Mechanical forces have been observed to affect various aspects of life, for example, cell differentiation, cell migration, locomotion and behavior of multicellular organisms etc. Such forces are generated either by external entities such as mechanical touch, fluid flow, electric and magnetic fields or by the living organisms themselves. Study of forces sensed and applied by living organisms is important to understand the interactions between organisms and their environment. Such studies may reveal molecular mechanisms involved in mechanosensation and locomotion.

Several techniques have been successfully applied to measure forces exerted by single cells and cell monolayers. The earliest technique made use of functionalized soft surfaces and membranes as substrates on which cell monolayers were grown. The forces exerted by the cells could be measured by observing deformation of the substrates. Atomic Force Microscope (AFM) is another sensitive instrument that allows one to exert and measure forces in pico-Newton range. Advances in micromachining technology have enabled development of miniature force sensors and actuators. Latest techniques for mechanical force application and measurement use micromachined Silicon cantilevers in single as well as array form and micropillar arrays. Micropillar arrays fabricated using soft lithography enabled the use of biocompatible materials for force sensors. Together, these techniques provide access to a wide range of forces, from sub micro-Newton to milli-Newton.

In the present work, types of forces experienced in biological systems and various force measurement and actuation techniques will be introduced. This will be followed by in depth description of the two major contributions of this thesis,

1) “Colored polydimethylsiloxane micropillar arrays for high throughput measurements of forces applied by genetic model organisms”. *Biomicrofluidics*, January 29, 2015. doi: 10.1063/1.4906905

2) “Air microjet system for non-contact force application and the actuation of micro-structures”. *Journal of micromechanics and microengineering*, December 15, 2015. doi: 10.1088/0960-1317/26/1/017001

Device developed for force measurement consists of an array of micropillars made of a biocompatible polymer Poly Dimethyl Siloxane (PDMS). Such devices have been used by researchers to measure traction forces exerted by single cells and also by nematode worm *Caenorhabditis elegans* (*C. elegans*). *C. elegans* is allowed to move in between the micropillars and the locomotion is video recorded. Deflection of the micropillar tips as the worm moves is converted into force exerted. Transparent appearance of *C. elegans* and PDMS poses difficulties in distinguishing micropillars from the worm, thus making it challenging to automate the analysis process. We address this problem by developing a technique to color the micropillars selectively. This enabled us to develop a semi-automated graphical user interface (GUI) for high throughput data extraction and analysis, reducing the analysis time for each worm to minutes. Moreover, increased contrast because of the color also delivered better images. Addition of color changed the Young's modulus of PDMS. Thus the dye-PDMS composite was characterized using hyper-elastic model. The micropillars were also calibrated using commercial force sensor.

Analysis of forces exerted by wild type and mutant *C. elegans* moving on an agarose surface was performed. Wild type *C. elegans* exerted a total average force of 7.68 μN and an average force of ~1 μN on an individual pillar. We show that the middle of *C. elegans* exerts more force than its extremities. We find that *C. elegans* mutants with defective body wall muscles apply significantly lower force on individual pillars, while mutants defective in sensing externally applied mechanical forces still apply the same average force per pillar compared to wild type animals. Average forces applied per pillar are independent of the length, diameter, or cuticle stiffness of the animal. It was also observed that the motility of the worms with mechanosensation defects, lower cuticle stiffness, and body wall muscle defects was reduced with worms that have defective body wall muscle having the largest degree. Thus, we conclude that while reduced ability to apply forces affects the locomotion of the worm in the micropillar array, the reduced motility/locomotion may not indicate that the worm has reduced ability to apply forces on the micropillars.

We also used the colored micropillar array for the first time to measure forces exerted by *Drosophila* larvae. Our device successfully captured the peristaltic rhythm of the body wall muscles of the larva and allowed us to measure the forces applied on each deflected pillar during this motion. Average force exerted by 1st instar wild type *Drosophila* larvae was measured to be ~ 1.5 μN per pillar.

We demonstrated that a microjet of air can be used to apply forces in micro-Newton range. We developed a standalone system to generate a controlled air microjet. Microjet was generated using a controlled electromagnetic actuation of a diaphragm. With a nozzle diameter of 150 μm, the microjet diameter was maintained to a maximum of 1 mm at a distance of 5 mm from the nozzle. The force generated by the microjet was measured using a commercial force sensor to determine the velocity profile of the jet. Axial flow velocities of up to 25 m/s were obtained at distances as long as 6 mm. The microjet exerted a force up to 1 μN on a poly dimethyl siloxane (PDMS) micropillar (50 μm in diameter, 157 μm in height) and 415 μN on a PDMS membrane (3 mm in diameter, 28 μm thick). We also demonstrate that from a distance of 6 mm our microjet can exert a peak pressure of 187 Pa with a total force of about 84 μN on a flat surface with 8 V operating voltage. Next, we demonstrated that the response of *C. elegans* worms to the impinging air microjet is similar to the response evoked using a manual gentle touch. This contactless actuation tool avoids contamination and mechanical damage to the samples. Out of the cleanroom fabrication and robust design make this system cost effective and durable.

Magnetic micropillars have been used as actuators. We fabricated magnetic micropillar arrays and designed actuation mechanisms using permanent magnet and a pulsed electromagnet. Force of about 19 μN was achievable using a permanent magnet actuation. In a pulsed electromagnetic field micropillar exerted a force of about 10 μN on a commercial force sensor. These techniques have promising applications when actuation needs to be controlled from long distances.