In [1]:
```
'''
Research Project: Gaussian Differential Privacy

Code Implementation: GDP with Machine Learning

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Description:

Parameters: sensitivity=1, delta=1e-5, epsilon=0.1

Note: In our research, we decided to focus on values of epsilon that epsilon ∈ (0, 1) which are e=0.1, e=0.3,
e=0.5, e=0.9

For the third topic in the research project, we work on independent variables of Heart Disease data to study
how the 4
different privacy budget epsilon ∈ (0, 1) influence 7 ML models' accuracy.

After the code implementation of the third topic, We can:
(1) Try to gain insights into the utility of different privacy
(2) Identify which models are most suitable for analyzing data with different levels of privacy protection

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In the code implementation of GDP with Machine Learning, we aim to examine the impact of the different budget
s on 7
classification models by implementing it on:
Lab 2.1 continuous independent variables with e=0.1, e=0.3, e=0.5, e=0.9
Lab 2.2 categorical independent variables (excluding dummy variables and its corresponding features) with e=
0.1,
        e=0.3, e=0.5, e=0.9

And then, examin the differences among accuracies via two intuitive and standard rules:

Rule 1. After applying GDP, if the differences in accuracies are changed within 20% and accuracies are still
greater than 80%,
we consider the models trained on noise data still has statistical information to provide meaningful insight
s.

Rule 2. After applying GDP, if the differences in accuracies are changed by more than 20%, we consider the mo
```

```
dels trained on
noise data do not have statistical information to provide meaningful insights. Healthcare statisticians canno
t make use of it
to make decisions.

'''
```

Out[1]:

```
"\nYuanyuan Sun | cs528, Spring 2023 | College of Computing, Illinois Tech\n\nResearch Project: Gaussian Diff
erential Privacy\n\nCode Implementation: GDP with Machine Learning\n\n---------------------------------------
-----------------------------------------------------------------------------------\n\nDescription: \n\nPara
meters: sensitivity=1, delta=1e-5, epsilon=0.1\n\nNote: In our research, we decided to focus on values of eps
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ct, we work on independent variables of Heart Disease data to study how the 4 \ndifferent privacy budget epsi
lon ∈ (0, 1) influence 7 ML models' accuracy. \n\nAfter the code implementation of the third topic, We ca
n:\n(1) Try to gain insights into the utility of different privacy \n(2) Identify which models are most suita
ble for analyzing data with different levels of privacy protection\n\n---------------------------------------
-----------------------------------------------------------------------------------\nIn the code implementat
ion of GDP with Machine Learning, we aim to examine the impact of the different budgets on 7 \nclassification
models by implementing it on:\nLab 2.1 continuous independent variables with e=0.1, e=0.3, e=0.5, e=0.9\nLab
2.2 categorical independent variables (excluding dummy variables and its corresponding features) with e=0.1,
\n         e=0.3, e=0.5, e=0.9\n\nAnd then, examin the differences among accuracies via two intuitive and stan
dard rules: \n\nRule 1. After applying GDP, if the differences in accuracies are changed within 20% and accur
acies are still greater than 80%, \nwe consider the models trained on noise data still has statistical inform
ation to provide meaningful insights.\n\nRule 2. After applying GDP, if the differences in accuracies are cha
nged by more than 20%, we consider the models trained on \nnoise data do not have statistical information to
provide meaningful insights. Healthcare statisticians cannot make use of it \nto make decisions.\n\n"
```

In [2]:
```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
import warnings
import os
import yellowbrick
import pickle
from tabulate import tabulate
from matplotlib.collections import PathCollection
from statsmodels.graphics.gofplots import qqplot
from sklearn.preprocessing import MinMaxScaler
from sklearn.model_selection import train_test_split
from sklearn.linear_model import LogisticRegression
from sklearn.neighbors import KNeighborsClassifier
from sklearn.svm import SVC
from sklearn.naive_bayes import GaussianNB
from sklearn.tree import DecisionTreeClassifier
from sklearn.ensemble import RandomForestClassifier, GradientBoostingClassifier, AdaBoostClassifier, ExtraTre
esClassifier
from sklearn.metrics import classification_report, accuracy_score
from xgboost import XGBClassifier
from yellowbrick.classifier import PrecisionRecallCurve, ROCAUC, ConfusionMatrix
from yellowbrick.style import set_palette
from yellowbrick.model_selection import LearningCurve, FeatureImportances
from yellowbrick.contrib.wrapper import wrap

# --- Libraries Settings ---
warnings.filterwarnings('ignore')
sns.set_style('whitegrid')
plt.rcParams['figure.dpi']=100
set_palette('dark')

# --- Create List of Color Palletes ---
red_grad = ['#FF0000', '#BF0000', '#800000', '#400000', '#000000']
pink_grad = ['#8A0030', '#BA1141', '#FF5C8A', '#FF99B9', '#FFDEEB']
purple_grad = ['#4C0028', '#7F0043', '#8E004C', '#A80059', '#C10067']
color_mix = ['#F38BB2', '#FFB9CF', '#FFD7D7', '#F17881', '#E7525B']
black_grad = ['#100C07', '#3E3B39', '#6D6A6A', '#9B9A9C', '#CAC9CD']
```

In [3]:
```
# --- Importing Dataset ---
df = pd.read_csv("datasets/heart_original.csv")

# --- Reading Dataset ---
df.head().style.background_gradient(cmap='Reds').set_properties(**{'font-family': 'Segoe UI'}).hide_index()
```

Out[3]:

age	sex	cp	trestbps	chol	fbs	restecg	thalach	exang	oldpeak	slope	ca	thal	target
52	1	0	125	212	0	1	168	0	1.000000	2	2	3	0
53	1	0	140	203	1	0	155	1	3.100000	0	0	3	0
70	1	0	145	174	0	1	125	1	2.600000	0	0	3	0
61	1	0	148	203	0	1	161	0	0.000000	2	1	3	0
62	0	0	138	294	1	1	106	0	1.900000	1	3	2	0

In [4]:
```
# --- Print Dataset Info ---
print('\033[1m'+'.: Dataset Info :.'+'\033[0m')
print('*' * 30)
print('Total Rows:'+'\033[1m', df.shape[0])
print('\033[0m'+'Total Columns:'+'\033[1m', df.shape[1])
print('\033[0m'+'*' * 30)
print('\n')

# --- Print Dataset Detail ---
print('\033[1m'+'.: Dataset Details :.'+'\033[0m')
print('*' * 30)
df.info(memory_usage = False)
```

```
.: Dataset Info :.
******************************
Total Rows: 1025
Total Columns: 14
******************************


.: Dataset Details :.
******************************
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 1025 entries, 0 to 1024
Data columns (total 14 columns):
 #   Column    Non-Null Count  Dtype  
---  ------    --------------  -----  
 0   age       1025 non-null   int64  
 1   sex       1025 non-null   int64  
 2   cp        1025 non-null   int64  
 3   trestbps  1025 non-null   int64  
 4   chol      1025 non-null   int64  
 5   fbs       1025 non-null   int64  
 6   restecg   1025 non-null   int64  
 7   thalach   1025 non-null   int64  
 8   exang     1025 non-null   int64  
 9   oldpeak   1025 non-null   float64
 10  slope     1025 non-null   int64  
 11  ca        1025 non-null   int64  
 12  thal      1025 non-null   int64  
 13  target    1025 non-null   int64  
dtypes: float64(1), int64(13)
```

In [5]:
```
'''
Create 1 new data sets: df_v2;

How many people are the oldest in the processed.cleveland data set?
What is the oldest age?
'''
df_v1 = df

# df_v2 ------------------------------------------------------------------------------------------------------------
# Find the maximum age
max_age = df_v1['age'].max()

# Count the number of people with the maximum age
num_oldest = df_v1[df_v1['age'] == max_age]['age'].count()

# Output the results
print("There are {} people who are the oldest in the dataset, with an age of {}.".format(num_oldest, max_ag
e))

#--------------------------------------
# Find the index of the oldest individual
oldest_idx = df_v1['age'].idxmax()

# Remove the row with the oldest individual and create a new DataFrame
df_v2 = df_v1.drop(oldest_idx)

# Reset the index of the new DataFrame
df_v2 = df_v2.reset_index(drop=True)

# Comparison -------------------------------------------------------------------------------------------------
-----------------------
# Number of records in df_v1 and df_v2
num_records = [["df_v1", len(df_v1)], ["df_v2", len(df_v2)]]

# Output as table
print(tabulate(num_records, headers=["Dataset", "Number of Records"], tablefmt="grid"))
```

```
There are 3 people who are the oldest in the dataset, with an age of 77.
+-----------+---------------------+
| Dataset   |   Number of Records |
+===========+=====================+
| df_v1     |                1025 |
+-----------+---------------------+
| df_v2     |                1024 |
+-----------+---------------------+
```

In [6]:
```
'''
Since two data sets differ in one record, remove or add one record, the sensitivey for features are 1
'''
sensitivity = 1
epsilon = 0.1
delta = 1e-5
sigma = sensitivity / epsilon

# Compute the standard deviation of the Gaussian noise
std_dev = np.sqrt(2 * np.log(1.25 / delta)) * sensitivity / epsilon

# Gaussian noise
noise = np.random.normal(loc=0, scale=std_dev)

# Add noise to categorical features except dummy variable including corresponding features which are cp, tha
l, slope
df_v2['sex'] = df_v2['sex'] + noise
df_v2['fbs'] = df_v2['fbs'] + noise
df_v2['restecg'] = df_v2['restecg'] + noise
df_v2['exang'] = df_v2['exang'] + noise
df_v2['ca'] = df_v2['ca'] + noise

df_v2.head().style.background_gradient(cmap='Reds').set_properties(**{'font-family': 'Segoe UI'}).hide_index
()
```

Out[6]:

age	sex	cp	trestbps	chol	fbs	restecg	thalach	exang	oldpeak	slope	ca	thal	target
52	0.426936	0	125	212	-0.573064	0.426936	168	-0.573064	1.000000	2	1.426936	3	0
53	0.426936	0	140	203	0.426936	-0.573064	155	0.426936	3.100000	0	-0.573064	3	0
70	0.426936	0	145	174	-0.573064	0.426936	125	0.426936	2.600000	0	-0.573064	3	0
61	0.426936	0	148	203	-0.573064	0.426936	161	-0.573064	0.000000	2	0.426936	3	0
62	-0.573064	0	138	294	0.426936	0.426936	106	-0.573064	1.900000	1	2.426936	2	0

In [7]:
```
df2_categorical = df_v2[['sex', 'fbs', 'restecg', 'exang', 'ca']]

df1_categorical = df_v1[['sex', 'fbs', 'restecg', 'exang', 'ca']]

print("After Applying GDP when e = 0.1:")
df2_categorical.head().style.background_gradient(cmap='Reds').set_properties(**{'font-family': 'Segoe UI'}).h
ide_index()
```

```
After Applying GDP when e = 0.1:
```

Out[7]:

sex	fbs	restecg	exang	ca
0.426936	-0.573064	0.426936	-0.573064	1.426936
0.426936	0.426936	-0.573064	0.426936	-0.573064
0.426936	-0.573064	0.426936	0.426936	-0.573064
0.426936	-0.573064	0.426936	-0.573064	0.426936
-0.573064	0.426936	0.426936	-0.573064	2.426936

In [8]:
```
print("Original Categorical Data:")
df1_categorical.head().style.background_gradient(cmap='Reds').set_properties(**{'font-family': 'Segoe UI'}).h
ide_index()
```

```
Original Categorical Data:
```

Out[8]:

sex	fbs	restecg	exang	ca
1	0	1	0	2
1	1	0	1	0
1	0	1	1	0
1	0	1	0	1
0	1	1	0	3

In [9]:
```
# calculate the difference
df_diff = df2_categorical.subtract(df1_categorical)

# print the result
print("When e = 0.1, the categorical features' values difference between the original data set and the noise data set")
df_diff.head().style.background_gradient(cmap='Reds').set_properties(**{'font-family': 'Segoe UI'}).hide_index()
```

```
When e = 0.1, the categorical features' values difference between the original data set and the noise data se
t
```

Out[9]:

sex	fbs	restecg	exang	ca
-0.573064	-0.573064	-0.573064	-0.573064	-0.573064
-0.573064	-0.573064	-0.573064	-0.573064	-0.573064
-0.573064	-0.573064	-0.573064	-0.573064	-0.573064
-0.573064	-0.573064	-0.573064	-0.573064	-0.573064
-0.573064	-0.573064	-0.573064	-0.573064	-0.573064

In [10]:

```
'''
Calculate the mean difference on each categorical features
'''
mean_diff = df_diff.mean()

# print the result
print("When e = 0.1, the mean difference between the original and noise categorical features:")
# print(mean_diff)
mean_diff = df_diff.mean().to_frame(name='mean_diff')

mean_diff.style.background_gradient(cmap = "Reds_r")
```

```
When e = 0.1, the mean difference between the original and noise categorical features:
```

Out[10]:

	mean_diff
sex	-0.573064
fbs	-0.573064
restecg	-0.572087
exang	-0.574040
ca	-0.575017

In [11]:

```
'''
Calculate the varriance difference on each categorical features
'''
variance_diff = df2_categorical.var() - df1_categorical.var()
print("When e = 0.1, the variance difference between the original and noise categorical features:")
# print(variance_diff)
variance_diff = pd.DataFrame({'variance_diff': variance_diff})
variance_diff.style.background_gradient(cmap = "Reds_r")
```

When e = 0.1, the variance difference between the original and noise categorical features:

Out[11]:

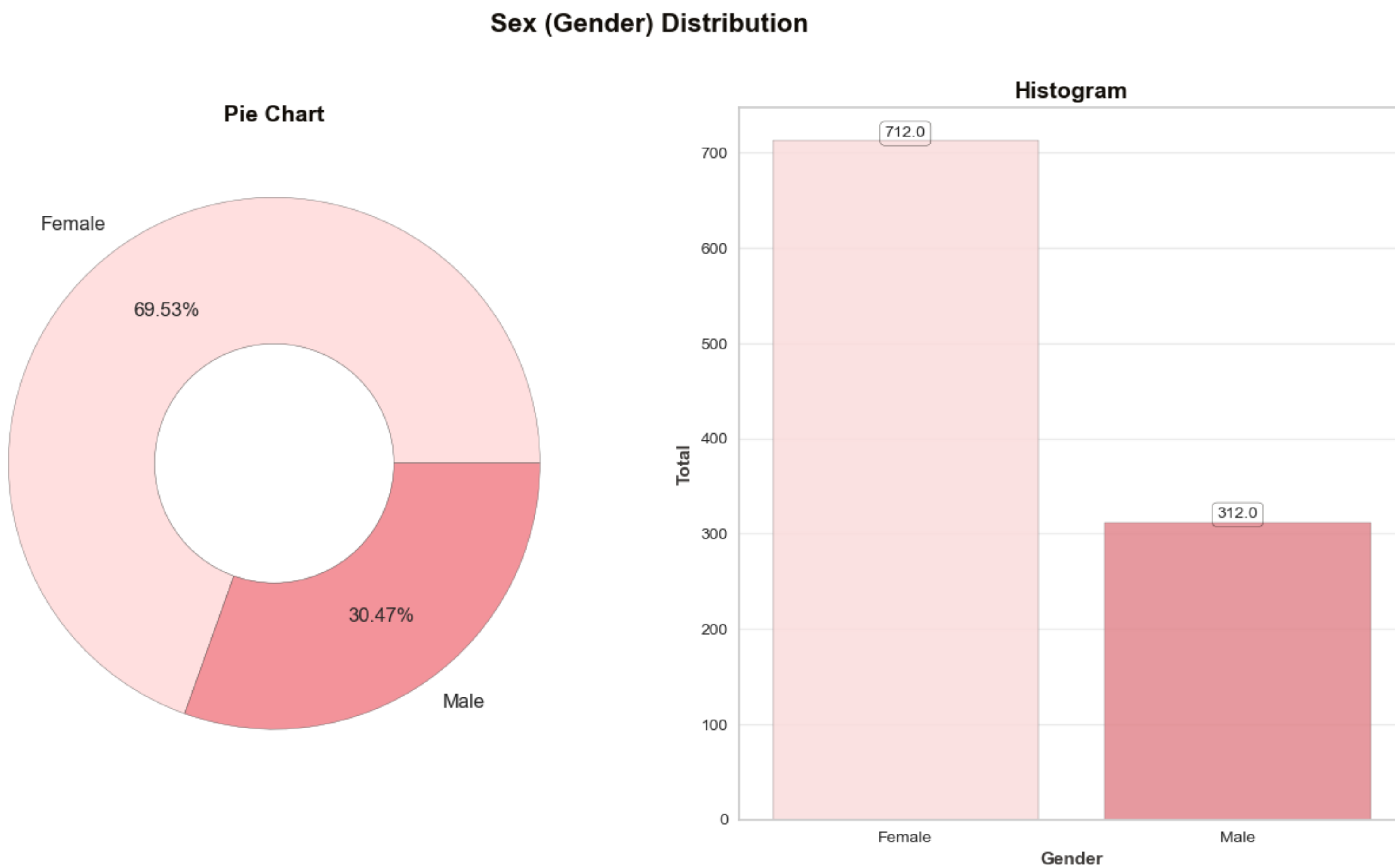
	variance_diff
sex	0.000117
fbs	0.000102
restecg	-0.000002
exang	-0.000212
ca	-0.003897

In [12]:
```
'''
Pay more attention to check the attributes we added noise to see the change/difference by comparing with
'''
# --- Setting Colors, Labels, Order ---
colors=color_mix[2:4]
labels=['Female', 'Male']
order=df_v2['sex'].value_counts().index

# --- Size for Both Figures ---
plt.figure(figsize=(16, 8))
plt.suptitle('Sex (Gender) Distribution', fontweight='heavy',
             fontsize='16', fontfamily='sans-serif', color=black_grad[0])

# --- Pie Chart ---
plt.subplot(1, 2, 1)
plt.title('Pie Chart', fontweight='bold', fontsize=14,
          fontfamily='sans-serif', color=black_grad[0])
plt.pie(df_v2['sex'].value_counts(), labels=labels, colors=colors, pctdistance=0.7,
        autopct='%.2f%%', wedgeprops=dict(alpha=0.8, edgecolor=black_grad[1]),
        textprops={'fontsize':12})
centre=plt.Circle((0, 0), 0.45, fc='white', edgecolor=black_grad[1])
plt.gcf().gca().add_artist(centre)

# --- Histogram ---
countplt = plt.subplot(1, 2, 2)
plt.title('Histogram', fontweight='bold', fontsize=14,
          fontfamily='sans-serif', color=black_grad[0])
ax = sns.countplot(x='sex', data=df_v2, palette=colors, order=order,
                   edgecolor=black_grad[2], alpha=0.85)
for rect in ax.patches:
    ax.text (rect.get_x()+rect.get_width()/2,
             rect.get_height()+4.25,rect.get_height(),
             horizontalalignment='center', fontsize=10,
             bbox=dict(facecolor='none', edgecolor=black_grad[0],
                       linewidth=0.25, boxstyle='round'))

plt.xlabel('Gender', fontweight='bold', fontsize=11, fontfamily='sans-serif',
           color=black_grad[1])
plt.ylabel('Total', fontweight='bold', fontsize=11, fontfamily='sans-serif',
           color=black_grad[1])
plt.xticks([0, 1], labels)
```

```
plt.grid(axis='y', alpha=0.4)
countplt
# --- Count Categorical Labels w/out Dropping Null Walues ---
print('*' * 25)
print('\033[1m'+'.: Sex (Gender) Total :.'+'\033[0m')
print('*' * 25)
df_v2.sex.value_counts(dropna=False)
```

```
************************
.: Sex (Gender) Total :.
************************
```

Out[12]:
```
 0.426936    712
-0.573064    312
Name: sex, dtype: int64
```

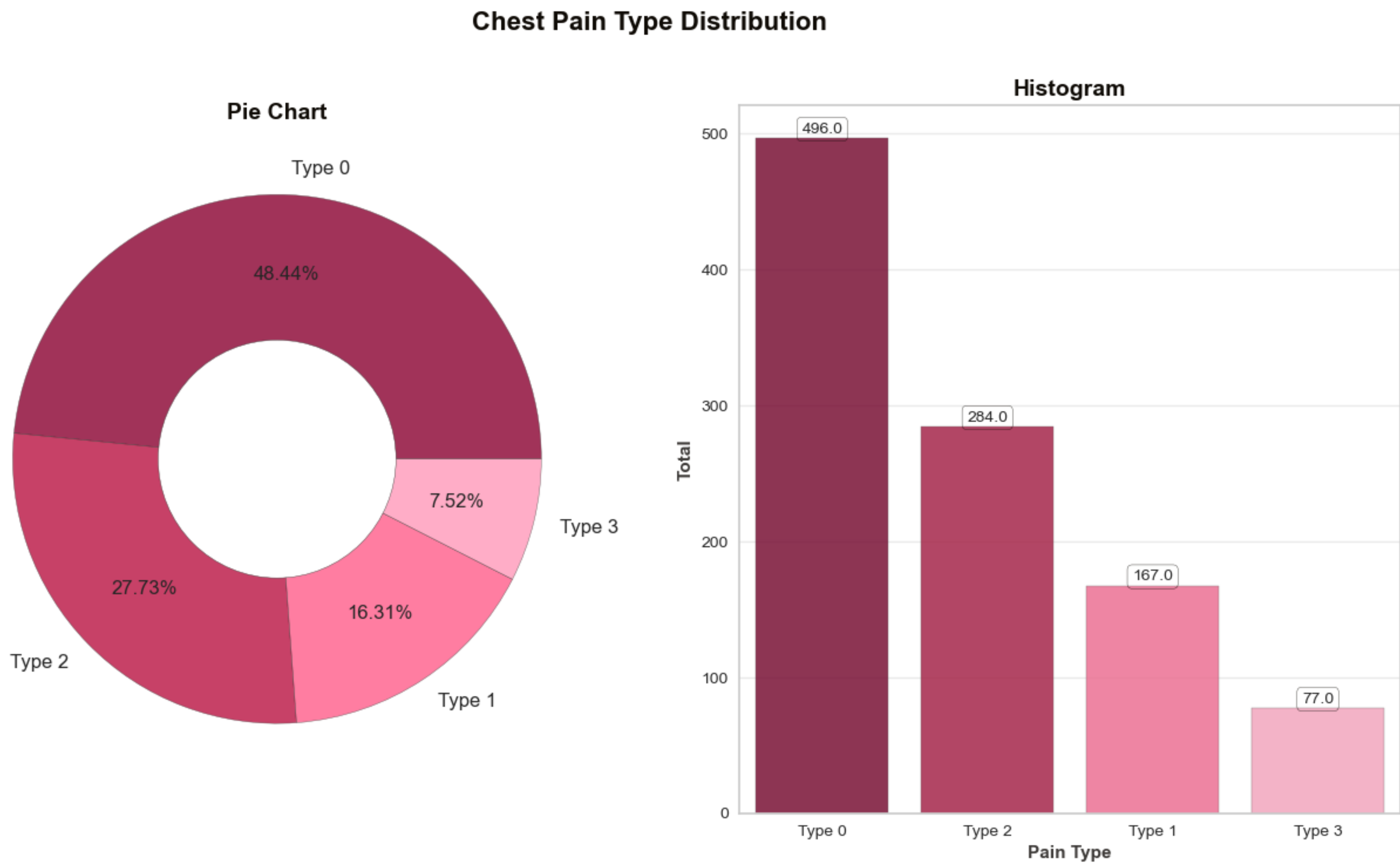


In [13]:
```
# --- Setting Colors, Labels, Order ---
colors=pink_grad[0:4]
labels=['Type 0', 'Type 2', 'Type 1', 'Type 3']
order=df_v2['cp'].value_counts().index

# --- Size for Both Figures ---
plt.figure(figsize=(16, 8))
plt.suptitle('Chest Pain Type Distribution', fontweight='heavy', fontsize=16,
             fontfamily='sans-serif', color=black_grad[0])

# --- Pie Chart ---
plt.subplot(1, 2, 1)
plt.title('Pie Chart', fontweight='bold', fontsize=14,fontfamily='sans-serif',
          color=black_grad[0])
plt.pie(df_v2['cp'].value_counts(), labels=labels, colors=colors, pctdistance=0.7,
        autopct='%.2f%%', textprops={'fontsize':12},
        wedgeprops=dict(alpha=0.8, edgecolor=black_grad[1]))
centre=plt.Circle((0, 0), 0.45, fc='white', edgecolor=black_grad[1])
plt.gcf().gca().add_artist(centre)

# --- Histogram ---
countplt = plt.subplot(1, 2, 2)
plt.title('Histogram', fontweight='bold', fontsize=14, fontfamily='sans-serif',
          color=black_grad[0])
ax = sns.countplot(x='cp', data=df_v2, palette=colors, order=order,
                   edgecolor=black_grad[2], alpha=0.85)
for rect in ax.patches:
    ax.text (rect.get_x()+rect.get_width()/2,
             rect.get_height()+4.25,rect.get_height(),
             horizontalalignment='center', fontsize=10,
             bbox=dict(facecolor='none', edgecolor=black_grad[0], linewidth=0.25,
                       boxstyle='round'))

plt.xlabel('Pain Type', fontweight='bold', fontsize=11, fontfamily='sans-serif',
           color=black_grad[1])
plt.ylabel('Total', fontweight='bold', fontsize=11, fontfamily='sans-serif',
           color=black_grad[1])
plt.xticks([0, 1, 2, 3], labels)
plt.grid(axis='y', alpha=0.4)
countplt
```

```
# --- Count Categorical Labels w/out Dropping Null Walues ---
print('*' * 30)
print('\033[1m'+'.: Chest Pain Type Total :.'+'\033[0m')
print('*' * 30)
df_v2.cp.value_counts(dropna=False)
```

```
******************************
.: Chest Pain Type Total :.
******************************
```

Out[13]:
```
0    496
2    284
1    167
3     77
Name: cp, dtype: int64
```

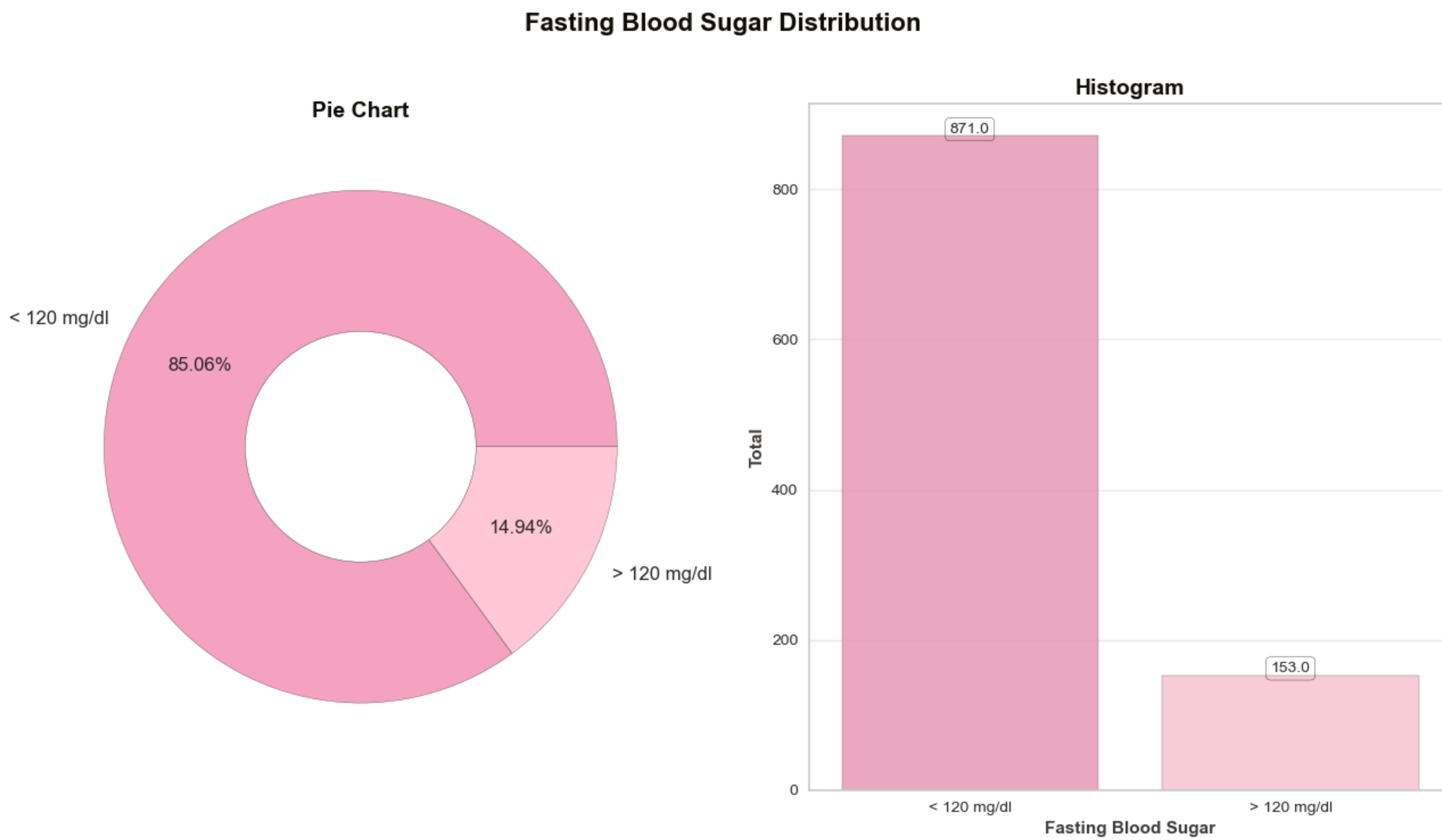


In [14]:
```
# --- Setting Colors, Labels, Order ---
colors=color_mix[0:2]
labels=['< 120 mg/dl', '> 120 mg/dl']
order=df_v2['fbs'].value_counts().index

# --- Size for Both Figures ---
plt.figure(figsize=(16, 8))
plt.suptitle('Fasting Blood Sugar Distribution', fontweight='heavy',
             fontsize=16, fontfamily='sans-serif', color=black_grad[0])

# --- Pie Chart ---
plt.subplot(1, 2, 1)
plt.title('Pie Chart', fontweight='bold', fontsize=14, fontfamily='sans-serif',
          color=black_grad[0])
plt.pie(df_v2['fbs'].value_counts(), labels=labels, colors=colors,
        wedgeprops=dict(alpha=0.8, edgecolor=black_grad[1]), autopct='%.2f%%',
        pctdistance=0.7, textprops={'fontsize':12})
centre=plt.Circle((0, 0), 0.45, fc='white', edgecolor=black_grad[1])
plt.gcf().gca().add_artist(centre)

# --- Histogram ---
countplt = plt.subplot(1, 2, 2)
plt.title('Histogram', fontweight='bold', fontsize=14, fontfamily='sans-serif',
          color=black_grad[0])
ax = sns.countplot(x='fbs', data=df_v2, palette=colors, order=order,
                   edgecolor=black_grad[2], alpha=0.85)
for rect in ax.patches:
    ax.text (rect.get_x()+rect.get_width()/2,
             rect.get_height()+4.25,rect.get_height(),
             horizontalalignment='center', fontsize=10,
             bbox=dict(facecolor='none', edgecolor=black_grad[0], linewidth=0.25,
                       boxstyle='round'))

plt.xlabel('Fasting Blood Sugar', fontweight='bold', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])
plt.ylabel('Total', fontweight='bold', fontsize=11, fontfamily='sans-serif',
           color=black_grad[1])
plt.xticks([0, 1], labels)
plt.grid(axis='y', alpha=0.4)
countplt
```

```
# --- Count Categorical Labels w/out Dropping Null Walues ---
print('*' * 32)
print('\033[1m'+'.: Fasting Blood Sugar Total :.'+'\033[0m')
print('*' * 32)
df_v2.fbs.value_counts(dropna=False)
```

```
********************************
.: Fasting Blood Sugar Total :.
********************************
```

Out[14]:
```
-0.573064    871
 0.426936    153
Name: fbs, dtype: int64
```

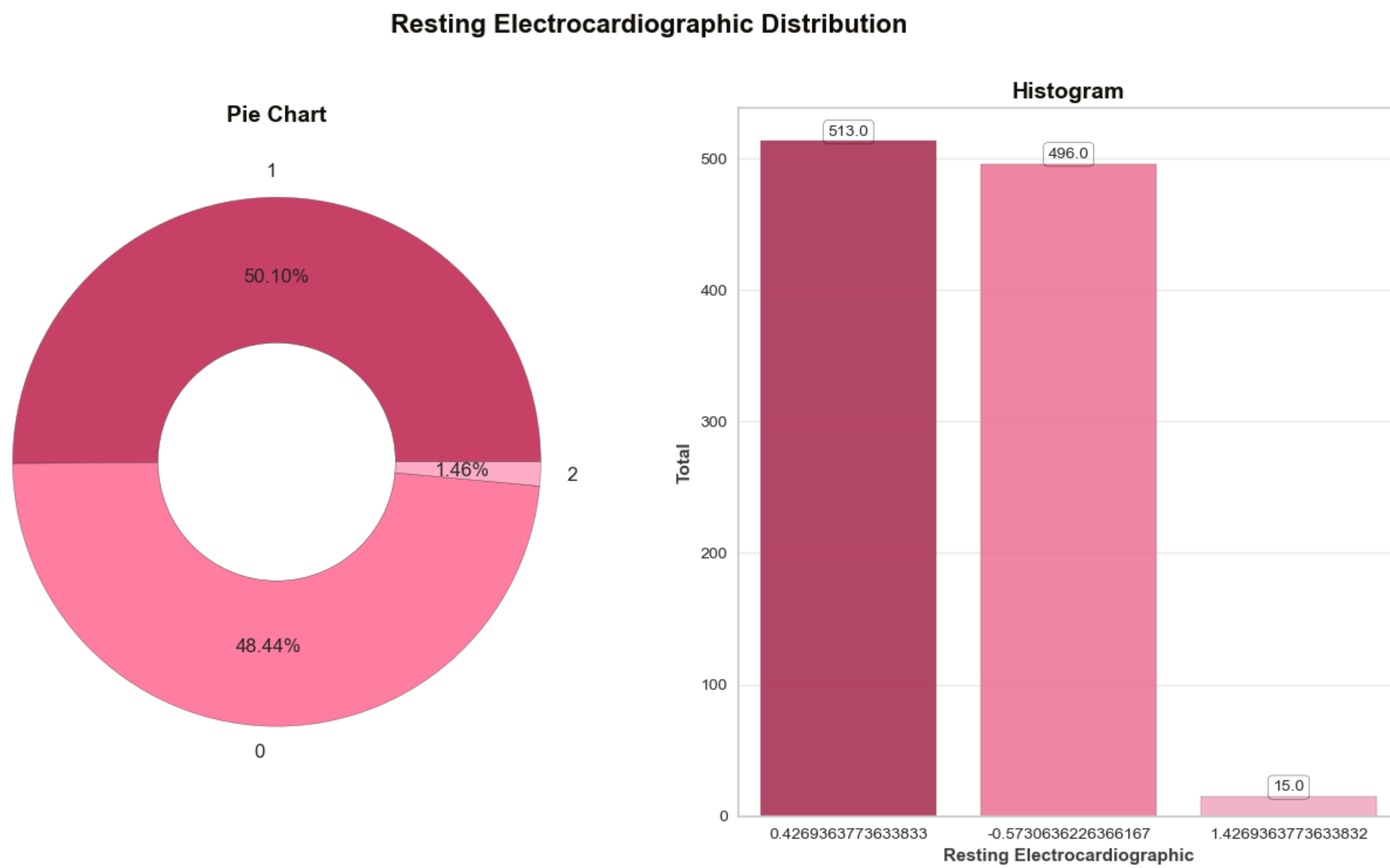


In [15]:
```
# --- Setting Colors, Labels, Order ---
colors=pink_grad[1:4]
labels=['1', '0', '2']
order=df_v2['restecg'].value_counts().index

# --- Size for Both Figures ---
plt.figure(figsize=(16, 8))
plt.suptitle('Resting Electrocardiographic Distribution', fontweight='heavy',
             fontsize=16, fontfamily='sans-serif', color=black_grad[0])

# --- Pie Chart ---
plt.subplot(1,2,1)
plt.title('Pie Chart', fontweight='bold', fontsize=14, fontfamily='sans-serif',
          color=black_grad[0])
plt.pie(df_v2['restecg'].value_counts(), labels=labels, colors=colors,
        wedgeprops=dict(alpha=0.8, edgecolor=black_grad[1]), autopct='%.2f%%',
        pctdistance=0.7, textprops={'fontsize':12})
centre=plt.Circle((0, 0), 0.45, fc='white', edgecolor=black_grad[1])
plt.gcf().gca().add_artist(centre)

# --- Histogram ---
countplt = plt.subplot(1, 2, 2)
plt.title('Histogram', fontweight='bold', fontsize=14, fontfamily='sans-serif',
          color=black_grad[0])
ax = sns.countplot(x='restecg', data=df_v2, palette=colors, order=order,
                   edgecolor=black_grad[2], alpha=0.85)
for rect in ax.patches:
    ax.text (rect.get_x()+rect.get_width()/2,
             rect.get_height()+4.25,rect.get_height(),
             horizontalalignment='center', fontsize=10,
             bbox=dict(facecolor='none', edgecolor=black_grad[0], linewidth=0.25,
                       boxstyle='round'))

plt.xlabel('Resting Electrocardiographic', fontweight='bold', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])
plt.ylabel('Total', fontweight='bold', fontsize=11, fontfamily='sans-serif',
           color=black_grad[1])
plt.grid(axis='y', alpha=0.4)
countplt

# --- Count Categorical Labels w/out Dropping Null Walues ---
```

```
print('*' * 50)
print('\033[1m'+'.: Resting Electrocardiographic Results Total :.'+'\033[0m')
print('*' * 50)
df_v2.restecg.value_counts(dropna=False)
```

```
**************************************************
.: Resting Electrocardiographic Results Total :.
**************************************************
```

Out[15]:
```
 0.426936    513
-0.573064    496
 1.426936     15
Name: restecg, dtype: int64
```

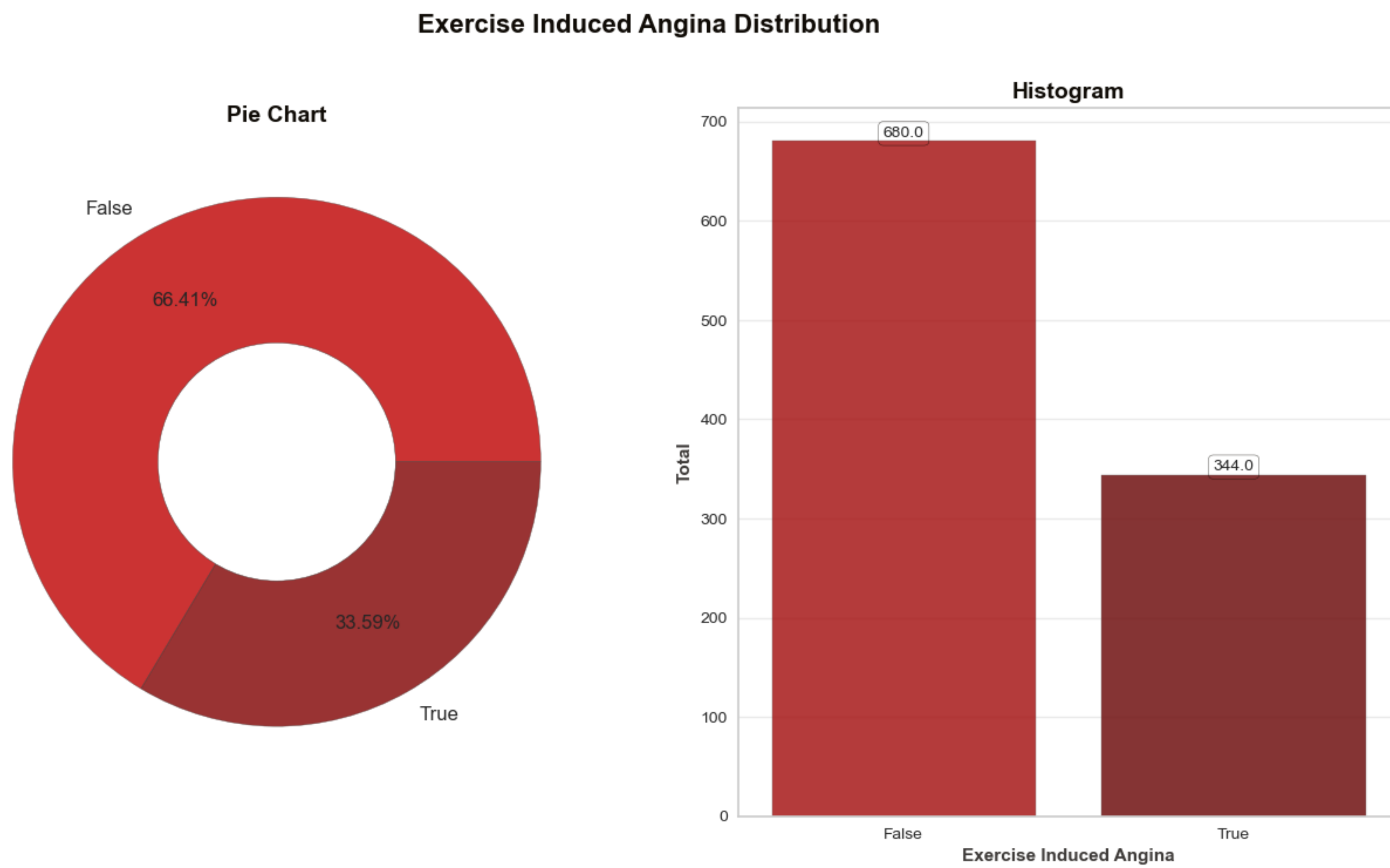


In [16]:
```
# --- Setting Colors, Labels, Order ---
colors=red_grad[1:3]
labels=['False', 'True']
order=df_v2['exang'].value_counts().index

# --- Size for Both Figures ---
plt.figure(figsize=(16, 8))
plt.suptitle('Exercise Induced Angina Distribution', fontweight='heavy',
             fontsize=16, fontfamily='sans-serif', color=black_grad[0])

# --- Pie Chart ---
plt.subplot(1,2,1)
plt.title('Pie Chart', fontweight='bold', fontsize=14, fontfamily='sans-serif',
          color=black_grad[0])
plt.pie(df_v2['exang'].value_counts(), labels=labels, colors=colors,
        wedgeprops=dict(alpha=0.8, edgecolor=black_grad[1]), autopct='%.2f%%',
        pctdistance=0.7, textprops={'fontsize':12})
centre=plt.Circle((0, 0), 0.45, fc='white', edgecolor=black_grad[1])
plt.gcf().gca().add_artist(centre)

# --- Histogram ---
countplt = plt.subplot(1, 2, 2)
plt.title('Histogram', fontweight='bold', fontsize=14, fontfamily='sans-serif',
          color=black_grad[0])
ax = sns.countplot(x='exang', data=df_v2, palette=colors, order=order,
                   edgecolor=black_grad[2], alpha=0.85)
for rect in ax.patches:
    ax.text (rect.get_x()+rect.get_width()/2,
             rect.get_height()+4.25,rect.get_height(),
             horizontalalignment='center', fontsize=10,
             bbox=dict(facecolor='none', edgecolor=black_grad[0], linewidth=0.25,
                       boxstyle='round'))

plt.xlabel('Exercise Induced Angina', fontweight='bold', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])
plt.ylabel('Total', fontweight='bold', fontsize=11, fontfamily='sans-serif',
           color=black_grad[1])
plt.xticks([0, 1], labels)
plt.grid(axis='y', alpha=0.4)
countplt
```

```
# --- Count Categorical Labels w/out Dropping Null Walues ---
print('*' * 35)
print('\033[1m'+'.: Exercise Induced Angina Total :.'+'\033[0m')
print('*' * 35)
df_v2.exang.value_counts(dropna=False)
```

```
***********************************
.: Exercise Induced Angina Total :.
***********************************
```

Out[16]:
```
-0.573064    680
 0.426936    344
Name: exang, dtype: int64
```

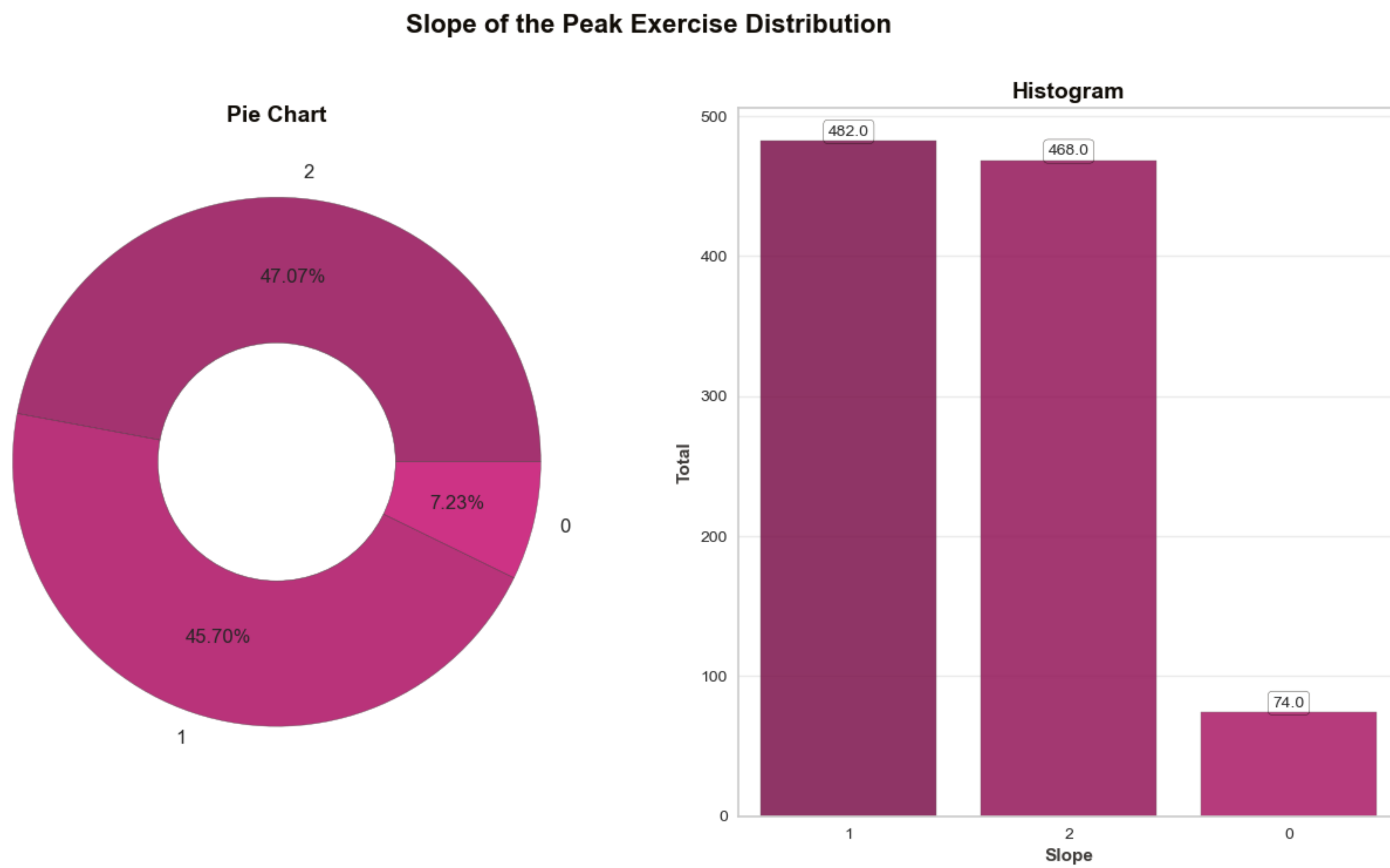


In [17]:
```
# --- Setting Colors, Labels, Order ---
colors=purple_grad[2:5]
labels=['2', '1', '0']
order=df_v2['slope'].value_counts().index

# --- Size for Both Figures ---
plt.figure(figsize=(16, 8))
plt.suptitle('Slope of the Peak Exercise Distribution', fontweight='heavy',
             fontsize=16, fontfamily='sans-serif', color=black_grad[0])

# --- Pie Chart ---
plt.subplot(1, 2, 1)
plt.title('Pie Chart', fontweight='bold', fontsize=14,
          fontfamily='sans-serif', color=black_grad[0])
plt.pie(df_v2['slope'].value_counts(), labels=labels, colors=colors,
        wedgeprops=dict(alpha=0.8, edgecolor=black_grad[1]), autopct='%.2f%%',
        pctdistance=0.7, textprops={'fontsize':12})
centre=plt.Circle((0, 0), 0.45, fc='white', edgecolor=black_grad[1])
plt.gcf().gca().add_artist(centre)


# --- Histogram ---
countplt = plt.subplot(1, 2, 2)
plt.title('Histogram', fontweight='bold', fontsize=14, fontfamily='sans-serif',
          color=black_grad[0])
ax = sns.countplot(x='slope', data=df_v2, palette=colors, order=order,
                   edgecolor=black_grad[2], alpha=0.85)
for rect in ax.patches:
    ax.text (rect.get_x()+rect.get_width()/2,
             rect.get_height()+4.25,rect.get_height(),
             horizontalalignment='center', fontsize=10,
             bbox=dict(facecolor='none', edgecolor=black_grad[0], linewidth=0.25,
                       boxstyle='round'))

plt.xlabel('Slope', fontweight='bold', fontsize=11, fontfamily='sans-serif',
           color=black_grad[1])
plt.ylabel('Total', fontweight='bold', fontsize=11, fontfamily='sans-serif',
           color=black_grad[1])
plt.grid(axis='y', alpha=0.4)
countplt
# --- Count Categorical Labels w/out Dropping Null Walues ---
```

```
print('*' * 20)
print('\033[1m'+'.: Slope Total :.'+'\033[0m')
print('*' * 20)
df_v2.slope.value_counts(dropna=False)
```

```
********************
.: Slope Total :.
********************
```

Out[17]:
```
1    482
2    468
0     74
Name: slope, dtype: int64
```

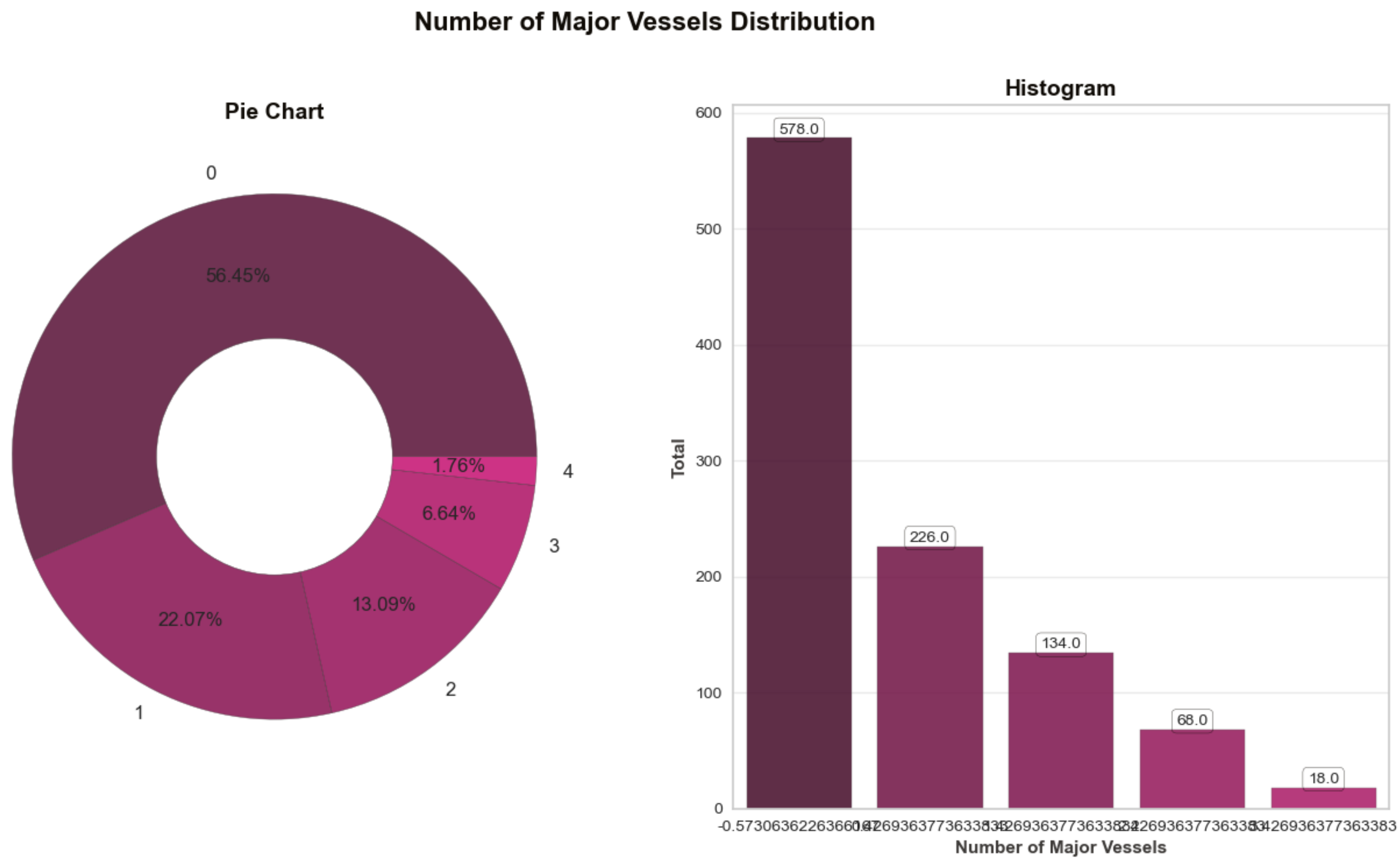


In [18]:
```
# --- Setting Colors, Labels, Order ---
colors=purple_grad
labels=['0', '1', '2', '3', '4']
order=df_v2['ca'].value_counts().index

# --- Size for Both Figures ---
plt.figure(figsize=(16, 8))
plt.suptitle('Number of Major Vessels Distribution', fontweight='heavy',
             fontsize=16, fontfamily='sans-serif', color=black_grad[0])

# --- Pie Chart ---
plt.subplot(1,2,1)
plt.title('Pie Chart', fontweight='bold', fontsize=14, fontfamily='sans-serif',
          color=black_grad[0])
plt.pie(df_v2['ca'].value_counts(), labels=labels, colors=colors,
        wedgeprops=dict(alpha=0.8, edgecolor=black_grad[1]),
        autopct='%.2f%%', pctdistance=0.7, textprops={'fontsize':12})

centre=plt.Circle((0, 0), 0.45, fc='white', edgecolor=black_grad[1])
plt.gcf().gca().add_artist(centre)

# --- Histogram ---
countplt = plt.subplot(1, 2, 2)
plt.title('Histogram', fontweight='bold', fontsize=14, fontfamily='sans-serif',
          color=black_grad[0])
ax = sns.countplot(x='ca', data=df_v2, palette=colors, order=order,
                   edgecolor=black_grad[2], alpha=0.85)
for rect in ax.patches:
    ax.text (rect.get_x()+rect.get_width()/2,
             rect.get_height()+4.25,rect.get_height(),
             horizontalalignment='center', fontsize=10,
             bbox=dict(facecolor='none', edgecolor=black_grad[0], linewidth=0.25,
                       boxstyle='round'))

plt.xlabel('Number of Major Vessels', fontweight='bold', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])
plt.ylabel('Total', fontweight='bold', fontsize=11, fontfamily='sans-serif',
           color=black_grad[1])
plt.grid(axis='y', alpha=0.4)
countplt
```

```
# --- Count Categorical Labels w/out Dropping Null Walues ---
print('*' * 40)
print('\033[1m'+'.: Number of Major Vessels Total :.'+'\033[0m')
print('*' * 40)
df_v2.ca.value_counts(dropna=False)
```

```
****************************************
.: Number of Major Vessels Total :.
****************************************
```

Out[18]:
```
-0.573064    578
 0.426936    226
 1.426936    134
 2.426936     68
 3.426936     18
Name: ca, dtype: int64
```

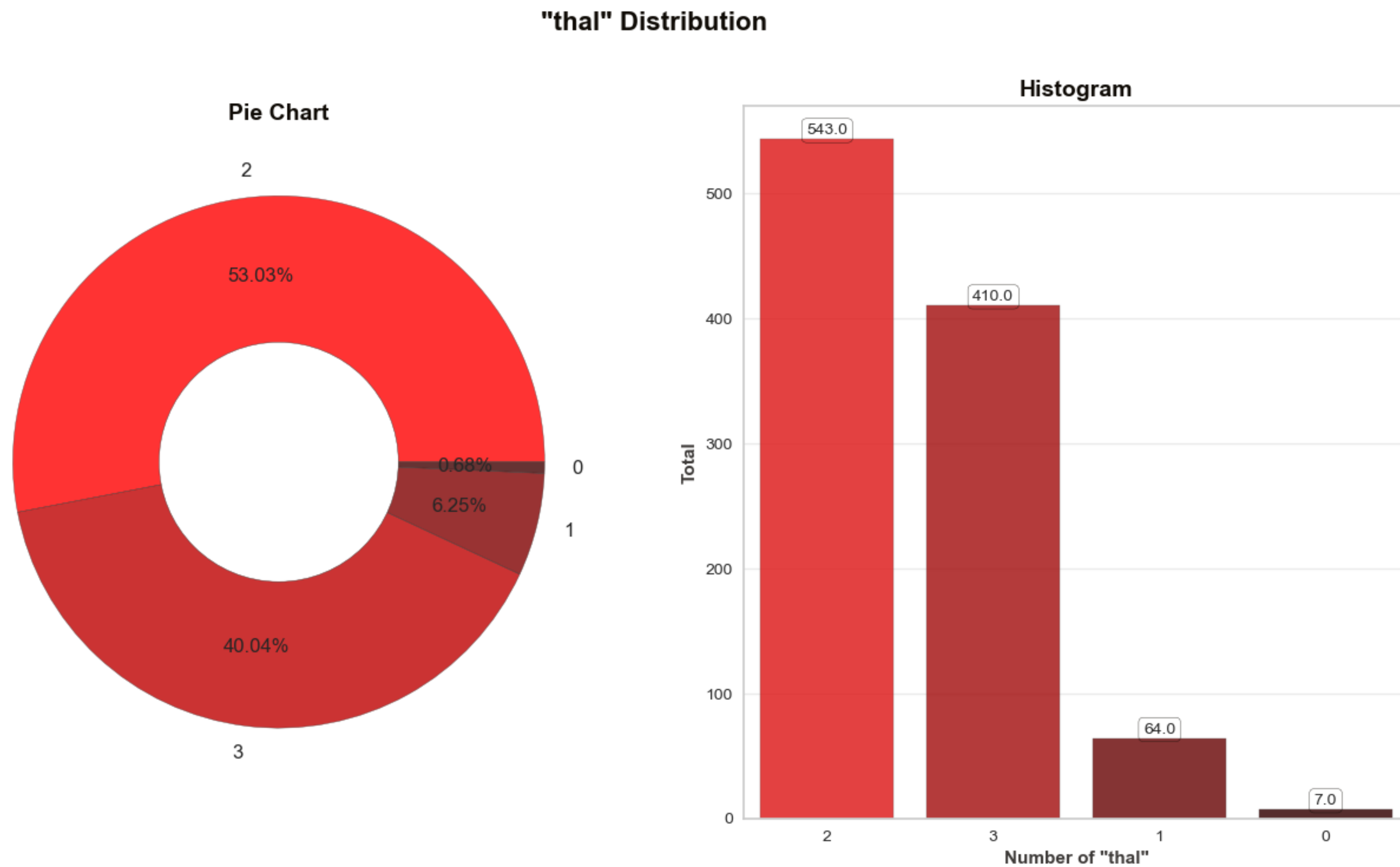


In [19]:
```
# --- Setting Colors, Labels, Order ---
colors=red_grad[0:4]
labels=['2', '3', '1', '0']
order=df_v2['thal'].value_counts().index

# --- Size for Both Figures ---
plt.figure(figsize=(16,8))
plt.suptitle('"thal" Distribution', fontweight='heavy', fontsize=16,
             fontfamily='sans-serif', color=black_grad[0])

# --- Pie Chart ---
plt.subplot(1,2,1)
plt.title('Pie Chart', fontweight='bold', fontsize=14, fontfamily='sans-serif',
          color=black_grad[0])
plt.pie(df_v2['thal'].value_counts(), labels=labels, colors=colors,
        wedgeprops=dict(alpha=0.8, edgecolor=black_grad[1]),
        autopct='%.2f%%', pctdistance=0.7, textprops={'fontsize':12})

centre=plt.Circle((0, 0), 0.45, fc='white', edgecolor=black_grad[1])
plt.gcf().gca().add_artist(centre)

# --- Histogram ---
countplt = plt.subplot(1, 2, 2)
plt.title('Histogram', fontweight='bold', fontsize=14, fontfamily='sans-serif',
          color=black_grad[0])
ax = sns.countplot(x='thal', data=df_v2, palette=colors, order=order,
                   edgecolor=black_grad[2], alpha=0.85)
for rect in ax.patches:
    ax.text (rect.get_x()+rect.get_width()/2,
             rect.get_height()+4.25,rect.get_height(),
             horizontalalignment='center', fontsize=10,
             bbox=dict(facecolor='none', edgecolor=black_grad[0], linewidth=0.25,
                       boxstyle='round'))

plt.xlabel('Number of "thal"', fontweight='bold', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])
plt.ylabel('Total', fontweight='bold', fontsize=11, fontfamily='sans-serif',
           color=black_grad[1])
plt.grid(axis='y', alpha=0.4)
countplt
```

```
# --- Count Categorical Labels w/out Dropping Null Walues ---
print('*' * 20)
print('\033[1m'+'.: "thal" Total :.'+'\033[0m')
print('*' * 20)
df_v2.thal.value_counts(dropna=False)
```

```
*******************
.: "thal" Total :.
*******************
```

Out[19]:
```
2    543
3    410
1     64
0      7
Name: thal, dtype: int64
```

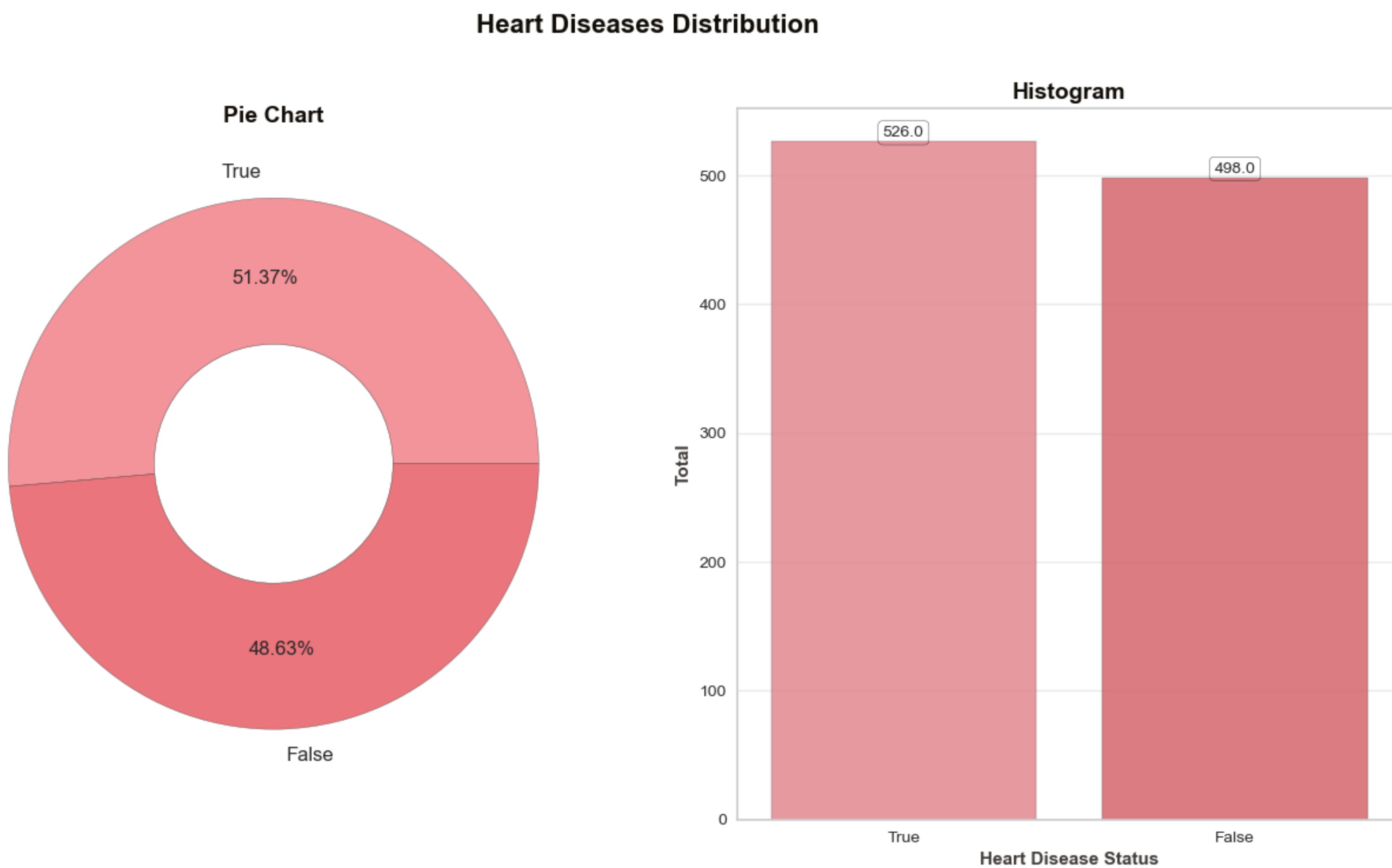


In [20]:
```
# --- Setting Colors, Labels, Order ---
colors=color_mix[3:5]
labels=['True', 'False']
order=df_v2['target'].value_counts().index

# --- Size for Both Figures ---
plt.figure(figsize=(16,8))
plt.suptitle('Heart Diseases Distribution', fontweight='heavy',
             fontsize=16, fontfamily='sans-serif', color=black_grad[0])

# --- Pie Chart ---
plt.subplot(1, 2, 1)
plt.title('Pie Chart', fontweight='bold', fontsize=14, fontfamily='sans-serif',
          color=black_grad[0])
plt.pie(df_v2['target'].value_counts(), labels=labels, colors=colors,
        wedgeprops=dict(alpha=0.8, edgecolor=black_grad[1]), autopct='%.2f%%',
        pctdistance=0.7, textprops={'fontsize':12})
centre=plt.Circle((0, 0), 0.45, fc='white', edgecolor=black_grad[1])
plt.gcf().gca().add_artist(centre)

# --- Histogram ---
countplt = plt.subplot(1, 2, 2)
plt.title('Histogram', fontweight='bold', fontsize=14, fontfamily='sans-serif',
          color=black_grad[0])
ax = sns.countplot(x='target', data=df_v2, palette=colors, order=order,
                   edgecolor=black_grad[2], alpha=0.85)
for rect in ax.patches:
    ax.text (rect.get_x()+rect.get_width()/2,
             rect.get_height()+4.25,rect.get_height(),
             horizontalalignment='center', fontsize=10,
             bbox=dict(facecolor='none', edgecolor=black_grad[0], linewidth=0.25,
                       boxstyle='round'))

plt.xlabel('Heart Disease Status', fontweight='bold', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])
plt.ylabel('Total', fontweight='bold', fontsize=11, fontfamily='sans-serif',
           color=black_grad[1])
plt.xticks([0, 1], labels)
plt.grid(axis='y', alpha=0.4)
countplt
```

```
# --- Count Categorical Labels w/out Dropping Null Walues ---
print('*' * 45)
print('\033[1m'+'.: Heart Diseases Status (target) Total :.'+'\033[0m')
print('*' * 45)
df_v2.target.value_counts(dropna=False)
```

```
*********************************************
.: Heart Diseases Status (target) Total :.
*********************************************
```

Out[20]:
```
1    526
0    498
Name: target, dtype: int64
```



In [21]:

```
'''
Numerical Variable
Descriptive Statistics

'''
# --- Descriptive Statistics ---
df.select_dtypes(exclude='object').describe().T.style.background_gradient(cmap='PuRd').set_properties(**{'font-family': 'Segoe UI'})
```

Out[21]:

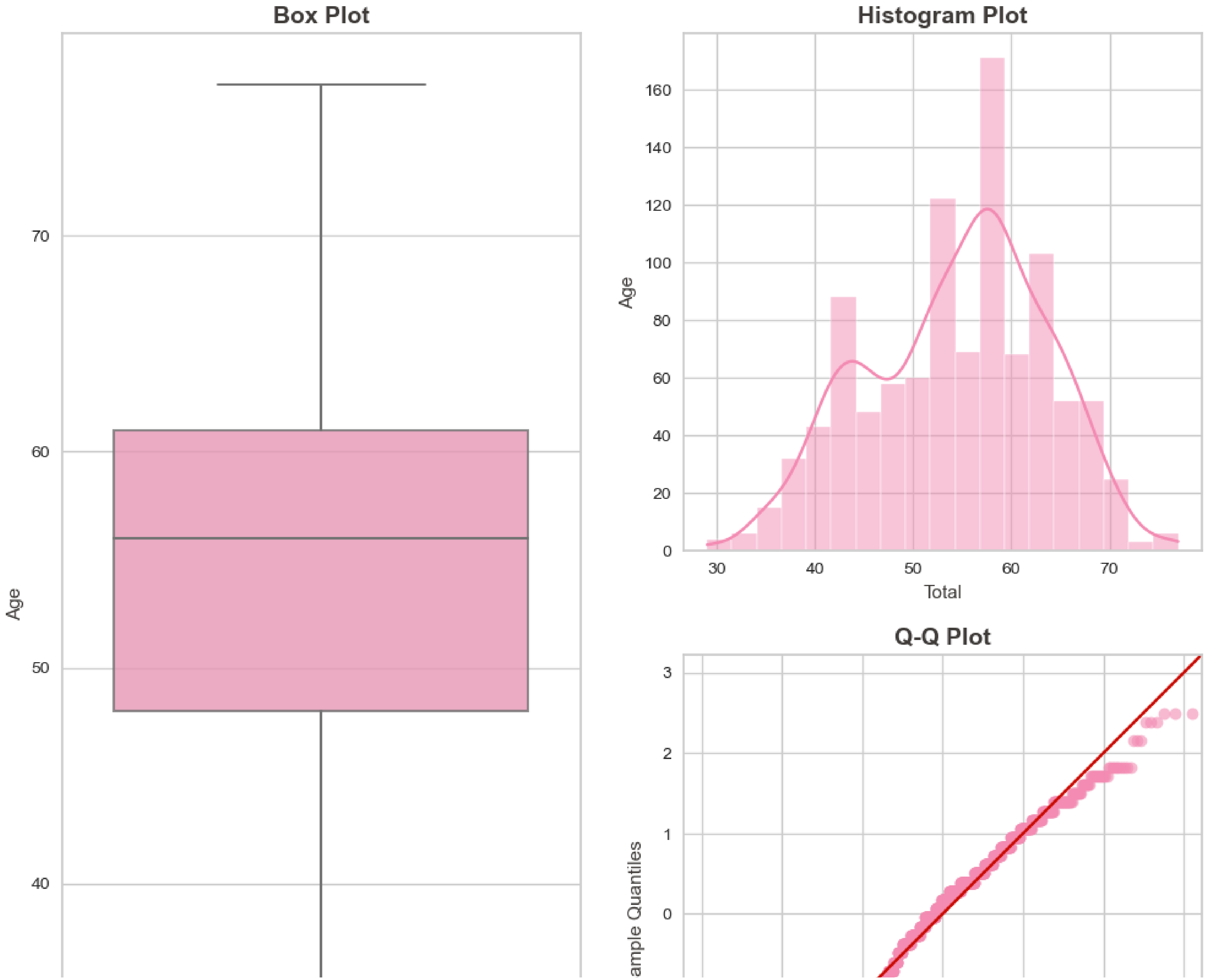
	count	mean	std	min	25%	50%	75%	max
age	1025.000000	54.434146	9.072290	29.000000	48.000000	56.000000	61.000000	77.000000
sex	1025.000000	0.695610	0.460373	0.000000	0.000000	1.000000	1.000000	1.000000
cp	1025.000000	0.942439	1.029641	0.000000	0.000000	1.000000	2.000000	3.000000
trestbps	1025.000000	131.611707	17.516718	94.000000	120.000000	130.000000	140.000000	200.000000
chol	1025.000000	246.000000	51.592510	126.000000	211.000000	240.000000	275.000000	564.000000
fbs	1025.000000	0.149268	0.356527	0.000000	0.000000	0.000000	0.000000	1.000000
restecg	1025.000000	0.529756	0.527878	0.000000	0.000000	1.000000	1.000000	2.000000
thalach	1025.000000	149.114146	23.005724	71.000000	132.000000	152.000000	166.000000	202.000000
exang	1025.000000	0.336585	0.472772	0.000000	0.000000	0.000000	1.000000	1.000000
oldpeak	1025.000000	1.071512	1.175053	0.000000	0.000000	0.800000	1.800000	6.200000
slope	1025.000000	1.385366	0.617755	0.000000	1.000000	1.000000	2.000000	2.000000
ca	1025.000000	0.754146	1.030798	0.000000	0.000000	0.000000	1.000000	4.000000
thal	1025.000000	2.323902	0.620660	0.000000	2.000000	2.000000	3.000000	3.000000
target	1025.000000	0.513171	0.500070	0.000000	0.000000	1.000000	1.000000	1.000000

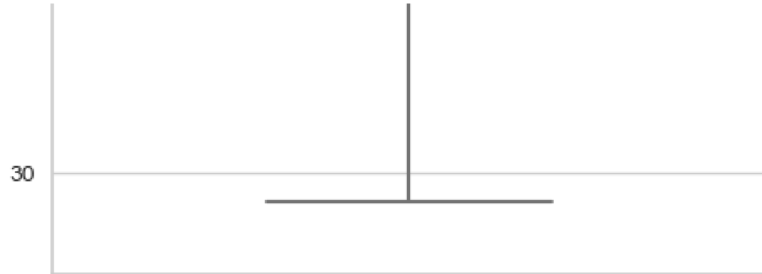
In [22]:
```
'''
Categorical Column Distribution
'''
# --- Variable, Color & Plot Size ---
var = 'age'
color = color_mix[0]
fig=plt.figure(figsize=(12, 12))

# --- Skewness & Kurtosis ---
print('\033[1m'+'.: Age Column Skewness & Kurtosis :.'+'\033[0m')
print('*' * 40)
print('Skewness:'+'\033[1m {:.3f}'.format(df[var].skew(axis = 0, skipna = True)))
print('\033[0m'+'Kurtosis:'+'\033[1m {:.3f}'.format(df[var].kurt(axis = 0, skipna = True)))
print('\n')

# --- General Title ---
fig.suptitle('Age Column Distribution', fontweight='bold', fontsize=16,
             fontfamily='sans-serif', color=black_grad[0])
fig.subplots_adjust(top=0.9)

# --- Histogram ---
ax_1=fig.add_subplot(2, 2, 2)
plt.title('Histogram Plot', fontweight='bold', fontsize=14,
          fontfamily='sans-serif', color=black_grad[1])
sns.histplot(data=df, x=var, kde=True, color=color)
plt.xlabel('Total', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])
plt.ylabel('Age', fontweight='regular', fontsize=11, fontfamily='sans-serif',
           color=black_grad[1])

# --- Q-Q Plot ---
ax_2=fig.add_subplot(2, 2, 4)
plt.title('Q-Q Plot', fontweight='bold', fontsize=14,
          fontfamily='sans-serif', color=black_grad[1])
qqplot(df[var], fit=True, line='45', ax=ax_2, markerfacecolor=color,
       markeredgecolor=color, alpha=0.6)
plt.xlabel('Theoritical Quantiles', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])
plt.ylabel('Sample Quantiles', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])
```

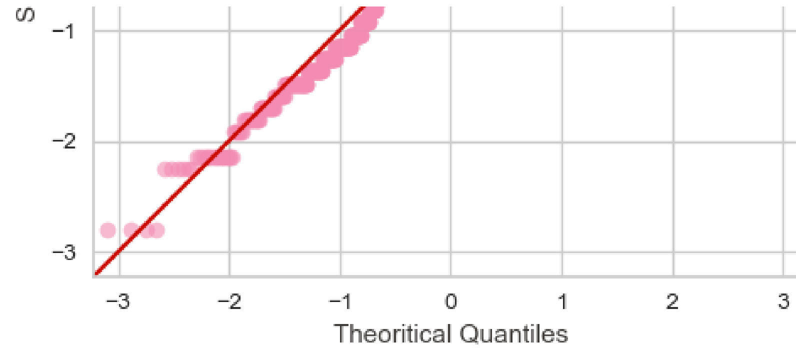
```
# --- Box Plot ---
ax_3=fig.add_subplot(1, 2, 1)
plt.title('Box Plot', fontweight='bold', fontsize=14, fontfamily='sans-serif',
          color=black_grad[1])
sns.boxplot(data=df, y=var, color=color, boxprops=dict(alpha=0.8), linewidth=1.5)
plt.ylabel('Age', fontweight='regular', fontsize=11, fontfamily='sans-serif',
           color=black_grad[1])

plt.show()
```

.: Age Column Skewness & Kurtosis :.
****
Skewness: **-0.249**
Kurtosis: **-0.526**

Age Column Distribution




30


S
−1
−2
−3
−3
−2
−1
0
1
2
3
Theoritical Quantiles

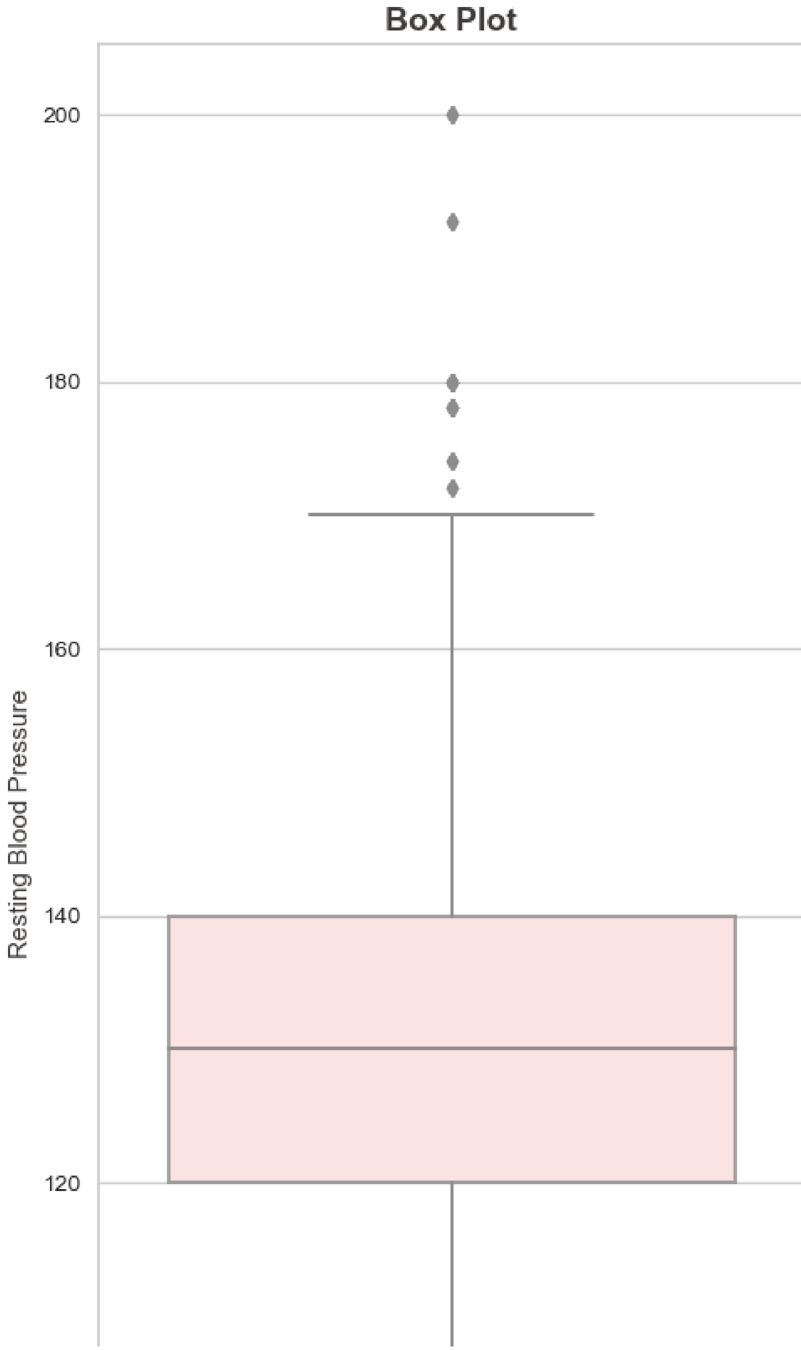
In [23]:
```
# --- Variable, Color & Plot Size ---
var = 'trestbps'
color = color_mix[2]
fig=plt.figure(figsize=(12, 12))

# --- Skewness & Kurtosis ---
print('\033[1m'+'.: Resting Blood Pressure Column Skewness & Kurtosis :.'+'\033[0m')
print('*' * 55)
print('Skewness:'+'\033[1m {:.3f}'.format(df[var].skew(axis = 0, skipna = True)))
print('\033[0m'+'Kurtosis:'+'\033[1m {:.3f}'.format(df[var].kurt(axis = 0, skipna = True)))
print('\n')

# --- General Title ---
fig.suptitle('Resting Blood Pressure Column Distribution', fontweight='bold',
             fontsize=16, fontfamily='sans-serif', color=black_grad[0])
fig.subplots_adjust(top=0.9)

# --- Histogram ---
ax_1=fig.add_subplot(2, 2, 2)
plt.title('Histogram Plot', fontweight='bold', fontsize=14,
          fontfamily='sans-serif', color=black_grad[1])
sns.histplot(data=df, x=var, kde=True, color=color)
plt.xlabel('Total', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])
plt.ylabel('Resting Blood Pressure', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])

# --- Q-Q Plot ---
ax_2=fig.add_subplot(2, 2, 4)
plt.title('Q-Q Plot', fontweight='bold', fontsize=14,
          fontfamily='sans-serif', color=black_grad[1])
qqplot(df[var], fit=True, line='45', ax=ax_2, markerfacecolor=color,
       markeredgecolor=color, alpha=0.6)
plt.xlabel('Theoritical Quantiles', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])
plt.ylabel('Sample Quantiles', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])

# --- Box Plot ---
ax_3=fig.add_subplot(1, 2, 1)
plt.title('Box Plot', fontweight='bold', fontsize=14, fontfamily='sans-serif',
```

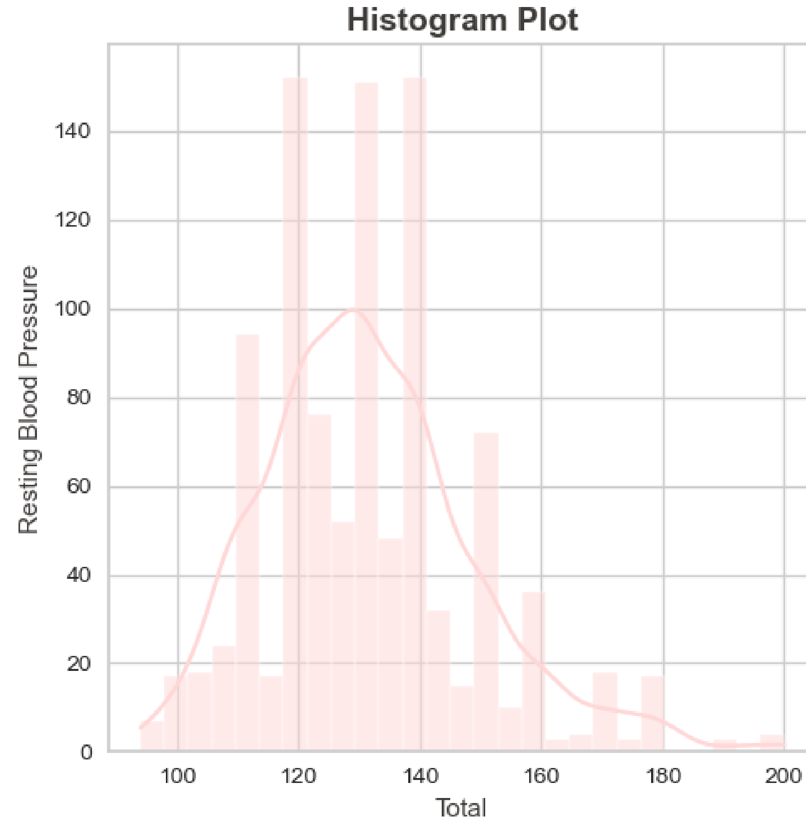
```
          color=black_grad[1])
sns.boxplot(data=df, y=var, color=color, boxprops=dict(alpha=0.8), linewidth=1.5)
plt.ylabel('Resting Blood Pressure', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])

plt.show()
```

.: Resting Blood Pressure Column Skewness & Kurtosis :.
****

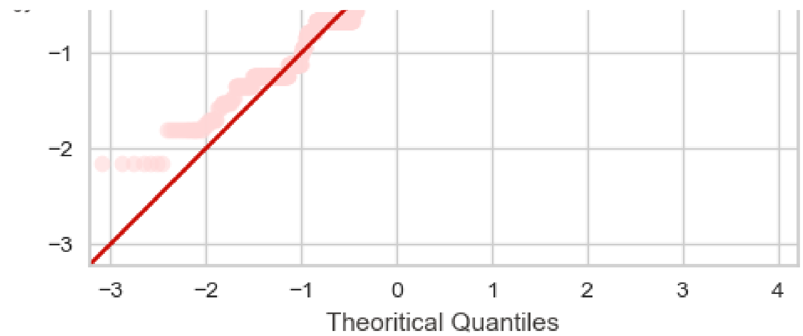
Skewness: **0.740**
Kurtosis: **0.991**

Resting Blood Pressure Column Distribution






100

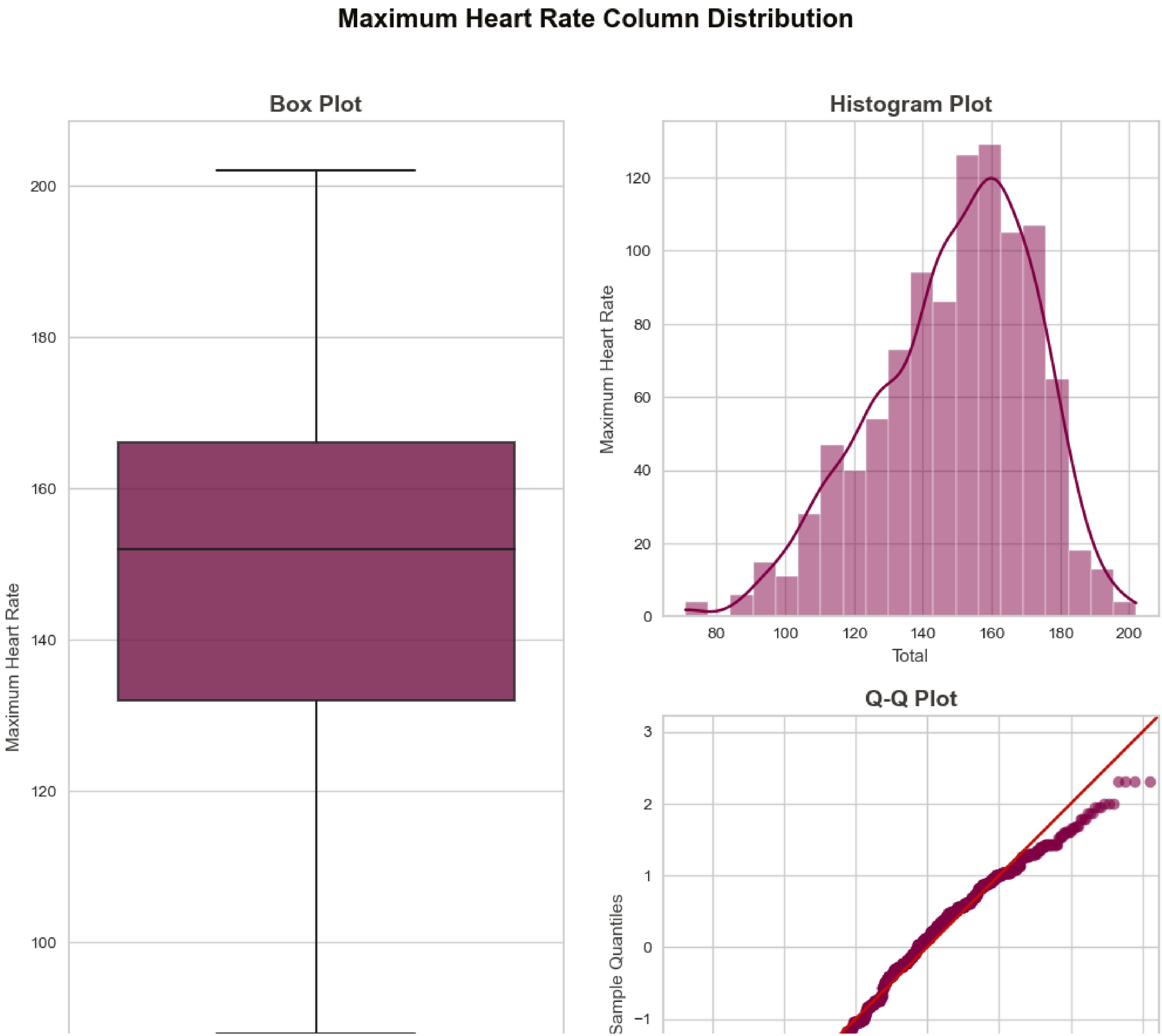

−1
−2
−3
−3
−2
−1
0
1
2
3
4
Theoritical Quantiles

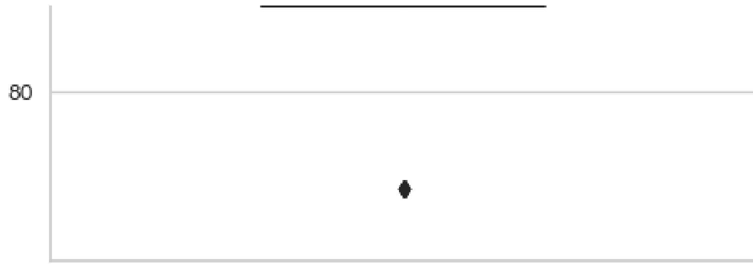
In [24]:
```
# --- Variable, Color & Plot Size ---
var = 'thalach'
color = purple_grad[1]
fig=plt.figure(figsize=(12, 12))

# --- Skewness & Kurtosis ---
print('\033[1m'+'.: Maximum Heart Rate Column Skewness & Kurtosis :.'+'\033[0m')
print('*' * 50)
print('Skewness:'+'\033[1m {:.3f}'.format(df[var].skew(axis = 0, skipna = True)))
print('\033[0m'+'Kurtosis:'+'\033[1m {:.3f}'.format(df[var].kurt(axis = 0, skipna = True)))
print('\n')

# --- General Title ---
fig.suptitle('Maximum Heart Rate Column Distribution', fontweight='bold',
             fontsize=16, fontfamily='sans-serif', color=black_grad[0])
fig.subplots_adjust(top=0.9)

# --- Histogram ---
ax_1=fig.add_subplot(2, 2, 2)
plt.title('Histogram Plot', fontweight='bold', fontsize=14,
          fontfamily='sans-serif', color=black_grad[1])
sns.histplot(data=df, x=var, kde=True, color=color)
plt.xlabel('Total', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])
plt.ylabel('Maximum Heart Rate', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])

# --- Q-Q Plot ---
ax_2=fig.add_subplot(2, 2, 4)
plt.title('Q-Q Plot', fontweight='bold', fontsize=14, fontfamily='sans-serif',
          color=black_grad[1])
qqplot(df[var], fit=True, line='45', ax=ax_2, markerfacecolor=color,
       markeredgecolor=color, alpha=0.6)
plt.xlabel('Theoritical Quantiles', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])
plt.ylabel('Sample Quantiles', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])

# --- Box Plot ---
ax_3=fig.add_subplot(1, 2, 1)
plt.title('Box Plot', fontweight='bold', fontsize=14,
```

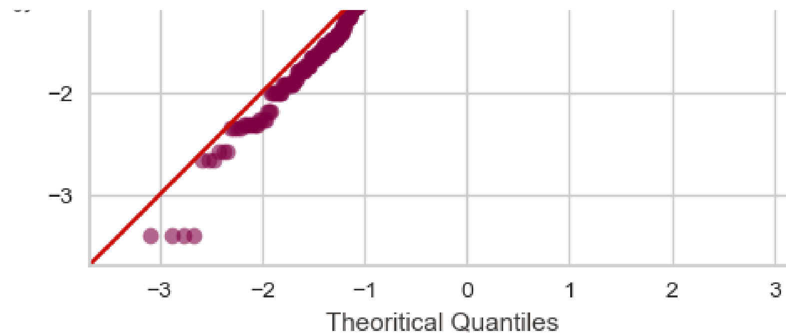
```
          fontfamily='sans-serif', color=black_grad[1])
sns.boxplot(data=df, y=var, color=color, boxprops=dict(alpha=0.8), linewidth=1.5)
plt.ylabel('Maximum Heart Rate', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])

plt.show()
```

.: Maximum Heart Rate Column Skewness & Kurtosis :.
****

Skewness: **-0.514**
Kurtosis: **-0.089**


Maximum Heart Rate Column Distribution
Box Plot
Maximum Heart Rate
200
180
160
140
120
100
Histogram Plot
Maximum Heart Rate
120
100
80
60
40
20
0
80
100
120
140
160
180
200
Total
Q-Q Plot
Sample Quantiles
3
2
1
0
−1


80

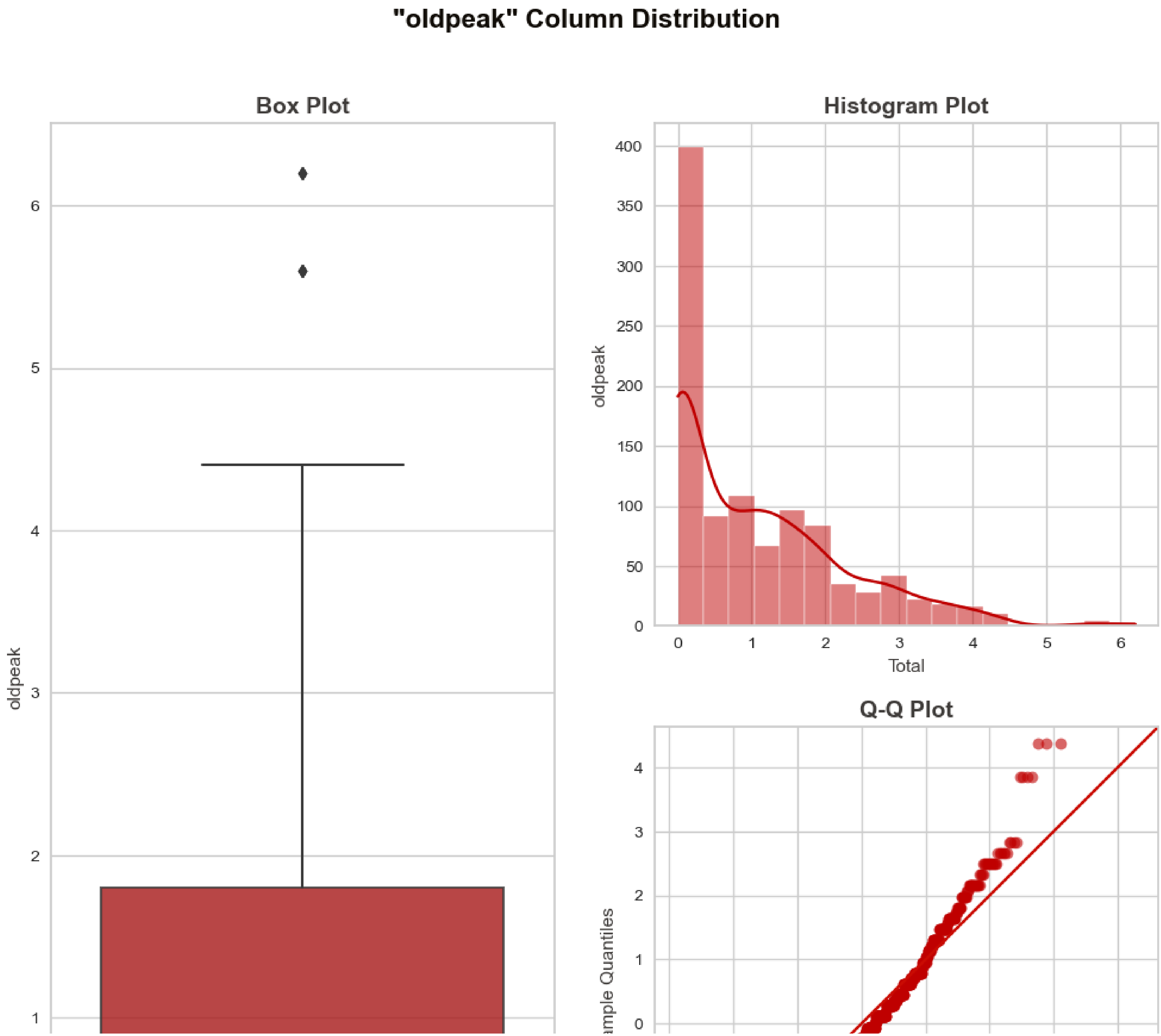

−2
−3
−3 −2 −1 0 1 2 3
Theoritical Quantiles

In [25]:
```
# --- Variable, Color & Plot Size ---
var = 'oldpeak'
color = red_grad[1]
fig=plt.figure(figsize=(12, 12))

# --- Skewness & Kurtosis ---
print('\033[1m'+'.: "oldpeak" Column Skewness & Kurtosis :.'+'\033[0m')
print('*' * 40)
print('Skewness:'+'\033[1m {:.3f}'.format(df[var].skew(axis = 0, skipna = True)))
print('\033[0m'+'Kurtosis:'+'\033[1m {:.3f}'.format(df[var].kurt(axis = 0, skipna = True)))
print('\n')

# --- General Title ---
fig.suptitle('"oldpeak" Column Distribution', fontweight='bold',
             fontsize=16, fontfamily='sans-serif', color=black_grad[0])
fig.subplots_adjust(top=0.9)

# --- Histogram ---
ax_1=fig.add_subplot(2, 2, 2)
plt.title('Histogram Plot', fontweight='bold', fontsize=14,
          fontfamily='sans-serif', color=black_grad[1])
sns.histplot(data=df, x=var, kde=True, color=color)
plt.xlabel('Total', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])
plt.ylabel('oldpeak', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])

# --- Q-Q Plot ---
ax_2=fig.add_subplot(2, 2, 4)
plt.title('Q-Q Plot', fontweight='bold', fontsize=14, fontfamily='sans-serif',
          color=black_grad[1])
qqplot(df[var], fit=True, line='45', ax=ax_2, markerfacecolor=color,
       markeredgecolor=color, alpha=0.6)
plt.xlabel('Theoritical Quantiles', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])
plt.ylabel('Sample Quantiles', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])

# --- Box Plot ---
ax_3=fig.add_subplot(1, 2, 1)
plt.title('Box Plot', fontweight='bold', fontsize=14,
```

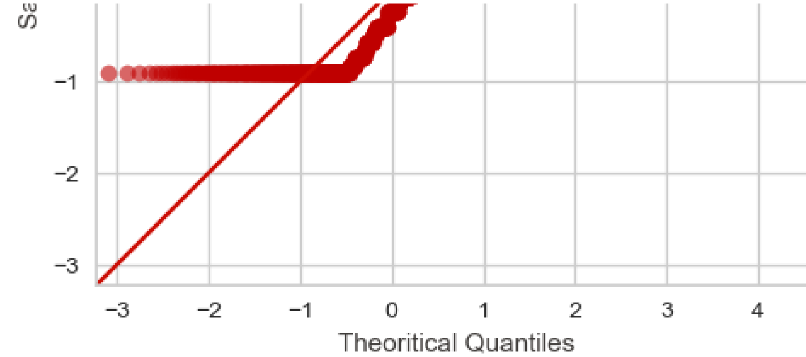
```
          fontfamily='sans-serif', color=black_grad[1])
sns.boxplot(data=df, y=var, color=color, boxprops=dict(alpha=0.8), linewidth=1.5)
plt.ylabel('oldpeak', fontweight='regular', fontsize=11,
           fontfamily='sans-serif', color=black_grad[1])

plt.show()
```

.: "oldpeak" Column Skewness & Kurtosis :.
****

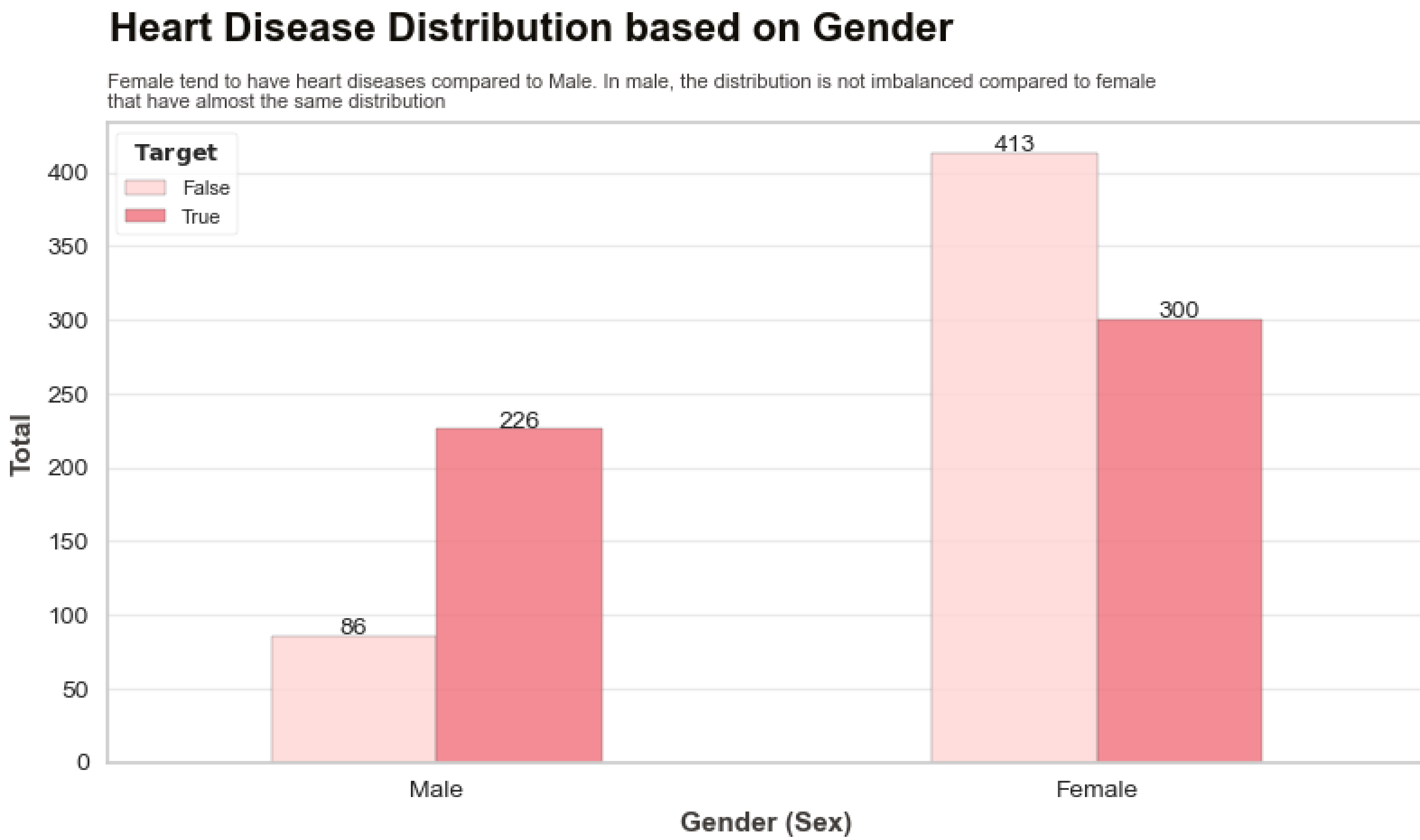
Skewness: **1.211**
Kurtosis: **1.314**


"oldpeak" Column Distribution
Box Plot
oldpeak
1
2
3
4
5
6
Histogram Plot
oldpeak
Total
0
50
100
150
200
250
300
350
400
0
1
2
3
4
5
6
Q-Q Plot
ample Quantiles
0
1
2
3
4

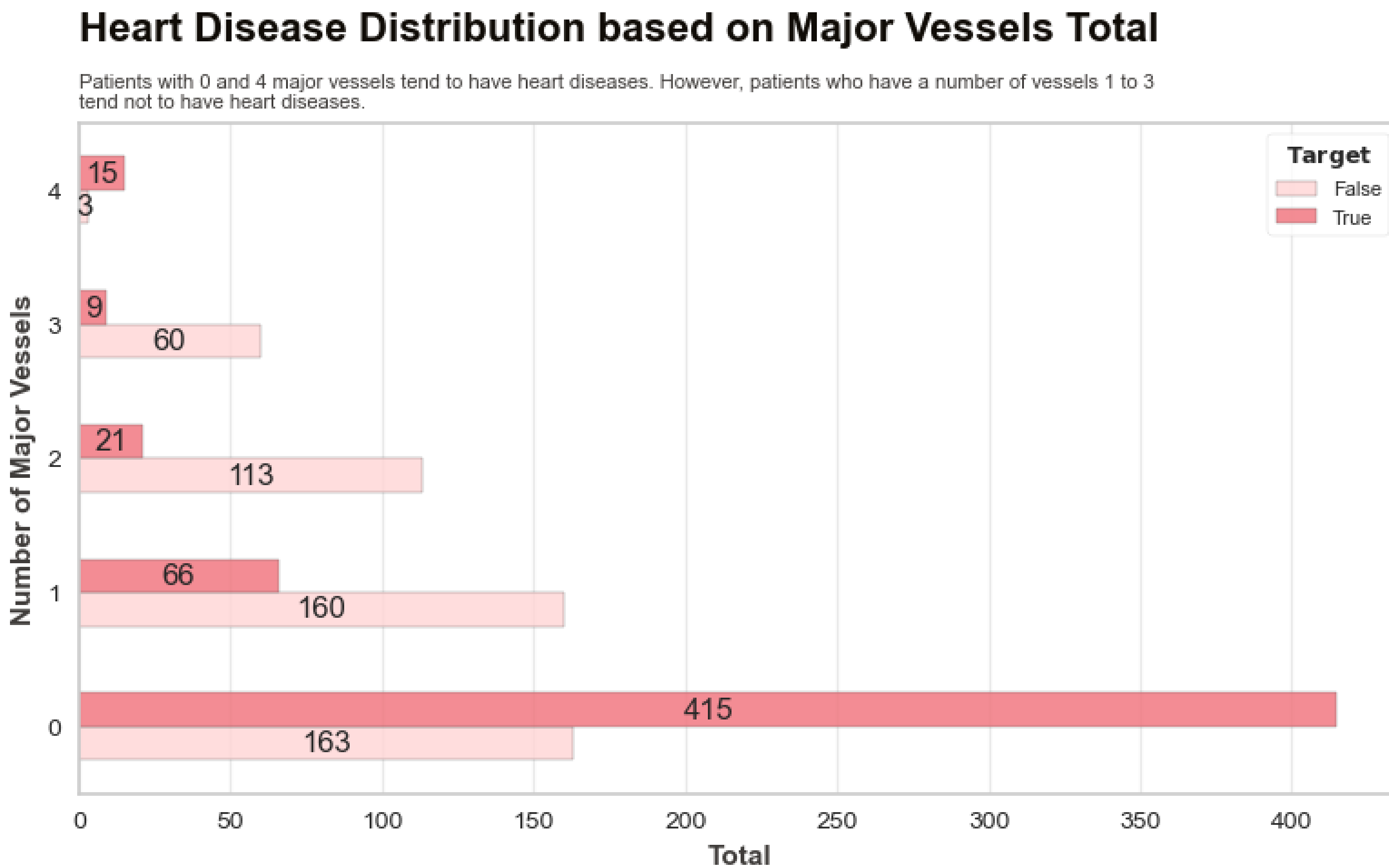

0


Sa
−1
−2
−3
−3
−2
−1
0
1
2
3
4
Theoritical Quantiles

In [26]:
```
'''
EDA
Heart Disease Distribution based on Gender

'''
# --- Labels Settings ---
labels = ['False', 'True']
label_gender = np.array([0, 1])
label_gender2 = ['Male', 'Female']

# --- Creating Bar Chart ---
ax = pd.crosstab(df.sex, df.target).plot(kind='bar', figsize=(8, 5),
                                          color=color_mix[2:4],
                                          edgecolor=black_grad[2], alpha=0.85)
# --- Bar Chart Settings ---
for rect in ax.patches:
    ax.text (rect.get_x()+rect.get_width()/2,
             rect.get_height()+1.25,rect.get_height(),
             horizontalalignment='center', fontsize=10)

plt.suptitle('Heart Disease Distribution based on Gender', fontweight='heavy',
             x=0.065, y=0.98, ha='left', fontsize='16', fontfamily='sans-serif',
             color=black_grad[0])
plt.title('Female tend to have heart diseases compared to Male. In male, the distribution is not imbalanced c
ompared to female\nthat have almost the same distribution',
          fontsize='8', fontfamily='sans-serif', loc='left', color=black_grad[1])
plt.tight_layout(rect=[0, 0.04, 1, 1.025])
plt.xlabel('Gender (Sex)', fontfamily='sans-serif', fontweight='bold',
           color=black_grad[1])
plt.ylabel('Total', fontfamily='sans-serif', fontweight='bold',
           color=black_grad[1])
plt.xticks(label_gender, label_gender2, rotation=0)
plt.grid(axis='y', alpha=0.4)
plt.grid(axis='x', alpha=0)
plt.legend(labels=labels, title='$\\bf{Target}$', fontsize='8',
           title_fontsize='9', loc='upper left', frameon=True);
```


Heart Disease Distribution based on Gender
Female tend to have heart diseases compared to Male. In male, the distribution is not imbalanced compared to female that have almost the same distribution
Target
False
True
413
300
226
86
400
350
300
250
200
150
100
50
0
Total
Male
Female
Gender (Sex)

In [27]:
```
'''
Heart Disease Distribution based on Major Vessels Total
'''
# --- Labels Settings ---
labels = ['False', 'True']

# --- Creating Horizontal Bar Chart ---
ax = pd.crosstab(df.ca, df.target).plot(kind='barh', figsize=(8, 5),
                                         color=color_mix[2:4],
                                         edgecolor=black_grad[2], alpha=0.85)
# --- Horizontal Bar Chart Settings ---
for rect in ax.patches:
    width, height = rect.get_width(), rect.get_height()
    x, y = rect.get_xy()
    ax.text (x+width/2, y+height/2, '{:.0f}'.format(width),
             horizontalalignment='center', verticalalignment='center')

plt.suptitle('Heart Disease Distribution based on Major Vessels Total',
             fontweight='heavy', x=0.069, y=0.98, ha='left', fontsize='16',
             fontfamily='sans-serif', color=black_grad[0])
plt.title('Patients with 0 and 4 major vessels tend to have heart diseases. However, patients who have a numb
er of vessels 1 to 3\ntend not to have heart diseases.',
          fontsize='8', fontfamily='sans-serif', loc='left', color=black_grad[1])
plt.tight_layout(rect=[0, 0.04, 1, 1.025])
plt.xlabel('Total', fontfamily='sans-serif', fontweight='bold', color=black_grad[1])
plt.ylabel('Number of Major Vessels', fontfamily='sans-serif', fontweight='bold',
           color=black_grad[1])
plt.yticks(rotation=0)
plt.grid(axis='x', alpha=0.4)
plt.grid(axis='y', alpha=0)
plt.legend(labels=labels, title='$\\bf{Target}$', fontsize='8', frameon=True,
           title_fontsize='9', loc='upper right');
```



In [ ]:

In [28]:
```
'''
The following steps are GDP with machine learning.
'''
```

Out[28]: '\nThe following steps are GDP with machine learning.\n'

In [29]:
```
# --- Fix Data Types ---
lst=['sex', 'cp', 'fbs', 'restecg', 'exang', 'slope', 'ca', 'thal']
df[lst] = df[lst].astype(object)


'''
Dataset Pre-processing
One-Hot Encoding
'''
# --- Creating Dummy Variables for cp, thal and slope ---
cp = pd.get_dummies(df['cp'], prefix='cp')
thal = pd.get_dummies(df['thal'], prefix='thal')
slope = pd.get_dummies(df['slope'], prefix='slope')

# --- Merge Dummy Variables to Main Data Frame ---
frames = [df, cp, thal, slope]
df = pd.concat(frames, axis = 1)


# --- Display Data Frame ---
df.head().style.background_gradient(cmap='PuRd').hide_index().set_properties(**{'font-family': 'Segoe UI'})
```

Out[29]:

age	sex	cp	trestbps	chol	fbs	restecg	thalach	exang	oldpeak	slope	ca	thal	target	cp_0	cp_1	cp_2	cp_3	thal_0	thal_1	th
52	1	0	125	212	0	1	168	0	1.000000	2	2	3	0	1	0	0	0	0	0	
53	1	0	140	203	1	0	155	1	3.100000	0	0	3	0	1	0	0	0	0	0	
70	1	0	145	174	0	1	125	1	2.600000	0	0	3	0	1	0	0	0	0	0	
61	1	0	148	203	0	1	161	0	0.000000	2	1	3	0	1	0	0	0	0	0	
62	0	0	138	294	1	1	106	0	1.900000	1	3	2	0	1	0	0	0	0	0	

In [30]:
```
'''
Dropping Unnecessary Variables
'''
# --- Drop Unnecessary Variables ---
df = df.drop(columns = ['cp', 'thal', 'slope'])
```

In [31]:
```
# --- Display New Data Frame ---
df.head().style.background_gradient(cmap='Reds').hide_index().set_properties(**{'font-family': 'Segoe UI'})
```

Out[31]:

age	sex	trestbps	chol	fbs	restecg	thalach	exang	oldpeak	ca	target	cp_0	cp_1	cp_2	cp_3	thal_0	thal_1	thal_2	thal_3	slo
52	1	125	212	0	1	168	0	1.000000	2	0	1	0	0	0	0	0	0	1	
53	1	140	203	1	0	155	1	3.100000	0	0	1	0	0	0	0	0	0	1	
70	1	145	174	0	1	125	1	2.600000	0	0	1	0	0	0	0	0	0	1	
61	1	148	203	0	1	161	0	0.000000	1	0	1	0	0	0	0	0	0	1	
62	0	138	294	1	1	106	0	1.900000	3	0	1	0	0	0	0	0	1	0	

In [32]:
```
'''
Features Separating
'''
# --- Seperating Dependent Features ---
x = df.drop(['target'], axis=1)
y = df['target']



'''
Data Normalization
'''
# --- Data Normalization using Min-Max Method ---
x = MinMaxScaler().fit_transform(x)



'''
Splitting the Dataset
'''
# --- Splitting Dataset into 80:20 ---
x_train, x_test, y_train, y_test = train_test_split(x, y, test_size=0.2, random_state=4)


'''
Machine Learning Training on Categorical Features
===============================================================================================================
'''



'''
Logistic Regression
'''
# --- Applying Logistic Regression ---
LRclassifier = LogisticRegression(max_iter=1000, random_state=1, solver='liblinear', penalty='l1')
LRclassifier.fit(x_train, y_train)
y_pred_LR = LRclassifier.predict(x_test)

# --- LR Accuracy ---
LRAcc = accuracy_score(y_pred_LR, y_test)
```

```
print('.:. Logistic Regression Accuracy:'+'\033[1m {:.2f}%'.format(LRAcc*100)+' .:.')



'''
K-Nearest Neighbour (KNN)
'''
# --- Applying KNN ---
KNNClassifier = KNeighborsClassifier(n_neighbors=3)
KNNClassifier.fit(x_train, y_train)
y_pred_KNN = KNNClassifier.predict(x_test)

# --- KNN Accuracy ---
KNNAcc = accuracy_score(y_pred_KNN, y_test)
print('.:. K-Nearest Neighbour Accuracy:'+'\033[1m {:.2f}%'.format(KNNAcc*100)+' .:.')

# ------------------------------------------------------------------------------------------------------------
-------------

'''
Support Vector Machine (SVM)
'''
# --- Applying SVM ---
SVMclassifier = SVC(kernel='linear', max_iter=1000, C=10, probability=True)
SVMclassifier.fit(x_train, y_train)
y_pred_SVM = SVMclassifier.predict(x_test)

# --- SVM Accuracy ---
SVMAcc = accuracy_score(y_pred_SVM, y_test)
print('.:. Support Vector Machine Accuracy:'+'\033[1m {:.2f}%'.format(SVMAcc*100)+' .:.')

# ------------------------------------------------------------------------------------------------------------
-------------

'''
Gaussian Naive Bayes
'''
# --- Applying Gaussian NB ---
GNBclassifier = GaussianNB(var_smoothing=0.1)
GNBclassifier.fit(x_train, y_train)
y_pred_GNB = GNBclassifier.predict(x_test)
```

```
# --- GNB Accuracy ---
GNBAcc = accuracy_score(y_pred_GNB, y_test)
print('.:. Gaussian Naive Bayes Accuracy:'+'\033[1m {:.2f}%'.format(GNBAcc*100)+' .:.')

# ---------------------------------------------------------------------------------------------------------------
-------------

'''
Decision Tree
'''
# --- Applying Decision Tree ---
DTCclassifier = DecisionTreeClassifier(max_depth=3, min_samples_leaf=5, criterion='entropy', min_samples_spli
t=5,
                                       splitter='random', random_state=1)
DTCclassifier.fit(x_train, y_train)
y_pred_DTC = DTCclassifier.predict(x_test)

# --- Decision Tree Accuracy ---
DTCAcc = accuracy_score(y_pred_DTC, y_test)
print('.:. Decision Tree Accuracy:'+'\033[1m {:.2f}%'.format(DTCAcc*100)+' .:.')
# ---------------------------------------------------------------------------------------------------------------
-------------

'''
Random Forest
'''
# --- Applying Random Forest ---
RFclassifier = RandomForestClassifier(n_estimators=1000, random_state=1, max_leaf_nodes=20, min_samples_split
=15)
RFclassifier.fit(x_train, y_train)
y_pred_RF = RFclassifier.predict(x_test)

# --- Random Forest Accuracy ---
RFAcc = accuracy_score(y_pred_RF, y_test)
print('.:. Random Forest Accuracy:'+'\033[1m {:.2f}%'.format(RFAcc*100)+' .:.')

# ---------------------------------------------------------------------------------------------------------------
-------------

'''
Gradient Boosting
'''
```

```
# --- Applying Gradient Boosting ---
GBclassifier = GradientBoostingClassifier(random_state=1, n_estimators=100, max_leaf_nodes=3, loss='exponenti
al',
                                          min_samples_leaf=20)
GBclassifier.fit(x_train, y_train)
y_pred_GB = GBclassifier.predict(x_test)

# --- Gradient Boosting Accuracy ---
GBAcc = accuracy_score(y_pred_GB, y_test)
print('.:. Gradient Boosting Accuracy:'+'\033[1m {:.2f}%'.format(GBAcc*100)+' .:.')

# ==============================================================================================================
==========

'''
Model Comparison
'''
# --- Create Accuracy Comparison Table ---
compare = pd.DataFrame({'Model': ['Logistic Regression', 'K-Nearest Neighbour', 'Support Vector Machine',
                                  'Gaussian Naive Bayes', 'Decision Tree', 'Random Forest', 'Gradient Boostin
g'
                                  ],
                        'Accuracy': [LRAcc*100, KNNAcc*100, SVMAcc*100, GNBAcc*100, DTCAcc*100, RFAcc*100, GB
Acc*100,
                                     ]})

# --- Create Accuracy Comparison Table ---
print("\n Model Performance on noise data when e=0.1 ")
compare.sort_values(by='Accuracy', ascending=False).style.background_gradient(cmap='PuRd').hide_index().set_p
roperties(**{'font-family': 'Segoe UI'})
```

```
.:. Logistic Regression Accuracy: 83.90% .:.
.:. K-Nearest Neighbour Accuracy: 95.61% .:.
.:. Support Vector Machine Accuracy: 83.90% .:.
.:. Gaussian Naive Bayes Accuracy: 82.44% .:.
.:. Decision Tree Accuracy: 83.90% .:.
.:. Random Forest Accuracy: 88.78% .:.
.:. Gradient Boosting Accuracy: 86.83% .:.

 Model Performance on noise data when e=0.1
```

Out[32]:

Model	Accuracy
K-Nearest Neighbour	95.609756
Random Forest	88.780488
Gradient Boosting	86.829268
Logistic Regression	83.902439
Support Vector Machine	83.902439
Decision Tree	83.902439
Gaussian Naive Bayes	82.439024

In [ ]: