143.49	150.21	152.96
S MsT D-P	10	0	125.96	1.77	5.60	114.60	120.56	128.00	130.39	131.83
S MsT P-D	10	0	124.87	1.36	4.29	119.87	121.43	124.16	127.75	132.19
S MsT P-P	10	0	112.09	1.67	5.27	102.74	108.44	113.48	115.89	118.49
S UT D-D	10	0	141.63	2.08	6.58	127.89	138.06	142.04	147.57	149.81
S UT D-P	10	0	124.66	1.60	5.05	115.19	118.72	127.44	127.97	128.55
S UT P-D	10	0	123.31	1.44	4.54	116.98	120.19	122.75	126.03	131.24
S UT P-P	10	0	110.54	1.84	5.81	99.87	106.99	111.96	115.22	115.92
SP EW D-D	10	0	143.87	2.44	7.72	128.09	138.19	144.74	151.22	153.22
SP EW D-P	10	0	126.80	1.78	5.63	115.20	121.85	128.09	131.92	132.74
SP EW P-D	10	0	125.45	1.37	4.35	120.72	121.45	124.94	129.00	132.14
SP EW P-P	10	0	112.99	1.67	5.28	103.36	109.18	114.76	116.96	119.07
SP MsW D-D	10	0	143.21	2.36	7.45	128.08	137.83	144.14	150.45	152.34
SP MsW D-P	10	0	126.29	1.70	5.37	115.48	121.49	127.38	131.27	132.03
SP MsW P-D	10	0	125.02	1.38	4.37	120.82	121.08	123.97	128.01	132.43
SP MsW P-P	10	0	112.56	1.52	4.80	103.07	109.54	113.61	115.93	118.84
SP UW D-D	10	0	141.78	2.13	6.72	128.37	137.77	142.17	147.88	150.43
SP UW D-P	10	0	125.12	1.61	5.09	115.54	119.41	127.47	128.50	130.13
SP UW P-D	10	0	123.60	1.31	4.13	117.94	120.68	123.17	125.84	130.90
SP UW P-P	10	0	111.10	1.80	5.70	100.64	107.86	111.97	115.99	117.15
SP ET D-D	10	0	144.35	2.42	7.65	128.91	138.62	145.37	151.51	153.82
SP ET D-P	10	0	127.00	1.74	5.51	115.61	122.03	128.42	131.88	132.82
SP ET P-D	10	0	126.14	1.38	4.35	121.72	122.37	125.30	129.07	133.56
ST ET P-P	10	0	113.44	1.70	5.36	103.73	109.43	115.06	117.10	120.06
SP MsT D-D	10	0	143.74	2.40	7.59	128.88	137.85	144.65	150.93	153.40
SP MsT D-P	10	0	126.34	1.66	5.26	115.56	121.69	127.62	131.05	131.90
SP MsT P-D	10	0	125.41	1.33	4.20	121.37	121.49	124.45	128.42	132.39
SP MsT P-P	10	0	113.06	1.65	5.23	103.68	109.56	114.47	116.77	119.60
SP UT D-D	10	0	141.83	2.10	6.65	128.18	138.16	142.24	147.97	150.33
SP UT D-P	10	0	124.70	1.52	4.80	115.27	119.37	127.19	128.01	128.64
SP UT P-D	10	0	124.42	2.01	6.36	118.78	120.40	122.81	126.04	139.94

SP UT P-P	10	0	110.89	1.80	5.69	100.43	107.51	111.79	115.51	117.22
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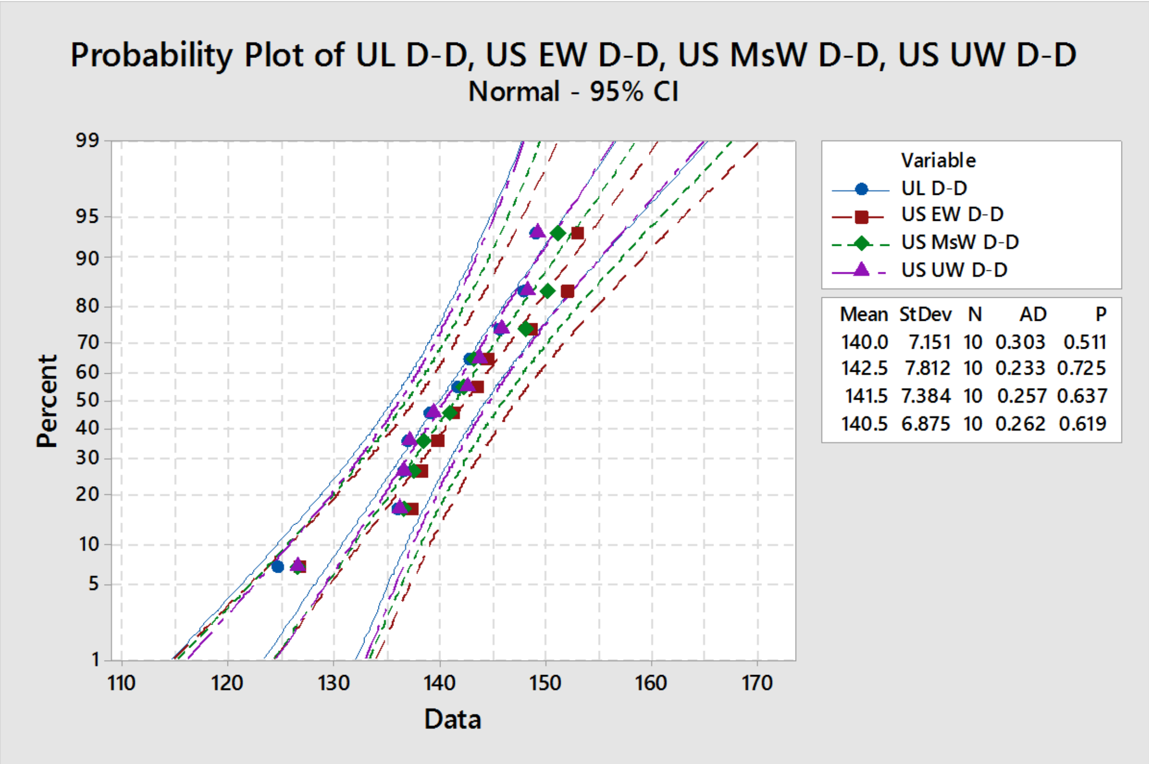
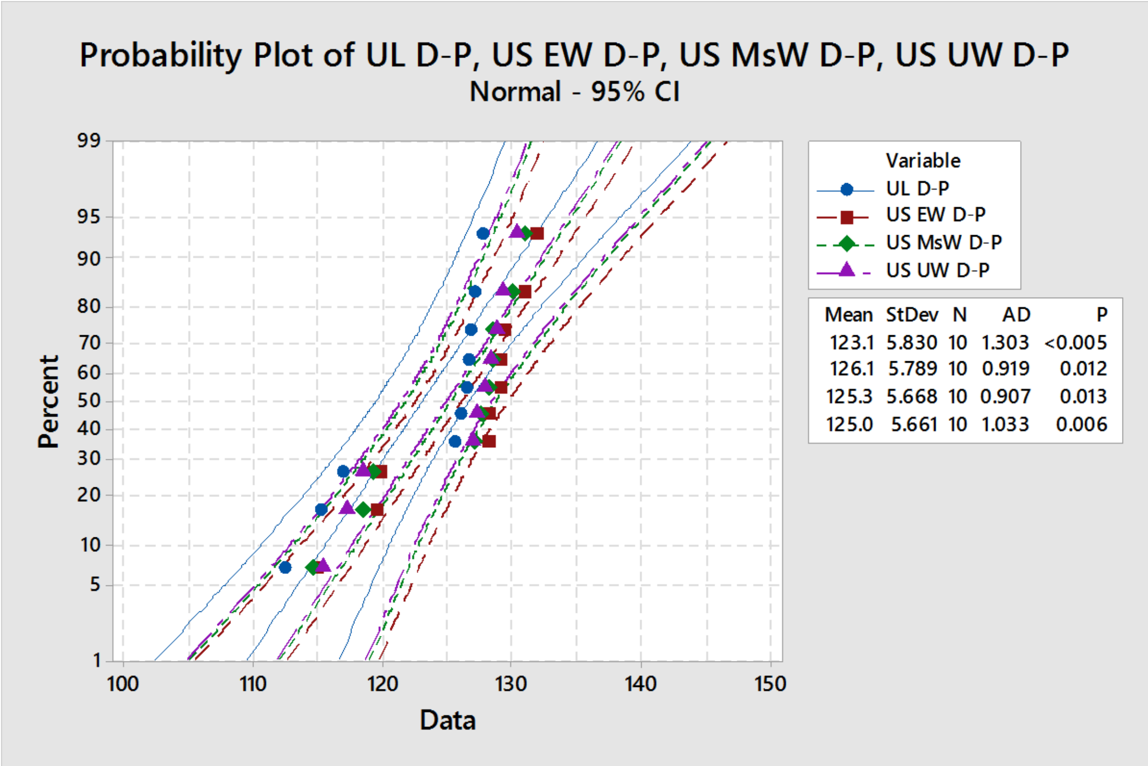
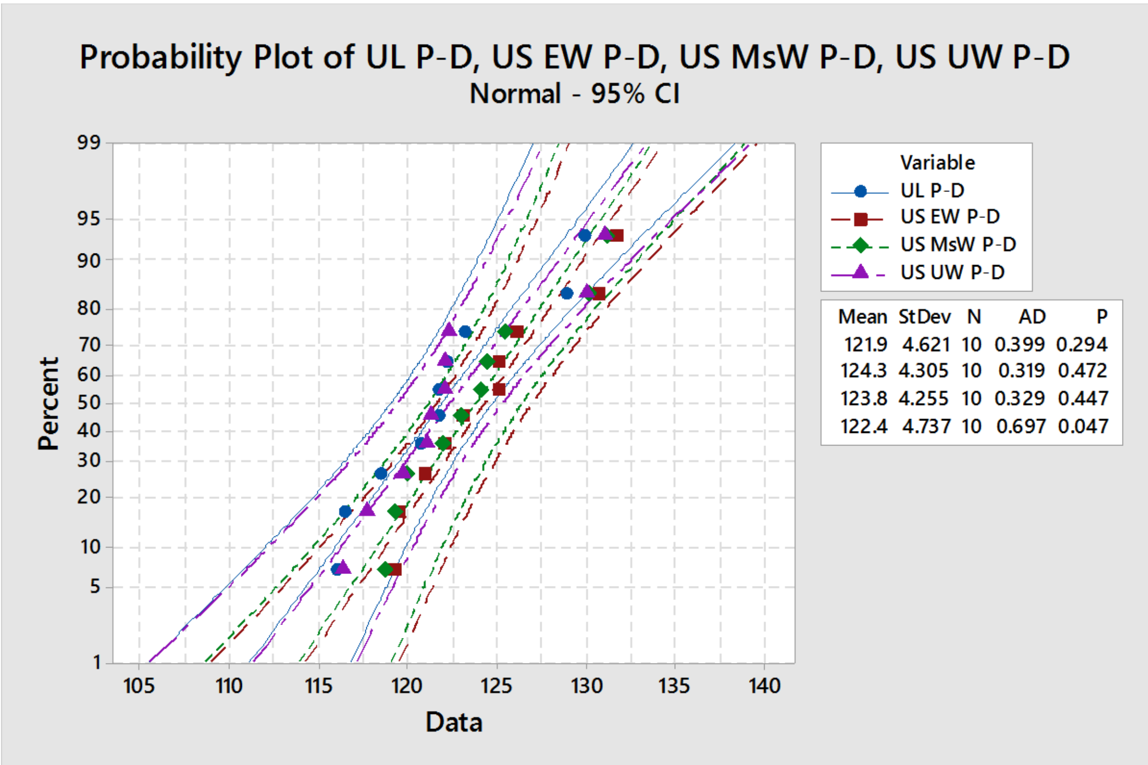
MP EW D-P	10	0	127.03	1.71	5.40	115.80	122.75	128.01	132.08	132.99
MP EW P-D	10	0	126.07	1.43	4.51	121.20	121.99	125.19	129.77	133.18
MP EW P-P	10	0	113.63	1.61	5.11	103.93	110.30	114.85	116.76	121.78
MP MsW D-D	10	0	144.11	2.43	7.67	129.04	138.13	144.87	151.57	153.82
MP MsW D-P	10	0	126.75	1.72	5.43	115.74	122.07	127.74	131.92	132.85
MP MsW P-D	10	0	125.52	1.42	4.48	120.33	121.28	124.73	129.29	132.52
MP MsW P-P	10	0	113.06	1.58	4.99	103.59	109.69	114.16	116.26	120.52
MP UW D-D	10	0	141.99	2.09	6.62	128.85	138.05	142.28	148.03	150.62
MP UW D-P	10	0	125.28	1.61	5.10	115.91	119.57	127.30	128.79	130.92
MP UW P-D	10	0	123.83	1.33	4.20	118.27	120.75	123.25	126.42	131.10
MP UW P-P	10	0	111.53	1.83	5.78	100.98	108.04	112.59	116.10	117.94
MP ET D-D	10	0	145.01	2.60	8.22	129.12	138.15	146.01	152.72	155.42
MP ET D-P	10	0	127.63	1.73	5.48	116.49	122.96	128.56	132.77	133.62
MP ET P-D	10	0	126.50	1.47	4.66	121.50	122.35	125.50	130.18	133.90
MP ET P-P	10	0	114.19	1.61	5.10	104.74	110.60	115.28	117.11	122.43
MP MsT D-D	10	0	144.31	2.48	7.84	129.03	137.89	145.43	151.52	154.28
MP MsT D-P	10	0	126.99	1.74	5.50	115.57	122.41	128.01	132.12	132.89
MP MsT P-D	10	0	125.91	1.39	4.38	121.44	122.20	124.82	129.66	132.97
MP MsT P-P	10	0	113.27	1.62	5.14	103.89	110.04	114.02	116.80	120.92
MP UT D-D	10	0	142.07	2.12	6.72	128.74	137.93	142.48	148.17	150.90
MP UT D-P	10	0	125.00	1.47	4.65	115.91	119.84	127.23	128.11	128.89
MP UT P-D	10	0	123.83	1.25	3.95	119.23	120.86	123.14	126.34	130.73
MP UT P-P	10	0	111.46	1.84	5.83	100.97	107.70	112.78	115.82	117.98
HP EW D-D	10	0	145.12	2.51	7.94	129.72	138.06	146.29	152.51	154.90
HP EW D-P	10	0	127.77	1.65	5.22	116.90	124.01	128.71	132.57	133.42
HP EW P-D	10	0	126.58	1.41	4.46	121.19	122.64	125.77	130.36	133.66
HP EW P-P	10	0	114.28	1.57	4.97	105.18	111.21	115.17	117.23	122.37
HP MsW D-D	10	0	144.46	2.50	7.89	129.37	137.49	145.67	151.92	154.22
HP MsW D-P	10	0	127.38	1.64	5.20	116.74	123.56	128.16	132.32	133.17
HP MsW P-D	10	0	126.15	1.34	4.24	121.23	122.58	125.15	129.82	132.94
HP MsW P-P	10	0	113.57	1.58	4.98	104.42	110.04	114.56	116.54	121.34
HP UW D-D	10	0	141.95	2.17	6.86	129.10	136.92	142.53	148.24	150.93
HP UW D-P	10	0	125.56	1.62	5.12	116.26	119.78	127.48	129.31	131.03
HP UW P-D	10	0	124.06	1.37	4.32	118.52	120.70	123.18	127.08	131.49
HP UW P-P	10	0	111.82	1.82	5.74	101.32	108.25	113.35	116.01	118.47
HP ET D-D	10	0	145.71	2.58	8.14	130.13	138.47	146.88	153.11	155.89

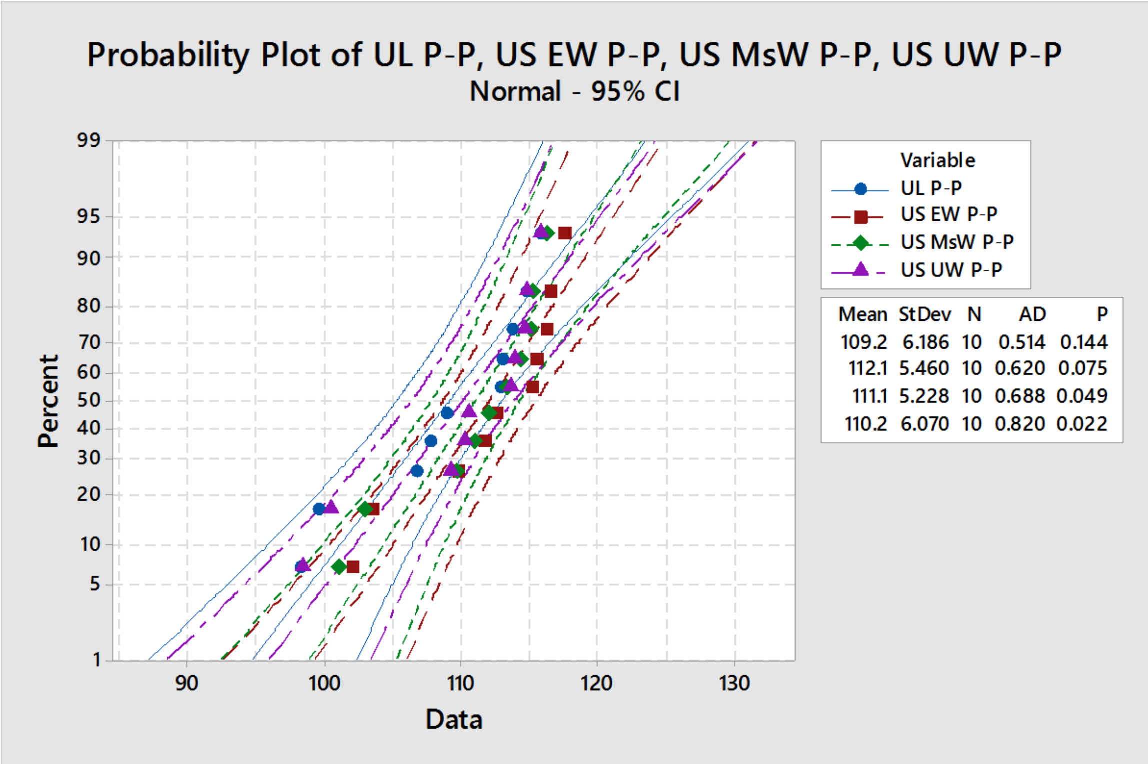
HP ET D-P	10	0	128.04	1.69	5.36	117.01	124.31	128.74	133.17	133.97
HP ET P-D	10	0	127.08	1.43	4.53	121.93	122.85	126.32	131.13	133.99
HP ET P-P	10	0	115.06	1.62	5.14	105.71	111.32	116.08	118.24	123.02
HP MsT D-D	10	0	144.78	2.74	8.67	126.64	138.17	146.28	152.32	155.13
HP MsT D-P	10	0	127.51	1.69	5.33	116.67	123.77	128.04	132.78	133.54
HP MsT P-D	10	0	126.50	1.43	4.53	121.35	122.34	125.91	130.46	133.65
HP MsT P-P	10	0	113.89	1.59	5.02	104.71	110.95	114.47	117.18	121.98
HP UT D-D	10	0	142.26	2.10	6.65	129.52	137.88	142.67	148.48	151.17
HP UT D-P	10	0	125.17	1.43	4.52	116.49	120.10	127.19	128.27	129.21
HP UT P-D	10	0	124.24	1.25	3.95	119.84	121.13	123.29	127.06	131.20
HP UT P-P	10	0	111.70	1.81	5.72	101.39	107.97	113.02	115.84	118.52

Appendices 2

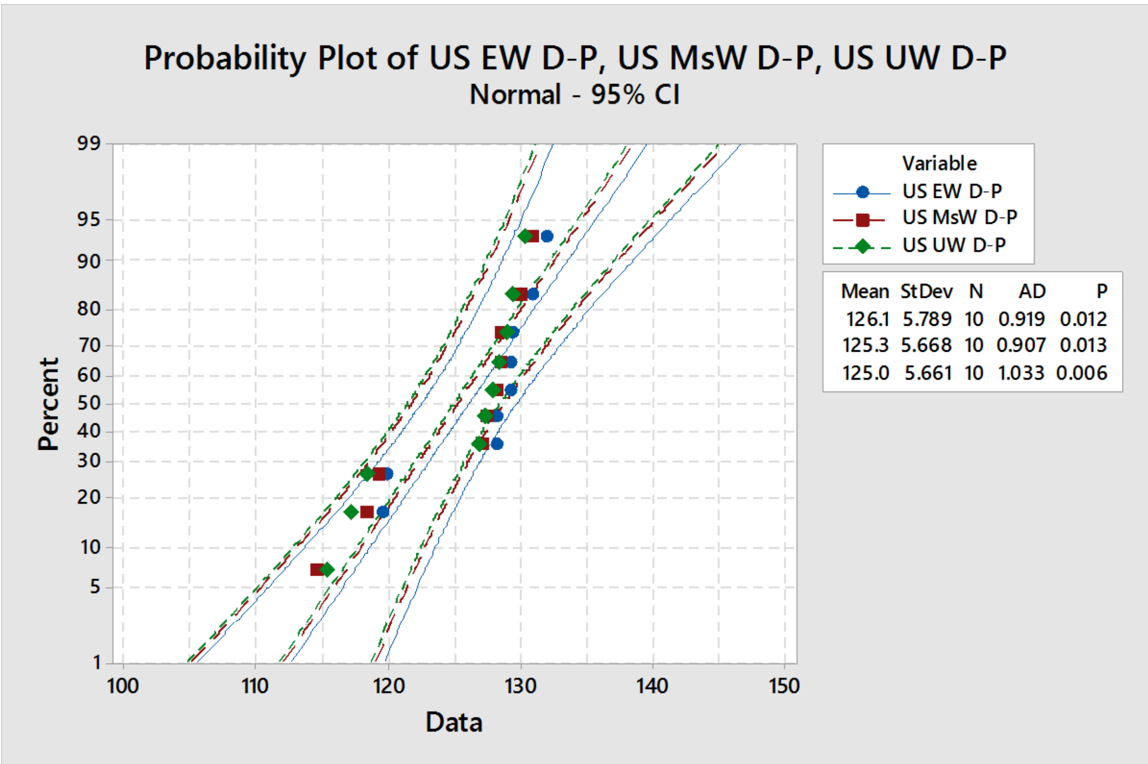



Probability Plot of UL D-P, US EW D-P, US MsW D-P, US UW D-P
Normal - 95% CI
Percent
Data
Variable
UL D-P
US EW D-P
US MsW D-P
US UW D-P
Mean StDev N AD P
123.1 5.830 10 1.303 <0.005
126.1 5.789 10 0.919 0.012
125.3 5.668 10 0.907 0.013
125.0 5.661 10 1.033 0.006

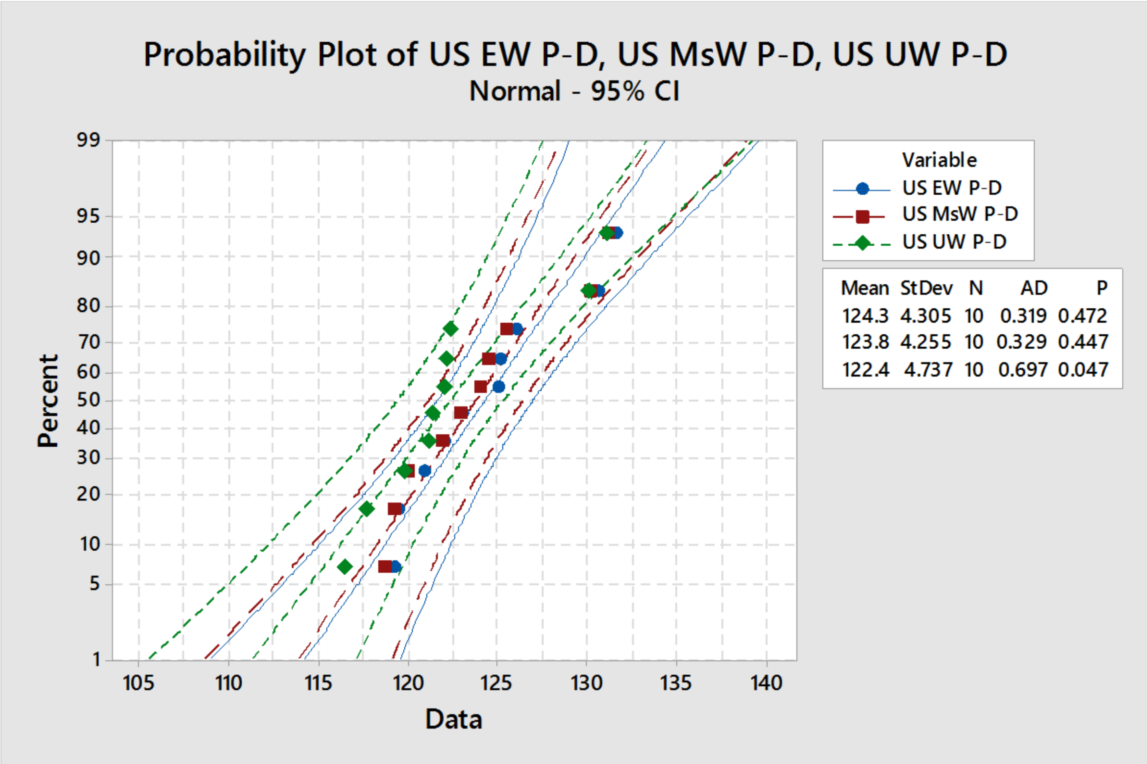

Probability Plot of UL P-D, US EW P-D, US MsW P-D, US UW P-D
Normal - 95% CI
Percent
Data
Variable
UL P-D
US EW P-D
US MsW P-D
US UW P-D
Mean StDev N AD P
121.9 4.621 10 0.399 0.294
124.3 4.305 10 0.319 0.472
123.8 4.255 10 0.329 0.447
122.4 4.737 10 0.697 0.047



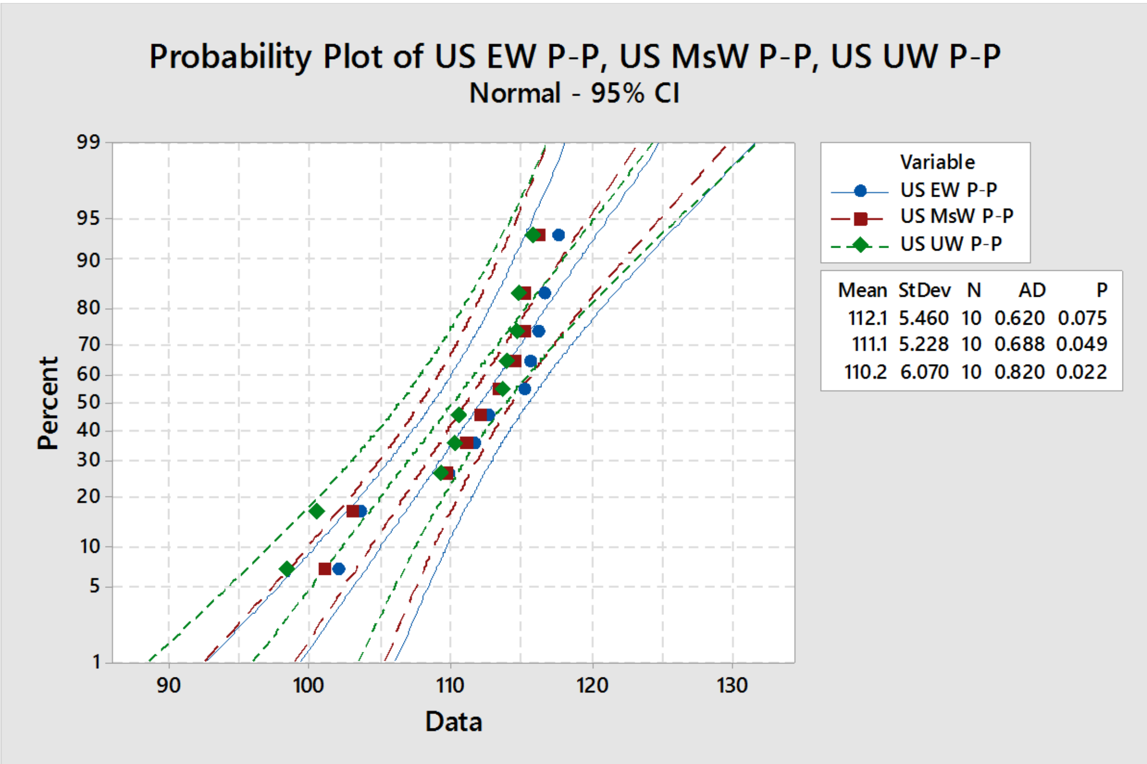
Probability Plot of UL P-P, US EW P-P, US MsW P-P, US UW P-P
Normal - 95% CI
Percent
Data
Variable
UL P-P
US EW P-P
US MsW P-P
US UW P-P
Mean StDev N AD P
109.2 6.186 10 0.514 0.144
112.1 5.460 10 0.620 0.075
111.1 5.228 10 0.688 0.049
110.2 6.070 10 0.820 0.022



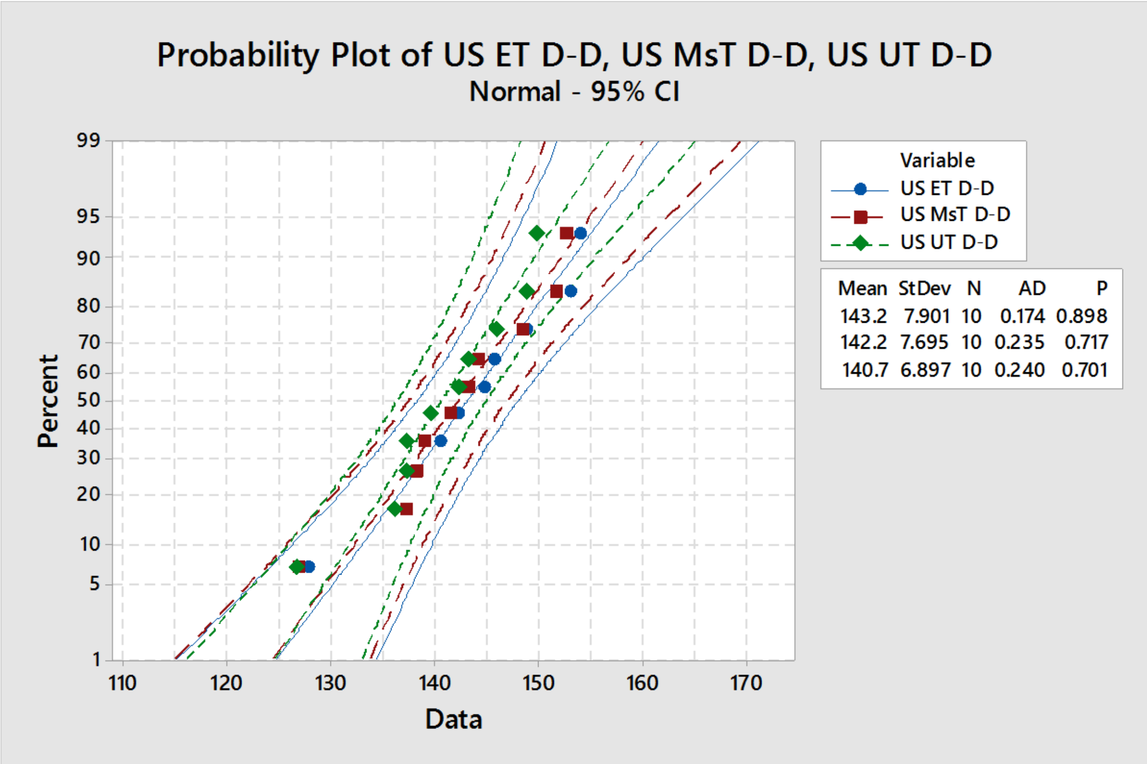
Probability Plot of US EW D-P, US MsW D-P, US UW D-P
Normal - 95% CI
Percent
Data
Variable
US EW D-P
US MsW D-P
US UW D-P
Mean StDev N AD P
126.1 5.789 10 0.919 0.012
125.3 5.668 10 0.907 0.013
125.0 5.661 10 1.033 0.006

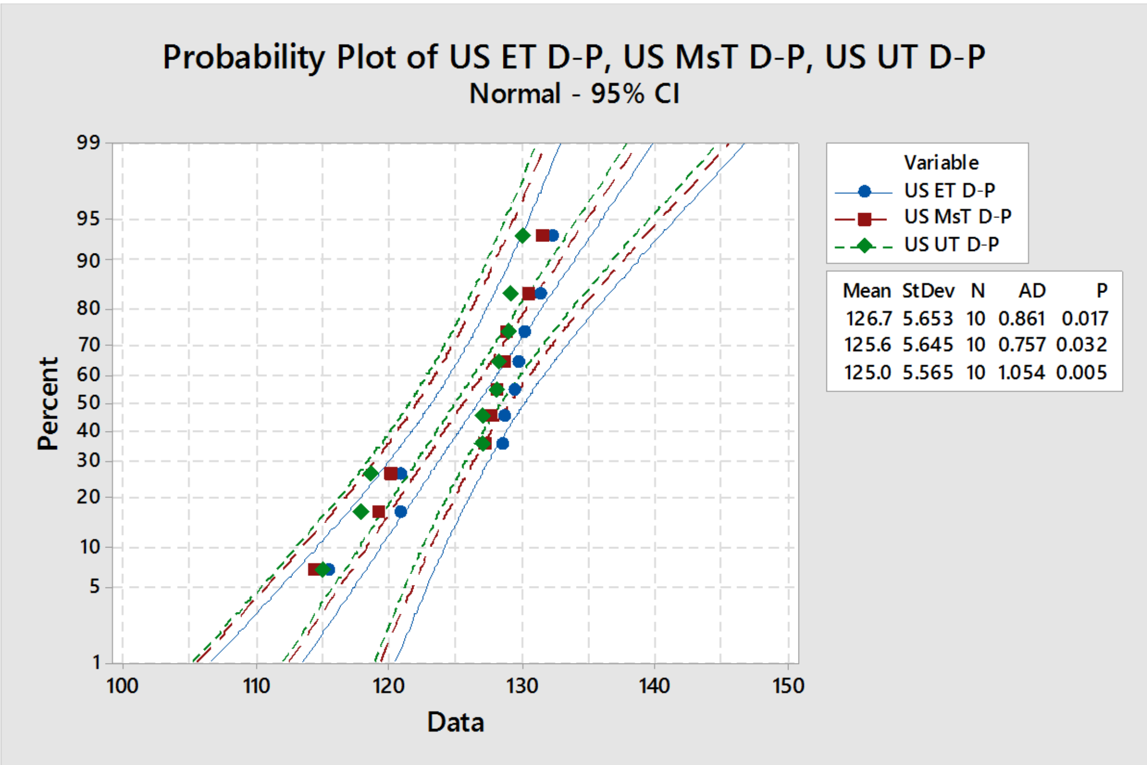


Probability Plot of US EW P-D, US MsW P-D, US UW P-D
Normal - 95% CI
Percent
Data
Variable
US EW P-D
US MsW P-D
US UW P-D
Mean StDev N AD P
124.3 4.305 10 0.319 0.472
123.8 4.255 10 0.329 0.447
122.4 4.737 10 0.697 0.047



Probability Plot of US EW P-P, US MsW P-P, US UW P-P
Normal - 95% CI
Percent
Data
Variable
US EW P-P
US MsW P-P
US UW P-P
Mean StDev N AD P
112.1 5.460 10 0.620 0.075
111.1 5.228 10 0.688 0.049
110.2 6.070 10 0.820 0.022


Probability Plot of US ET D-D, US MsT D-D, US UT D-D
Normal - 95% CI
Variable
US ET D-D
US MsT D-D
US UT D-D
Mean StDev N AD P
143.2 7.901 10 0.174 0.898
142.2 7.695 10 0.235 0.717
140.7 6.897 10 0.240 0.701
Percent
Data
99
95
90
80
70
60
50
40
30
20
10
5
1
110
120
130
140
150
160
170


Probability Plot of US ET D-P, US MsT D-P, US UT D-P
Normal - 95% CI
Variable
US ET D-P
US MsT D-P
US UT D-P
Mean StDev N AD P
126.7 5.653 10 0.861 0.017
125.6 5.645 10 0.757 0.032
125.0 5.565 10 1.054 0.005
Percent
Data
99
95
90
80
70
60
50
40
30
20
10
5
1
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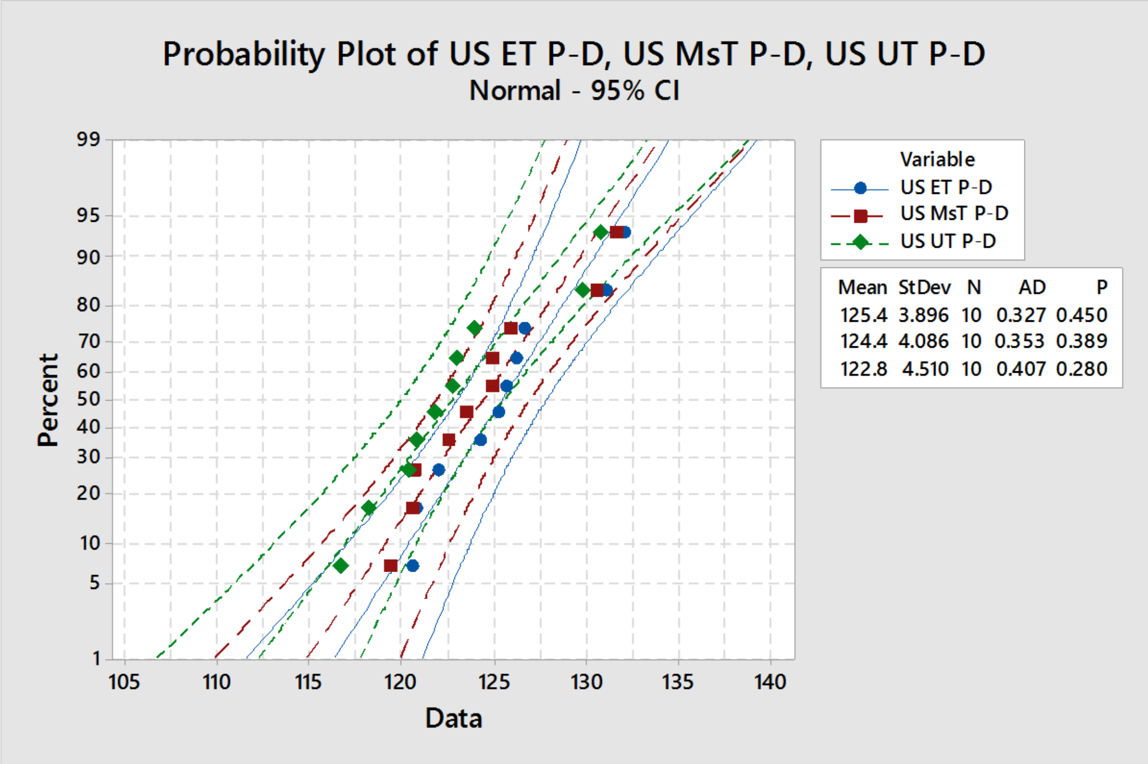
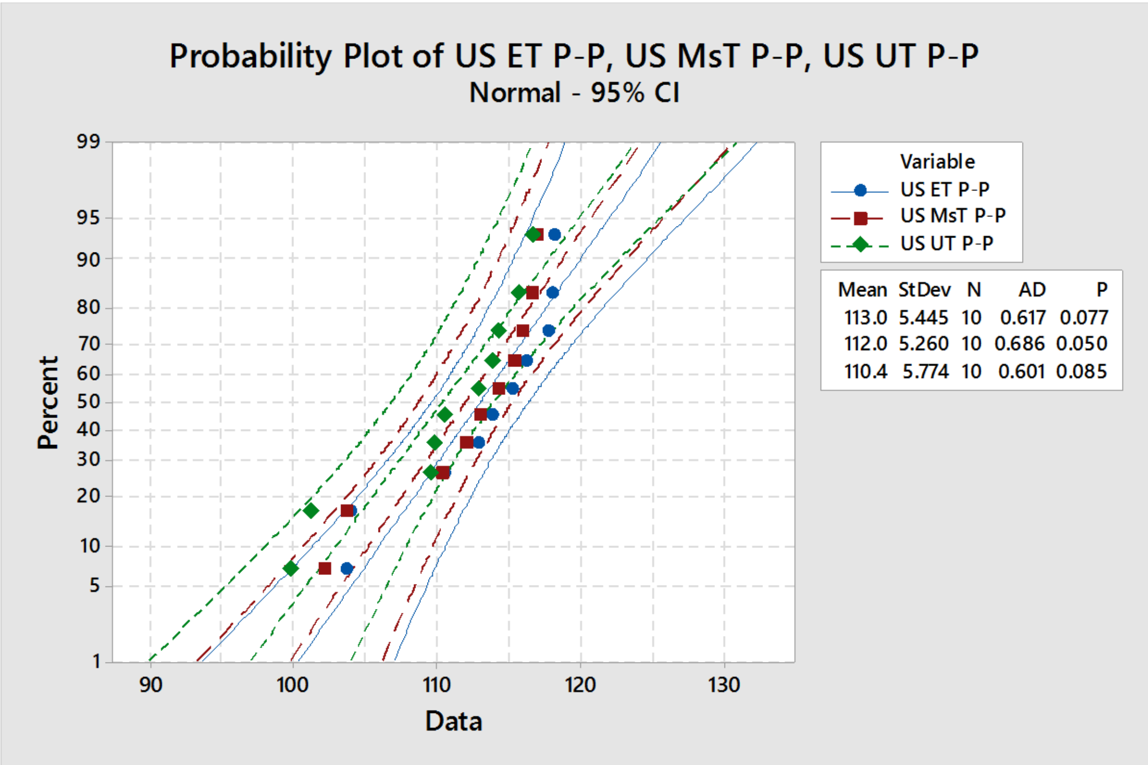
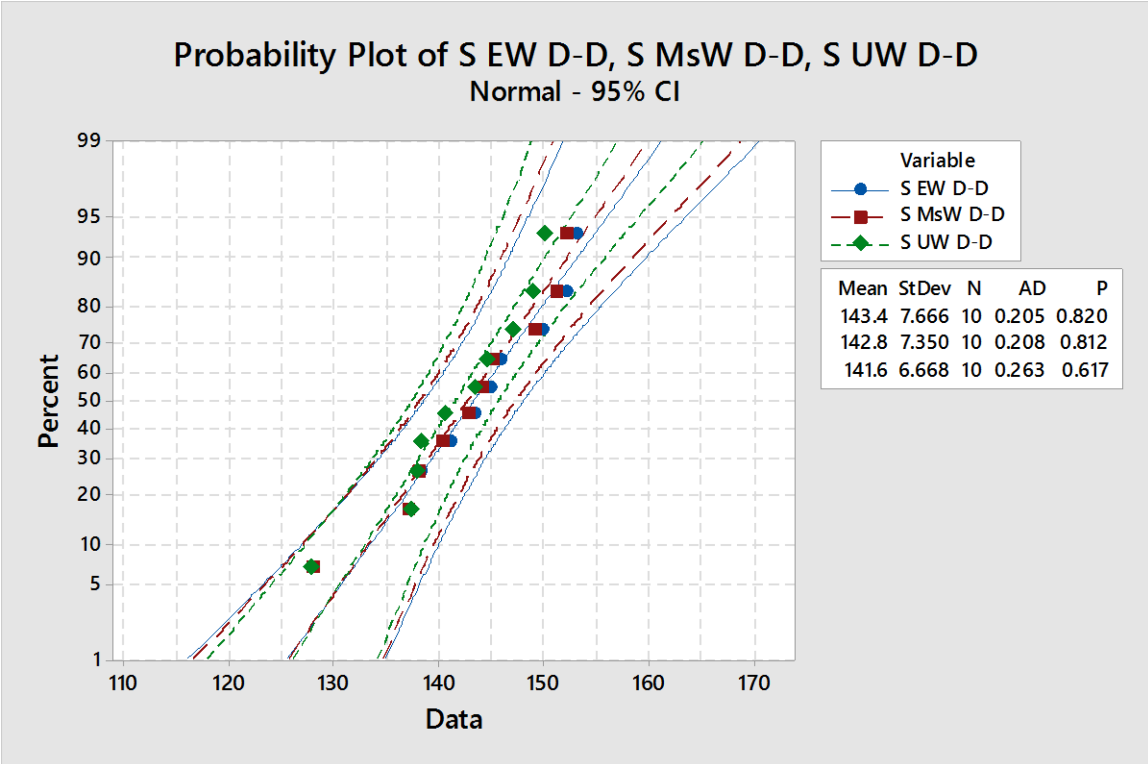
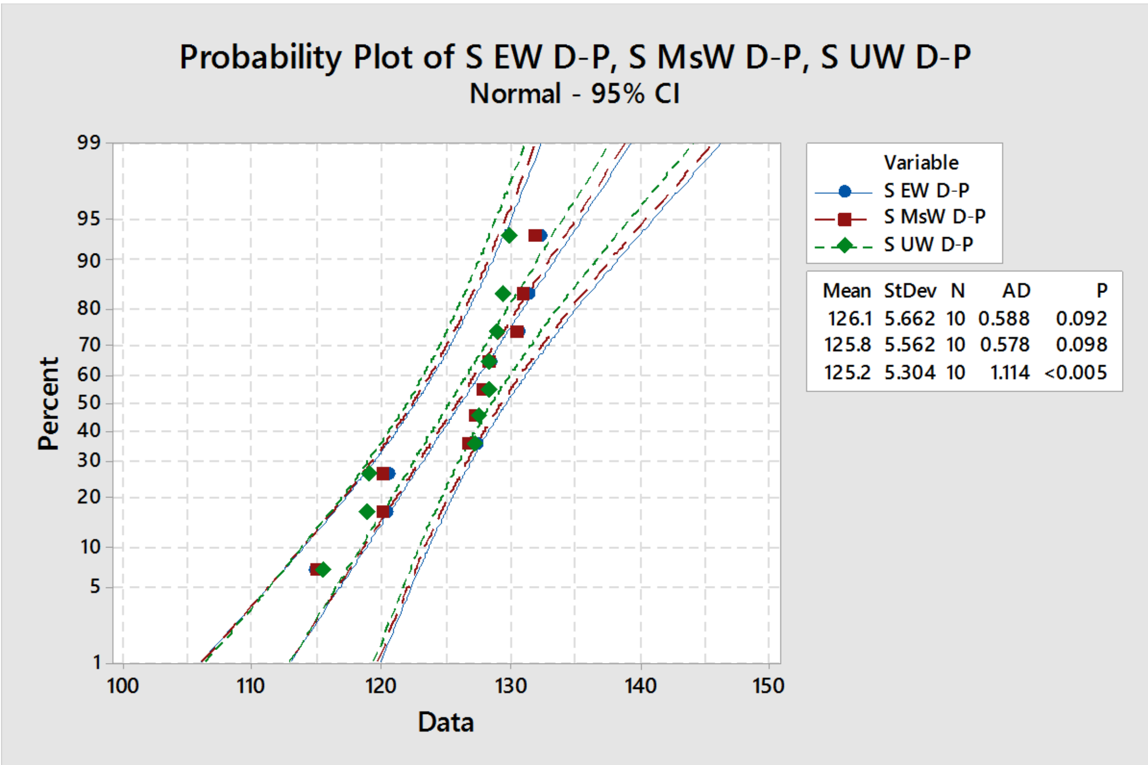
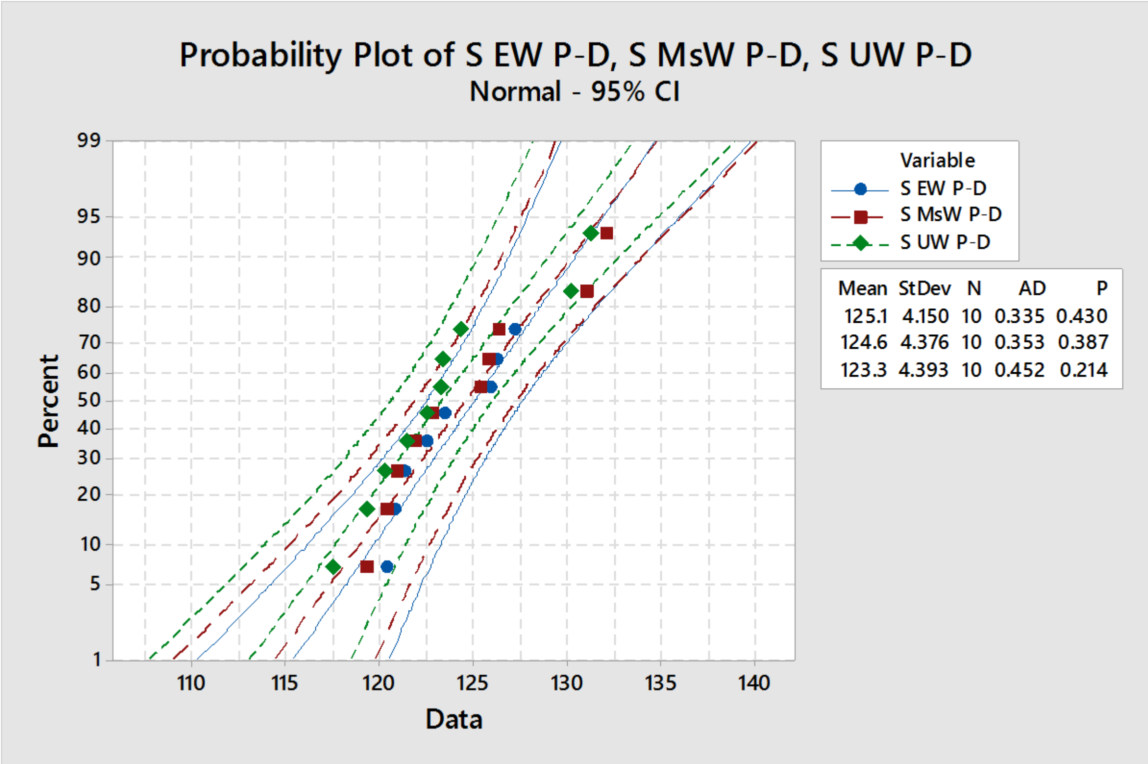
110
120
130
140
150

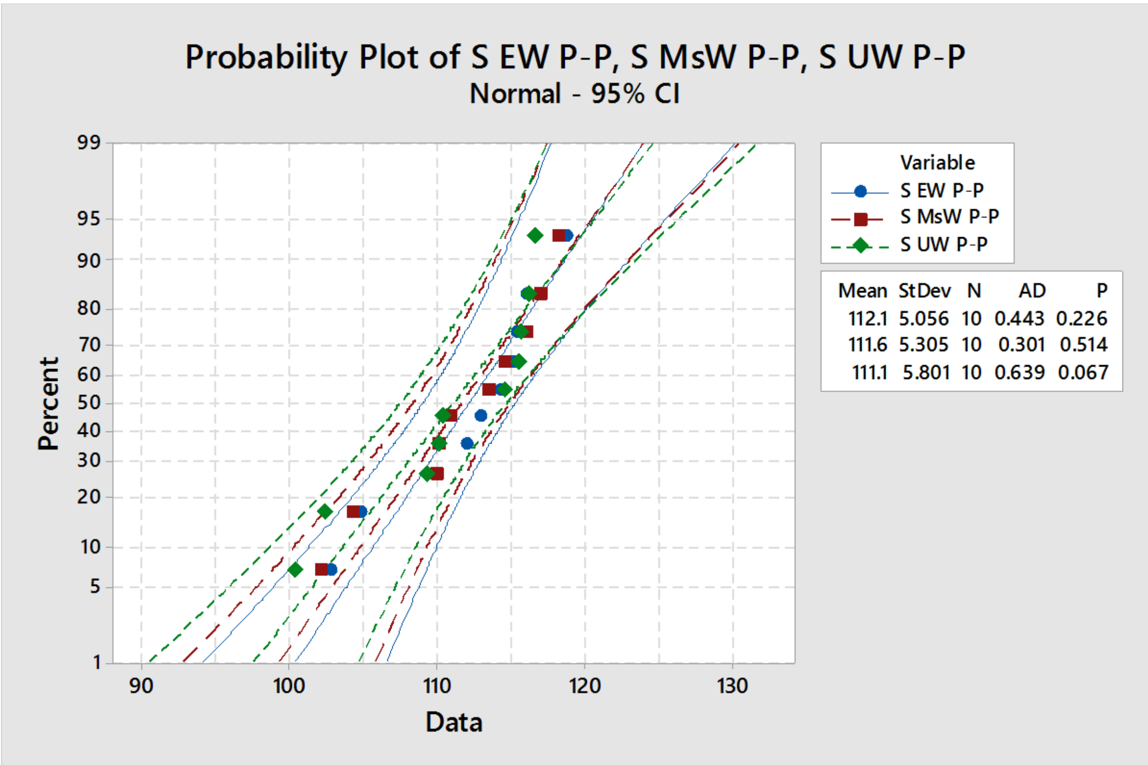

Probability Plot of US ET P-D, US MsT P-D, US UT P-D
Normal - 95% CI
Percent
Data
Variable
US ET P-D
US MsT P-D
US UT P-D
Mean StDev N AD P
125.4 3.896 10 0.327 0.450
124.4 4.086 10 0.353 0.389
122.8 4.510 10 0.407 0.280

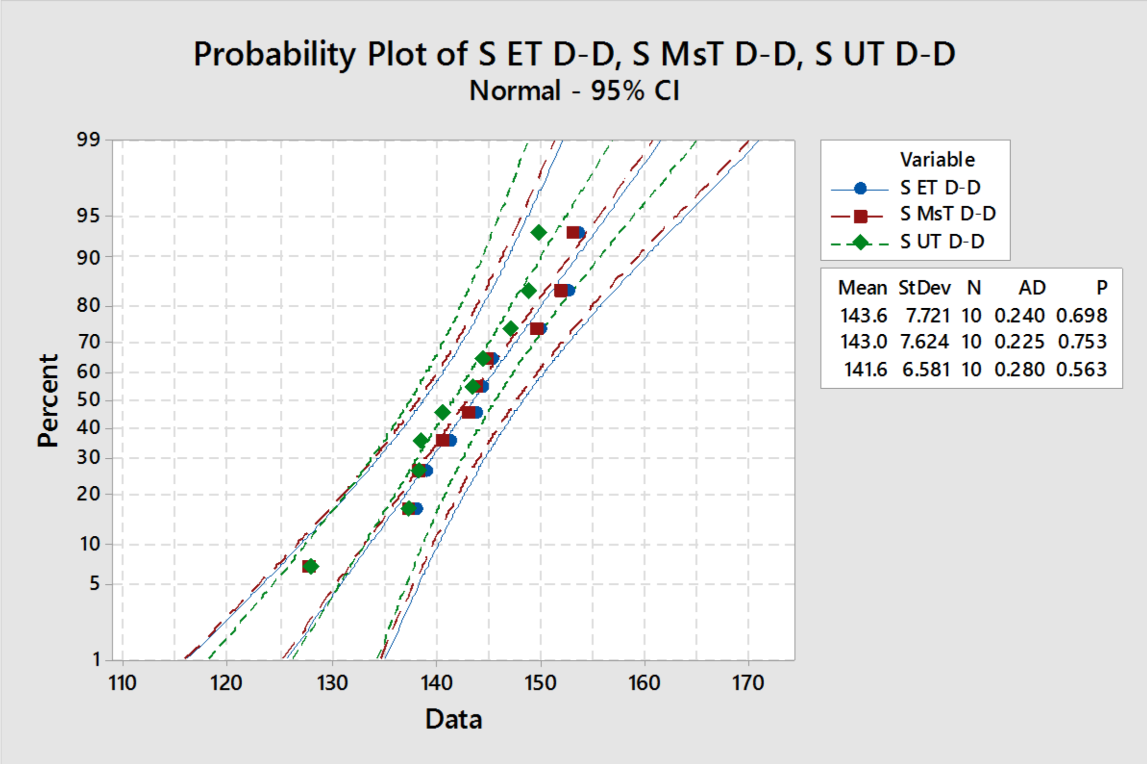

Probability Plot of US ET P-P, US MsT P-P, US UT P-P
Normal - 95% CI
Percent
Data
Variable
US ET P-P
US MsT P-P
US UT P-P
Mean StDev N AD P
113.0 5.445 10 0.617 0.077
112.0 5.260 10 0.686 0.050
110.4 5.774 10 0.601 0.085


Probability Plot of S EW D-D, S MsW D-D, S UW D-D
Normal - 95% CI
Percent
Data
Variable
S EW D-D
S MsW D-D
S UW D-D
Mean StDev N AD P
143.4 7.666 10 0.205 0.820
142.8 7.350 10 0.208 0.812
141.6 6.668 10 0.263 0.617


Probability Plot of S EW D-P, S MsW D-P, S UW D-P
Normal - 95% CI
Percent
Data
Variable
S EW D-P
S MsW D-P
S UW D-P
Mean StDev N AD P
126.1 5.662 10 0.588 0.092
125.8 5.562 10 0.578 0.098
125.2 5.304 10 1.114 <0.005


Probability Plot of S EW P-D, S MsW P-D, S UW P-D
Normal - 95% CI
Variable
S EW P-D
S MsW P-D
S UW P-D
Mean StDev N AD P
125.1 4.150 10 0.335 0.430
124.6 4.376 10 0.353 0.387
123.3 4.393 10 0.452 0.214
Percent
Data


Probability Plot of S EW P-P, S MsW P-P, S UW P-P
Normal - 95% CI
Variable
S EW P-P
S MsW P-P
S UW P-P
Mean StDev N AD P
112.1 5.056 10 0.443 0.226
111.6 5.305 10 0.301 0.514
111.1 5.801 10 0.639 0.067
Percent
Data


Probability Plot of S ET D-D, S MsT D-D, S UT D-D
Normal - 95% CI
Variable
S ET D-D
S MsT D-D
S UT D-D
Mean StDev N AD P
143.6 7.721 10 0.240 0.698
143.0 7.624 10 0.225 0.753
141.6 6.581 10 0.280 0.563
Percent
Data
99
95
90
80
70
60
50
40
30
20
10
5
1
110
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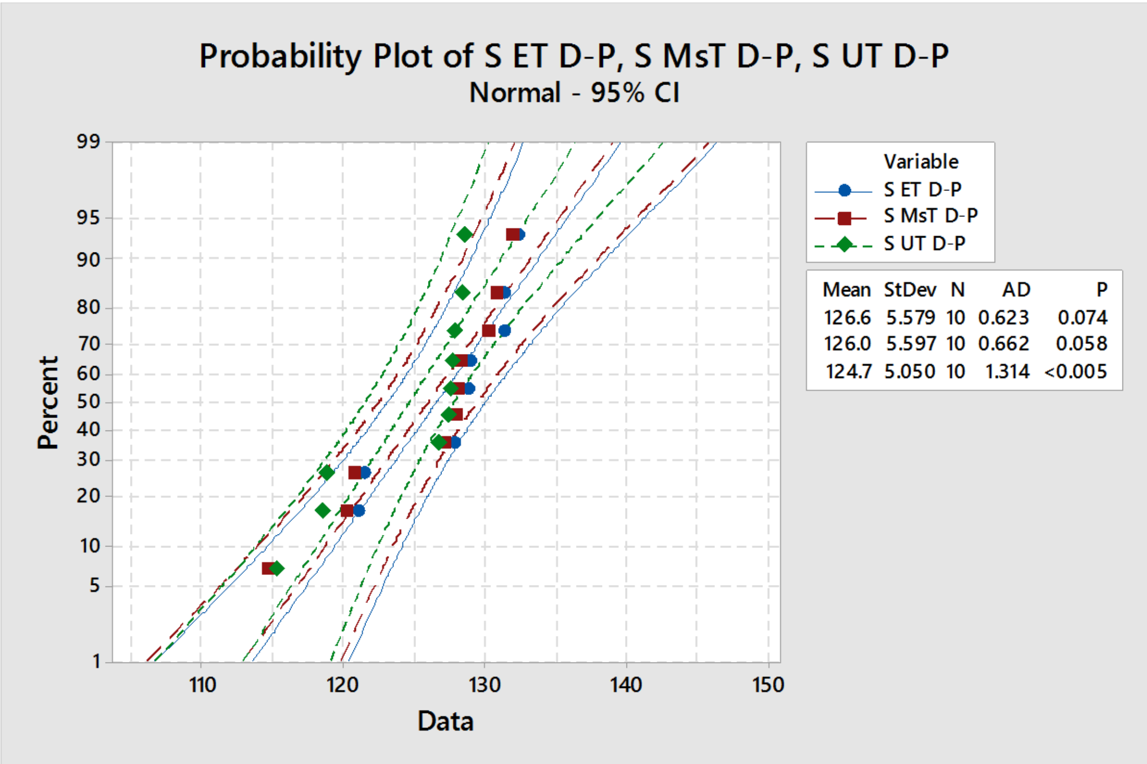
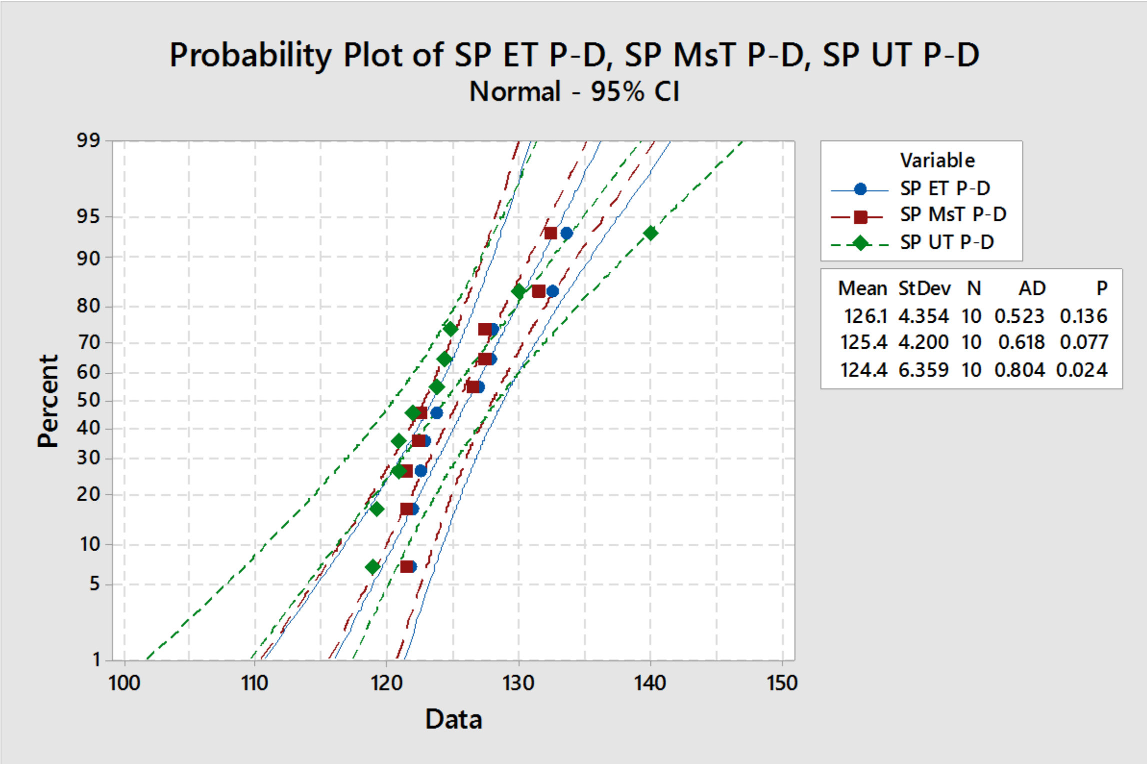
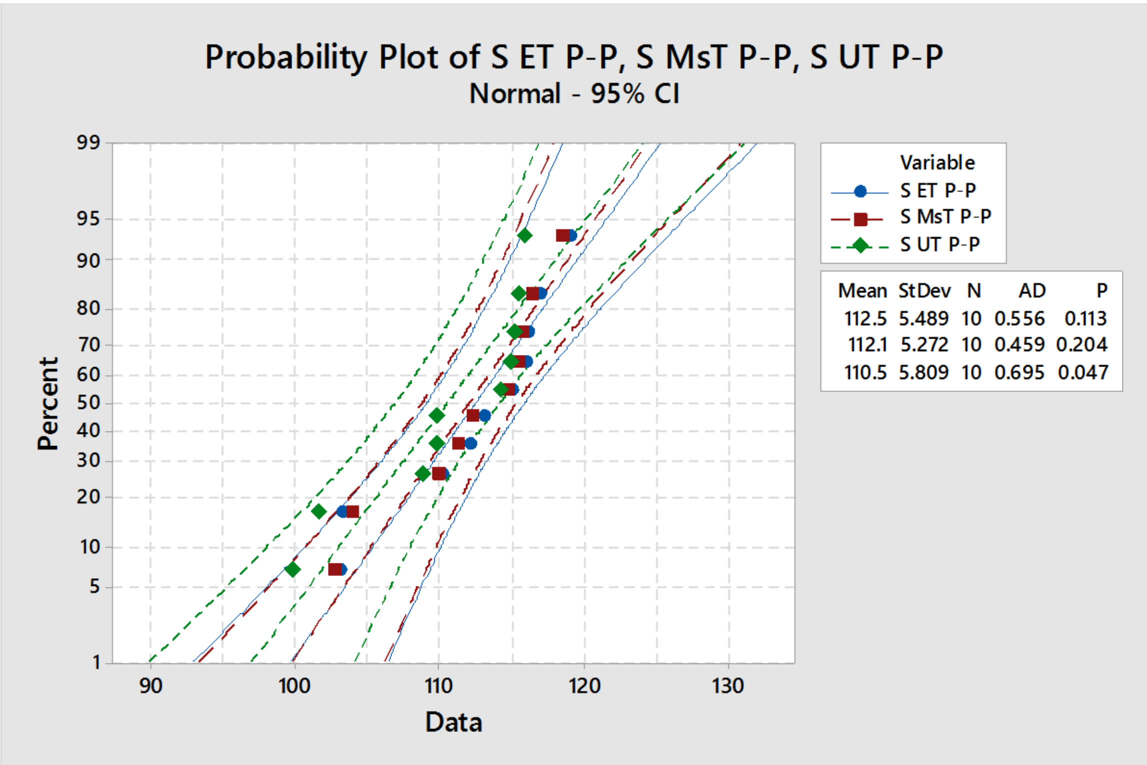
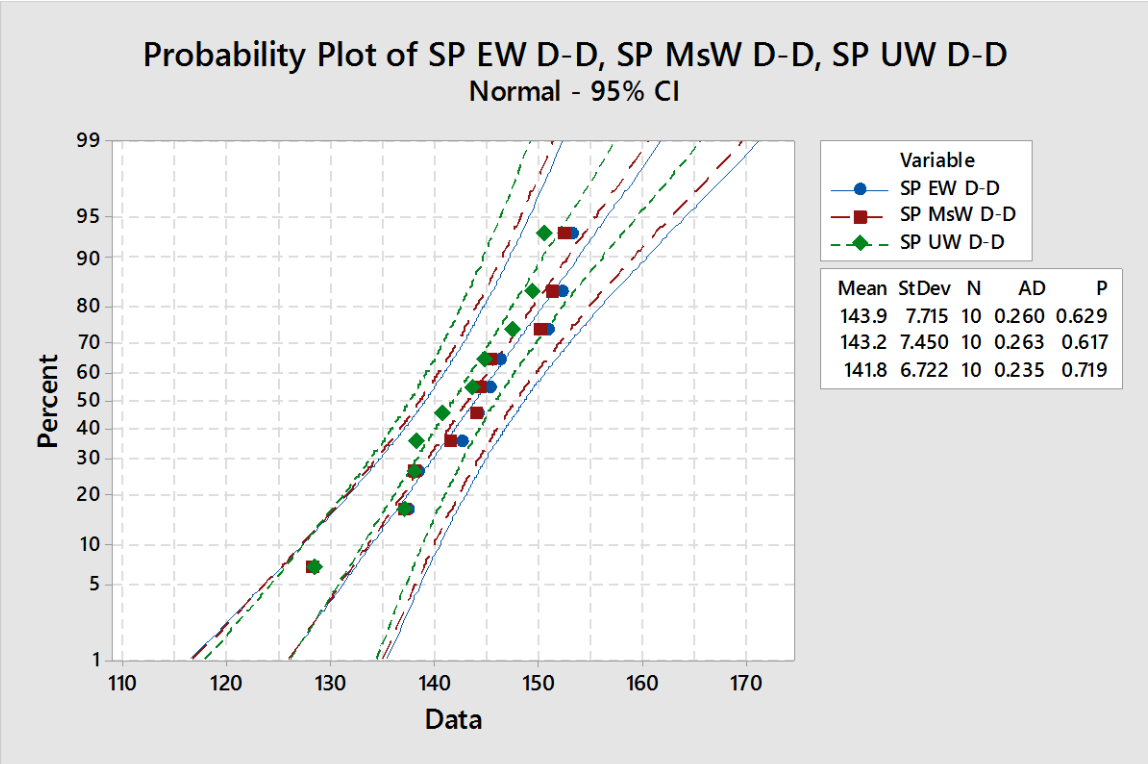
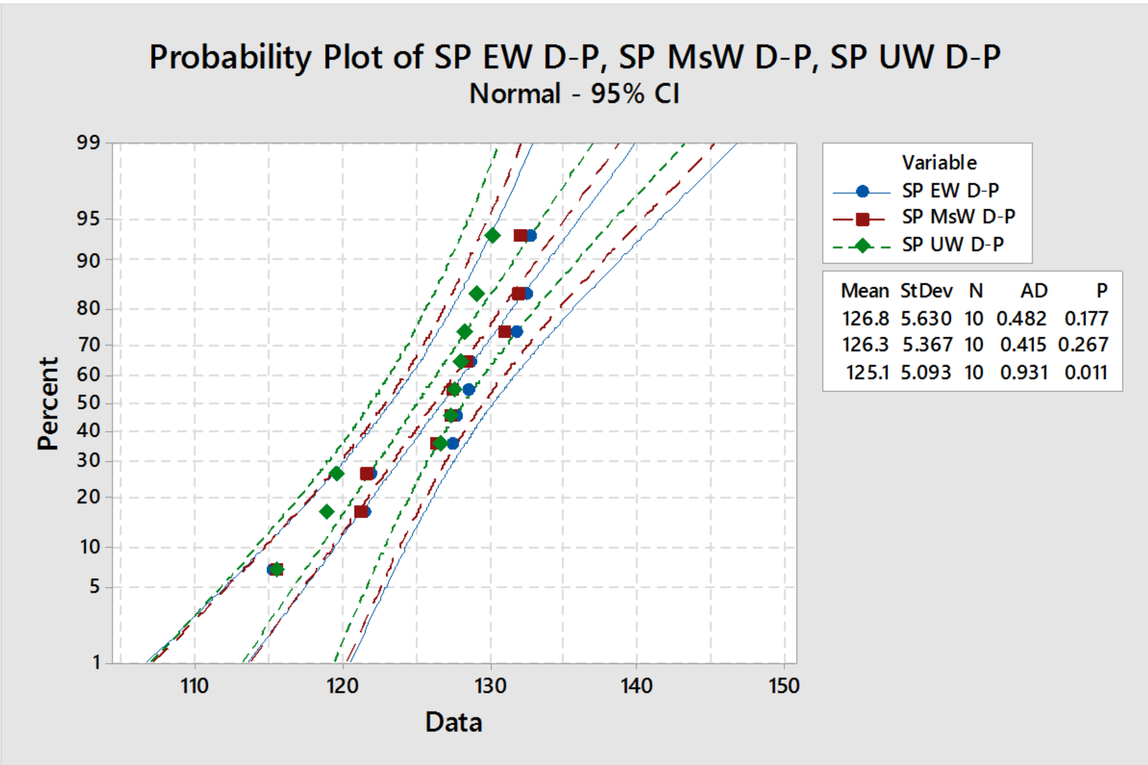
130
140
150
160
170

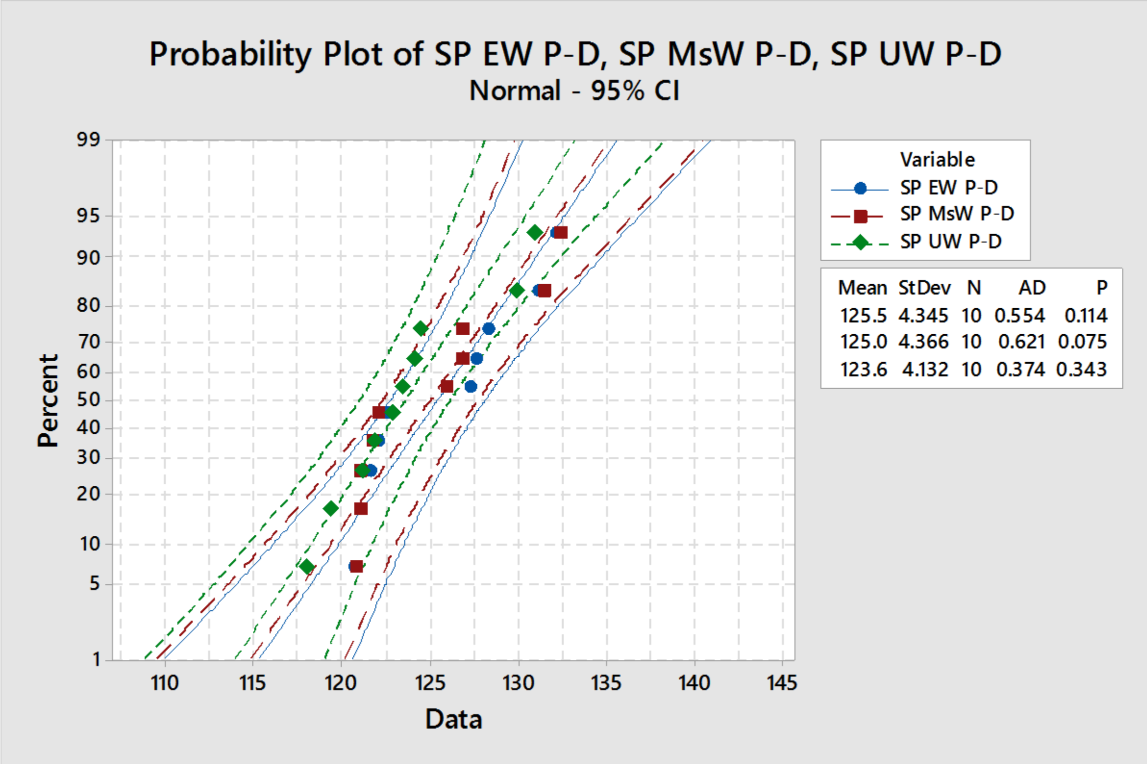

Probability Plot of S ET D-P, S MsT D-P, S UT D-P
Normal - 95% CI
Variable
S ET D-P
S MsT D-P
S UT D-P
Mean StDev N AD P
126.6 5.579 10 0.623 0.074
126.0 5.597 10 0.662 0.058
124.7 5.050 10 1.314 <0.005
Percent
Data
99
95
90
80
70
60
50
40
30
20
10
5
1
110
120
130
140
150


Probability Plot of SP ET P-D, SP MsT P-D, SP UT P-D
Normal - 95% CI
Percent
Data
Variable
SP ET P-D
SP MsT P-D
SP UT P-D
Mean StDev N AD P
126.1 4.354 10 0.523 0.136
125.4 4.200 10 0.618 0.077
124.4 6.359 10 0.804 0.024

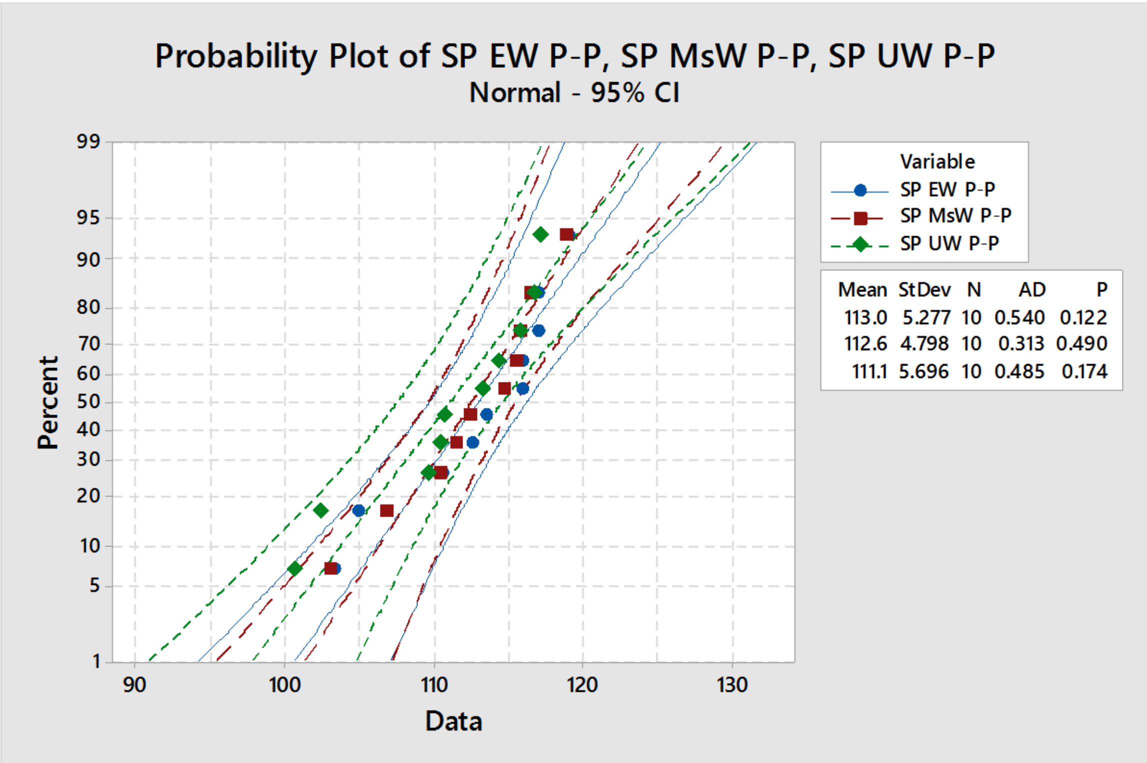

Probability Plot of S ET P-P, S MsT P-P, S UT P-P
Normal - 95% CI
Percent
Data
Variable
S ET P-P
S MsT P-P
S UT P-P
Mean StDev N AD P
112.5 5.489 10 0.556 0.113
112.1 5.272 10 0.459 0.204
110.5 5.809 10 0.695 0.047


Probability Plot of SP EW D-D, SP MsW D-D, SP UW D-D
Normal - 95% CI
Percent
99
95
90
80
70
60
50
40
30
20
10
5
1
110
120
130
140
150
160
170
Data
Variable
SP EW D-D
SP MsW D-D
SP UW D-D
Mean StDev N AD P
143.9 7.715 10 0.260 0.629
143.2 7.450 10 0.263 0.617
141.8 6.722 10 0.235 0.719

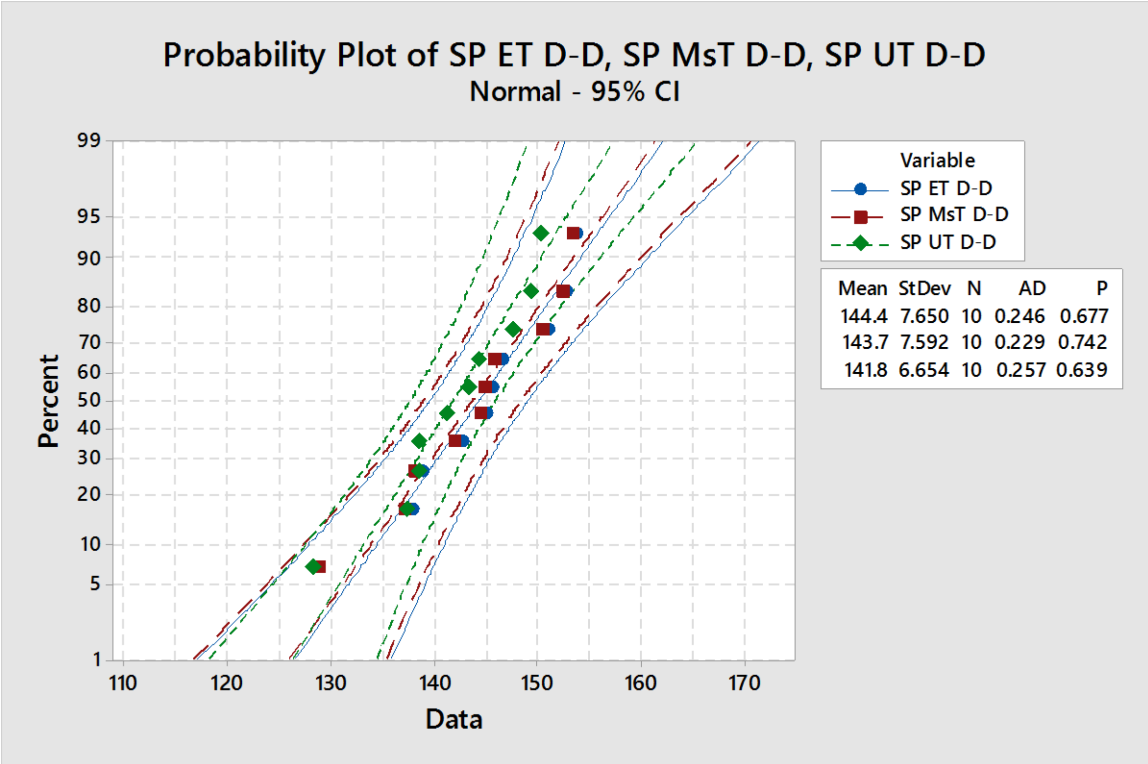

Probability Plot of SP EW D-P, SP MsW D-P, SP UW D-P
Normal - 95% CI
Percent
99
95
90
80
70
60
50
40
30
20
10
5
1
110
120
130
140
150
Data
Variable
SP EW D-P
SP MsW D-P
SP UW D-P
Mean StDev N AD P
126.8 5.630 10 0.482 0.177
126.3 5.367 10 0.415 0.267
125.1 5.093 10 0.931 0.011



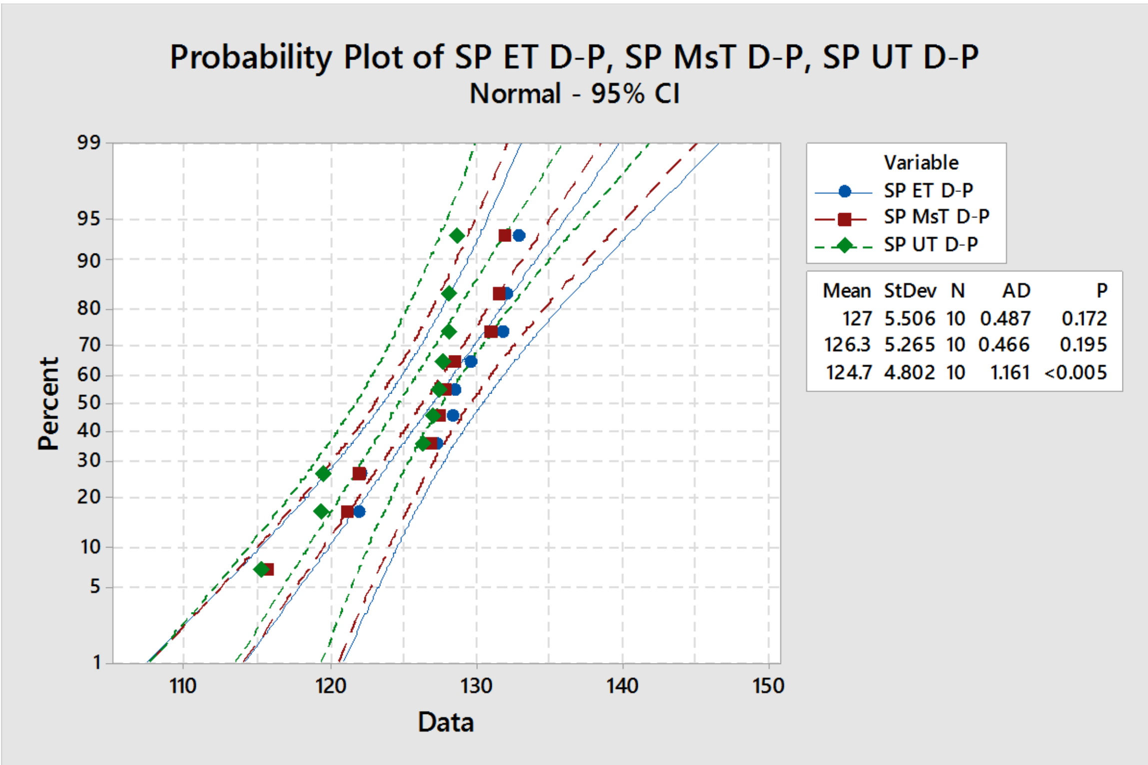
Probability Plot of SP EW P-D, SP MsW P-D, SP UW P-D
Normal - 95% CI
Percent
Data
Variable
SP EW P-D
SP MsW P-D
SP UW P-D
Mean StDev N AD P
125.5 4.345 10 0.554 0.114
125.0 4.366 10 0.621 0.075
123.6 4.132 10 0.374 0.343



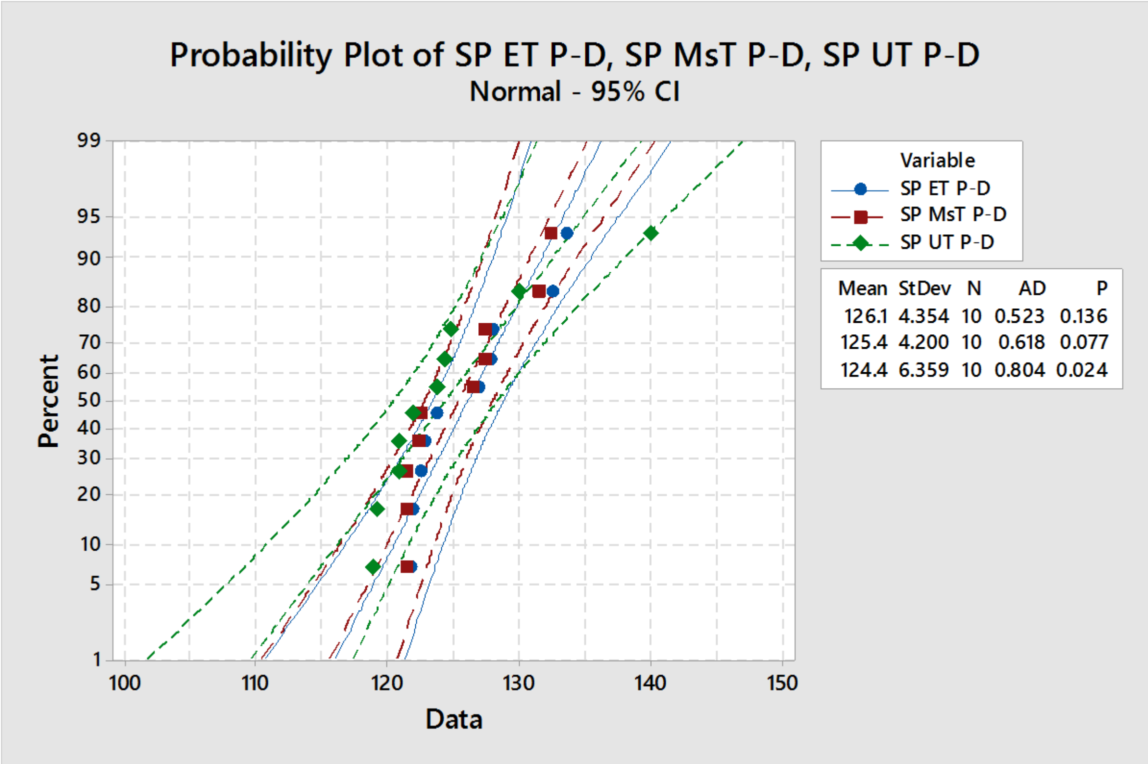
Probability Plot of SP EW P-P, SP MsW P-P, SP UW P-P
Normal - 95% CI
Percent
Data
Variable
SP EW P-P
SP MsW P-P
SP UW P-P
Mean StDev N AD P
113.0 5.277 10 0.540 0.122
112.6 4.798 10 0.313 0.490
111.1 5.696 10 0.485 0.174

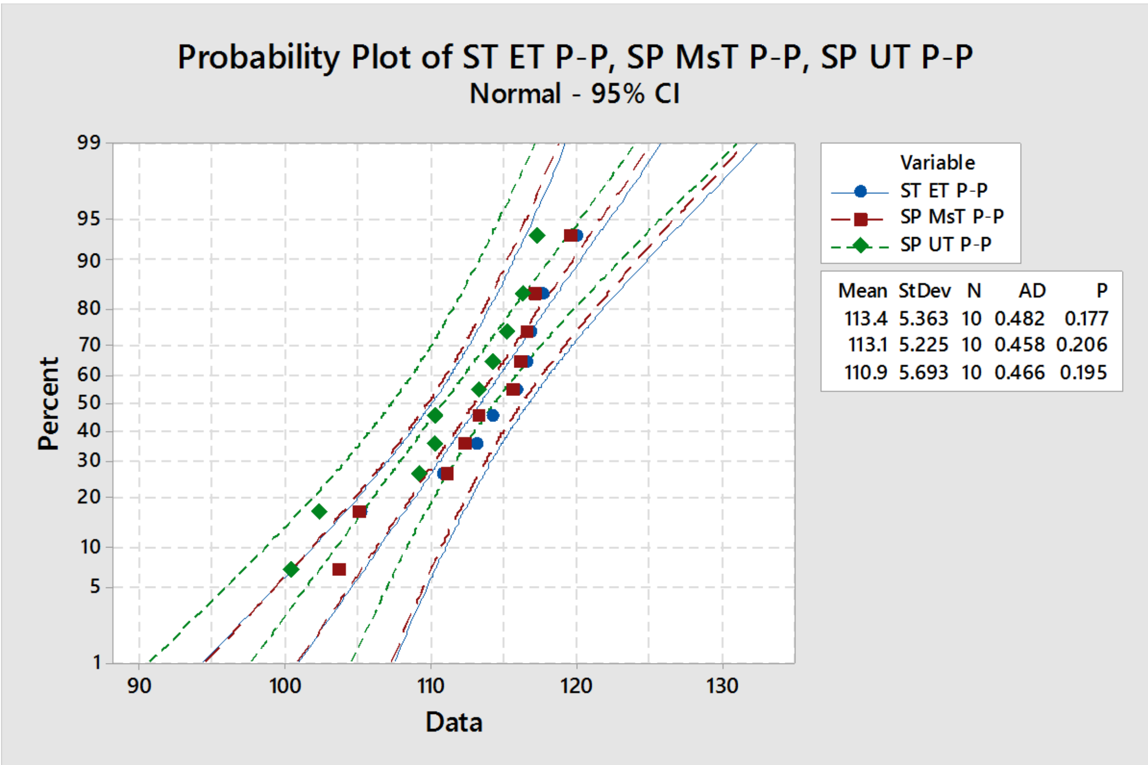


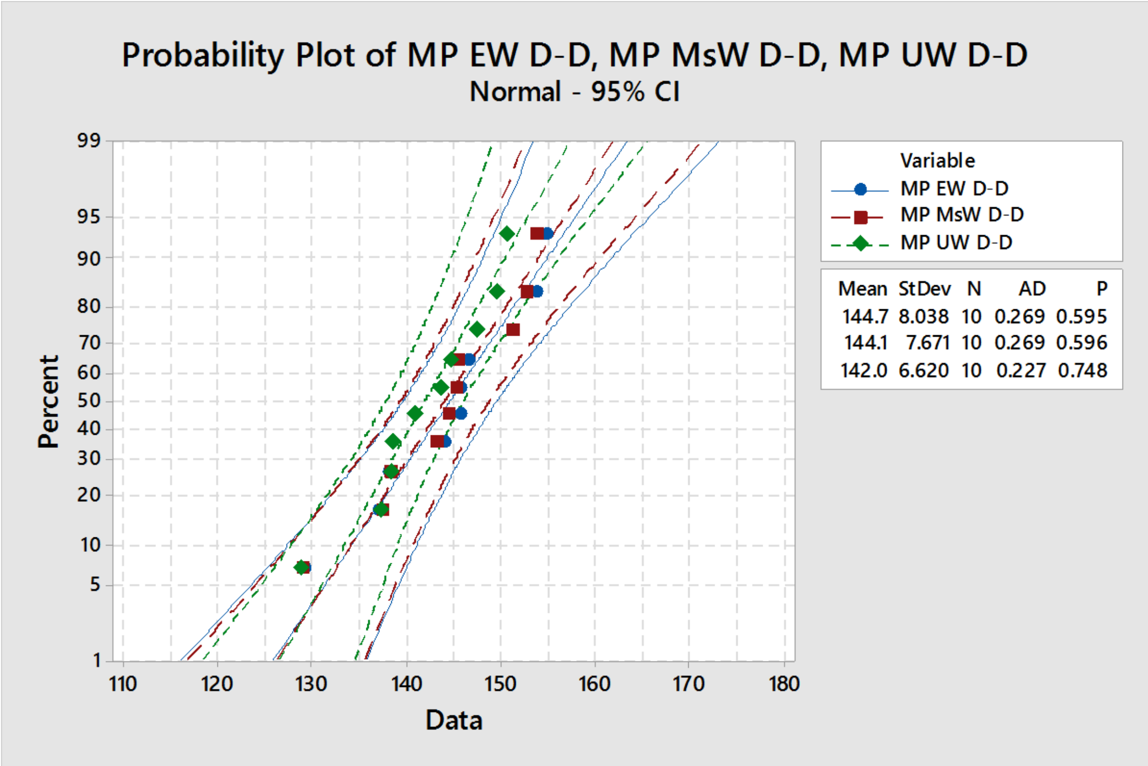
Probability Plot of SP ET D-D, SP MsT D-D, SP UT D-D
Normal - 95% CI
Percent
Data
Variable
SP ET D-D
SP MsT D-D
SP UT D-D
Mean StDev N AD P
144.4 7.650 10 0.246 0.677
143.7 7.592 10 0.229 0.742
141.8 6.654 10 0.257 0.639

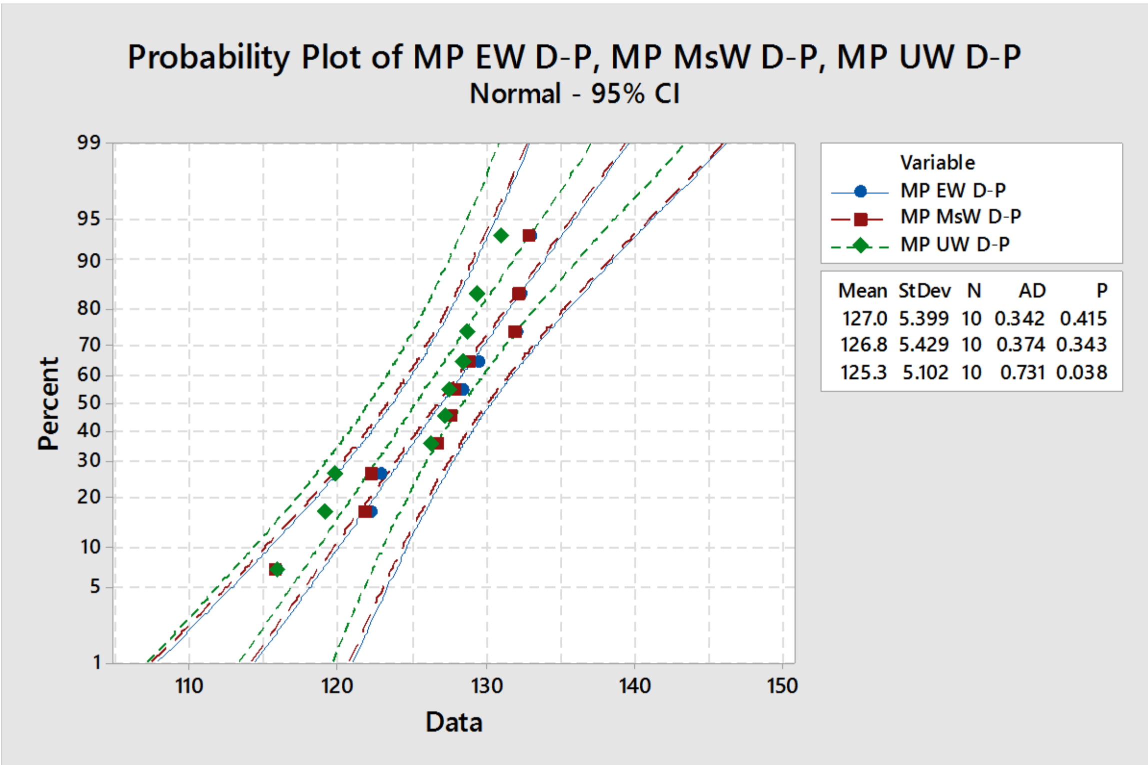


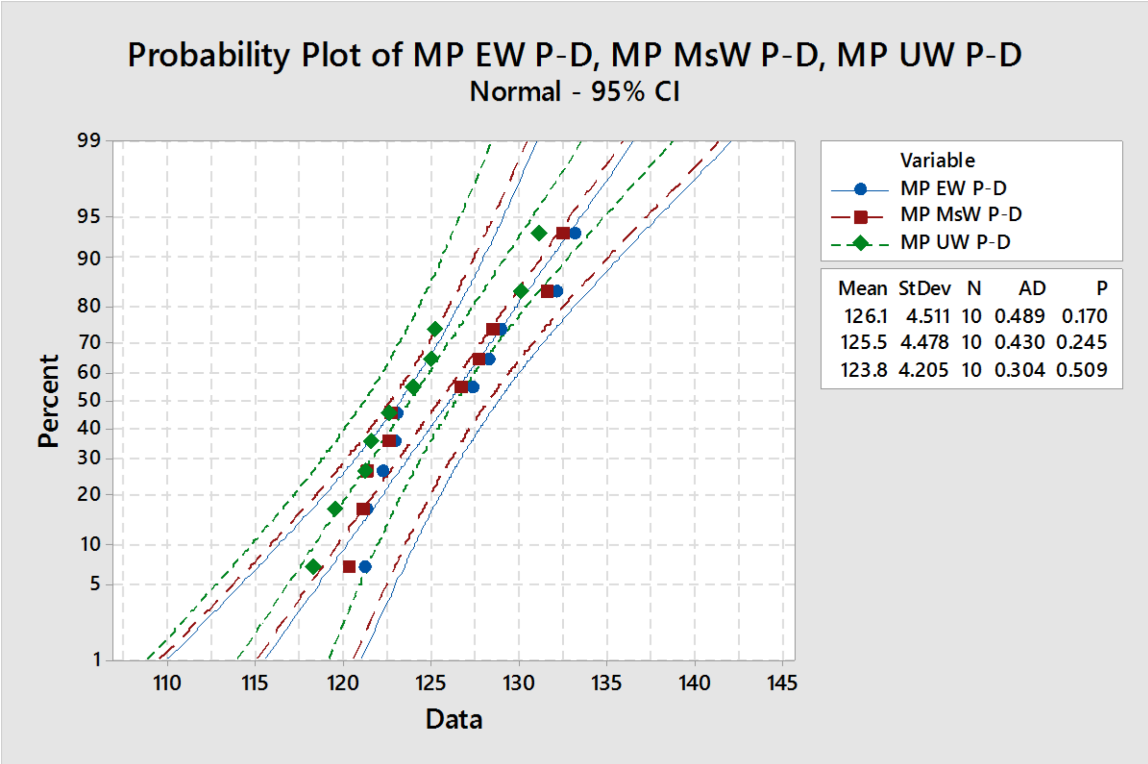
Probability Plot of SP ET D-P, SP MsT D-P, SP UT D-P
Normal - 95% CI
Percent
Data
Variable
SP ET D-P
SP MsT D-P
SP UT D-P
Mean StDev N AD P
127 5.506 10 0.487 0.172
126.3 5.265 10 0.466 0.195
124.7 4.802 10 1.161 <0.005


Probability Plot of SP ET P-D, SP MsT P-D, SP UT P-D
Normal - 95% CI
Percent
Data
Variable
SP ET P-D
SP MsT P-D
SP UT P-D
Mean StDev N AD P
126.1 4.354 10 0.523 0.136
125.4 4.200 10 0.618 0.077
124.4 6.359 10 0.804 0.024

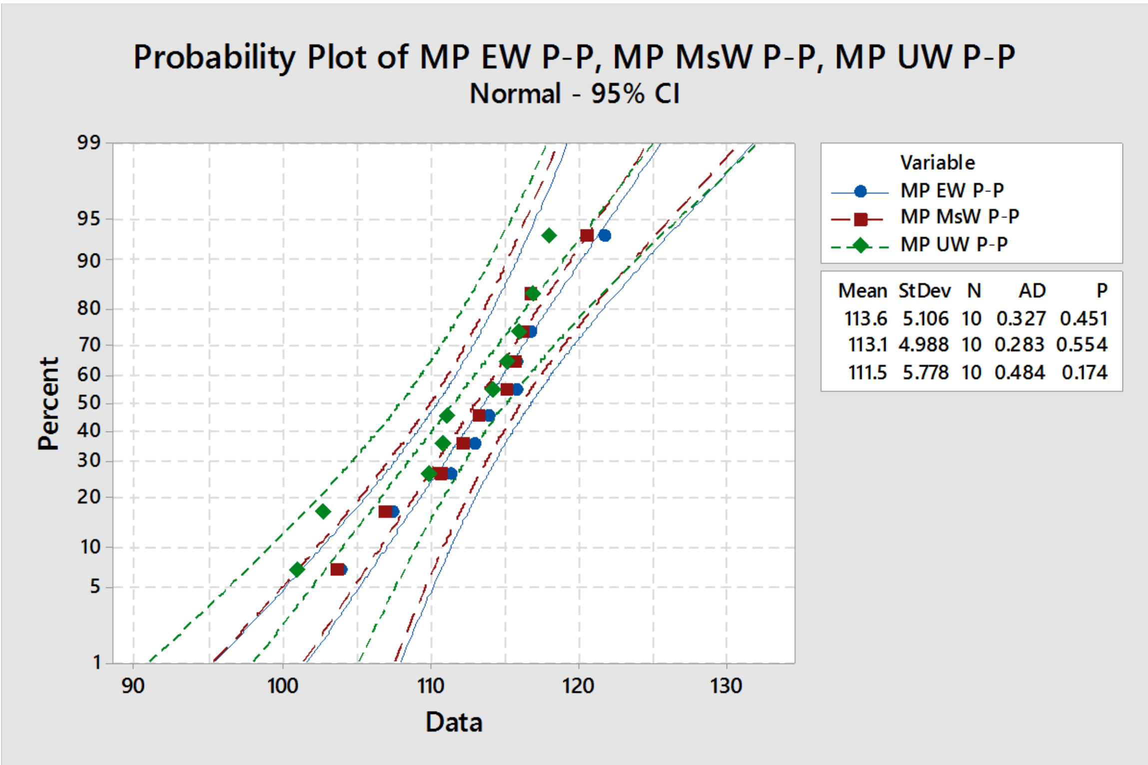

Probability Plot of ST ET P-P, SP MsT P-P, SP UT P-P
Normal - 95% CI
Percent
Data
Variable
ST ET P-P
SP MsT P-P
SP UT P-P
Mean StDev N AD P
113.4 5.363 10 0.482 0.177
113.1 5.225 10 0.458 0.206
110.9 5.693 10 0.466 0.195


Probability Plot of MP EW D-D, MP MsW D-D, MP UW D-D
Normal - 95% CI
Percent
Data
Variable
MP EW D-D
MP MsW D-D
MP UW D-D
Mean StDev N AD P
144.7 8.038 10 0.269 0.595
144.1 7.671 10 0.269 0.596
142.0 6.620 10 0.227 0.748

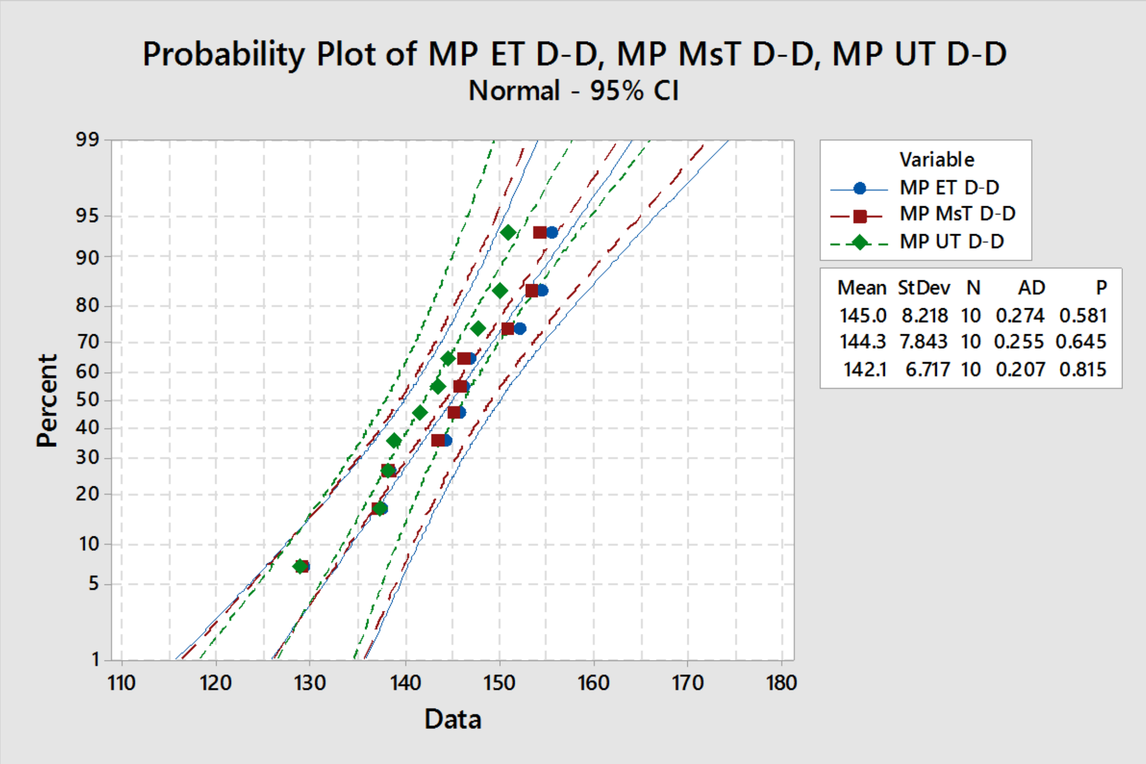

Probability Plot of MP EW D-P, MP MsW D-P, MP UW D-P
Normal - 95% CI
Percent
Data
Variable
MP EW D-P
MP MsW D-P
MP UW D-P
Mean StDev N AD P
127.0 5.399 10 0.342 0.415
126.8 5.429 10 0.374 0.343
125.3 5.102 10 0.731 0.038

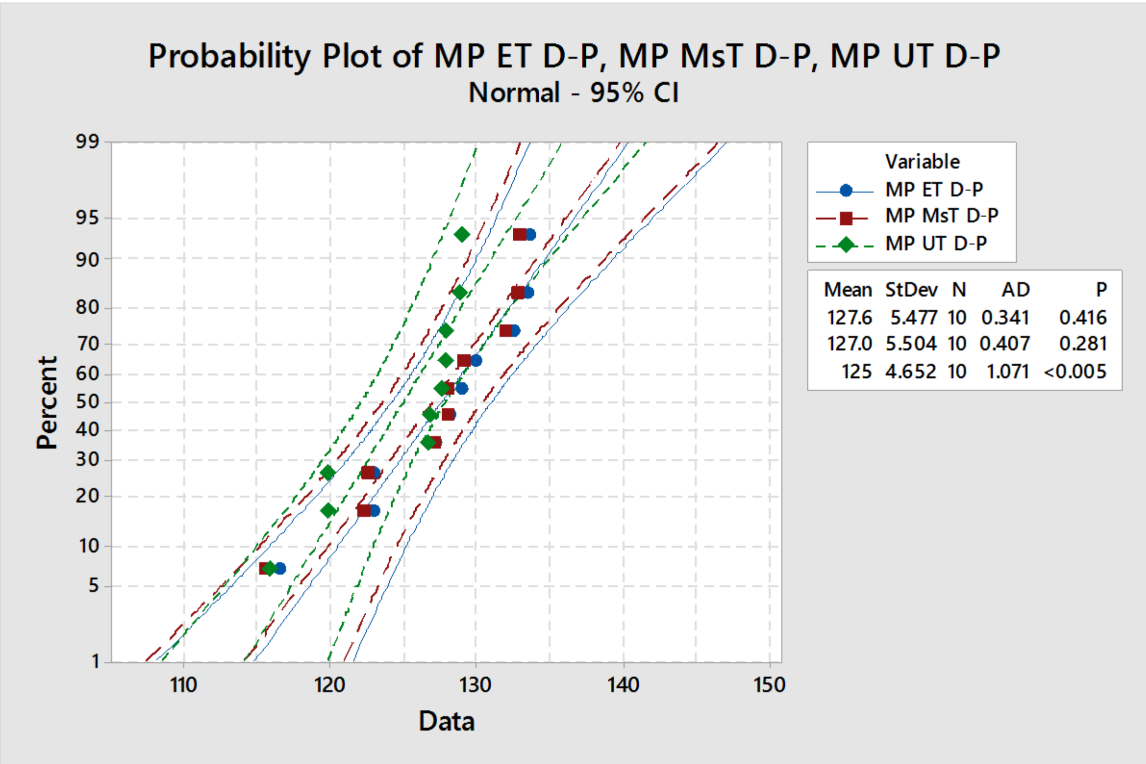


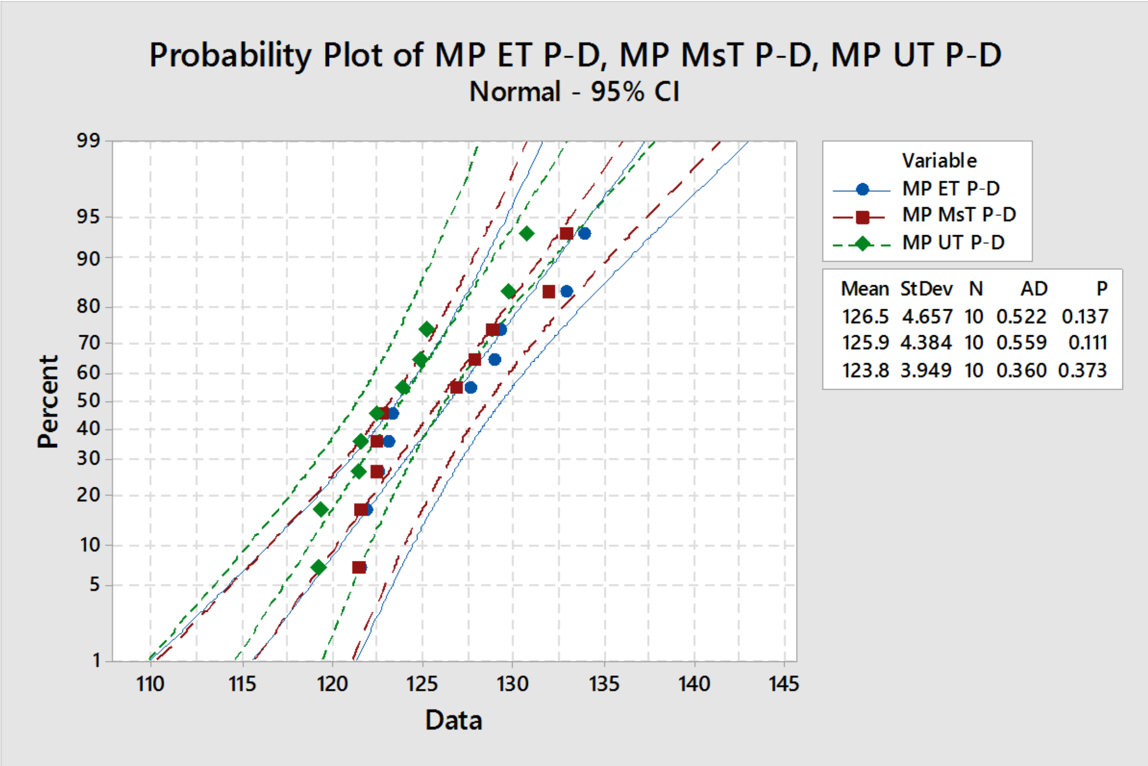
Probability Plot of MP EW P-D, MP MsW P-D, MP UW P-D
Normal - 95% CI
Percent
Data
Variable
MP EW P-D
MP MsW P-D
MP UW P-D
Mean StDev N AD P
126.1 4.511 10 0.489 0.170
125.5 4.478 10 0.430 0.245
123.8 4.205 10 0.304 0.509

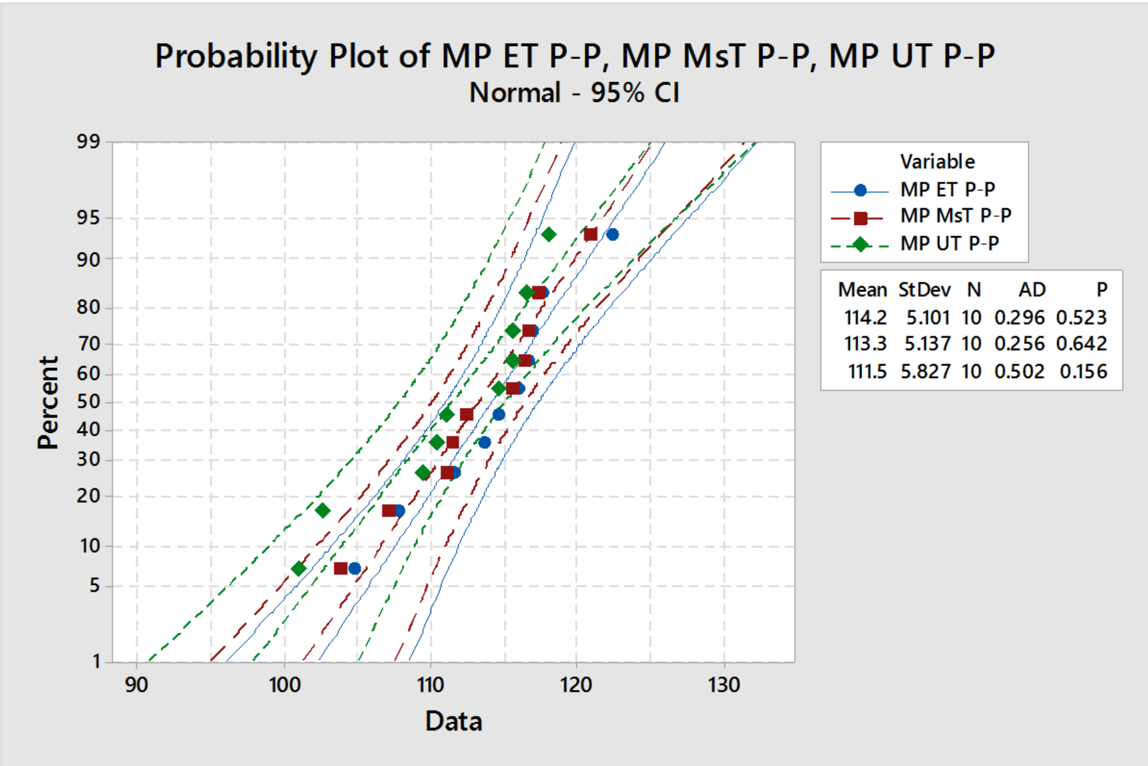


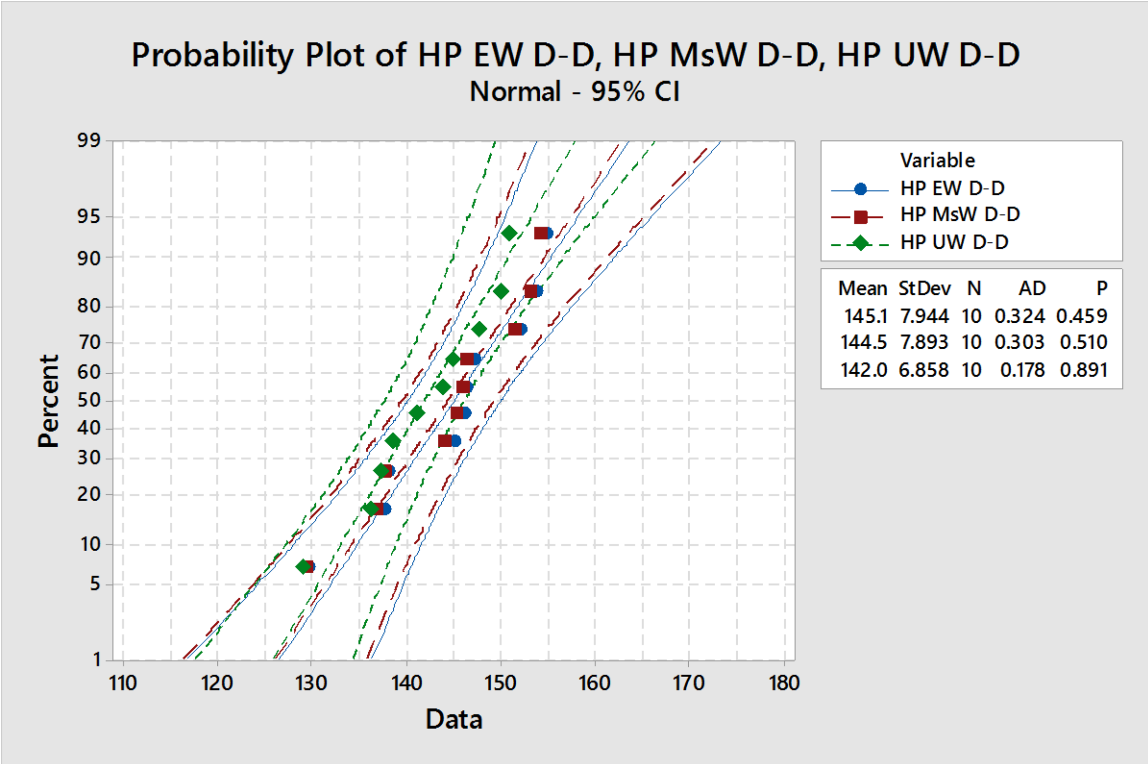
Probability Plot of MP EW P-P, MP MsW P-P, MP UW P-P
Normal - 95% CI
Percent
Data
Variable
MP EW P-P
MP MsW P-P
MP UW P-P
Mean StDev N AD P
113.6 5.106 10 0.327 0.451
113.1 4.988 10 0.283 0.554
111.5 5.778 10 0.484 0.174

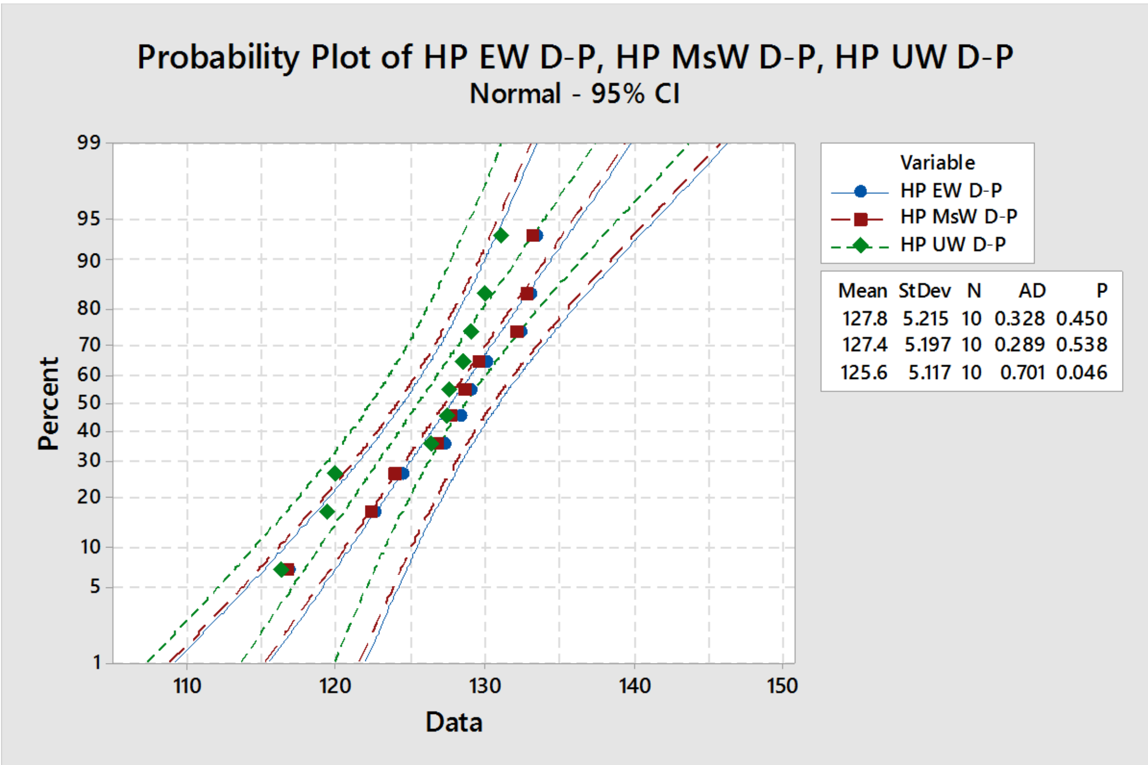

Probability Plot of MP ET D-D, MP MsT D-D, MP UT D-D
Normal - 95% CI
Percent
Data
Variable
MP ET D-D
MP MsT D-D
MP UT D-D
Mean StDev N AD P
145.0 8.218 10 0.274 0.581
144.3 7.843 10 0.255 0.645
142.1 6.717 10 0.207 0.815

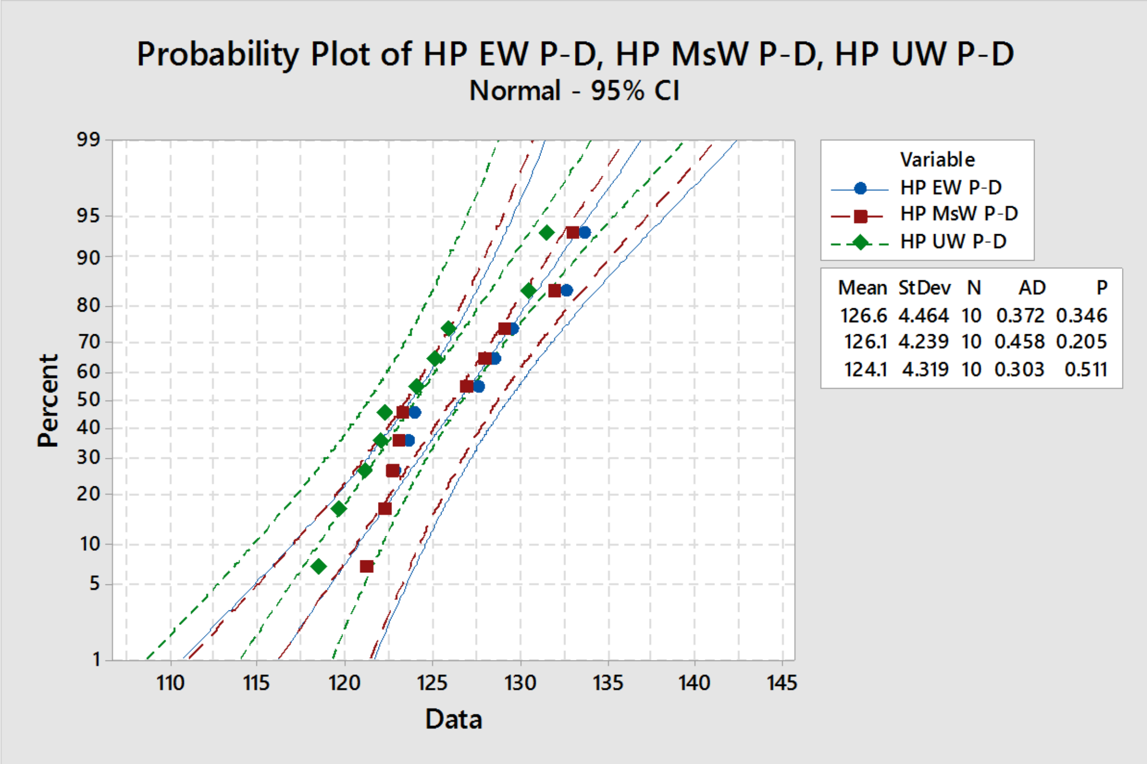

Probability Plot of MP ET D-P, MP MsT D-P, MP UT D-P
Normal - 95% CI
Percent
Data
Variable
MP ET D-P
MP MsT D-P
MP UT D-P
Mean StDev N AD P
127.6 5.477 10 0.341 0.416
127.0 5.504 10 0.407 0.281
125 4.652 10 1.071 <0.005

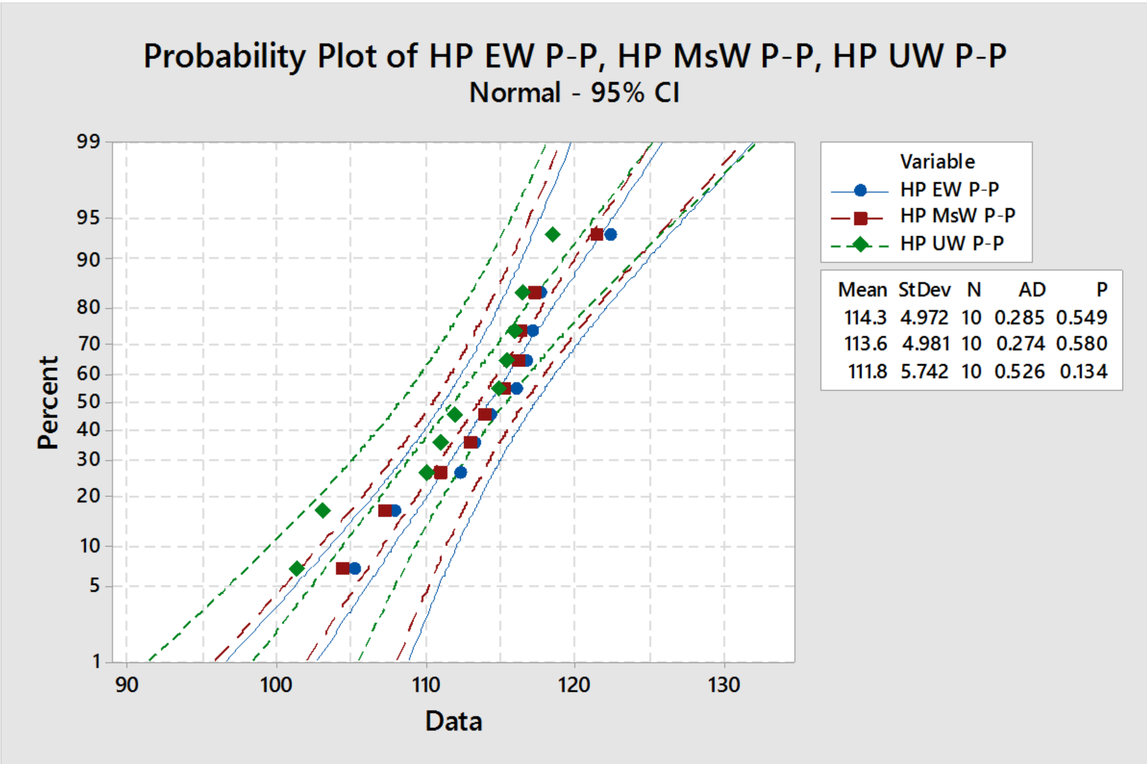

Probability Plot of MP ET P-D, MP MsT P-D, MP UT P-D
Normal - 95% CI
Percent
Data
Variable
MP ET P-D
MP MsT P-D
MP UT P-D
Mean StDev N AD P
126.5 4.657 10 0.522 0.137
125.9 4.384 10 0.559 0.111
123.8 3.949 10 0.360 0.373

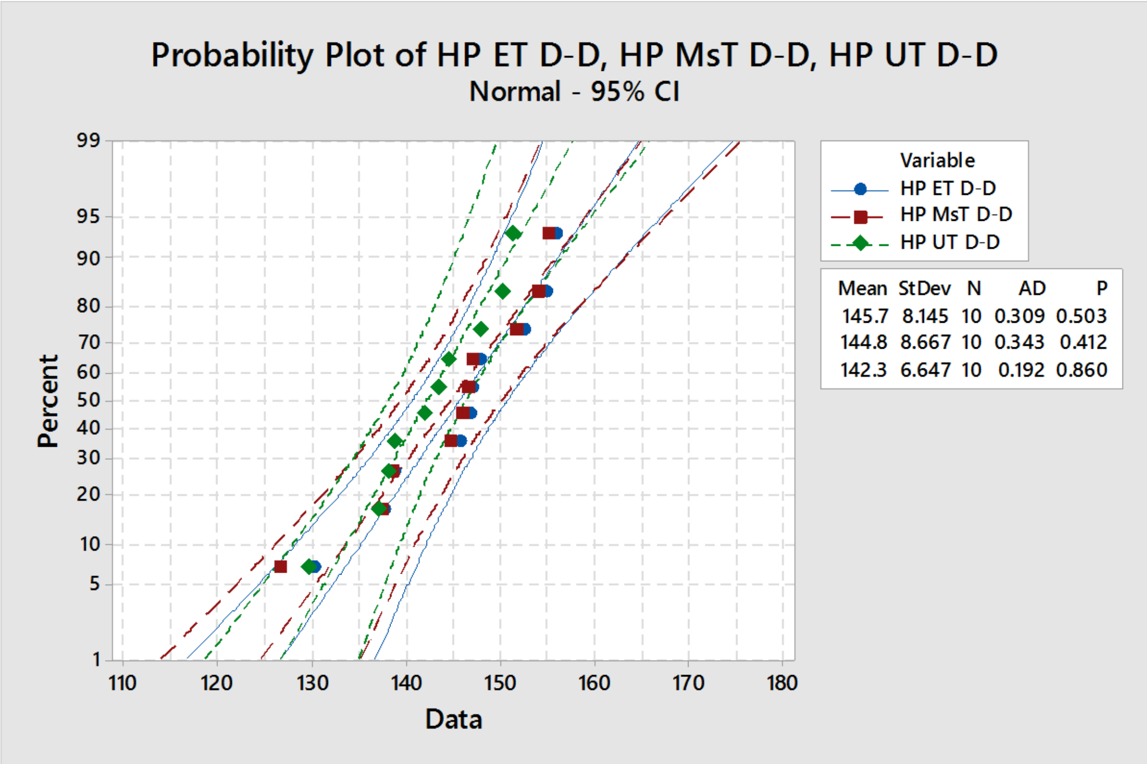

Probability Plot of MP ET P-P, MP MsT P-P, MP UT P-P
Normal - 95% CI
Percent
Data
Variable
MP ET P-P
MP MsT P-P
MP UT P-P
Mean StDev N AD P
114.2 5.101 10 0.296 0.523
113.3 5.137 10 0.256 0.642
111.5 5.827 10 0.502 0.156

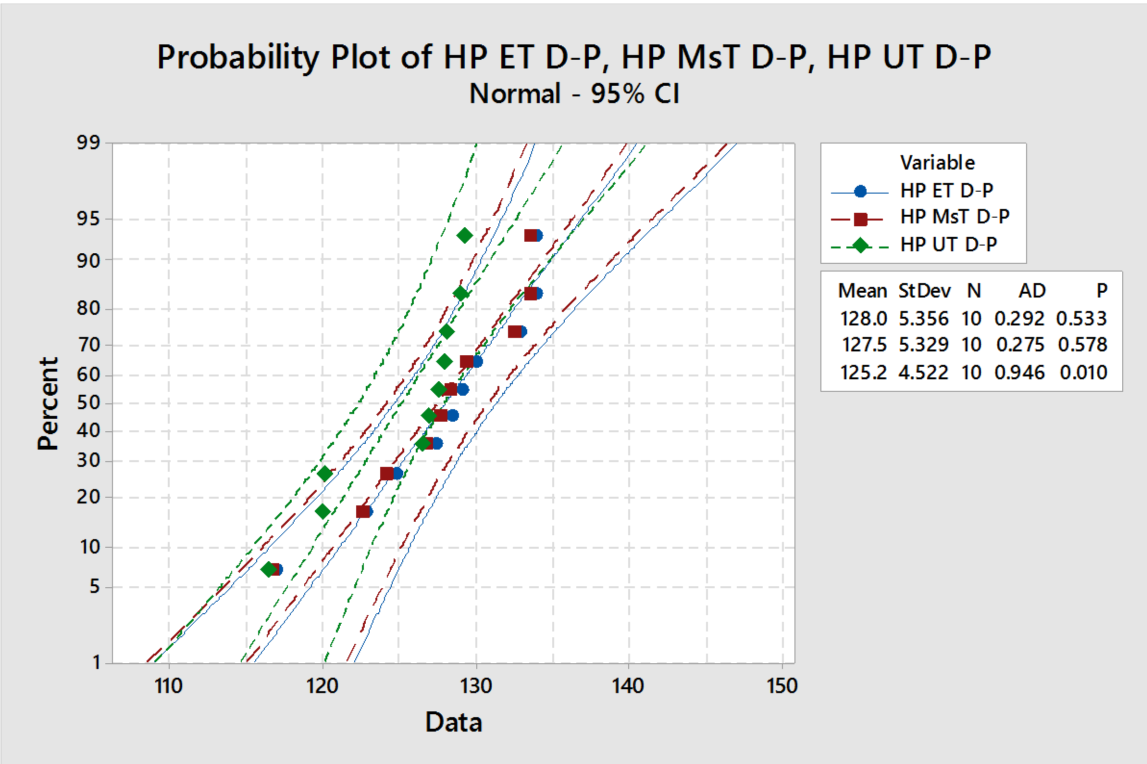

Probability Plot of HP EW D-D, HP MsW D-D, HP UW D-D
Normal - 95% CI
Percent
Data
Variable
HP EW D-D
HP MsW D-D
HP UW D-D
Mean StDev N AD P
145.1 7.944 10 0.324 0.459
144.5 7.893 10 0.303 0.510
142.0 6.858 10 0.178 0.891

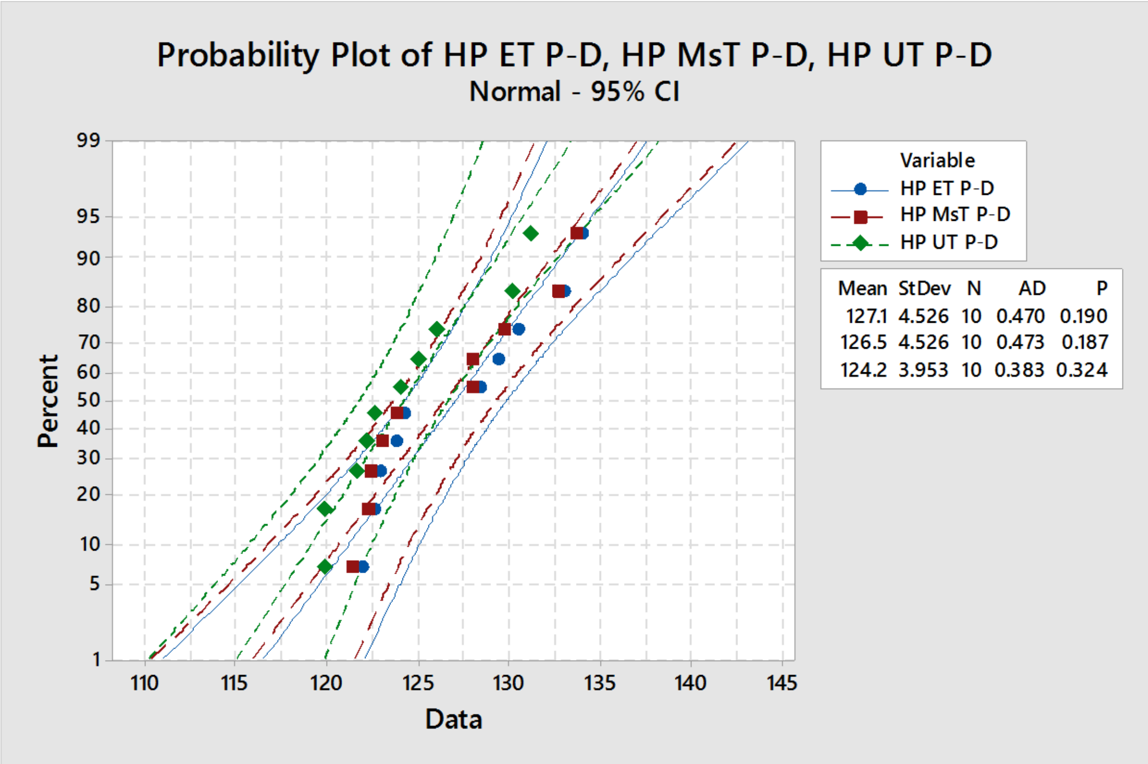

Probability Plot of HP EW D-P, HP MsW D-P, HP UW D-P
Normal - 95% CI
Percent
Data
Variable
HP EW D-P
HP MsW D-P
HP UW D-P
Mean StDev N AD P
127.8 5.215 10 0.328 0.450
127.4 5.197 10 0.289 0.538
125.6 5.117 10 0.701 0.046

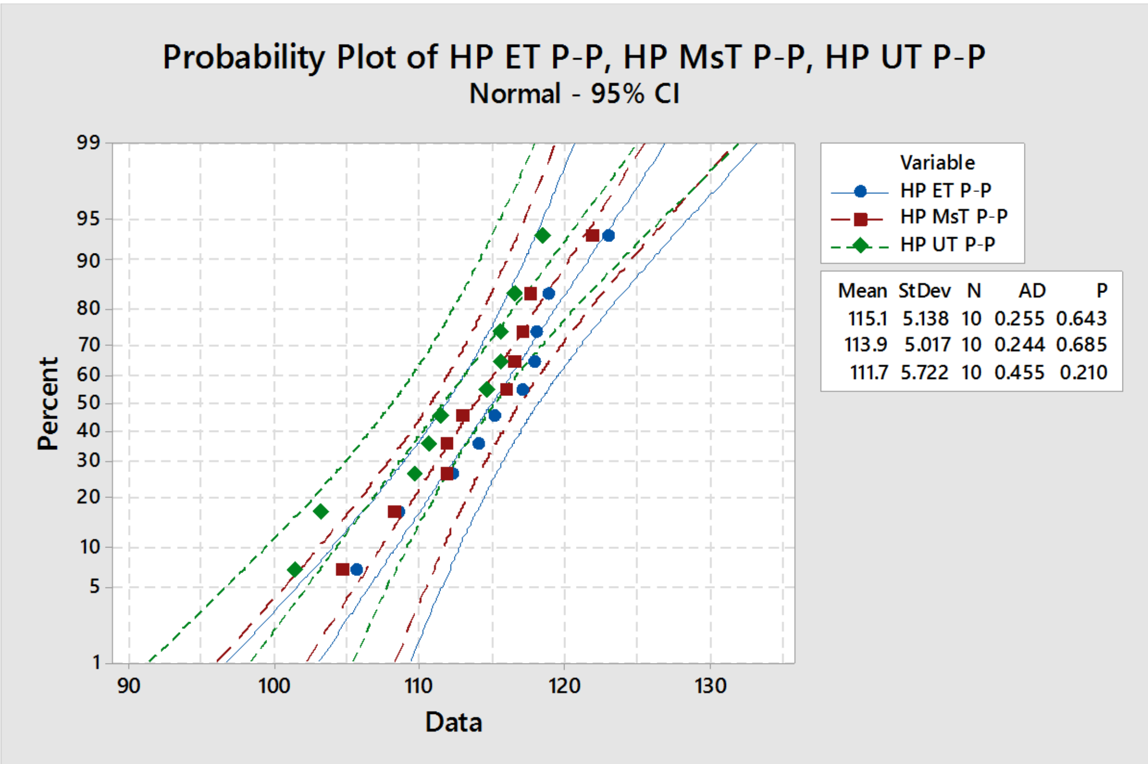

Probability Plot of HP EW P-D, HP MsW P-D, HP UW P-D
Normal - 95% CI
Percent
Data
Variable
HP EW P-D
HP MsW P-D
HP UW P-D
Mean StDev N AD P
126.6 4.464 10 0.372 0.346
126.1 4.239 10 0.458 0.205
124.1 4.319 10 0.303 0.511


Probability Plot of HP EW P-P, HP MsW P-P, HP UW P-P
Normal - 95% CI
Percent
Data
Variable
HP EW P-P
HP MsW P-P
HP UW P-P
Mean StDev N AD P
114.3 4.972 10 0.285 0.549
113.6 4.981 10 0.274 0.580
111.8 5.742 10 0.526 0.134


Probability Plot of HP ET D-D, HP MsT D-D, HP UT D-D
Normal - 95% CI
Percent
Data
Variable
HP ET D-D
HP MsT D-D
HP UT D-D
Mean StDev N AD P
145.7 8.145 10 0.309 0.503
144.8 8.667 10 0.343 0.412
142.3 6.647 10 0.192 0.860


Probability Plot of HP ET D-P, HP MsT D-P, HP UT D-P
Normal - 95% CI
Percent
Data
Variable
HP ET D-P
HP MsT D-P
HP UT D-P
Mean StDev N AD P
128.0 5.356 10 0.292 0.533
127.5 5.329 10 0.275 0.578
125.2 4.522 10 0.946 0.010


Probability Plot of HP ET P-D, HP MsT P-D, HP UT P-D
Normal - 95% CI
Percent
Data
Variable
HP ET P-D
HP MsT P-D
HP UT P-D
Mean StDev N AD P
127.1 4.526 10 0.470 0.190
126.5 4.526 10 0.473 0.187
124.2 3.953 10 0.383 0.324


Probability Plot of HP ET P-P, HP MsT P-P, HP UT P-P
Normal - 95% CI
Percent
Data
Variable
HP ET P-P
HP MsT P-P
HP UT P-P
Mean StDev N AD P
115.1 5.138 10 0.255 0.643
113.9 5.017 10 0.244 0.685
111.7 5.722 10 0.455 0.210